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PREFACE

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This issue contains the information published during May 2012. The arrangement of the contents is alphabetical wise starting from A-Z. The Full text of the article which is either subscribed by the University or available in the web has been provided in this Bulletin.

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A Novel Approach to Fast Image Filtering Algorithm of Infrared Images based on Intro Sort Algorithm

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Abstract

In this study we investigate the fast image filtering algorithm based on Intro sort algorithm and fast noise reduction of infrared images. Main feature of the proposed approach is that no prior knowledge of noise required. It is developed based on Stefan-Boltzmann law and the Fourier law. We also investigate the fast noise reduction approach that has advantage of less computation load. In addition, it can retain edges, details, text information even if the size of the window increases. Intro sort algorithm begins with Quick sort and switches to heap sort when the recursion depth exceeds a level based on the number of elements being sorted. This approach has the advantage of fast noise reduction by reducing the comparison time. It also significantly speed up the noise reduction process and can apply to real-time image processing. This approach will extend the Infrared images applications for medicine and video conferencing.

Keywords: Image filtering, Intro Sort, infrared Images, Noise reduction, Digital Image Processing.

1. Introduction

In Infrared images, impulse noise detection and removal is an important process as the images are corrupted by those noise because of transmission and acquisition. The main aim of the noise removal is to suppress the noise when preserving the edge information. Images and videos belong to the most important information carriers in today's world (e.g., traffic observations, surveillance systems, autonomous navigation, etc.). However, the images are likely to be corrupted by noise due to bad acquisition, transmission or recording. Such degradation negatively influences the performance of many image processing techniques and a preprocessing module to filter the images is often required.

The sensitive spectrum of an IR camera is about 3–5 μ m and 8–14 μ m. So, the IR images are robust under a wide-range of lighting conditions. However, the low signal-to-noise (S/N) ratio [1,2] is the inherent limitation of IR images that affect their quality and hinder their deployment. The low S/N ratio results in low signal and high noise that degrades the quality of IR images. This is significant for un-cooled IR camera, even though the un-cooled IR camera is much cheaper than the cooled one and more prevalently used to capture IR images in recent years. The high noise is caused by the IR sensors and read-out circuits of IR cameras, and the low IR signal detected by IR sensors is due to the bad atmospheric weather's degrading the IR signal radiating from objects. To enhance image quality and improve the adoption of IR-based applications, image preprocessing is necessary. Improvement in noise reduction is the crucial task of IR image preprocessing.

In this paper, a Fast Image Filtering approach to Infrared images is developed that is based on *Infrared imaging mechanism* to detect noise and median-based to remove noise with low computation load. It is performed without any prior knowledge about the IR image noise is necessary and any parameters must be preset. This property is quite different from some state-of-the-art noise reduction methods [5–8] which performance relies on one or more external heuristically preset parameter.

2. Previous Research

The standard median filter (MF) [3] has been prevalently used in for noise reduction of image preprocessing. However, there are two inherent limitations of the MF. The first is high computation load. The second is that it

removes the thin lines and small objects of interest and blurs the details even at low noise densities, while the size of the filter window increasing. The later makes it worse when the objects of interest are with few pixels in IR images. The MF will consider the few pixel objects as noise and remove them. The weighted median filter and the center-weight median filter (CWMF) [3,4] which are modified the MF to alleviate the inherent limitations of MF at the expense of reduced noise removal performance. In addition, there are many methods [5–20] combine the MF with impulse detection have been proposed to remedy the MF's limitations. Their performances inherently rely on the performance of the impulse detector. Mean-based filters [21–24] are the alternative approach to remedy the limitations of MF. These filter usually exhibit good filter performance at the cost of increased computational complexity. In recent years, a number of literatures [25–28] proposed the impulse noise reduction based on fuzzy technologies. However all these literatures mentioned previously considered on visual images.

3. Fast noise reduction approach

There is a main difference between visual image and infrared image imaging mechanism. The visual sensor receives the visual light reflected from object's surface to image visual image. It needs an external light source to offer a sufficient light power. This approach is called active imaging mechanism. An object reflects the light power based on the texture, color, roughness and other factors of its surface. These factors induce the reflected light power irregularly. Median filter filters the impulse noise from visual images based on an assumption that signal pixels have high correspondence with their neighbor pixels inside a small area. This assumption is reasonable but not theoretical. Because of this, the images processed by median filter will possibly lose some thin lines, textures or details. On the other hand, the IR sensor receives the infrared emitted from objects themselves to image IR images. It does not need external light sources to offer the IR to illuminate objects. This approach is called passive imaging mechanism. The temperature distribute on object's surface monotonically. Thus, object's surface also emits infrared power to IR sensor monotonically. The gray-level of signal pixels on the same object surface will vary monotonically while noise pixels cannot do it. The proposed algorithm developed based on the infrared image imaging mechanism theoretically. The details are described in following.

3.1 Stephen-Boltzmann law

The imaging mechanism is derived based on the Stefan-Boltzmann law [29] (heat radiation law) and the Fourier

law (heat conduction law). The heat radiation law is shown in Eq. (1):

$$PW = \epsilon \sigma T^4 \quad (1)$$

where PW is the radiant emittance (W/cm²), ϵ is the emissivity, σ is the Stefan-Boltzmann constant ($\approx 5.6705 \times 10^{-12} \text{ W/cm}^2 \text{ K}^4$), T is the temperature (K) of the object surface. The intensity of IR radiation emitted by the objects in the range of 3–14 μm [30] is dependent on the emissivity of the object surface, the surface temperature, the air molecules, the humidity of the air, and the distance between the IR camera and the objects. The IR transmission spectrum for the atmosphere is about 3–5 μm and 8–14 μm [31], which means that the radiant emittance of the IR spectrum at 3–5 μm and 8–14 μm has only minimum attenuation in the atmosphere. In Eq. (1), σ is a constant and ϵ is also a constant for objects. The temperature T of the object surface is the only variable that dominates the PW that significantly affects the thermal image contrast and quality.

3.2 Fourier law (heat conduction law)

the gray-level of pixels has a positive relationship with the temperature T of the object surface. Moreover, heat conduction affects the temperature distribution on the skin surface. Based on the Fourier law (heat conduction law (2)), the temperature gradient will vary over the surface of an object, and the direction of the temperature gradient changes slowly from high to low.

$$Q_1 = -kA (dT/dl), \quad (2)$$

where Q_1 is the rate of heat flow through area A in the positive l direction, and the constant k is the thermal conductivity of the material. The heat conduction law means that the rate of heat flow is proportional to the area and the temperature gradient in a given direction. Thus, the temperature T of the object varies monotonically on a surface.

3.3 Noise detection

In order to explain how to perform the noise detection, we must define some parameters of image pixels. x and y represent the horizontal and vertical coordinates of a pixel, respectively. p(x, y) is the pixel with coordinates x and y. g(x, y) is the gray-level of the pixel p(x, y). S_{xy} is the set that includes g(x, y) and its neighbor pixels. For example, a 3×3 window, $S_{xy} = \{g(x-1, y-1), g(x, y-1), g(x+1, y-1), g(x-1, y), g(x, y), g(x+1, y), g(x-1, y+1), g(x, y+1), g(x+1, y+1)\}$, g_m is the median gray-level of the S_{xy} , g(x, y) represents the gray-level of the central position pixel that will be processed, (s, t) denotes the coordinates of the pixels belonging to S_{xy} , and g(s, t) represents the gray-level of the pixels belonging to S_{xy} .

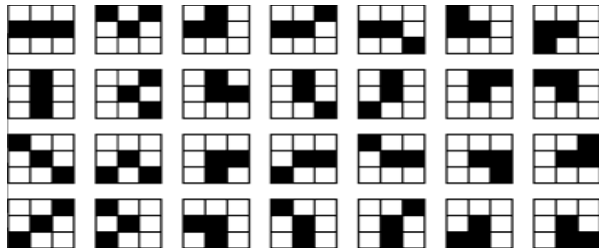


Fig. 1. Comparisons of central pixel to its two neighbors pixels in 3×3 Window

we propose the noise detection algorithm to find noisy pixels inside the filter window in IR images based on two steps. First, the noise detection method employs Eq. (3a) and (3b) to find the maximum and minimum gray-level inside the filter window. Next, we check the gray-level $g(x, y)$ with g_{\min} and g_{\max} , to consider whether the pixel $p(x, y)$ is noise or signal. This process can be performed in the following steps.

Step 1. Determine the maximum and minimum gray-level inside the filter window.

$$g_{\max} = \text{Arg max}\{g(s, t)\} \quad (3a)$$

$(s, t) \in S_{xy}$

$$g_{\min} = \text{Arg min}\{g(s, t)\} \quad (3b)$$

$(s, t) \in S_{xy}$

Step 2. Based on the IR imaging mechanism, check $g(x, y)$ with gray-level g_{\min} and g_{\max} to determine whether the pixel $p(x, y)$ is noise or signal.

If $g(x, y) = g_{\min}$ or g_{\max} then $p(x, y)$ is a noisy pixel. Otherwise $p(x, y)$ is considered as a signal pixel.

3.4 Noise removal based on Intro sort algorithm

In order to reduce noise, a pixel is considered as a noisy pixel which has to be removed from the IR image. According to the property of IR imaging mechanism, the pixel with median gray-level inside the window is adopted replacing the noisy pixels. In the proposed approach, the procedure to find out median gray-level is performed by the sort algorithm with a low computation complexity. In addition, it only processes the noisy pixels, but not the signal pixels.

Sorting is the main computation load of the noise removal. So, in order to speed up the noise removal, reducing the computation load is critical. This paper adopts a sort algorithm with low computation load. Sort algorithms are normally divided into two groups called internal sort and external sort. The former is suitable to small databases, and the latter is usually used on large databases. Hence, the number of pixels inside the filter window is small that may be 3×3 , 5×5 , 7×7 , and so on. Based on the

properties of the sort algorithm and the number of pixels sorted, we adopt the internal sort algorithm to sort the pixel gray-levels inside a filter window. The internal sort algorithm includes Bubble sort, Insertion sort, Selection sort, Shell sort, Quick sort, Heap sort, Radix sort, and so on. [32,33]. From an analysis of the properties of the versatile sort algorithms, a Intro sort with suitable parameters should run faster even than Quick sort or Heap sort. The complexity of Intro sort is described as Eq. (4).

$$\text{Complexity of Intro sort} = O(n \log n) \quad (4)$$

Where n is the number of data.

It begins with Quick sort and switches to Heap sort when the recursion depth exceeds a level based on the number of elements being sorted. It is the best of both worlds, with a worst-case $O(n \log n)$ runtime and practical performance comparable to Quick sort on typical data sets. Since both algorithms it uses are comparison sorts, it is a comparison sort too. Then the Intro sort algorithm is performed on bits to select the pixel with the median gray-level g_m inside a filter window. The selected pixel with gray-level g_m is utilized to replace the noisy pixel in the central position inside the filter window and the noise removal is accomplished. The Fast noise reduction approach does not act like the Median Filter in sorting each pixel in a whole Infrared image; it only processes that on noisy pixels. In general, there are far fewer noisy pixels than signal pixels. The FNR approach has to spend extra computation load to determine the maximum and minimum gray-level in the noise detection procedure.

(3a)

4. Experimental Results

4.1 Platform for evaluation

The platform utilized to evaluate the proposed approach includes a dual core CPU, the Intel Core 2 E6600 with clock rate 2.4 GHz and memory 1 Gbytes DDR2 667. The display card has GPU GeForce 7600 GT of NVIDIA Inc. and 256 MB memory. The program to simulate the approach was developed by Matlab. One noisy life-time IR images are used as test samples to assess the effect on the proposed approach. Their details are described in the following section.

4.2 Test samples of the IR image

In order to validate the proposed approach, one gray-scale noisy life-time IR images are collected as test sample, as shown in Fig. 2. There are 364×244 pixels in the images, respectively, and each pixel is represented by 8-bits in gray-scale. Fig. 2 shows people walking on the street on a rainy day. The people (objects) are small compared with the street scenery rendered as background.



Fig. 2 An Infrared image taken of some people walking on the street on a rainy day.

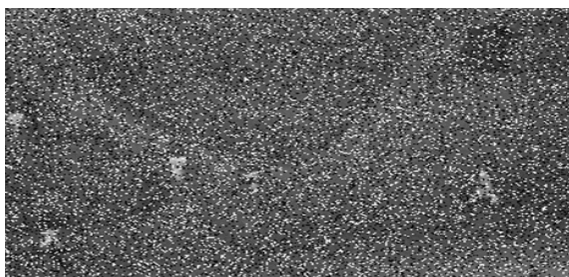


Fig. 3 Shows Fig. 2 with impulse noise processed by FNR iteratively with 20% impulse noise.



Fig. 4 Shows Fig. 2 with impulse noise processed by FNR iteratively with 30% impulse noise.



Fig. 5 The result of Fig. 3. iteratively processed by Fast noise reduction approach two times.



Fig. 6 The result of Fig. 4. iteratively processed by Fast noise reduction approach two times.



Fig. 7 The result of Fig.3. iteratively processed by MF two times,.

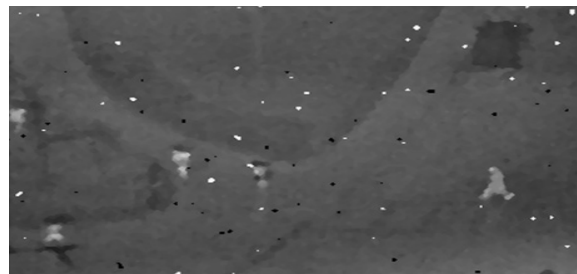


Fig. 8 The result of Fig.4. iteratively processed by MF two times,.

In order for the small objects of interest in these IR images to be observed easily, quickly, and accurately, they have to be preprocessed using a noise reduction.

The performances of FNR approach are address in this paragraph. Fig. 3 & 4 show the Fig. 2 with impulse noise 20%, 30%. Fig. 5 & 6 exhibit the result of performing FNR to iteratively filter two times. the impulse noise is filtered out and preserve the edges, textures and detail information simultaneously Fig.7 & 8 iteratively processed by MF two times they show the more noises are not filtered out and more edges, textures and detail information are lost. In addition, the proposed FNR approach can preserve the edge and texture information regardless of increases in filter size while removing noise. When the filter size increases, the image processed by the MF is blurred, and the edges and texture information are

lost. The experimental results of performing the MF and FNR Table 1 illustrates the different performances between utilizing the MF and FNR approach on Fig. 3 and 4 one time. The MF processes each pixel in a whole image so it has to perform a sorting algorithm 88,816 times for Fig. 3 and spend 24 ms. On the other hand, the FNR approach performs a sorting algorithm for noisy pixels only, performing the sorting algorithm 24,587 times for Fig. 3 and spending 15 ms, which includes finding the g_{\max} and g_{\min} 88,816 times. Hence, the computation load is reduced 37.5% by the proposed FNR approach. The FNR reduces the computation load 25%.

A typical noise measure used is peak signal-to-noise ratio (PSNR) [3], defined as.

$$\text{PSNR} = 10 \log_{10}(\text{MAX}^2 / \text{MSE}) \quad (5)$$

where MSE is the mean square error between the original and processed image and Max is the maximum gray scale of pixels, e.g., 255 for 8 bits. We use the PSNR to assess the noise reduction performance of the FNR approach and MF.

Table 1 : The differences in performance between utilizing the MF and the FNR approach on Fig. 3&4.

Image Size (Pixels) 364×244 (88, 816)			
Noise Image		Fig.3(20% noise)	Fig.4(30% noise)
Noisy image	PSNR(db)	34.11	32.26
Processed by MF	Sort times	88,816	88,816
	Process time(ms)	24	24
	PSNR(db)	40.23	38.79
Processed by FNR approach	Time of finding g_{\max} & g_{\min}	88,816	88,816
	Sort times	24,587	30,832
	Process Time(ms)	15	18
	PSNR(db)	43.45	41.39
Process time improved by FNR (%)		37.50%	25%
PSNR improved by FNR (dB)		3.22	2.60

5. Conclusions

In this paper, we present an effective FNR approach to reduce the noise of IR images. Based on the results shown in Figs. 5,6,7 and 8 and in Tables 1 the FNR approach possesses three main advantages. The first is that FNR approach utilizes noise detection based on IR imaging mechanism to identify noisy pixels in IR images, and median-based noise removal performed by Intro sorting with bits decomposition effectively decreases the

computation load for performing noise reduction. It can be applied to real-time video processing by software. The second advantage of FNR approach is that remedies the shortcomings of MF while increasing the filter window size. Finally, no prior knowledge about the IR images. necessary and no parameter must be manually preset to perform the proposed approach.

Experimental results demonstrate that the proposed approach can improve the performance of noise reduction and enhance quality IR images. In the applications of IR images, it is a considerable challenge to provide a removal on noise but not on the edges, text information and small objects of interest. In order to conquer the challenge, we propose an FNR approach consisting of the noise detection and noise removal. Experimental results demonstrate that the proposed approach can meet this challenge.

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References

- [1] A. Dawoud, M.S. Alam, A. Bal, C. Loo, Target tracking in infrared imagery using weighted composite reference function-based decision fusion, IEEE Trans. Image Process. 15 (2) (2006) 404–410.
- [2] A. Bal, M.S. Alam, Automatic target tracking in FLIR image sequences using intensity variation function and template modeling, IEEE Trans. Instrum. Meas. 54 (5) (2005) 846–1852.
- [3] AI. Bovik, Handbook of Image & Video Processing., second ed., Elsevier Academic Press, 2005.
- [4] T.C. Lin, A new adaptive center weighted median filter for suppressing impulsive noise in images, Inf. Sciences 177 (4) (2007) 1073–1087.
- [5] V. Crnojevic, V. Senk, Z. Trpovski, Advanced impulse detection based on pixelwise MAD, IEEE Signal Process. Lett. 11 (7) (2004) 589–592.
- [6] V.V. Khryashchev, I.V. Apalkov, A.L. Priorov, P.S. Zovanarev, Image denoising using adaptive switching median filter, In: Proc. IEEE Int. Conf. Image Process. (ICIP 2005) 1 (2005) 117–120.
- [7] T. Chen, H.R. Wu, Adaptive impulse detection using center-weighted median filters, IEEE Signal Process. Lett. 8 (1) (2001) 1–3.
- [8] T. Chen, H.R. Wu, Space variant median filters for the restoration of impulse noise corrupted images, IEEE Trans. Circ. Syst. II 48 (8) (2001) 784–789.
- [9] R.H. Chan, C. Hu, M. Nikolova, An iterative procedure for removing randomvalued impulse noise, IEEE Signal Process. Lett. 11 (12) (2004) 921–924.

- [10] I. Aizenberg, C. Butakoff, D. Paliy, Impulsive noise removal using threshold Boolean filtering based on the impulse detecting functions, *IEEE Signal Process. Lett.* 12 (1) (2005) 63–66.
- [11] S. Zhang, M.A. Karim, A new impulse detector for switching median filters, *IEEE Signal Process. Lett.* 9 (11) (2002) 360–363.
- [12] G. Pok, Y. Liu, A.S. Nair, Selective removal of impulse noise based on homogeneity level information, *IEEE Trans. Image Process.* 12 (1) (2003) 85–92.
- [13] E. Besdok, M.E. Yüksel, Impulsive noise rejection from images with JarqueBerra test based median filter, *Int. J. Electron. Commun.* 59 (2) (2005) 105–109.
- [14] R. Garnett, T. Huegerich, C. Chui, W. He, A universal noise removal algorithm with an impulse detector, *IEEE Trans. Image Process.* 14 (11) (2005) 1747–1754.
- [15] J.Y. Chang, J.L. Chen, Classifier-augmented median filters for image restoration, *IEEE Trans. Instrum. Meas.* 53 (2) (2004) 351–356.
- [16] S.Q. Yuan, Y.H. Tan, Impulse noise removal by a global–local noise detector and adaptive median filter, *Signal Process.* 86 (8) (2006) 2123–2128.
- [17] B. Smolka, A. Chydzinski, Fast detection and impulsive noise removal in color images, *Real-Time Image* 11 (4) (2005) 389–402.
- [18] H.-L. Eng, K.-K. Ma, Noise adaptive soft-switching median filter, *IEEE Trans. Image Process.* 10 (2) (2001) 242–251.
- [19] M.E. Yüksel, E. Besdok, A simple neuro-fuzzy impulse detector for efficient blur reduction of impulse noise removal operators for digital images, *IEEE Trans. Fuzzy Syst.* 12 (6) (2004) 854–865.
- [20] S. Schulte, M. Nachtgael, V. DeWitte, D. Van derWeken, E.E. Kerre, A fuzzy impulse noise detection and reduction method, *IEEE Trans. Image Process.* 15 (5) (2006) 1153–1162.
- [21] S.K. Mitra, G.L. Sicuranza, J.D. Gibson, *Nonlinear Image Processing (Communications, Networking and Multimedia)*, Academic, Orlando, FL, 2001.
- [22] E. Abreu, Signal-dependent rank-ordered mean (SD-ROM) filter, in: S.K. Mitra, G.L. Sicuranza, J.D. Gibson (Eds.), *Nonlinear Image Processing (Communications, Networking and Multimedia)*, Academic, Orlando, FL, 2001. pp. 111–133.
- [23] D. S. Zhang, D. J. Kouri, Varying weight trimmed mean filter for the restoration of impulse noise corrupted images, In: *Proc. IEEE Int. Conf. Acoust., Speech Signal Process. (ICASSP 2005)*, vol. 4, pp. 137–140.
- [24] W. Luo, An efficient detail-preserving approach for removing impulse noise in images, *IEEE Signal Process. Lett.* 13 (7) (2006) 413–416.
- [25] S. Schulte, V. De Witte, E.E. Kerre, A fuzzy noise reduction method for color images, *IEEE Trans. Image Process.* 16 (5) (2007) 1425–1436.
- [26] A. Toprak, I. Güler, Impulse noise reduction in medical images with the use of switch mode fuzzy adaptive median filter, *Digital Signal Process.* 17 (4) (2007) 711–723.
- [27] S. Morillas, V. Gregori, G. Peris-Fajarnés, A. Sapena, Local self-adaptive fuzzy filter for impulsive noise removal in color images, *Signal Process.* 88 (2) (2008) 390–398.
- [28] M. Tülin Yıldırım, Alper Bas türk, M. Emin Yüksel, Impulse noise removal from digital images by a detail-preserving filter based on type-2, *IEEE Trans. Fuzzy Logic Fuzzy Syst.* 16 (4) (2008) 920–928.
- [29] J.M. Lloyd, *Thermal Image System*, Plenum Press, 1975.
- [30] E.F. Godik, Y.V. Guljaev, Functional imaging of the human body, *IEEE Eng. Med. Biol.* 10 (4) (1991) 21–29.
- [31] D.C. Harris, *Infrared Window And Dome Materials*, The Int. Society Opt. Eng., SPIE, Bellingham, Washington, 1992. July.
- [32] A. Drozdek, *Data Structures and Algorithms in C++*, second ed., Thomson learning, USA, 2001.
- [33] M.T. Goodrich, R. Tamassia, D.M. Mount, *Data Structures and Algorithms in C++*, John Wiley & Sons, Inc., USA, 2004.
- [34] W.L. Lee, K.C. Fan, Design of optimal stack filter and under MAE criterion, *IEEE Trans. Signal Process.* 47 (December) (1999) 3345–3355.
- [35] Rafael C. Gonzalez, Richard E. Woods, *Digital Image Processing*, second ed., Prentice Hall, 2002.
- [36] Tukey J. M. *Exploratory Data Analysis*[M]. Reading , Massachusetts: Addison, Wesley, 1971. 55-105.
- [37] Castleman Kenneth R. *Digital Image Processing*[M]. Beijing: Electronics Industry Press, 2002. 204-206.
- [38] Xin Wang. Adaptive Multistage Median Filter[J]. *IEEE Transactions on signal processing*, 1992, 40(4):1015-1017.
- [39] Xiahua Yang and Peng Seng Toh. Adaptive Fuzzy Multilevel Median Filter[J]. *IEEE Transactions on image processing*, 1995, 4(5):680-682.
- [40] H. Hwang and R.A.Haddad. Adaptive Median Filters: New Algorithms and Results[J]. *IEEE Transactions on image processing*, 1995, 4(4):244-502.
- [41] Yüksel M. Emin, Besdok Erkan. A simple neuro-fuzzy impulse detector for efficient blur reduction of impulse noise removal operators for digital images[J]. *IEEE Transactions on Fuzzy Systems*, 2004, 12 (12) : 854-865.
- [42] Sorin Zoican. Improved median filter for impulse noise removal[J]. *TELSIKS Serbia and Motenegro*, Ni, 2003, 10(123):681-684.
- [43] Nelson H C Yung. Novel filter algorithm for removing impulse noise in digital image[J]. *SPIE*, 1995, 250(1):210-220.
- [44] Chih-Lung Lin, Chih-Wei Kuo, Chih-Chin Lai, Ming-Dar Tsai, Yuan-Chang Chang, Hsu-Yung Cheng, A novel approach to fast noise reduction of infrared image, *Infrared Physics & Technology* 54(1), (2011):1–9.



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A Novel Framework for Security Requirement Prioritization

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ABSTRACT

Security Requirements prioritization is one of the important Processes in the Software engineering, which aims at identifying and prioritizing the most crucial security requirements for the software project. In order to systematically perform this activity, many approaches have been introduced so far. Despite of the functionalities offered, these techniques have got certain pitfalls imbibed in them such as inefficient and inappropriate requirement gathering prioritization and hike in the specified project budget that leads to degradation in the software quality and security. So there is an imperative need for the efficient solution to overcome them. Thus In this paper, we have proposed a new methodology to prioritize the software security requirements generation process. This methodology improves the security in software applications of the business environment by gathering the properly processed requirements, identifying the vulnerabilities and their corresponding threats. Thus, it leads to the reduction in the estimated budget of the software application along with the security implication.

Keywords

Security Requirements, Threats, Vulnerabilities, Assets, Prioritization, Security.

1. INTRODUCTION

Software applications have become frequently ubiquitous, heterogeneous and susceptible. As reported in CERT [26], a lot of threats are being directed towards software community. These threats are too dangerous and harmful in nature. We need to extend such systems which would be threat-free. Thus, our major focus is to identify all the vital threats and prioritize them. Insecure software system increases the cost, time and may lead to the loss of customer's confidential data, which result into customer's dissatisfaction about using software.

To develop secure software, a lot of investments have to be done. In order to ensure safe and effective capital investment, we need to develop a threat-free system. If we don't develop a secure system then losses will be imparted on the software industry and hence, other industries will also be affected [31].

In general, any software can easily be targeted by viruses, outside attackers, application threats and intruders, etc [31]. If redundant applications are embedded within our main software, then its efficiency will not only be degraded but may even be vanished. Consequently, its reliability and performance gets deteriorated. To avoid failure of software applications, most of the software engineers generate software security requirements. This stage identifies, captures all the major threats to the system

and then constructs a firewall that can defend the system from all such threats. System Requirements have been developed by software generators to avoid failure of cost potential system [11, 12, 14, 23] which could get priority to be detected, sustained and further applied. Same principle may be applied to derive security mechanism. Our study shows that current software-development processes implement security events during design phase. In order to ensure safety of the software system, we must detect and collect the security requirements during early phase of SDLC. It thus intervenes with the efficient implementation by specifying the security related constraints. Contrastingly, the performance may be improved if we opted for some other mechanisms [10].

Security requirements are in sync along with functional requirements and hence are required to be captured along with. Security requirements should be accurate, adequate, absolute and non- conflicting with other requirements. Once they have been explicitly specified, they can then be implemented and maintained [33].

These requirements are associated with assets that must be protected and managed. Security requirements should be properly completed. If the assets are damaged, then it will be highly critical for the system and moreover, the value of the assets will also be increased. Some security systems (power point, Banking, Army plan, Science project) are more critical and their security is vital, because even a single threat can cause the complete failure of the system which may force the whole process to start from the scratch.

We aim to develop a well-defined process for security prioritization. Our study shows that we need to use the requirement prioritization which will prioritize each security requirement according to asset value, vulnerability and threat to decrease the cost and hence reducing the application development time.

2. RELATED WORK

There are numbered of proposals for eliciting security requirements using techniques like an abuse case [4], misuse case [1, 2, 21, 22] common criteria [3, 24] or attack trees [6]. These had been implemented using templates [19] but do not signify integrated with the traditional requirement engineering process. There have been proposed certain methods of modeling languages and methodologies like secure tropos, extension of tropos methodology [29]. Intentional anti model extension of KAOS methodology with security requirement oriented to construct [30]. However, these proposals do not account for the cost effectiveness to ensure security.

According to Fire Smith [7], the security requirements had been defined as being a necessary and fundamental component of the system that rendered detailed specification

of uncharacterized system behavior. He also distinguished security requirements had been discriminated from security related architectural constraints so that true security requirements can be figured out by the requirement engineer. Different types of security requirements as proposed by Firesmith [7] are given in [25]. Many vulnerability and security assessment tools have been developed [17, 19]. However, nearly all these efforts are collocated in finding vulnerabilities in the software that have been developed and deployed. Moreover, most of these tools [17] figured out security breaches in network-based systems. Clear point [20] is one of the methodologies to assess the overall security state of a software system that also takes into account the organizational security policies.

Various Risk Management approaches are AHP method [5], Impact validation method [7], cost-value approach [8] and OCTAVE [28]. DREAD [26] has been signified, which enhance security measurement levels in accordance with applied risk levels. An approach has been proposed recently by N.Mayer in order to integrate security constructs and risk management techniques for information system development method. According to AHP method, Karlsson and Ryan [8] proposed cost-value approach. It suggests that the comparison of requirement pairs is based on their significance and applicable costs. The percentage proportion in accordance with each requirement with total value and total cost related to all requirements are manipulated [3].

Karlsson and Regnell [8] have defined the proposed Ordinal cost-value approach. They categorized requirements into three groups in accordance with their value to customers and their implementation costs.

Impact validation method [7] suggested that every proposed requirement has an influence over acquired high level project targets. The most influencing requirement becomes the most critical one, and accordingly, the others may be given less priority.

Octave model [32] made the organizations understand, assess and address their information security risks from the organization's point of view. The analysis team had been formed of the people from operational, business and IT department and deals with addressing the security needs of the organization so that the risk of critical assets had been reduced. There had been no consideration of which security prioritization strategy to be applied for prioritizing the vulnerability and security requirements. OWASP does not anticipate [13] that OCTAVE will be used widely by application designers or developers, because it fails to take threat risk modeling into consideration, which is useful during all stages of development by all participants, to reduce the overall risk of an application becoming vulnerable to attack.

Security Quantification Methodology [9] provided the proper steps to prioritize the vulnerability based upon security requirements. But this model lags to identify the security requirements and their counterpart vulnerabilities. In the absence of proper values, the project might be executed but failure triggered [15].

The proposed framework is hybrid of Octave and Security Quantitative model. First, we are going to address Octave model to identify the security requirement, assets, threats and organizational vulnerability. Then we have applied the Security Quantification Methodology to address vulnerability and security prioritization [32][16][9].

3. PROPOSED FRAMEWORK FOR EARLY SECURITY REQUIREMENT PRIORITIZATION

The block diagram (see fig1) given below describes the major components and work flow of Hybrid Security Requirement Prioritization framework.

3.1 Workshop-based approach

The Workshop-based approach [7, 32] is used for gathering information and making decisions for organization. Knowledge elicitation workshops are facilitated by the analysis team of senior management, operational area management, project manager and staff. The purpose of the knowledge elicitation workshops is to identify the following information which could differ from organization to organization, depending on the perspective of business:

- Important assets and their relative values.
- Perceived threats to the assets.
- Security requirements.
- Organizational vulnerabilities.

3.2 Relationship between vulnerability and error

We need to gather all the vulnerabilities and respective error, which can cause these vulnerabilities in a particular software system [9].

3.3 Relationship between vulnerability and Security Requirement

The next step is to identify a relationship between security requirements and vulnerability so that after ranking these, we can remove all the vulnerabilities from the security requirements [28].

3.4 Relationship between assets and vulnerability

The relationship between assets and vulnerability [9] defines the impact of the vulnerability over the assets and then mentions the potential damage cost (($DANVXOY$ ((where $DAiVjOk$ is the damage caused to the i th asset by the k th occurrence of the j th vulnerability))) to each asset caused by vulnerability occurrence. Then it defines the implementation cost.

3.5 Calculate total damage

Here we have been computing the total damage cost ($TDVXOY$) [9] which may be caused by vulnerability as per the assets. We need to get the total of all the assets damage values as per vulnerability occurrence.

$$TDV_X O_Y = \sum_{n=1}^m DA_n V_X O_Y \quad (1)$$

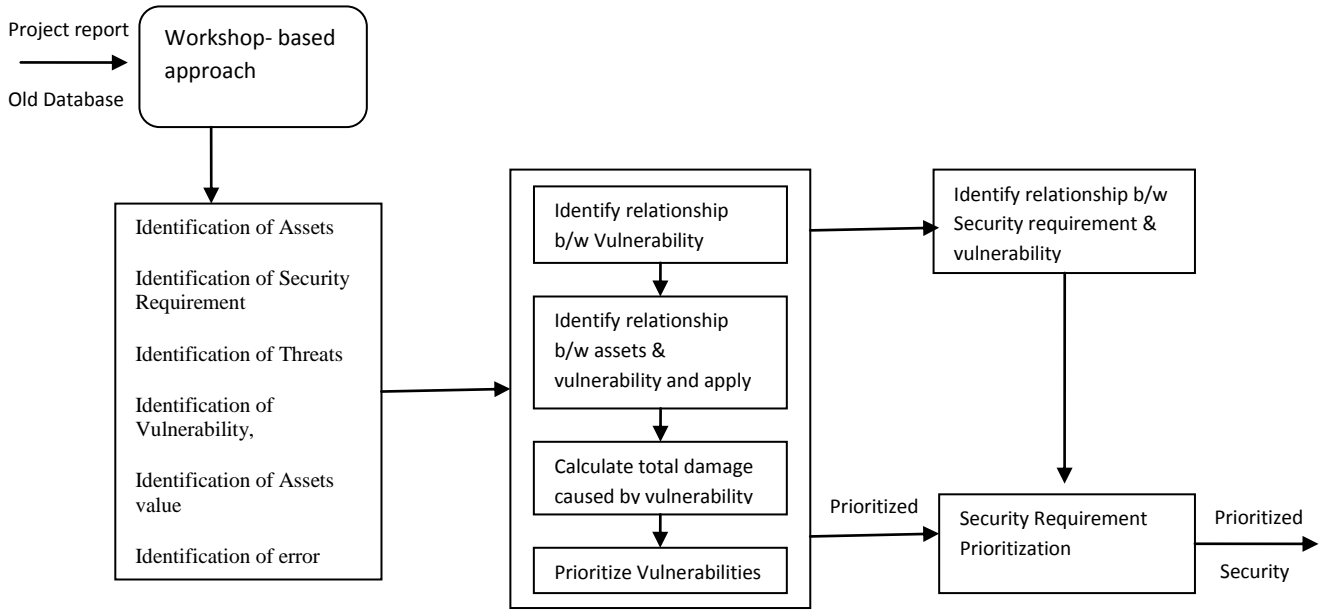


Fig 1: Hybrid Security Requirement Prioritization Block Diagram

3.6 Vulnerability Prioritization

Vulnerability prioritization [9] is based on the difference between the total possible damage cost (TDVXOY) to each asset and the implementation cost (CVXOY) to remove errors which causing a vulnerability occurrence.

$$PV_X O_Y = TDV_X O_Y - CV_X O_Y \quad (2)$$

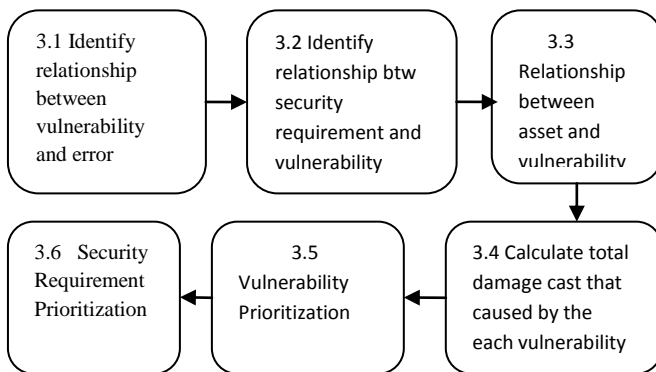


Fig 2: Modified Security Quantification Methodology

3.7 Security Requirement Prioritization

Security requirements have been prioritized according to the value of vulnerability prioritization. First, we have to identify a relationship between security requirement and vulnerabilities. According to that relationship the value of vulnerability priority will be assigned to corresponding security requirement.

Case1 – It is the sum of the priority values of all vulnerabilities, if corresponding to one security requirement there are more than one vulnerabilities.

Case2 – If there is only vulnerability corresponding to security requirement than what so ever is the value of vulnerability priority that will be assigned to the security requirement.

4. A HYPOTHETICAL SECURITY REQUIREMENT PRIORITIZATION ANALYSIS

In this section, we will implement the proposed framework using a case study of “Online Banking system (OBS)”. In this application, the customer can create an account electronically through internet and can get the account id on their email-id. The customer can perform online transactions through electronic payment gateways and can also inquire about account details viz canceled transaction details, etc.

4.1 Implementation and Results

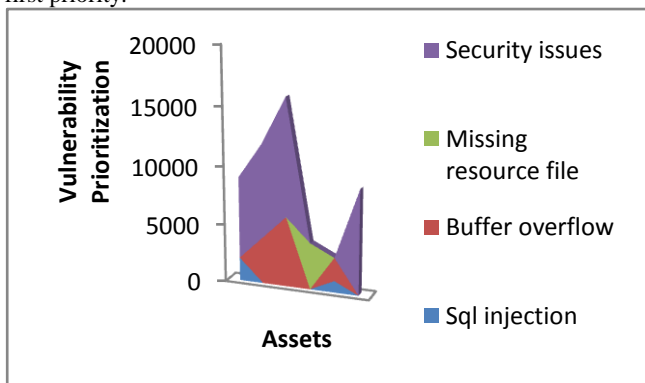
In order to elicit the software requirements for OBS we have used the Workshop-based approach. After applying this, we have collected the number of Assets, Vulnerabilities, Threats and Security Requirements and defined the relationship between each other.

We have summarized six assets and their corresponding vulnerabilities in the following table.

Table 1: Measure of Relationship between assets and vulnerability occurrences

Assets	Sql injection Vulnerability	Buffer overflow Vulnerability	Missing resource file Vulnerability	Security issues Vulnerability
User Login IP	$DA_{uV_{sql}}O_1 = 2,000$, $CV_{sql}O_1 = 1,000$			$DA_{uV_{si}}O_1 = 7,000$, $CV_{si}O_1 = 1,000$
Credit card IP		$DA_{ciV_{bov}}O_1 = 4,000$, $CV_{bov}O_1 = 1,000$		$DA_{ciV_{si}}O_1 = 8,000$, $CV_{si}O_1 = 1,000$
Debit card IP		$DA_{dcV_{bov}}O_1 = 6,000$, $CV_{bov}O_1 = 1,000$		$DA_{dcV_{si}}O_1 = 10,000$, $CV_{si}O_1 = 1,000$
Communication page			$DA_{accV_{ms}}O_1 = 4,000$, $CV_{ms}O_1 = 1,000$	
Cancellation IP	$DA_{ciV_{sql}}O_1 = 1,000$, $CV_{sql}O_1 = 1,000$	$DA_{ciV_{bov}}O_1 = 2,000$, $CV_{bov}O_1 = 1,000$		
Make payment IP				$DA_{mpV_{si}}O_1 = 9,000$, $CV_{si}O_1 = 1,000$
TDVXOY	3,000	12,000	3,000	34,000

The Total damage cost per assets for the OBS is (3,000, 12,000, 3,000, 34,000). Thus Information content with the highest value of total damage cost is most valuable and it has got the first priority.

**Graph 1: Measure of Vulnerability Prioritization**

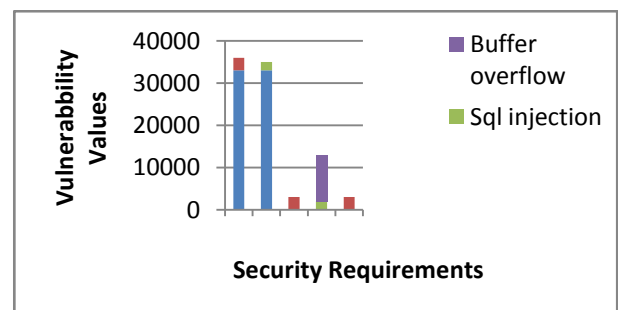
Graph1 shows the prioritization of different vulnerabilities. As per result, after applying the equation2, Vulnerability Prioritization has been ordered. Security issues vulnerability has first priority then buffer overflow vulnerability has second priority and so on.

Finally, we have arrived at our real task that is the calculation of priority of security requirement. We calculate the priority of security requirement just from the value of vulnerability priority.

Table 2: Measure of Security Requirement Prioritization

Security Requirement	Assets Name	Vulnerabilities	Vulnerability prioritization value	Security Requirement Prioritization
Authorization Requirement	Ussr login page, Credit card info, Debit card info, Communication channel, Make payment page	Security issues Missing Resources	33,000 3,000	36,000
Authentication Requirement	Communication channel, User login page, Cancellation page	Sql injection Security issues	2,000 33,000	35,000
Privacy Requirement	Communication channel	Missing Resource	3,000	3,000
Integrity Requirement	Credit card info page Debit card info page Cancellation page	Sql injection Buffer overflow	2,000 11,000	13,000
Identification Requirement	User login page Communication channel page	Missing Resources	3,000	3,000

Table 2 shows the different requirements and the values of their associated vulnerabilities, that we used for the process of prioritization of security requirements.

**Graph 2: Measure of Security Requirement Prioritization**

Graph2 shows the prioritization of different security requirements viz authorization, authentication, integrity, privacy and identification with respect to the occurrence of different vulnerabilities such as buffer overflow, sql injection, missing resources and security issues. It has come to notice that the Authorization Requirement has got the first priority, Authentication Requirement has second, Integrity Requirement comes at Third level; Privacy and Identification Requirement have fourth priority.

5. CONCLUSION

In this paper, we have presented the techniques for discovering security requirements along with functional and non-functional requirements. In addition, we have shown a method first to prioritize the vulnerabilities and based on that we prioritize the security requirements. We have illustrated this method with the help of example. Further complexities in these techniques are under processing. We are also implementing a system-based tool to incorporate these steps. In the future, try to be extend this work to incorporate the security characteristics, besides the CAME tool MERU [9] will be initiated in the construction of method, which includes the security engineering.

6. REFERENCES

- [1] Alexander IF, "Modeling the interplay of conflicting goals with use and misuse cases". In: Proceedings of the 8th international workshop on requirements engineering: foundation for software quality (REFSQ'02), Essen, Germany, 2002.
- [2] Alexander IF, "Misuse cases, use cases with hostile intent". IEEE Software, 2003, pp. 58– 66.
- [3] Common criteria for information technology security evaluation. Technical report CCIMB 99–031, Common Criteria Implementation Board, 1999.
- [4] John Mc Dermott, Chris Fox, "Using abuse case models for security requirements analysis." Department of Computer Science, James Madison University, 1999.
- [5] KARLSSON, J. and RYAN, K. "A Cost- Value Approach for Prioritizing Requirements", IEEE Software 14 (5), pp. 67–74, 1997.
- [6] Robert J. Ellison, "Attack Trees", Software Engineering Institute, Carnegie Mellon University, 2005.
- [7] Donald G. Firesmith, "Engineering Security Requirements", Journal of object technology, 2003, vol 2, no.1, pp.53-68.
- [8] KARLSSON, L. and REGNELL, B. "Comparing Ordinal and Ratio Scale Data in Requirements Prioritisation", Workshop on Comparative Evaluation in Requirements Engineering, 2005.
- [9] Muhammad Umair Ahmed Khan and Mohammad Zulkernine, "Quantifying Security in Secure Software Development Phases", Annual IEEE International Computer Software and Applications ConferenceIEEE, 2008.
- [10] GILB, K. "Evo - Evolutionary Project Management & Product Development". Book, 2006.
- [11] Johnson, J. "Chaos: The Dollar Drain of IT Project Failures," Application Development Trends, January 1995, pp. 41-47.
- [12] Lubars M., Potts C., Richer C., "A review of the state of the practice in requirements modeling", Proc. IEEE Symp. Requirements Engineering, San diego 1993
- [13] OWASP, https://www.owasp.org/index.php/Threat_Risk_Modeling#OCTAVE.
- [14] Karen Mc Graw, Karan Harbison, "User Centered Requirements, The scenario based", 1997.
- [15] VILHELM VERENDEL," Some Problems in Quantified Security", CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden 2010.
- [16] EBIOS-Expression of need and identification of security objectives, DCSSI, France, February, 2004.
- [17] Nessus. Configuring Nessus to perform local security checks on Unix hosts. <http://nessus.org/documentation/index.php>, Last Accessed 30-01-2008.
- [18] STAT Scanner. <http://www.lumension.com>, Last Accessed 30-01-2008.
- [19] F. Guo, Y. Yu, and T. Chiueh, "Automated and Safe Vulnerability Assessment", In Proc. of the 21st Annual Computer Security Applications Conference, Tucson, AZ, USA, 2005, pp. 150-159.
- [20] Clearpoint. <http://www.clearpointmetrics.com> Last Accessed 30-01-2008.
- [21] Sindre G, Opdahl AL, "Eliciting security requirements by misuse cases". In proceeding 37th Conference Techniques of Object-Oriented Languages and Systems, TOOLS Pacific 2000, pp 120-131.
- [22] Sindre G, Opdahl AL, "Eliciting security requirements with misuse cases". Requirements Engineering 10, Springer-Verlag London Ltd, January 2005, pp. 34-44.
- [23] The Standish group, Chaos. Standish Group Internal Report, 1995, <http://www.standishgroup.com/chaos.html>.
- [24] M. Ware, J. Bowles, C. Eastman, "Using the common criteria to Elicit security Requirements with use cases", 2006 IEEE Computer Society.
- [25] Agarwal A, Gupta D, "Security Requirement Elicitation Using View Points for online System". 2008 IEEE Computer Society.
- [26] CERT/Internet security vulnerabilities. Available Online: <http://www.cert.org>.
- [27] N. Mayer, P. Heymans, R. Matulevičius "Design of a Modelling Language for Information System Security Risk Management", In Proceedings of the First International Conference RCIS – 2007.

- [28] Alberts, Christopher and Dorofee, Audrey. OCTAVE Method Implementation Guide v2.0. Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University, 2001. <http://www.cert.org/octave>.
- [29] a) Paolo Giorgini, G.Manson, Haralambos Mouratidis. I.Philip, "A Natural Extension of Tropos Methodology for Modelling Security". In the workshop on Agent - oriented methodologies, at OOPSLA 2002.
- b) Paolo Giorgini, G.Manson, Haralambos Mouratidis. I.Philip, "Modelling Secure Multi agent System". AAMAS- 2003.
- [30] A.van Lamsweerde, "Elaborating security requirements by construction of intentional anti-models", Proceedings of the 26th International Conference on software engineering (ICSE'04), IEEE Computer Society, Washington DC USA, 2004, pp. 148-157.
- [31] Tom Olzak" A Practical Approach to Threat Modeling", March 2006.
- [32] Alberts, Christopher and Dorofee, Audrey. "OCTAVE Method Implementation Guide" v2.0. Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University, 2001. <http://www.cert.org/octave>.
- [33] Yngve Espelid" Practices in Software Security", University of Bergen, Norway, 2008.

A Survey of Cache Coherence Protocols in Multiprocessors with Shared Memory

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Abstract— Appropriate solution to illustrious Cache Coherence Problem in shared memory multiprocessors system is one of the crucial issue for improving system performance and scalability. In this paper we have surveyed various cache coherence mechanisms in shared memory multiprocessor. Various hardware based and software based protocol have been investigated in depth including recent protocols. We have concluded that hardware based cache coherence protocol are better than software based protocol according to presently available protocols, but hardware based protocol have added the cost to implement them. In comparison analysis of protocols on SMP Cache simulator by varying certain parameters we noticed that the Dragon Protocol is giving the best results in terms of number of hits at great extent. As software based cache coherence protocol are more economical therefore more devotion is needed for software based protocol as they show great promise for future work.

Keywords—Shared Memory, Multiprocessors, Cache Coherence Problem, Hardware Based Protocol, Software Based Protocol.

I. INTRODUCTION

These days the speed of processor is increasing exponentially. Multiprocessors are the best type of computer responsible for continuously increasing computing power. Among these multiprocessors with shared memory is the most efficient class of multiprocessors. In 2000, the sales of shared-memory systems with more than eight processors passed \$16 billion [1]. In multiprocessors system with shared memory, work load can be divided among these processors therefore, they work faster than uniprocessor. These systems allow the easier development of parallel software and also can increase the system throughput, reliability and they are economical too.

The shared memory multiprocessors suffer with significant problem of accessing shared resources in a shared memory it will result in longer latencies consequently the performance of the system will get affected. With the object of solving the problem of increased access latency due to large number of processors with shared memory, Cache is being used.

Every processor has its own private cache, now they can update or access the data comfortably but again it leads to another serious issue i.e. cache coherence problem.

Cache coherence problem arises when multiple processes are trying to access the same data for updating purpose or one processor is trying to modify the data and rest processors are trying to read simultaneously. It may lead to inconsistent state of data at cache of different processors and the main memory. We will discuss the solutions of cache coherence problem in detail.

In shared memory multiprocessors system where we can have multiple copies of same data in the private cache of processor. If all the processors are allowed to independently update the data then it will lead to malfunction. This is the well-known impression of cache coherence problem. We call the cache of the system coherent only if every read operation results in the value which is updated by previous write operation, even by the process at any other processor of that system. To resolve this problem the system must comprise of some mechanisms to maintain the coherent view of memory and assures execution of program with correct version data.

Cache coherence problem has attracted the attention of various universities and companies in last two decades. In fact the researchers had come out with lots of solutions to this problem. This problem is not only forcing the mal-functioning of the program but also impacting the system performance drastically. Efficiency of cache coherence depends on system

II. BACKGROUND

On the basis of write operation Cache Coherence Protocol can be categorized as [2]: 1. Write Update 2. Write invalidate. Difference between these two is that when one processor issues write operation Invalidate protocol modifies the copy of cache and invalidates all other copies of that data block. In case of update protocol it will not only write on that processor's cache which is trying to update but also

will forward this change to other existing copies. In 1993, Gee et al. compared invalidate, update, and adaptive protocols for cache coherence in [3][4]. They showed that invalidate protocols were best for vector data, update protocols were best for scalar data, and adaptive protocols were the best on average.

On the basis that how memory is updated we can categorize these protocol as [2] : 1. Write Through Protocol 2. Write Back Protocol. In write through protocol, when processor tries to update the shared data block, it will update in memory too. But in write-back protocol when processor tries to update, the main memory can be updated as:

- When the only valid copy of data block is available in the processor and it replaces that block
- When processor reads it from another processor's cache.

We can classify cache coherence mechanisms as:

1. Software-based solutions: These solutions generally rely on compiler or operating system dealing with coherence problem. Hardware-based solution: This approach can deal with coherence problem at run time.

If we compare these two strategies then we see that though hardware based solutions are expensive as it adds up new hardware cost but it is scalable up to hundreds or thousands of processors [5]. But when it come to software based solution, since it is not adding any hardware so cost is not getting enhanced but its scalable up to 32 processors only. And software based protocol are not capable to deal with coherence problem at run time.

III. HARDWARE BASED PROTOCOL

A. Snoopy Protocol

Snoopy Cache Coherence Protocol is primarily suited for multiprocessors system with shared memory that has bus with global interconnect, as the shared bus provide very inexpensive and fast broadcast to exchange coherence information among processors. It strictly maintains consistent view of data as any update done by the processor is immediately visible to all other processors of that system. But the shared bus becomes bottleneck for large number of processors. Though it can be resolved by increasing the bandwidth of the bus but consequently it will increase the memory delay. Therefore this protocol can be scaled up to 32 processors only[6].

B. Directory Based Protocol

In Directory Based Protocol the global system-wide status information relevant for coherence maintenance is stored in some kind of directory [7]. The responsibility of coherence is predominately delegated to centralized directory controller. On individual request from local cache controller, the centralized controller checks the directory and issue necessary command for transfer of data between caches or cache and memory. It also keeps the information about status, so that any local action which can impact the global state of block must be acknowledged to the central controller.

There is also a private cache, which keeps local state information about cached block. We can organize this global directory as [8]:

- Full Map Directory: In this all the cache can have a copy of every data block, i.e. each directory entry has P pointers where P is a number of processors of that multiprocessor system. The first protocol of this class was developed in IBM 3081 [9].
- Limited Directory: This scheme reduces the size of directory by having limited number of pointers for each entry in the directory without any concern with number of processors. The organization of limited directory scheme is described in [10]
- Chained Directory: Chained directory imitates the full map directory scheme by distributing the directory among caches. This scheme does not restrict the number of copies of shared data block. It actually keeps the track of shared data block by maintaining a chain of directory pointers and it does not use broadcast too that mean it does not introduce any increase in the traffic

These days many commercial multiprocessor systems implement directory-based coherence including the new SGI Origin which can have 1,024 processors in a maximal configuration.[11] Many versions of directory schemes have been proposed and many machines with hardware cache coherence have been built [12] [13] [14] [15].

C. Hybrid Cache Coherence Protocol

As we know that different data block present different access behavior, for this we require Cache Coherence Protocol which is capable of applying more than one protocol, is known as Hybrid Cache Coherence Protocol. This protocol has potentially enhanced the performance of multiprocessor system. It uses two basic protocol viz. invalidate protocol and update protocol[16][17].

In Hybrid Cache Coherence Protocol we have decision function as quintessence, which selects the appropriate protocol prior to or during execution of the program. The decision function is classified as: 1. Online Decision function. 2. Offline Decision Function. In Dynamic or Adaptive Hybrid Cache Coherence protocol, the shared data block residing in specific cache might get updated during the execution of an application. Hybrid Cache Coherence Protocol is also known as Competitive Update Protocol. The performance of this protocol is not good when we have migratory data i.e. data which is read or modified by multiple processors.

D. Lock Based Protocol

This Lock Based Cache Coherence Protocol is improvement of Directory based protocol presented in [18]. This is more promised towards scalability than directory based scheme by implementing scope consistency. The scope consistency is a compromise between lazy release consistency and entry consistency [18]. In this mechanism we do not have directory. All the memory coherence actions are taken through reading and writing to and from lock, which takes care of shared memory. When lock gets released it sends all the write notices to the home of the lock and all the modified memory lines. On acquisition of lock, processor knows from the home of the lock that which lines have been modified and can also access those modifications. This mechanism is more scalable as no directory is required but this scheme is slow as processor has to wait until lock is released and for all the writes to be transmitted and acknowledged.

IV. Software Based Protocol

A. MSI Protocol

This is basic protocol for write-back cache. It has three states, used for write-back cache to determine the valid data block which is not modified (dirty blocks). These states are:

- **Modified:** This is also known as dirty state. This cache has the only valid copy of data blocks, even main memory has incoherent copy of that shared data block.
- **Shared:** This means it is consistent copy of data.
- **Invalid:** This means that it is inconsistent copy of shared data block. In this protocol before write operation, all other copies of data shared data block must be invalidated.

B. MESI Protocol

It is also known as Illinois protocol, due to its development in university of Illinois at Urbana-Champaign [19]. This protocol is very renowned, supports write-back cache. It is better than MSI protocol as for every write operation there are two transitions, even when that data block is not shared then too. In the first transition it gets the memory block in shared state and in second transition causes write it also changes the state of that data block to shared state from modified state. It adds a new state to MSI protocol i.e. Exclusive state which reduces the traffic because of write operation of shared data block.

C. MOSI Protocol

MOSI is also an extension of basic MSI protocol. One new state has been added to it i.e. Owned state. When the cache line is in owned state has the most recent and correct copy of data. This new state: (i) is like shared state of data. (ii) it is also like modified state as main memory can have the stale copy of the data. At a time only one cache can be in owned state and all other cache hold the data in shared state. After writing, it changes to shared state by modifying the main memory.

D. MOESI Protocol

MOESI protocol encompasses all of the possible states used in other protocols. It has five states. The Owned state represents the data which is modified and shared. This avoids the need to write modified data back to main memory before sharing it.

E. Dragon Protocol

Dragon protocol was first time proposed by researchers at Xerox PARC for their dragon multiprocessor system [19]. It consists of four states:

- **Exclusive Clean (Exclusive):** It's like exclusive state of cache. In this case main memory is up to date.
- **Shared Clean:** More than one cache can have this data block but it may or may not be consistent with main memory.
- **Shared Modified:** More than one cache can hold this data block, but main memory does not have the recent copy of that data. The responsibility of updating this data block has been delegated to cache. At a time only one cache is in this state.
- **Modified:** It is like modified state of MSI protocol, which can modify shared data block and at this time main memory has stale copy of that data block which is updated by cache.

It does not have any explicit invalid state like MOSI, since it is an update-based protocol. It keeps the cache up-to-date, therefore we can use the data present in this cache at any time if the tag match is successful.

V. CSC(Coherent with Shared Cache) Protocol

This is the most recent cache coherence protocol, introduced in 2010 [20]. In this processor has three cache memories: 1.Current processor's private cache (local cache), 2.Remote processor's private cache (remote cache), 3. SC-cache. The SC-cache (Shared Coherence cache) is a small capacity cache, placed between private cache and the bus. This protocol is a combination of write-through and write-back mechanisms. This includes four states: 1.PI (Private Invalidate) 2. PD(Private Dirty) 3. PE (Private Exclusive) 4. SS (Share Shared).

The first three states are for local and remote cache but the fourth state exists in SC-cache only. In CSC protocol processor first access the local cache, if miss occurs then it searches at remote cache and if again miss occurs then local cache controller broadcast this request in the bus. The simulation results showed that as compared to Dragon protocol and MESI protocol, CSC protocol has reduced the number of times the write back to main memory and number of times the read operation and also total execution time is also reduced by nearly 10% [20]. It is better to employ CSC protocol with SC-cache then traditional protocol.

VI. MECSIF Protocol

MECSIF is recently developed hybrid cache coherence protocol which takes advantage of both directory based and snoopy protocol. This protocol introduced a small volume directory—DCache, which has overcome the problem of the shortcoming of undifferentiated broadcasting in snoopy protocol. [21]. It has seven states given as following: 1. E: Exclusive, 2. PC: Primary Clean, 3. SC: Slave Clean, 4. M: Modified, 5. S: Shared, 6. F: Forwarding, 7. I: Invalid. Simulation results show that the MECSIF protocol extent improves the efficiency of processor data access comparing with MESI protocol [21].

VII. Related Work

We have used SMP Cache simulator, by varying some parameters and keeping certain parameters fix we have drawn various results. As shown in table1. The Dragon Protocol is giving the best result in terms of increased number of hits and by reducing number of misses at great extent. The best results are shown in table 1. On whole we can conclude that if we want the best performance than SMP Cache simulator says

that the selection of dragon protocol will be the best decision.

TABLE I. COMAPRISON ANALYSIS.

Sr. No.	Set Associative	Cache Miss Ratio		
		MSI	MESI	DRAGON
1	2- Way	0.8794	0.1418	0.0095
2	4-Way	0.1387	0.1337	0.0313

VIII. Conclusion

This survey tries to give a comprehensive overview of hardware and software-based solution to cache coherence problem in shared memory processor. Both approaches perform well but their selection depends on the type of access pattern of shared data block and also number of processors we want to connect. Cache coherence significantly impacts the performance of the processor. The performance includes latency, bandwidth and protocol overhead.

Despite of considerable advancement in this discipline it's still very active research area. There exist many research topics like verification of protocol correctness, performance evaluation, comparison, size of the directory, minimization of protocol overhead. And more, which are needed to digged in the future.

IX. References

- [1] Alan E. Charlesworth. The Sun Fireplane System Interconnect. IEEE Micro, 22(1):36{45, January 2002.
- [2] P. Stenstorm, "A survey of cache coherence Schemes for Multiprocessors", IEEE Computer, Vol. 23, No. 6, June 1990, pp. 12-24
- [3] Ramon Lawrence "A Survey of Cache Coherence Mechanisms in Shared Memory Multiprocessors" University of Manitoba, May 1998
- [4] Jeffrey G. Gee and Alan Jay Smith. Absolute and comparative performance of cache consistency algorithms. Technical Report CSD-93-753, University of California, Berkeley, 1993
- [5] M. Tomasevic and V. Milutinovic, " Hardware Solutions for Cache Coherence ins Shared-Memory Multiprocessors Systems", The Cache Coherence Problem in Shared-Memory Multiprocessors: Hardware Solutions, M. Tomasevic and V. Milutinovic, Ed., IEEE Computer Society Press, Los Alamitos, California, 1993, pp. 57-67
- [6] R.Lawrence, "A survey of cache coherence mechanisms in shared memory", University of Manitoba May 1998
- [7] M. Tomasevic and V. Milutinovic, " A Survey of Hardware Solutions for Maintenance of Cache Coherence in Shared Memory Multiprocessors" IEEE 1993
- [8] Agrawal A., Gupta A., " Temporal, Processor, and Spatial Locality in Multiprocessor Memory References", Technical Report MIT/LCS/TM-397, June1989
- [9] Tang761 Tang C., "Cache System Design in the Tightly Coupled Multiprocessor System," Proceedings of the National Computer Confmce, 1976, pp. 749-753.

- [10] Aganwal A., Simoni R., Hennessy J., Hmwitz U, "An Evaluation of Directory Schemes for Cache Coherence," Proceedings of the 16th ISCA, 1989, pp. 280-289.
- [11] James Laudon and Daniel Lenoski, "The SGI Origin: A ccNUMA highly scalable server", In Proceedings of the 24th Annual International Symposim on Computer Architecture, pages 241-251, 1997
- [12] Daniel Lenoski, James Laudon, Kourosh Gharachorloo, Anoop Gupta, and John L. Hennessy, "The Directory-Based Cache Coherence Protocol for the DASH Multiprocessor", In Proceedings of the 17th Annual International Symposium on Computer Architecture, pages 148{159, Seattle, Washington, June 1990.
- [13] David Chaiken, John Kubiawics, and Anant Agarwal. LimitLESS Directories, "A Scalable Cache Coherence Scheme. In Proceedings of the 4th International Conference on Architectural Support for Programming Languages and Operating System", volume 26, pages 224{234, Santa Clara, California, April 1991.
- [14] Mark Heinrich, Vijayaraghavan Soundararajan, John L. Hennessy, and Anoop Gupta, "A Quantitative Analysis of the Performance and Scalability of Distributed Shared Memory", IEEE Transactions on Computers, 48(2):205{217, February 1999.
- [15] Richard Simoni and Mark Horowitz, "Dynamic Pointer Allocation for Scalable Cache Coherence Directories", In Proceedings of the International Symposium on Shared Memory Multiprocessing, pages 72{81, Tokyo, Japan, April 1991.
- [16] Fredrik Dahlgren, "Boosting the performance of hybrid snooping cache protocols", In Proceedings of the 22th Annual International Symposim on Computer Architecture, pages 60–69, 1995
- [17] Jack E. Ve e n stra and Robert J. Fowler, "The prospects for on-line hybrid coherency protocols on bus-based multiprocessors", Technical Report TR490, University of Rochester, Computer Science Department, March 1994.
- [18] W. Hu, W. Shi, and Z. Tang. A lock-based cache control protocol for scope consistency. *Journal of Computer Science and Technology*, 13(2), March 1998.
- [19] Silvia Lametti, "Cache Coherence Techniques", A Technical Report, December 2010
- [20] J. Li, W. Liu, P. Jiao, "A new kind of cache coherence protocol with SC-cache for multiprocessor", IEEE 2010
- [21] J J. Li, P. Yang, N. Ding ,H. Guan, J. Zhang, C. Men, "A New Kind of Hybrid Cache Coherence Protocol for Multiprocessors with D-Cache", IEEE 2011

Cost Benefit Analysis of Cloud Computing in Education

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Abstract—In the current financial crisis and the growing need for quality education, the educational institutions are under increasing pressure to deliver more from less. Both public as well as private institutions can use the potential benefit of cloud computing to deliver better services even with fewer resources. Application of Cloud Computing in Education not only relieve the educational Institutions from the burden of handling the complex IT Infrastructure management as well as maintenance activities but also lead to huge cost savings. Government of India is having the ambitious plan to raise the present 16 million enrolments in higher education to 42 million by 2020 as well as interconnect electronically India's 572 universities, 25,000 colleges and at least 2,000 polytechnics for enabling e-learning and content sharing across country. The launch of low cost, affordable Aakash tablet PCs for the student community is likely to increase the number of users' for educational online resources exponentially. In this paper we have studied about the benefit of use of cloud computing by educational institutions.

Keywords—National Knowledge Network (NKN); Virtual Computing Lab (VCL); Meta-University; Cloud Computing & Total Cost of Ownership (TCO).

I. INTRODUCTION

Financial crisis as well as the exponential demand for quality education has put the educational institutions under increasing pressure to deliver more from less. By sharing IT services and resources among themselves educational institutions can better concentrate on their core academic and research activities.

Cloud computing is an evolutionary step in computing that unifies the resources of many computers to function as single entity, allowing the construction of massively scalable systems that can take in and store, process and analyze all the data [2] of an organization. With cloud computing as part of IT strategy, an organization can increase their capacity without compromising security or requiring the educational institutions to make heavy infrastructure investments while helping to lower the Total Cost of Ownership (TCO). Therefore they need to find ways to offer rich and inexpensive services and tools [1] for academic and research activities with the right balance of on-premise and cloud services.

By combining the best practices of Virtualization, Grid computing, Utility computing and Web technologies the Cloud computing is a resultant computing infrastructure that inherits the agility of Virtualization, scalability of Grid computing and simplicity of Web 2.0.

Cloud Computing is a recurring expenditure model and is much like telephone or electricity expenditure and hence it is

accounted as standard Operating Expense (OpEx). OpEx is beneficial as it gives the flexibility to terminate costs at will. With a capital purchase, the server or software being acquired is fully committed to regardless of whether it is being utilized or not. The ongoing costs by way of depreciation or financing costs still need to be borne contrast to OpEx, where, in case the item is no longer required, payments can cease accordingly. Due to this reason many organizations prefer leasing vehicles in place of purchasing them outright.

In this paper we have compared the costs of Total Cost of Ownership (TCO) versus **Cost per User per Month** model for an organization of **30 users** for a period of **3 years**. Another analysis for replacing **5 PCs** for an Office environment by shifting to cloud computing for an analysis period of **3 years** was also found very impressive in terms of cost savings as well as other benefits like relieve from the burden of maintenance of computing infrastructure etc.

The rest of this paper is organized into 9 Sections. Section-2 is about cloud computing application in education while section-3 is about the virtual computing lab. In Section-4 we have made a comparative study on Cloud versus Total Cost of Ownership. In section-5 we have mentioned about cloud initiative in Singapore Polytechnic. Section-6 is about the India cloud scenario in education. Section-7 is about the 5 steps for integrated cloud management. Section-8 is a case study on Ben-Gurion University, Israel. Finally section-9 is our observations & conclusion.

II. APPLICATION OF CLOUD COMPUTING IN EDUCATION

Cloud computing offers the educational institution the opportunity of concentrating more on teaching and research activities rather than on complex IT implementation.

Many universities have already utilized the potential and efficiency of cloud computing in higher education. Among which we mention University of California, Washington State University's School of Electrical Engineering and Computer Science, higher education institutions from UK, Africa, U.S and others. By utilizing the cloud services, North Carolina State University achieved substantially decreasing expenses of software licensing as well as reduced the campus IT staff from 15 to 3 employees with full working schedule [3].

Florida Atlantic University (FAU) established in 1964 is the first public university in southeastern Florida with intake capacity of more than 29,000 students from a main campus in Boca Raton and 6 other campuses across southern Florida. Students are offered more than 170 degree programs. The faculty researchers use more than 40 research centers and the university offers hundreds of cultural and educational events

every year [4]. By virtualizing its data center using Hyper-V (a hypervisor based server virtualization product that allows consolidating workloads onto a single physical server), the University has been able to trim IT costs by at least U.S. \$600,000 and deliver new IT services without expanding its staff. The University was able to run Blackboard on Linux in the Hyper-V [22] environment, simplifying administration and delivering increased performance. By distributing computing power across campus locations and adding virtual machines on demand, the university can deliver higher availability of IT services and give students and staff a better computing experience [5].

Aga Khan University in Pakistan found that cloud computing helped strengthen security and improve protection against viruses, resulting in 66% reduction in calls to the IT department.

Cloud computing environment teaching resource library has the following characteristics:

- Stable with a powerful, convenient, fast search and query capabilities
- Standardization, classification specifications, user edit and use. Conducive to building the sustainability of the repository
- All information and data are in the clouds, local no need to retain and backup
- All types of users at all levels can be quickly and easily find the resources and the corresponding functions, and can be easily controlled cloud and treatment.

A. SaaS for Higher Education

Microsoft Live@edu is a program that provides students, staff, faculty and alumni long-term, primary e-mail addresses and other applications that they can use to collaborate and communicate online etc free of cost to educational Institutions. Students will be using Microsoft products similar to those used in many workplaces that help to prepare them for jobs after college. Microsoft's new customers include Portland Public Schools, Oregon; University at Albany, Fashion Institute of Technology, Vanderbilt University, City of Alexandria, Va [6] etc.

B. Cloud Computing in Distance Education

Modern Distance Education goal is to achieve 4A, namely Anyone, Anytime, Anyplace & Anything i.e. any person at any time, any place can be any content learning [7]. However, the services that current distance education sites to the learner's are far away from 4A. The organizations of educational resources are basically still in the information level, far short of the level of knowledge etc.

With the development of distance education network, the experiment has played an important role in learning. Experimental teaching is conducive to individualize learning for specific individual students with different learning requirement. Experimental teaching plays unique role as it has nonverbal communication and evaluation functions in the process of teaching. The basic requirements of students' hands-on practice are possible in experimental teaching while the distance learning mode cannot meet this requirement.

Collaborative Learning creates a community in which students can get emotional support as well as build trust among students [21].

Distance education based on Cloud Computing services will change this situation. With broadband Internet access the users are able to get all kinds of materials required for personal study environment by simply signing into their account. The cloud computing enhanced network flexibility and agility to learn and reduce the cost and difficulty of Web learning resources and services. It can supply a way of agile and flexible learning and a rich learning environment, helping to improve learning productivity and ultimately improve learning outcomes.

By combining the resources of different educational Institutions in the cloud will cut the resources investment to single [8]. The personal terminal devices which may be not a high quality to access the internet, the users can enjoy the cloud service and they don't need to upgrade the software. In order to avoid reconstruction and upgrade, there exists service or many services to store the resources [9].

In Cloud Computing teachers and students and students and students can implement collaborative learning such as the online exchange, online document editing, On-line using the concept map tool like Google Collaboration Platform [10]. Students will receive some emotional support in this community and there will formulate incentives to overcome the lazy in self-study between companies.

III. THE VIRTUAL COMPUTING LAB(VCL):A CLOUD COMPUTING SOLUTION FOR EDUCATION

Universities that are deploying a cloud expect some interesting benefits not associated with traditional labs and/or student workstations [11]. Some look forward to the increased personal safety of their students and the associated reduced security costs due to the ability to close those labs at night or even permanently. Students can access VCL using their laptops or workstations from their dorms or from home. Some universities are redefining those spaces for student collaboration environments or for other purposes and activities, saving construction costs etc.

Some of the benefits of VCL are summarized in the table:

Beneficiaries	Benefits
Students	<ul style="list-style-type: none"> • Raises computing resource accessibility, even in underserved districts • Increases availability and integrity of data, applications and research materials • Adds mobility • Reduces client application and system resource footprint • Amplifies application and computing performance • Improves server and data storage capacity • Offers convenient web access to the VCL
Faculty	<ul style="list-style-type: none"> • Grants accessibility to virtual machines • Schedules delivery of assignment instructions, study materials, syllabi or software • Enables faculty to create custom images for specific course, independent of (and not conflicting with) other faculty course images • Unites departments and campuses to eliminate information silos to deliver comprehensive

	educations
Administration	<ul style="list-style-type: none"> • Standardizes applications and processes • Provisions software, resources and management of data • Lightens the burden of software version control • Reduces total cost of ownership by nearly 50% to 90% • Lowers the need for in-house IT staff • Cuts resource management costs including power and cooling • Raises server utilization and software licenses, reducing purchasing requirements • Brings greater virtualization • Optimizes resource allocation

IV. CLOUD VERSUS TOTAL COST OF OWNERSHIP (TCO)

Storage is a considerable part of any desktop virtualization solution. Desktop virtualization software allows deploying and managing desktop environments and applications centrally. User access can be provided to a virtual desktop over standard network infrastructure without affecting the users' level of control over their desktop environments. The following table (survey by cloudservices@dinccloud.com) gives the comparative cost for Total Cost of Ownership (TOC) for 3 years and Cost per user per month (Cloud Computing) for 30 users for virtual Desktop [12].

TABLE II

Items	3 Years TCO	Cost/User/month
Hardware	\$ 761,892	\$ 622.45
Cables	\$ 480	\$ 0.4
IP Address	\$ 59,018	\$ 48.21
Management	Nil	Nil
MDS(Multilayer Director Switch)	\$ 17,895	\$ 14.62
Server	\$ 117,811	\$ 96.24
Storage	\$ 227,178	\$ 185.6
Switch	\$ 338,660	\$ 276.69
Thin PC	\$ 850	\$ 0.69
Software	\$ 210,019	\$ 171.57
Hosted Virtual Desktop(HVD)	\$ 43,414	\$ 35.47
Software		
Monitoring & Alerting	\$ 5,524	\$ 4.51
Office Standard	\$0	\$0
Patch Management	\$ 2,618	\$ 2.14
Profile Management	\$ 2,166	\$ 1.77
Profile Mobility	\$ 5,083	\$ 4.15
Security	\$ 3,507	\$ 2.87
Server License	\$ 116,429	\$ 95.12
Virtual Desktop Infrastructure(VDI) Assessment	\$ 1,666	\$ 1.36
Security Manager	\$ 8,000	\$ 6.53
Server Security	\$ 1,200	\$ 0.98
Virtual Desktop	\$ 14,746	\$ 12.04
Security	Nil	Nil
Email Security	\$ 2,611	\$ 2.13
Virtual Firewall	\$ 3,055	\$ 2.5
Support	\$ 46,930	\$ 38.34
Administration	\$ 28,215	\$ 23.05
Deployment	\$ 3,465	\$ 2.83
Help Desk	\$ 10,800	\$ 8.82
Power & Cooling	\$ 4,450	\$ 3.64
Grand Total	\$ 1,018,841	\$ 832.36

Hence the total savings is \$ 10, 18,009/-

A. Cloud vs. On-Premise Calculator

The following table shows the cost of On-premises versus Cloud computing environment [13] for an analysis period of 36 months (3 years) which is considered standard life of computing infrastructure. However, the analysis period and the number of PC to be replaced can be increased or decreased as per the requirement of the user. The calculations are for an identical office environment for 5 computers(10 users) developed by Uptime Systems, 708 South 3rd Street, Suite 110E, Minneapolis, MN 55415.

TABLE III

UP-FRONT COSTS		
Direct/Indirect Cost	On-premises	Cloud
Hardware: Server ,End points	\$ 5,500	Nil
Server OS & Client Access License	\$ 1,500	
Backup Hardware & Software	\$ 2,000	
Auxiliary Server Equipment	\$ 500	
Installation/Migration Costs	\$ 4,000	\$ 3000
Total	\$ 13,500/-	\$ 3000
MONTHLY COSTS		
Proactive Maintenance & Monitoring	\$ 300	Included
Backup Costs (Offsite/Online)	\$ 50	Included
Spam Filtering/POP3	Nil	Nil
Hosting Costs	Nil	\$ 450
Total Monthly Costs	\$ 350	\$ 450

Source: www.uptimesystems.net/Cloud

TABLE IV

Variable costs		
Unplanned Repair Costs	\$ 2000	Nil
SAVINGS ON PC'S		
No. PC's to Replace Over Analysis Period	Nil	5*
Savings per PC on Hardware	Nil	\$ 200
Savings per PC on Setup Labor	Nil	\$ 200
Savings per PC on Microsoft Office	Nil	\$ 200
Total Savings on PC's Over Analysis Period	Nil	\$ 3,000
=(\$200+\$200+\$200) x 5		

*No of PCs & analysis period can be increase/decrease as per requirement.

Total cost over estimated life of 36 months for On-premise=\$13,500/- + (36x \$350) +\$2000-0=\$28,100/-

Total cost over estimated life for cloud=\$3000/-+ (36 x \$450) +0-\$3000/-=\$16,200/-

Hence the saving for moving to cloud by replacing 5 PCs was \$11,900/-.

TABLE V

OTHER FACTORS	On-premises	Cloud
Accessible from Anywhere	Maybe	Yes
Subject to Facility Problems	*Yes	No
Built-In Business Continuity	No	Yes
Scalable	No	Yes
Built-In Branch Office Support	No	Yes
Consistent Desktop Environment	No	Yes
Microsoft Office Built-In	No	Yes
Secure & Private	Maybe	Yes
Likelihood of Outage	Low-Medium	Very low
Financing Necessary	Maybe	No

*An on premise server is subject to problems with the building, power, Internet, etc.

*With the business in the Cloud, the user has a built-in Business Continuity/Disaster Recovery plan.

*Owning a server is rigid and expensive to scale.

*Cloud allows flexibility and scalability.

*Virtual WORKPLACE provides a consistent desktop environment no matter where you are.

*Office licensing can be built into users plan and they are automatically entitled to new versions.

*Virtual WORKPLACE is protected by state-of-the art security and privacy systems.

*Virtual WORKPLACE guarantees 99.99% uptime. The significant up-front costs of a server may force user to obtain financing.

From the above analysis in both the cases the savings for moving to Cloud is impressive. The savings per user per month for the analysis of TCO versus cloud was \$942.60 whereas the savings in case of replacing office PCs by moving to cloud was \$33.05. In terms of cost savings the option of moving to cloud in comparison to TCO was more economic than replacing the PCs.

(i) On-premises versus Cloud:

The following table gives the details of the resources the user have to manage in On-premises, Hosted and Cloud environment:

TABLE VI		
On-premises	Hosted	Cloud
Application Runtimes SOA/Integration Databases Server Software Virtualization Server Hardware Storage Networking	Application Runtimes SOA/Integration Databases	Application

Hence in case of On-premises the entire responsibility of the computing environment is bestowed on the user.

V. SINGAPORE POLYTECHNIC CLOUD COMPUTING CENTER

Singapore Polytechnic Electrical and Electronic Engineering Cloud Computing Center (SPE3C3) at Singapore Polytechnic (SP) is the pioneer institute in Asia Pacific to equip its students with the latest skills in cloud computing through an operational data center environment.

Conceptualized by School of Electrical and Electronic Engineering of the polytechnic, the SPE3C3 will also provide teaching staff and students with on-demand, scalable, virtual computing and storage in labs to enable more sophisticated projects and research work. Singapore Polytechnic is utilizing the benefits of cloud computing to realize cost savings, energy efficiency and dynamic scalability.

The SPE3C3 was developed in collaboration with technology industry leaders Cisco, Citrix Systems and NetApp. While the resources will initially be available to the School of Electrical and Electronic Engineering students anywhere on campus, it will be accessible by all students on and outside of campus, as long as they have internet access, in the near future.

In the new academic year starting in April 2012, students in the 3rd year of the Diploma in Computer Engineering course at Singapore Polytechnic's School of Electrical and Electronic Engineering can look forward to two brand new elective modules- Data Center Management and System Virtualization -that will harness the power of the SPE3C3. These new courses are designed to train students to setup, manage and

support data centers, virtualization techniques including server, storage and network virtualization and data recovery.

II. INDIAN EDUCATION SYSTEM SCENARIO

Education sector is the 2nd largest sector globally and Indian school system is the world's largest school system with over 1.12 million schools. As on 26th August, 2011 in India there are 42 Central Universities, 280 State Universities 130 Deemed Universities and 94 Private Universities [14].

The development of the education sector is solution for economic growth and improvement in the standard of living. The challenges posed by the growing demand for education requirements are gigantic. India will have about 45 million people in the age group of 18 years to 20 years by 2020. To train them, we need more than 20 million teachers and the present vacant post of teachers in India is 1.2 million as on 05.09.2011. As per present trends, we will create only 20,000 teachers by 2020[10].

Government of India is having the ambitious plan to establish the meta-university with "new pedagogy" in tune with the requirements of the knowledge society of the 21st century.

Further on Government is seeking to open up establishment of foreign educational institutions in India through enactment of a Foreign Education Providers Act, which will allow for 100% foreign direct investment (FDI) in higher education.

Thus, the aim is to raise the present 16 million enrolments in higher education to 42 million by 2020. A 2nd wave of creating institution of excellence has been initiated by starting 8 Indian Institute of Technologies, 5 Indian Institutes of Science Education and Research, 16 central universities, 2 schools of Planning and Architecture, 3 Indian Institutes of Management, and 10 National Institutes of Technologies. The 14 innovation universities are also on anvil for setting up benchmarks in education and research. Government of India is also aiming to establish at least 50 research parks for quality research programs [15].

National Knowledge Network (NKN) [16] is a state-of-the-art multi-gigabit pan-India network for providing a unified high speed network backbone for all knowledge related institutions in the country. The NKN will enable scientists, researchers and students from different backgrounds and diverse geographies to work closely for advancing human development in critical and emerging areas. NKN has already connected 640 institutions and aims to connect electronically India's 572 universities, 25,000 colleges and at least 2,000 polytechnics for enabling e-Learning and content sharing across country soon [17].

The Indian clients such as mid-market vendors, universities, telecommunication companies and government bodies will be able to access the access the center for the resource they need to pilot cloud infrastructure and application to their customer. Indian Institute of Technology, Kanpur is the first to use IBM lab. Indian IT Industries like Infosys, IBM India, Accenture etc. have shown keen interest in promoting research in cloud computing.

India's Telecom Commission proposal to create a US \$4.5

billion National Optical Fibre Network (NOFN) approved by the Department of Telecom (DoT) which will broaden the country's existing fibre optic network from the district level to the village level giving the country of 1.2 billion people services like e-Education, e-Health, e-Banking etc [20].

VI. 5 STEPS TO SUCCESSFUL INTEGRATED CLOUD MANAGEMENT

A recent global IDC survey, sponsored by HP, examined the experience of this proactive group of integrated cloud managers. These organizations are actively integrating and automating application development, provisioning, security, and management across public and private cloud resources as well as Non-cloud application development and datacenter operations teams.

They are seeing many benefits, including faster application provisioning, lower application development and maintenance costs, improved business agility, higher service levels and improved business and IT relationships. Their experiences also highlight that success depends on cultural transformation as well as integrated and automated management processes and tools. An analysis of the experiences of these early adopters identifies five important steps for successful integrated cloud management. Specifically [18]:

- Define a plan that coordinates the organization's application modernization strategy with its cloud infrastructure and SaaS agenda
- Assess current costs and develop benchmarks for application support, provisioning and ongoing resource consumption
- Identify opportunities to reduce costs and speed up service delivery via use of automation for integrated application and infrastructure provisioning
- Implement systems to monitor and integrate application performance and real-time capacity planning analytics with automated provisioning solutions
- Integrate security strategies and priorities across the application development, release, and operations life cycle IDC recommends that organizations begin the journey toward integrated cloud management by targeting early pilot projects at developer teams and application environments that can deliver quick payback to validate the business agility benefits and operational efficiency improvements.

A. Security

Education institutions are entrusted with confidential information and private data. Security plays an important role in distance education [12]. The data either about hardware or software access Internet will be attacked by virus or Trojan when the users are dealing with the distance education. In worst case this will result in paralysis of the entire network system. The cloud storage mechanism can protect and monitor the data greatly enhanced the security of resources. As for the managers of Internet, they can unify data management, resources allocated, load balance, software deployment and the control of the security result in the reduction of investment

in human resources. NIST likens the adoption of cloud computing to wireless technology. Institutions learned how to protect their wireless data as they moved forward and they will do the same with cloud computing.

VII. CASE STUDY: BEN-GURION UNIVERSITY

Ben-Gurion University in Israel is a major center for teaching and research, with more than 19,000 students enrolled. The IT department at Ben-Gurion University is responsible for all computer related projects and issues for the entire university, including registration, academic research, computing classes and supported programs [19]. By utilizing a "Storage On-demand" model that enables researchers, labs, and whole departments to acquire managed disk space on an as-needed basis, Ben-Gurion allows groups to grow over time while ensuring all data is fully backed up to the university's backup filer and then archived to tape. Ben-Gurion was experiencing exponential data storage growth with an expanding number of research groups, university administration, and academic departments demanding ever-larger amounts of storage capacity. The department currently has a VMware server farm that runs over 50 virtual servers with 1.5 TB of disk space each from a centralized NetApp file server. With data storage demands continuing to grow rapidly, the IT department was looking for a new technology that would improve its storage efficiency. It needed a solution that would enable it to utilize existing disk capacity more efficiently without affecting performance or creating an additional layer of management complexity.

The university reduced storage management requirements and driving efficient utilization of its storage-on-demand services by 65% to 83%. The lifetime of its existing disk capacity extended and the frequency of new disk purchases reduced lowering the total cost of ownership of storage. This resulted in a better storage ROI for individual departments and research groups in less than one year. The IT department is able to offer its end users more storage capacity at the same cost and extend the life span of its current infrastructure despite growing storage requirements.

The seamless integration and transparency of the IBM Real-time Compression solution made the entire process transparent to the end users. In addition, the reduced storage footprint simplified storage management and made it easier to run mirroring and backup processes for ensuring data availability.

VIII. CONCLUSION

Application of Cloud Computing in Education not only relieve the educational Institutions from the burden of handling the complex IT infrastructure management as well as maintenance but also lead to huge cost savings. As the educational institutions facing lots of difficulties to handle the shortage of resources, the cloud is one of the viable options. Moving to Cloud the Educational Institutes can concentrate on their core activities of teaching and research.

Educational Institutes can start courses on cloud computing which will open up lots of job opportunities for the pass out. The existing computer centers of the Universities/

Engineering colleges can be upgraded to cloud computing center which will lead optimal utilization of computing resources as well as the technical expertise of the faculty/scholars of the institutions. Based on availability the computing services can be offered to nearby institutions which by beneficial for both the parties.

In case of On-premises computing infrastructure entire responsibility like Application, Runtimes, SOA/Integration, Databases, Server Software, Virtualization, Server Hardware Storage & Networking etc lies on the shoulder of the user. While in cloud the users have to manage only the Application stored on the Cloud.

The savings as a result of moving to Cloud is impressive. The total cost saving for 10 users for office PCs was found to be \$11,900/- for an analysis period of 3 years whereas the savings for same no of users' for the same analysis period was \$33, 9613/- for cost per user per month model vs. TCO (including hardware, software, networking equipment etc).

The following table shows the cloud computing market predicted by various surveys by 2020:

Cloud Type	Year 2011	Year 2020
Public Cloud	25.5	159.3
Virtual Private Cloud	7.5	66.4
Private Cloud	7.8	15.9
Total	40.8	241.6

All figures in US \$ in Billions

The transfer of the research results and the knowledge between cloud and networks and moving the knowledge to external providers may become a striking target to attackers.

For data protection issues special attention must be paid to the sensitive data from the institution such as research results, students' scholastic records, employees' accounts etc. The main options that may be taken regarding data are to preserve the sensitive data within the on-campus data centers and externalize the others with the risk of achieving a high latency for many applications and users. Externalize all the data with less potential for security risks.

The launch of Aakash tablet PCs for the student community is likely to increase the number of users' for educational online resources exponentially. Considering the mammoth Indian education sector, cloud computing can play a great role to bring a paradigm shift in teaching learning process in the future. The cloud computing has significant relevance in India considering the divergence of resources at multiple locations to converge it in an economical way.

Research and development of cloud computing in India has yet to take active role. In spite of having huge potential in human resources and marketing final product it is still in

nascent state.

An integrated approach is need of the hour to handle the situation. If the educational data is moved to the cloud, it can be very smoothly accessed by the NKN. The NOFN will be solving the connectivity problem to a great extent. As on date there is no Database of the passed out students of the Universities/Educational Institutions which is a handicap for cross verification/verification of the records in case of malpractices/forgery in India.

REFERENCES

- [1] The Transformation of Education through State Education Clouds, IBM Global Education, White Paper, IBM Cloud Academy
- [2] Cloud Computing: Big Data Technology by Michael Farber Senior Vice President 240/314-5671
- [3] Moving to the Cloud: An Introduction to Cloud Computing in Government by David C. Wyld Robert Maurin Professor of Management and Director of the Strategic e-Commerce/e-Government Initiative
- [4] <http://www.fau.edu/explore/>
- [5] http://www.microsoft.com/casestudies/Case_Study_Detail.aspx?CaseStudyID=4000011282
- [6] Using Cloud Computing in Higher Education: A Strategy to Improve Agility in the Current Financial Crisis, Marinela Mircea et al Academy of Economic Studies, Bucharest, Romania
- [7] A Cross Section of the Issues and Research Activities Related to Both Information Security and Cloud Computing, Naresh K Sehgal et al, IETE Technical Review pp-279-291
- [8] The Shallow Analysis of the Enlightenment of Cloud Computing to Distance Education, Ling Dong, Lun Han et al, 2010 International Conference on e-Health Networking, Digital Ecosystems & Technologies pp-301-303
- [9] The Application of Cloud Computing in Education Informatization, Bo Wang et al, 978-1-4244-9763-8/11/\$26.00 ©2011 IEEE pp-2673-2676
- [10] <http://www.mydigitalfc.com/op-ed/cloud-computing-education-112>
- [11] The Transformation of Education through State Education Clouds, IBM Global Education, White Paper, IBM Cloud Academy
- [12] <http://www.dincloud.com/tcoc/>
- [13] <http://www.uptimevirtual.com/CloudCalculator.htm>
- [14] <http://www.ugc.ac.in/inside/uni.html>
- [15] <http://timesofindia.indiatimes.com/home/education/news/Meta-university-may-start-from-next-academic-session-Sibal/articleshow/11748572.cms>
- [16] <http://nkn.in/index.php>
- [17] <http://www.livemint.com/2011/11/15224225/Prime-Minister-announces-meta.html>
- [18] <http://www.idc.com/getdoc.jsp?containerId=230389>
- [19] Ben-Gurion University with IBM Real-time Compression, IBM Systems and Technology case study
- [20] India Proposes National Fibre Network, By Xinghui Guo, 27th July 2011
- [21] Cloud computing in education, flexibility and choice for IT A Microsoft U.S. Education white paper, April 2010
- [22] <http://www.microsoft.com/en-us/server-cloud/hyper-v-server>

Environmental Assessment of Infrastructure Projects of Water Sector in Baghdad, Iraq

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ABSTRACT

In 1970s the city of Baghdad had a good infrastructure. Education and healthcare systems were widely regarded as the best in the Middle East. Income per capita rose to over US\$3600 in the early 1980s. Since that time, successive wars and a repressive, state-dominated economic system have stifled economic growth and development and debilitated basic infrastructure and social services. At the end of the 2003 war, Baghdad's infrastructure was seriously degraded. The majority of the population had limited or inadequate access to essential basic services. Currently, there is an ongoing effort by donor countries, such as the United States (US) (through the US Agency for International Development (USAID)), Japan, the European Union (EU), etc., as well as efforts by multilateral agencies such as the United Nations Children's Fund (UNICEF), the United Nations Development Programme (UNDP), the International Committee of the Red Cross (ICRC), and Non Governmental Organizations (NGOs), to restore the sector to standards that existed prior to the latest conflict. The present study deals with the evaluation of four projects proposed to improve the deteriorating status of water and wastewater treatment plants. Three methods viz. checklist, strategic environment assessment and cost and benefit analysis are used to evaluate the efficiency of the projects.

Keywords: Water Supply; Water and Sanitation; Wastewater; Infrastructure Projects; Drinking Water; WTPs; WWTPs; EIA; Cost and Benefit

1. Introduction

Infrastructural projects are very crucial in the overall development of society. They cater to the basic needs of the population and promote the growth of economy. The lack of basic infrastructure services, particularly electricity, has contributed to the general lack of security in various parts of the country. Today most Iraqis have limited access to essential basic services, including electricity, water supply, sanitation, and refuse collection. Serious environmental and health risks associated with contaminated water supplies, inappropriate handling of solid waste, and disposal of sewage threaten to further burden the already stressed health system [1].

After war against America in 2003, the young Iraqi government is trying to rebuild the basic infrastructures to cater to the needs of the people. Due to rapid industrialization and population growth in some of these regions, and increasing recognition of the regional and global environmental impacts of certain development projects, the need to apply EIA in these countries effectively is apparent. Environmental assessment of the infrastructural projects is a mandatory requirement of the international sponsoring loaning agencies (UNEP, UNESCO, WHO,

JICA, World Bank etc.). The International Organization for Standardisation (ISO) Standard 14011, which covers EIA, includes principal steps such as general requirements, environmental policy, planning, implementation and operation, checking and corrective action, and management review. Many of the current assessment approaches embody the steps of prediction, scaling and significant interpretation. The scientific validity of the technology available for the prediction of impacts varies depending upon the particular environmental descriptor.

2. Objectives and Approach

Environmental assessment of the proposed and ongoing Infrastructural projects in water sector is the primary objective of this study. Out of the various methodologies reportedly used to assess the environmental impact assessment of the infrastructural projects, three methods viz. Cost and benefit [2], Checklist [3] and Strategic Environmental Assessment (SEA) [4], have been used for each project. Checklist approaches present types of impacts typically associated with particular categories of projects. From a master list of environmental factors and environmental impacts, impact statements preparers select

and evaluate those impacts expected for the particular alternative under consideration. There are four basic categories of checklists viz. simple checklist, descriptive checklist, scaling checklist and scaling weighting checklist. Strategic environment assessment examines whether an intervention has achieved its intended outputs and outcomes. The challenge is to define clearly how to measure these achievements in an objective and robust manner. Finally the most contentious analysis in an EIA is the cost benefit analysis. It is a tool that decision-makers use to choose between alternative courses of action and in deciding whether a proposed project should go ahead or not.

3. Study Area

The capital city of Iraq, Baghdad has been selected as the study area (**Figure 1**). Baghdad is located at about 33.29°N, 44.40°E. The city lies on a vast plain bisected by the Tigris River. The Tigris splits Baghdad in half, with the Eastern half being called “Rusafa” and the Western half known as “Karkh”. The study area, covering the whole Baghdad Mayorality (BM) area, is divided into eleven administrative districts (municipalities) viz. Adhamiya, Sader 1, Sader 2, Rusafa, Nissan, Karadah, Khadamiyah, Mansour, Karkh, Rasheed and Doura [5]. Baghdad has a hot arid climate and is, in terms of max-

imum temperatures, one of the hottest cities in the world. The city has about 7.4 million inhabitants (2005 estimate), situated in the interior of the country on the Tigris River at the point where land transportation meets river transportation, and where the distance between Tigris and the other main river of Iraq, Euphrates, is the shortest. The soil consists of about 10 m deep silt-clay soil strata on the surface, and thick sand/gravel strata beneath it [6]. The study region has been classified to 25 land use/land cover classes from 1973 to 2007 using ArcGIS v.9.1 software [7]. There are a wide variety of industries, producing leather goods, furniture, wood products, chemicals, electrical equipment, textiles, clothing, bricks, cement, tobacco, processed food and beverages [8].

Since 1991, the water supply and sanitation sector has experienced a steady but devastating decline. At the end of the 2003 war, Iraq's infrastructure was seriously degraded. The deficiency of basic infrastructure services has added to the general lack of security in various parts of the city. The majority of the population had limited or inadequate access to essential basic services. Those who could afford it relied on costly alternatives for electricity and water services. Contaminated water supplies, improper handling of solid waste and disposal of sewage led to environmental degradation and increased health hazards. What had escaped destruction and looting operates at minimal capacity due to years of neglect and lack

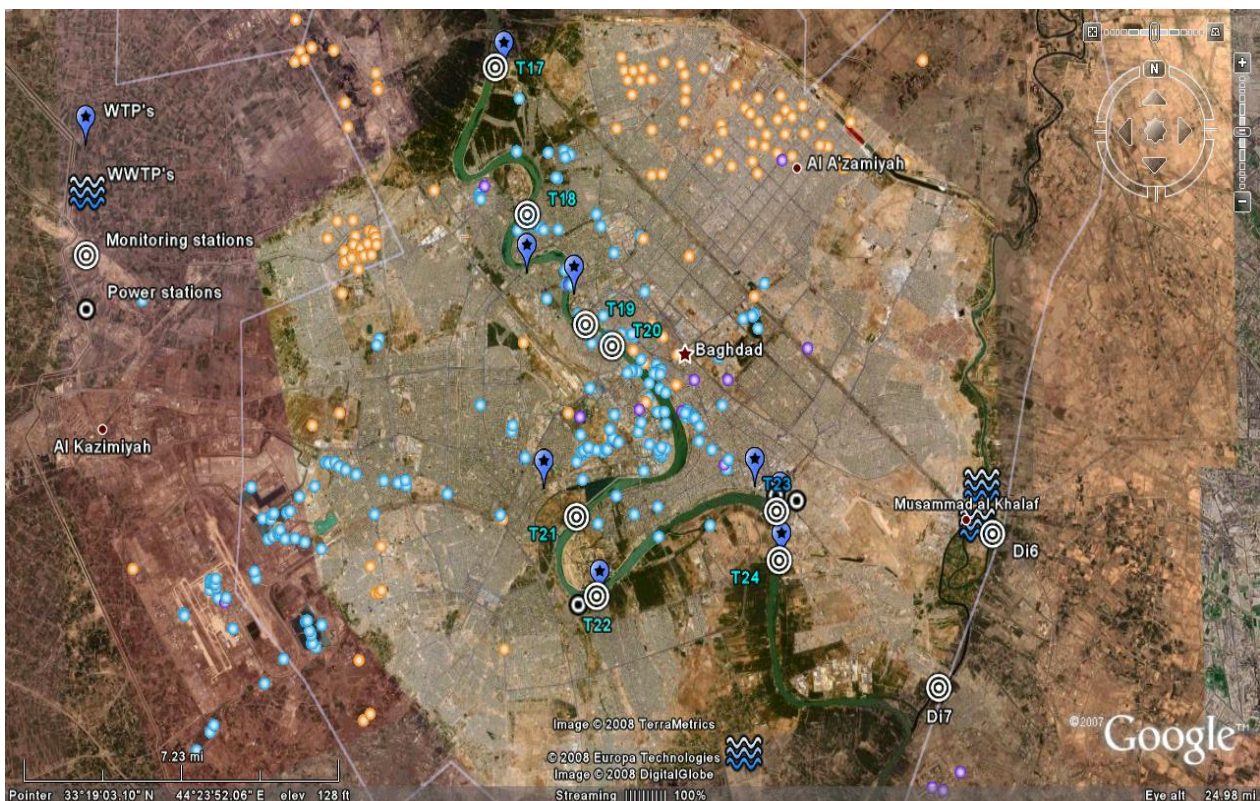


Figure 1. Baghdad map.

of maintenance. This situation weakened urban economies and the income of the population. Without the improvement project, the current severely deteriorated public health and water environment in Baghdad will further get worse, and reducing essential services to its people. Public health conditions will continue to deteriorate in the absence of adequate sewerage services in Baghdad. Pollution of local groundwater and of the Tigris River, already serious, could rise to more dangerous levels. The disposal and waste system, and animal retention areas and pens are primitive, ineffective, and a major health risk. Furthermore, environmental standards for odour control, waste disposal, and effluent control and treatment do not exist [1].

Furthermore, the unpaved and dilapidated conditions of roads in the cities and residential quarters, the lack of proper storm water drainage, and the formation of stagnant water pools and the muddy/sandy roads' conditions are impeding the flow of human and vehicular traffic and increasing health risks. The majorities of governorates suffer from insufficient and damaged urban roads and storm water drainage, street lighting and social facilities. Improving the roads' conditions and increasing their capacity in major urban areas becomes necessary for improved access of the populations to markets and social services and for the economic well-being of the city [9].

4. Proposed Projects

Various infrastructural projects that are considered for

the present study are described briefly below. These projects are the initiatives taken up by the government of Iraq with the support of the international funding organizations like World Bank, JICA etc. to improve the deteriorating status of water and wastewater treatment plants. They are briefly described in the following paragraphs.

4.1. Improvement of Integrated Sewerage System in Baghdad

In order to improve such acute deterioration of public health and environmental conditions in Baghdad, BM and the Japan International Cooperation Agency (JICA) started this project to establish an immediate improvement program for the Baghdad Sewerage System. **Figure 2** represents the activity locations of project 1. The study area, covering the whole BM area, was divided into eleven administrative districts (municipalities) viz. Adhamiya, Sader 1, Sader 2, Rusafa, Nissan, Karadah, Khadamiyah, Mansour, Karkh, Rasheed and Doura. The sewer service area was divided into two sewer districts, 1) Rusafa and 2) Karkh. The study report [10] presented the results of identification and field survey on the present situation of Baghdad's sewerage system, and provided planning bases for the forthcoming Master Plan (M/P) and Feasibility Study (F/S) on the improvement of Baghdad integrated sewerage system. Also the need for the sewerage system improvement strategy plan was examined, and priority sewerage components that are to be immediately rehabilitated and/or extended were selected [11].

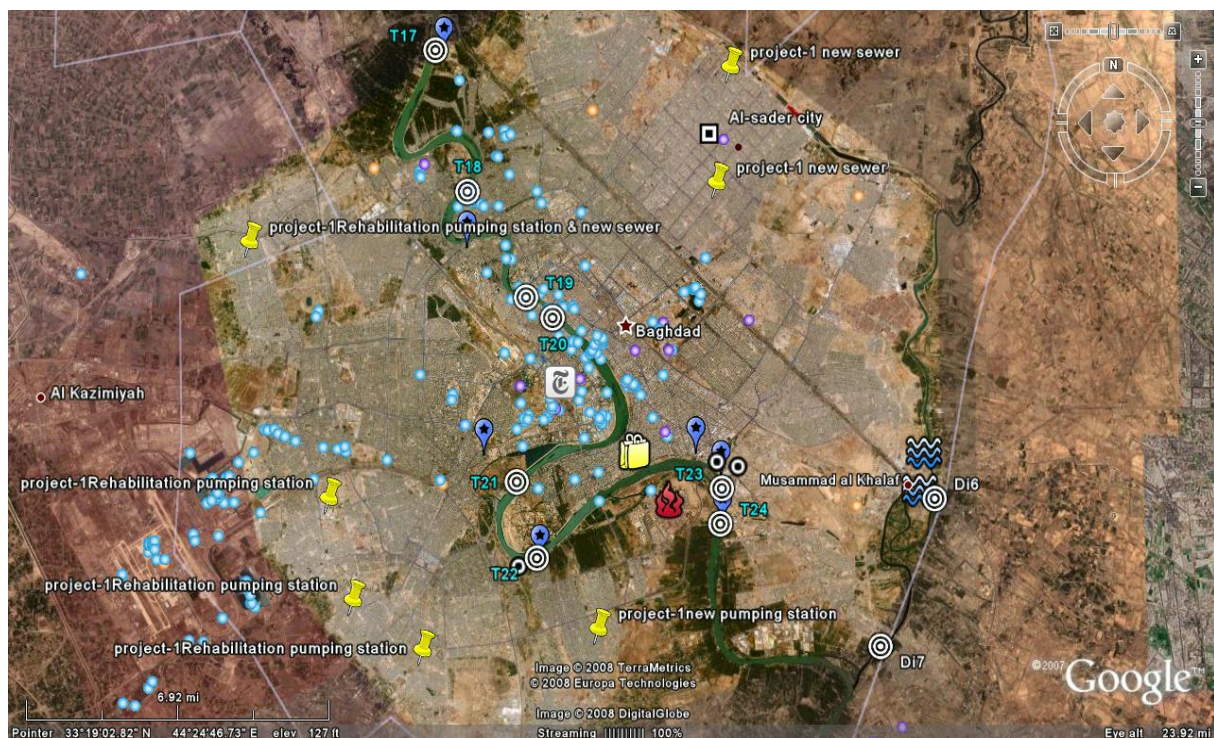


Figure 2. Location various 1st project in Baghdad.

4.2. Emergency Baghdad Water Supply and Sanitation Project

This project represented the first phase of the Emergency Infrastructure Reconstruction Program, described in the Project Information Document (PID) of April 21, 2004 [1], which intended to cover five sectors: water supply and sanitation, electricity, urban rehabilitation, transport, and telecommunications. The project addresses the urgent reconstruction needs of Baghdad including water mains, distribution pipes, sewer collectors, pumping stations, small treatment plants, and auxiliary facilities. It provides support to the MOB to better manage projects at the design, supervision, operation and maintenance stages by building the capacity of the staff working in the water supply and sanitation sector. It also includes the development of a Comprehensive City Development Plan (CCDP) to ensure that future expansion of the water supply and sanitation networks are in line with the overall urban development plan for the city. The principal objective of the project is to assist in restoring basic water supply and sanitation services for the capital city of Baghdad through 1) the reconstruction and rehabilitation of existing priority networks and treatment facilities and 2) providing capacity building support through training and technical assistance.

4.3. Emergency Water Supply, Sanitation and Urban Reconstruction Project

The project represents the part of the Emergency Infrastructure Reconstruction Program, described in the Project Information Document (PID) of April 21, 2004, which intended to cover five sectors: water supply and sanitation, electricity, urban rehabilitation, transport, and telecommunications [9]. The project addresses the urgent sectoral needs of urban communities outside Baghdad including rehabilitation of water and sewer networks, pumping stations, small treatment plants, community roads and other urban facilities. It provides support to the MMWP to better manage projects at the design, supervision, operation and maintenance stages by building the capacity of its staff.

The principal objective of the project is to restore some basic water supply, sanitation and urban services for urban areas outside Baghdad City through 1) the reconstruction and rehabilitation of existing facilities, and 2) providing capacity building support through training and technical assistance. This project also aims to improve the existing environmental and health conditions by renewing the old water networks and sanitation services. It will also contribute to the reduction of waterborne diseases through the reduction of water supply by tankers and the provision of potable water and sanitation networks. This would also help improve the economic con-

ditions of the population by reducing the amounts of water obtained from tankers, which is generally more expensive.

4.4. Baghdad Infrastructure Reconstruction

The principal objective of the project is to restore essential infrastructure and services by addressing the urgent reconstruction needs highlighted in the Needs Assessment. The project will also create badly needed employment; and it will help build Iraq's capacity to manage large-scale reconstruction. The component of this project includes rehabilitation of chlorine and chemical process in all water treatment plants, rehabilitation of pumping stations in all water treatment plants, constructing of new networks for newly planned cities and sub-cities, technical assistance and capacity building [12].

5. Results of Environmental Assessment

The details of evaluation for the first project are given below. The results of checklist are presented in **Table 1** (water supply checklist) and **Table 2** (sewage treatment checklist). The results for cost and benefit analysis are shown in **Table 3**. The same procedure of analysis has been adopted for the other three projects and overview is presented in the end. In the checklist for water supply and sewerage certain numerical values have been assigned which measure the impact of a particular condition in the checklist. These numerical values range from 0 to 5 where 0 means no impact and 5 means maximum impact. These values were assigned on the basis of visual interpretation of the project site and information provided by the Ministry of Environment.

The first project (Improvement of integrated sewerage system in Baghdad) satisfied all the conditions included in the checklist and the Strategic Environmental Assessment (SEA) method. From the cost and benefit method, the cost involved in the project was evaluated to be 2714×10^6 US\$ the benefit 6185×10^6 US\$. This gives a B.C Ratio of 2.28, which is greater than 1, indicating that the benefit obtained is more than the cost involved.

A brief discussion on the results obtained for the other projects is presented below:

In case of the second project there were certain conditions mentioned in the checklist for water supply that were not fulfilled. The intake wells were not adequately protected, inadequate buffer zone around pumping stations and treatment plants to reduce noise. This project also lead to relocation of people and an increase in road traffic due to interference of construction activities. There was an excessive abstraction of water affecting downstream water users. In the case of the checklist for sewage and sanitation many conditions were violated. There was interference with other utilities and blockage of

Table 1. Checklist for water supply for Project 1.**Rapid Environmental Assessment (REA) Checklists****WATER SUPPLY****Instructions:**

- ☐ This checklist is to be prepared to support the environmental classification of a project. It is to be attached to the environmental categorization form that is to be prepared and submitted to the Chief Compliance Officer of the Regional and Sustainable Development Department.
- ☐ This checklist is to be completed with the assistance of an Environment Specialist in a Regional Department.
- ☐ This checklist focuses on environmental issues and concerns. To ensure that social dimensions are adequately considered, refer also to ADB checklists and handbooks on (i) involuntary resettlement, (ii) indigenous peoples planning, (iii) poverty reduction, (iv) participation, and (v) gender and development.
- ☐ Answer the questions assuming the "without mitigation" case. The purpose is to identify potential impacts. Use the "remarks" section to discuss any anticipated mitigation measures.

Country/Project Title:

Improvement of integrated sewerage system

Sector Division:

Baghdad, IRAQ

SCREENING QUESTIONS	Yes	No	Range (5-0)
A. Project Sitting Is the project area...	<input type="checkbox"/>	<input type="checkbox"/>	
▪ Densely populated?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
▪ Heavy with development activities?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
▪ Adjacent to or within any environmentally sensitive areas?			
• Cultural heritage site	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Protected Area	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Wetland	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Mangrove	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Estuarine	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Buffer zone of protected area	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Special area for protecting biodiversity	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Bay	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
B. POTENTIAL ENVIRONMENTAL IMPACTS Will the Project cause...			
▪ pollution of raw water supply from upstream wastewater discharge from communities, industries, agriculture, and soil erosion runoff?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ impairment of historical/cultural monuments/areas and loss/damage to these sites?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ hazard of land subsidence caused by excessive ground water pumping?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ social conflicts arising from displacement of communities ?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ conflicts in abstraction of raw water for water supply with other beneficial water uses for surface and ground waters?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ unsatisfactory raw water supply (e.g. excessive pathogens or mineral constituents)?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ delivery of unsafe water to distribution system?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ inadequate protection of intake works or wells, leading to pollution of water supply?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ over pumping of ground water, leading to salinization and ground subsidence?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ excessive algal growth in storage reservoir?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0

SCREENING QUESTIONS	Yes	No	Range (5-0)
▪ increase in production of sewage beyond capabilities of community facilities?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	3
▪ inadequate disposal of sludge from water treatment plants?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ inadequate buffer zone around pumping and treatment plants to alleviate noise and other possible nuisances and protect facilities?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ impairments associated with transmission lines and access roads?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ health hazards arising from inadequate design of facilities for receiving, storing, and handling of chlorine and other hazardous chemicals.	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ health and safety hazards to workers from the management of chlorine used for disinfection and other contaminants?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ dislocation or involuntary resettlement of people	<input checked="" type="checkbox"/>	<input type="checkbox"/>	3
▪ social conflicts between construction workers from other areas and community workers?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ noise and dust from construction activities?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1
▪ increased road traffic due to interference of construction activities?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
▪ continuing soil erosion/silt runoff from construction operations?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ delivery of unsafe water due to poor O&M treatment processes (especially mud accumulations in filters) and inadequate chlorination due to lack of adequate monitoring of chlorine residuals in distribution systems?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ delivery of water to distribution system, which is corrosive due to inadequate attention to feeding of corrective chemicals?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ accidental leakage of chlorine gas?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ excessive abstraction of water affecting downstream water users?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ competing uses of water?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ increased sewage flow due to increased water supply.	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1
▪ increased volume of sullage (wastewater from cooking and washing) and sludge from wastewater treatment plant	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0

Table 2. Checklist for sewage treatment for Project 1.

Rapid Environmental Assessment (REA) Checklist

SEWAGE TREATMENT

Instructions:

- ☐ This checklist is to be prepared to support the environmental classification of a project. It is to be attached to the environmental categorization form that is to be prepared and submitted to the Chief Compliance Officer of the Regional and Sustainable Development Department.
- ☐ This checklist is to be completed with the assistance of an Environment Specialist in a Regional Department.
- ☐ This checklist focuses on environmental issues and concerns. To ensure that social dimensions are adequately considered, refer also to ADB checklists and handbooks on (i) involuntary resettlement, (ii) indigenous peoples planning, (iii) poverty reduction, (iv) participation, and (v) gender and development.
- ☐ Answer the questions assuming the “without mitigation” case. The purpose is to identify potential impacts. Use the “remarks” section to discuss any anticipated mitigation measures.

Improvement of integrated sewerage system

Country/Project Title:

Sector Division:

Baghdad, IRAQ

SCREENING QUESTIONS	Yes	No	Range (5-0)
B. Project Siting Is the project area...			
▪ Densely populated?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
▪ Heavy with development activities?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
▪ Adjacent to or within any environmentally sensitive areas?	<input type="checkbox"/>	<input type="checkbox"/>	
• Cultural heritage site	<input type="checkbox"/>	<input type="checkbox"/>	
• Protected Area	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Wetland	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Mangrove	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Estuarine	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Buffer zone of protected area	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Special area for protecting biodiversity	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
• Bay	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
A. Potential Environmental Impacts Will the Project cause...			
▪ impairment of historical/cultural monuments/areas and loss/damage to these sites?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ interference with other utilities and blocking of access to buildings; nuisance to neighboring areas due to noise, smell, and influx of insects, rodents, etc.?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ dislocation or involuntary resettlement of people.	<input checked="" type="checkbox"/>	<input type="checkbox"/>	3
▪ impairment of downstream water quality due to inadequate sewage treatment or release of untreated sewage?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ overflows and flooding of neighboring properties with raw sewage?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ environmental pollution due to inadequate sludge disposal or industrial waste discharges illegally disposed in sewers?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ noise and vibration due to blasting and other civil works?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ discharge of hazardous materials into sewers, resulting in damage to sewer system and danger to workers?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1
▪ inadequate buffer zone around pumping and treatment plants to alleviate noise and other possible nuisances, and protect facilities?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
▪ social conflicts between construction workers from other areas and community workers?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ road blocking and temporary flooding due to land excavation during the rainy season?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ noise and dust from construction activities?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1
▪ traffic disturbances due to construction material transport and wastes?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	1
▪ temporary silt runoff due to construction?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ hazards to public health due to overflow flooding, and groundwater pollution due to failure of sewerage system?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ deterioration of water quality due to inadequate sludge disposal or direct discharge of untreated sewage water?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ contamination of surface and ground waters due to sludge disposal on land?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0
▪ health and safety hazards to workers from toxic gases and hazardous materials which maybe contained in sewage flow and exposure to pathogens in sewage and sludge?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0

Table 3. Cost and benefit analysis for Project 1.

Year	Cost	Benefit	Net benefit	Pwb	Pwc	Pwnb
	×10 ⁶	×10 ⁶	×10 ⁶	×10 ⁶	×10 ⁶	×10 ⁶
2005	0.00	0.00	0.00	0.00	0.00	0.00
2006	86.00	0.00	-86.00	-32.59	32.59	-65.18
2007	131.00	0.00	-131.00	-50.64	50.64	-101.27
2008	121.00	0.00	-121.00	-47.71	47.71	-95.41
2009	32.00	0.00	-32.00	-12.87	12.87	-25.74
2010	131.00	0.00	-131.00	-53.74	53.74	-107.47
2011	131.00	0.00	-131.00	-54.81	54.81	-109.62
2012	129.00	0.00	-129.00	-55.05	55.05	-110.11
2013	32.00	0.00	-32.00	-13.93	13.93	-27.86
2014	32.00	0.00	-32.00	-14.21	14.21	-28.42
2015	85.00	0.00	-85.00	-38.50	38.50	-76.99
2016	85.00	0.00	-85.00	-39.27	39.27	-78.53
2017	80.00	0.00	-80.00	-37.69	37.69	-75.39
2018	80.00	0.00	-80.00	-38.45	38.45	-76.90
2019	58.00	232.00	174.00	85.30	28.43	56.87
2020	59.16	236.64	177.48	88.74	29.58	59.16
2021	60.34	241.37	181.03	92.33	30.78	61.55
2022	61.55	246.20	184.65	96.06	32.02	64.04
2023	62.78	251.12	188.34	99.94	33.31	66.63
2024	64.04	256.15	192.11	103.98	34.66	69.32
2025	65.32	261.27	195.95	108.18	36.06	72.12
2026	66.62	266.50	199.87	112.55	37.52	75.03
2027	67.96	271.82	203.87	117.10	39.03	78.06
2028	69.32	277.26	207.95	121.83	40.61	81.22
2029	70.70	282.81	212.11	126.75	42.25	84.50
2030	72.12	288.46	216.35	131.87	43.96	87.91
2031	73.56	294.23	220.67	137.20	45.73	91.47
2032	75.03	300.12	225.09	142.74	47.58	95.16
2033	76.53	306.12	229.59	148.51	49.50	99.00
2034	78.06	312.24	234.18	154.51	51.50	103.00
2035	79.62	318.49	238.86	160.75	53.58	107.17
2036	81.21	324.86	243.64	167.24	55.75	111.50
2037	82.84	331.35	248.51	174.00	58.00	116.00
2038	84.50	337.98	253.49	181.03	60.34	120.69
2039	86.18	344.74	258.55	188.34	62.78	125.56
2040	87.91	351.63	263.73	195.95	65.32	130.63
2041	89.67	358.67	269.00	203.87	67.96	135.91
2042	91.46	365.84	274.38	212.11	70.70	141.40
2043	93.29	373.16	279.87	220.67	73.56	147.12
2044	95.16	380.62	285.47	229.59	76.53	153.06
2045	97.06	388.23	291.17	238.86	79.62	159.24
2046	99.00	396.00	297.00	248.51	82.84	165.68
2047	100.98	403.92	302.94	258.55	86.18	172.37
2048	103.00	412.00	309.00	269.00	89.67	179.33
2049	105.06	420.24	315.18	279.87	93.29	186.58
2050	107.16	428.64	321.48	291.17	97.06	194.12
2051	109.30	437.21	327.91	302.94	100.98	201.96
2052	111.49	445.96	334.47	315.18	105.06	210.12
2053	113.72	454.88	341.16	327.91	109.30	218.61
2054	115.99	463.97	347.98	341.16	113.72	227.44
Total				6185	2714	3471

B.C Ratio = 2.28.

access to buildings, nuisance to neighboring areas due to rodents, insects and noise. There was dislocation or involuntary resettlement of people, inadequate buffer zone around the pumping stations and social conflicts between construction workers from other areas. Apart from this there was a lot of noise and dust from construction activities, traffic disturbances due to construction material temporary silt runoff due to construction. The SEA method showed that the project is unable to avoid conflicts between the water users. There was inadequate protection of intake wells and no buffer facilities have been provided to alleviate noise. The pumping stations for waste were not given enough buffer facilities and due to improper waste disposal techniques the downstream water quality was found to be bad.

Finally the total cost involved in the project is 267×10^6 US\$ and the benefit attained was 367×10^6 US\$. The B.C Ratio thus came out to be 1.33. Since the B.C Ratio is greater than 1, it indicates that the benefit attained is greater than the cost involved.

For the third project the water supply checklist indicated that there was inadequate buffer zone around pumping and treatment plants to alleviate noise and other possible nuisances and protect facilities. The project caused dislocation or involuntary resettlement of people. There was a lot of noise and dust from construction activities. There was increased volume of sillage and sludge from the wastewater treatment plant. The sewage treatment plants were flooded with overflowing sewage, blocking access to building and some were breeding grounds for mosquitoes and rodents. In some places there was discharge of hazardous materials into sewers resulting in blockage. Due to lack of funds and frequent wars, proper care was not taken towards groundwater pollution due to untreated sewage. The SEA method showed that in case of water supply the project satisfies all the conditions except for one condition, which said that no buffer facility was provided around the project to alleviate noise and other nuisances. This resulted in a lot of noise pollution in the surrounding areas. In case of sewage and sanitation checklist, the sewage pumping stations were located within the city and not well kept. They were not well buffered and in unhygienic conditions. In some cases the intake of the sewage treatment plants was more than its capacity, which lead to unhygienic conditions in the surrounding areas. Further, considering the cost and benefit method it was found that the cost involved in this project was 37×10^6 US\$ and the benefit obtained was 62×10^6 US\$. Thus the B.C Ratio came out to be 1.67. Since the B.C Ratio is greater than 1, it showed that the benefit is greater than the cost, which further indicated that the project is good. The total cost involved was found to be 267×10^6 US\$ and the benefit attained, 367×10^6 US\$. The B.C. Ratio came out to be 1.33. In this

case also the B.C Ratio is greater than 1, which indicated that the benefit is greater than the cost.

In case of the 4th project, the checklist for water supply showed that there is an inadequate protection of intake wells or works, leading to the pollution of water supply, increase in production of sewage beyond capabilities of community facilities, inadequate buffer zone around pumping stations and treatment plants to lower down noise, insufficient health and safety hazards to workers from the management of chlorine used for disinfection and other contaminants. In the checklist for sewage treatment most of the conditions were not satisfied. The conditions that were satisfied were adequate protection of historical places, adequate buffer zone protection to the pumping stations, settling social conflicts among the water users, protection from noise and dust and avoiding traffic disturbances. From the SEA method it was seen that in case of water supply, sometimes the treatment plant capacity was less than the intake due to which large quantities of wastewater and sewage was thrown untreated. The pumping stations were located within the cities and were not well maintained giving rise to noise pollution and unhygienic conditions. Further, from the cost and benefit method, it was found that the total cost involved is 351×10^6 US\$ and benefit, 395×10^6 US\$. Thus the B.C Ratio was 1.12. This Ratio is again greater than 1, which shows the benefit is greater than the cost.

6. Conclusions

After evaluation one can say that the first project is the best project, the next best project is the third project followed by the second project and finally the least good project is the fourth project.

REFERENCES

- [1] World Bank, "Emergency Baghdad Water Supply and Sanitation Project," World Bank Iraq Trust Fund, Washington, DC, 2004, pp. 5-38.
- [2] R. J. Kopp, A. J. Krupnick and M. Toman, "Cost-Benefit Analysis and Regulatory Reform: An Assessment of the Science and the Art," Discussion Paper, Resources for the Future, Washington, DC, 1997, pp. 79-86.
- [3] ADB, "Environmental Assessment Guidelines," Asian Development Bank, Mandaluyong City, 2003, pp 96-145.
- [4] DAC, "Applying Strategic Environmental Assessment," Development Assistance Committee DAC Guidelines and Reference Series," OECD Organization for Economic Co-operation and Development, Washington, 2006, pp. 17-64.
- [5] S. A. H. Saleh, Al-Bayati Sataa A. F., Izzat Maha A. W., "Evaluation and Forecasting of Baghdad City Public Services by GIS Techniques," University of Technology Baghdad, Baghdad, 2007, pp. 5-12.
- [6] Md. J. B. Alam, M. S. Rahman and M. H. Hossain, "As-

- essment of Population Exposure Risk and Risk Zones due to Surface water quality by GIS—A case study on Sylhet,” *ARPJ Journal of Engineering and Applied Sciences*, 2006. (pp. 1-3).
- [7] S. A. H. Saleh, “Remote Sensing Technique for Land Use and Surface Temperature Analysis for Baghdad, Iraq,” University of Al-Nahrain, Baghdad, 2003, pp. 9-10.
- [8] Central Intelligence Agency (CIA), “The Online Factbook Is Updated Periodically throughout the Year,” McLean, 2008, pp. 1-13.
- [9] World Bank, “Emergency water Supply, Sanitation and Urban Reconstruction Project,” World Bank Iraq Trust Fund, Washington, DC, 2004, pp. 8-94.
- [10] UNEP Report, “Experience Funds for Project Provided to UN Trust Fund by Japanese Government, to Be Implemented by UNEP,” United Nations Environment Programme, Media, 2004, pp. 22-36.
- [11] JICA, Japan International Cooperation Agency Guidelines for Environmental and Social Considerations, Tokyo, 2004, pp. 11-20.
- [12] World Bank Report, “Emergency Infrastructure Reconstruction Project,” Washington, DC, 2004, pp. 1-8.

Event Driven test case selection for Regression Testing Web Applications

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Abstract— Traditional testing techniques are not apt for the multifaceted web-based applications, since they miss the additional features of web applications such as their multi-tier nature, hyperlink-based structure, and event-driven feature. As software systems evolve, errors sometimes sneak in; software that has been tested on certain inputs may fail to work on those same inputs in the future. Regression testing aims to detect these errors by comparing present behavior with past behavior. Although regression testing has been widely used to gain confidence in the reliability of software by providing information about the quality of an application, it has suffered limited use in this domain due to the frequent nature of updates to websites and the difficulty of automatically comparing test case output. In this paper we propose a new paradigm that exploits regression testing to be used by web applications. This event-driven technique is based on the creation of event-dependency graph of the original and modified web application, then converting the original and modified web application graph into event test tree, followed by the comparison of both trees to identify affected and potentially affected nodes which enables selection of test cases for regression testing web applications finally reducing the test set size. We apply this technique to a case study to demonstrate the usefulness of the proposed paradigm.

Keywords- Regression Testing, Web Application, Event Dependency Graph, Event Test Tree

I. INTRODUCTION

A web application is a software application that is accessible via a client (i.e. web browser) over a network such as the Internet or an Intranet [1]. Web applications generate web pages, which contains different kinds of information such as text, images and forms. It can be simple login page on web site or it can be as complex as word processor or spreadsheet. Web application contains code of server side as well as client side. Commonly used web applications include login, online shopping, online retail sales, online marketing and many other functions

The key intent of software testing is to assess or evaluate the capabilities or attributes of software's ability to adequately meet the applicable standards and customer needs. As software systems evolve, errors sometimes sneak in; software that has been tested on certain inputs may fail to work on those same inputs in the future. Regression testing aims to detect these errors by comparing present behavior with past behavior [2]. Regression testing is used to check

the code's integrity and is mainly performed during automated builds tightly to ensure that errors are detected and recovered as soon as possible.

Web applications are becoming more complex due to increase use of distributed servers, larger number of hyperlinks, and their usage in our daily life modeling can help us in engaging in these complex interactions. The main drawback in web application is that it may have several entry points, and users can not prevent from these complicated interactions. Traditional testing techniques are not suitable for web-based applications, since they miss their additional features such as their multi-tier nature, hyperlink-based structure, and event-driven feature. Although regression testing has been widely used to gain confidence in the reliability of software by providing information about the quality of an application, it has suffered limited use in this domain due to the frequent nature of updates to websites and the difficulty of automatically comparing test case output.

Web applications evolve and undergo changes in the maintenance phase, the retesting of changed programs is done thereafter, which involves selection of a subset of the whole test suite on the condition that the selected subset will give confidence about covering the changes [3]. Regression testing techniques are required for adequate selection of these subsets of test cases. Realizing this objective, in this paper we propose a new paradigm that exploits regression testing to be used by web applications. This event-driven technique relies on the creation of event-dependency graph for the original and modified web application, then converting the original and modified web application graph into event test tree to remove cyclic redundancies, followed by the comparison of both trees to identify changed and potentially affected nodes, which enables selection of test cases for regression testing web applications finally reducing the test set size.

II. RELATED WORK

Very limited work has been reported on regression testing web-based application. Xu [4] modeled web applications as three interacting models; the object model, the interactive relation model, and the architectural model, and they proposed four testing methods which are applicable to test web application. The authors pointed out that it is essential to regression test all the components changes; however, the

complexity and dynamic changes of the web application make it difficult to use the traditional testing techniques. In [5], Xu modeled web applications using System Dependent Graph (SDG) and introduced a regression testing technique for web application based on slicing. Although the SDG will increase the workload and cost of the testing process, the slicing technique gives the tester more focus on simplified contents, and improves the working efficiency. In [6], Ricca and Tonnella suggest a UML model of web applications and propose that all paths that satisfy selected criteria be tested. In [7], Tarhini et al. modeled a web application and its components behavior as a two level abstract model. The model that takes into consideration timing constraints is represented by a Timed Labeled Transition Systems TLTS. Further he suggested a safe regression testing algorithm to test web applications. In [3], Tarhini et al. proposed a safe regression testing selection technique, based on event dependency graphs (EDG); however, cyclic redundancies complicate the testing process visibly.

Instigated by the challenges related to the diversified web applications and identified need to develop simplified techniques for automatically comparing test case output, we propose an Event Driven test case selection paradigm for Regression Testing of Web Applications. The proposed work is a step forward to the work carried by Tarhini et al [3], thus providing a solution to the problem of cyclic redundancy, simplifying the test process required for adequate selection of these subsets of test cases. We apply this technique to a case study to demonstrate the usefulness of the proposed paradigm.

This paper is organized as follows; in section 3, the terminology related to the proposed paradigm is presented. Section 4 expounds our Event Driven test case selection paradigm for Regression Testing of Web Applications. In Section 5, we present a case study based on a web application. Section 6 concludes the paper.

III. TERMINOLOGY

The basic terminology used in the proposed paradigm is as follows:

A. Event

The events represent changes in the system state, and services define the states in which they can be running, and how the system reacts accordingly. The standard web application is event driven with event occurring whenever a user submits a page, i.e., Web applications are constructed by integrating components that can be invoked via events.

B. Event-based dependencies

When users browse any web application they traverse among various pages. When user clicks

on some event by clicking on hyperlink or pressing any button he is directed to some other page.

Thus, Event-based dependencies are classified into three categories namely, link, visible effect, and invisible effect dependencies.

- Link dependency: It holds between two pages if the first requests the second via an event (usually by enabling a hyperlink); the page requested by user is represented by solid arrow and
- Visible effect dependency: If the requesting page modifies the other via an event and the second page opens with the modified data; represented by square dashed arrow
- Invisible effect dependency: If one page modifies other page without displaying any effect; represented by square pointed arrow.

C. Event- Dependency Graph (EDG)

Event dependency graph is a graphic structure that represents any web application with its interacting components and dependencies. It depicts the relationship between two pages, i.e., the page/pages reached when a user clicks on some event. The drawback of an EDG is that it is cyclic (contain loops) and there is no termination. Further, it possesses scalability problem and makes the testing process complicated.

D. Event- Test Tree (ETT)

Event test tree removes all the disadvantages of EDG. ETT is a **spanning tree** made from EDG which does not contain any cyclic loops and from which shorter paths are generated.

E. Affected and Potentially Affected Nodes

The affected nodes are the nodes that are directly affected by the change. They are visibly different in original and modified web application.

The potentially affected nodes are the nodes that may be affected by the change. These nodes are connected either directly or indirectly to the affected nodes are potentially affected nodes.

The following section expounds the proposed paradigm.

IV. REGRESSION TESTING PARADIGM

The proposed event-driven technique relies on the creation of event-dependency graph for the original and modified web application, then converting the graphs into event test tree thereby removing cyclic redundancies, followed by the comparison of both trees (original &

modified) to identify affected and potentially affected nodes. This enables selection of test cases for regression testing thus reducing the test set size.

The following figure 1 illustrates the proposed approach.

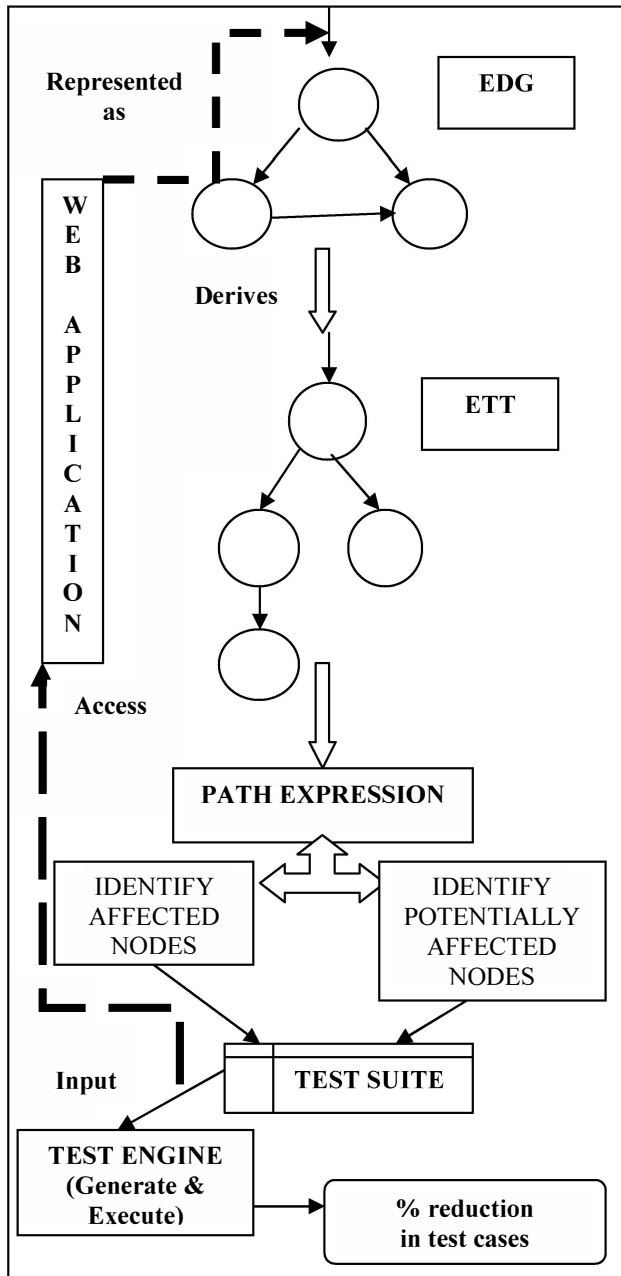


Figure 1. The Event Driven Regression Testing Paradigm

The approach can be summarized by the following steps:

- Model the web application and the modified web application by using **event dependency graph**.
- Convert **event dependency graph to event test tree** which will avoid scalability and redundancy issues for original and modified web application
- Identify the changed (affected) nodes by comparing the nodes from both trees.
- Identify the potentially affected nodes.
- Select the test cases that pass through the changed nodes and the potentially affected nodes.
- Calculate the reduction in test cases from original and modified one.

The following sub-section expounds the details of the approach.

A. Event Dependency Graph (EDG)

Event dependency graph of web application shows relationship between various pages. In our approach, the first step is to make EDG of original and modified web application. It will represent the web application (original & modified) with its interacting components and dependencies (link, visible effect, invisible effect).

A sample EDG is shown in figure 2. Entry to first node is default entry (home page). P1 to P2 is link dependency like when an event occurs by hyperlink. P4 to P6 is invisible effect dependence, i.e., P4 is modifying P6 without displaying the effects. P5 to P6 is visible effect dependence, i.e., P6 is opened with some new data.

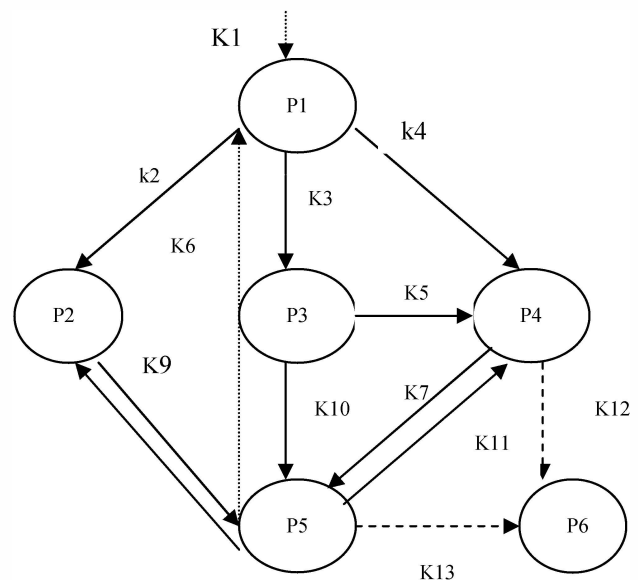


Figure 2. Event Dependency Graph

B. Event Test Tree (ETT)

The advantage of using EDG is that we can easily find path but the disadvantage is that the paths can be cyclic with no termination, i.e., there is starting node but no ending node specified. ETT derives the path expression like $p1 \rightarrow p3 \rightarrow p5$ which enables to know the exact path to be followed and that the starting or root node is $p1$ and the end node is $p5$. Thus, we convert the EDG to Event test tree, which is spanning tree from which shorter paths are generated. Thus, as the second step of our approach, the ETT of original and modified web application are constructed. The algorithm for the conversion is as follows[8]:

Input: An EDG

Output: An ETT derived from the EDG

Begin

1. Add the initial page identifier of the EDG into FIRST;
2. If FIRST is empty, then go to 6;
3. Select the first page identifier denoted by pid from FIRST.

If pid is within SECOND, then go to 5.

Otherwise, add it into the end of SECOND;

4. if pid is linking to other pages, then if some of the other

page identifiers are within FIRST or SECOND, then generate their copies;

- retain the links between pid and the other pages (or their copies) of the EDG, and
- add the other page identifiers (or their copies) into the end of FIRST;

5. delete pid from FIRST and then go to (2);

6. Output the derived ETT, which is the EDG with only the

retained links.

TABLE I. EDG to ETT

STEP	FIRST	SECOND
1	P1	NULL
2	P2,P3,P4	P1
3	P3,P4,P5	P1,P2
4	P4,P5,P4,P5	P1,P2,P3
5	P5,P4,P5,P5,P6	P1,P2,P3,P4
6	P4,P5,P5,P6,P6,P1	P1,P2,P3,P4,P5
7	P5,P5,P6,P6,P1	P1,P2,P3,P4,P5
8	P5,P6,P6,P1	P1,P2,P3,P4,P5
9	P6,P6,P1	P1,P2,P3,P4,P5
10	P6,P1	P1,P2,P3,P4,P5,P6

11	<u>P6,P1</u>	P1,P2,P3,P4,P5,P6
12	<u>P1</u>	P1,P2,P3,P4,P5,P6
13	<u>NULL</u>	P1,P2,P3,P4,P5,P6

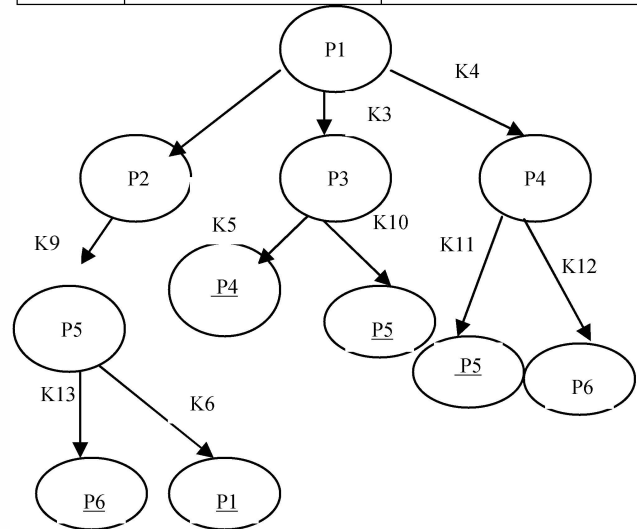


Figure 3. Event Test Tree

By converting the EDG to ETT, we obtain an expression, that is there is a path expression which shows path like $P1 \rightarrow P2 \rightarrow P5 (P6 + P1)$. Our next step is to identify the affected and potentially affected nodes.

C. Identify the Affected nodes

The EDG of the original and the modified web application constructed in step 1 and then converted into ETT in step2. Now we compare both the ETTs which represent the changed elements and dependencies.

1. For each element pi in original ETT find the corresponding node pi' in the modified ETT.
2. If pi' is found in modified web application then for each neighbor in the original tree, find the corresponding neighbor in the modified tree.
3. If we did not found element in the modified ETT, this means node has been removed from the modified web application. *This node is considered this node as affected by the change, affected node.*

D. Identify the Potentially Affected Nodes

Next we identify the potentially affected nodes. The potentially affected nodes, as defined previously, are the nodes that are connected either directly or indirectly to the affected nodes. All the dependencies are considered to identify the affected nodes. For each neighbor of the affected node, add it to the affected

1. Go through all the neighbors of the selected node
2. Checks if the neighbor is already added to the selected nodes list, do nothing
3. If the neighbor is not added to the list of selected nodes, add it to the list. Each new Neighbor is considered as the selected node, repeat the procedure from (1) for each new Neighbor.

be used to request for the first page of a Web application), i.e., a Index Page (p1), the user can enter into the Forget password page (p2) in case he/she forgets his/her password or enter into the login page (p3) by pressing the E4 or in validation page by pressing E5. In page p3, the user enters the userid and password, and presses the submit button. Upon pressing, the userid and password are sent to the Web server for authentication. Then if student enters proper login and password he/she can give test, can login, can change password and can download the material by clicking on various events. By clicking on test event student can give test and see the result. The EDG of the original web application is shown in the figure 4. Next we construct the EDG for the modified web application in figure 5. In modified EDG we have added, Fee detail page, i.e., if a student has submitted fees on time then only he can give test.

After identifying the nodes that are affected by the change, and the potentially affected nodes, the last step is to select a subset from the original test suite T that is modification revealing. The test cases that reveal the changes and show any possible error in the updated web application are the test cases that traverse the changed nodes and the potentially affected nodes. As input, we have the test suite T containing test cases and the nodes that each test case crosses. For each node in the list of affected nodes, go to the test suite, and check if the node is present in the test case. If the node is present in the test case, add the test case to the new test suite T' . Finally, we calculate the Test Case Reduction. We find test cases in original system and modified system and finally calculate the reduction in test cases, i.e., let

[illegible]

Figure 4. EDG of original web application

We apply this proposed approach to a case study to demonstrate its usefulness. We consider an example of simple web student login application, SWLS (Simple Web Student Login System)

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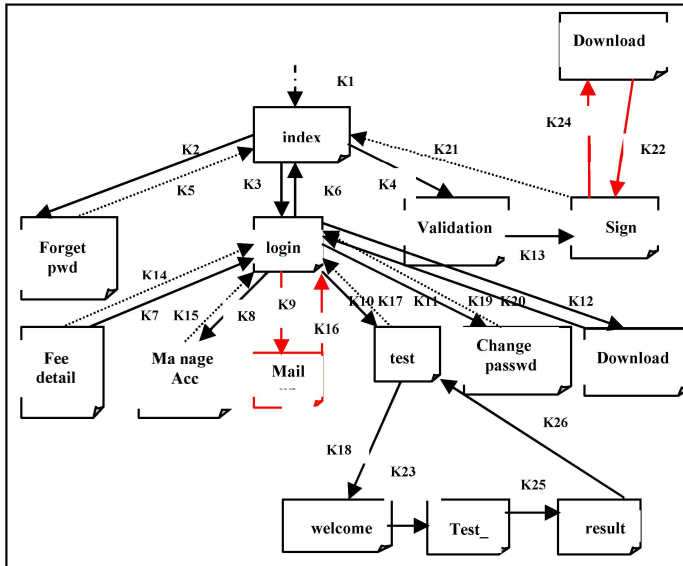


Figure 5. EDG of modified web application

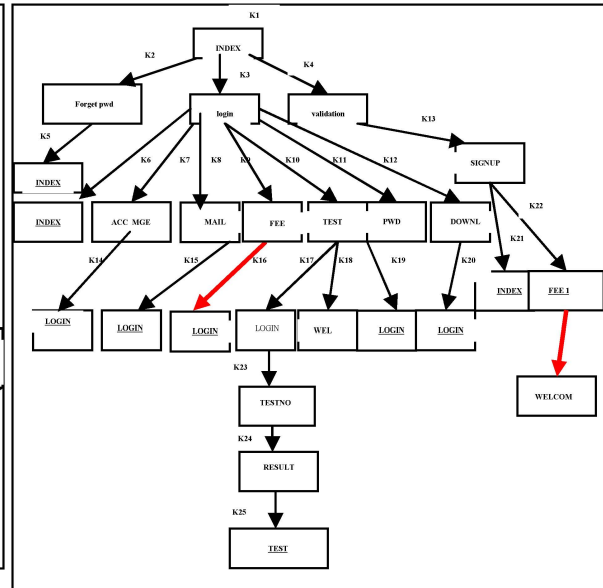


Figure 7*. Event Test Tree of the modified application

Step 2: Event Test Tree: We convert the EDG of original and modified web application to Event Test Tree as shown in figure 6 & 7 respectively.

*Quality figures of 6 & 7 can be obtained on request to the authors.

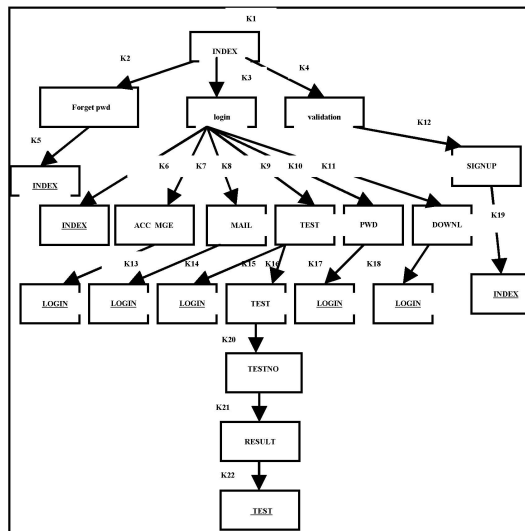


Figure 6*. Event Test Tree of the original application

Step 3: Regression testing comes into picture here as the product is changed in one part and we want to ensure that the change did not introduce any new defects. In third step from the constructed ETT we will see the nodes which are affected and potentially affected nodes by comparing both the trees. We will see each node in original tree as well as corresponding node in modified tree. If there is any change then those nodes are considered as affected or potentially affected nodes. From these trees we get the path that is known as Test expression. We give this test expression to the compiler and generate the test cases for original and modified web application.

FOR ORIGINAL SYSTEM

Path expression

$k1 \rightarrow (k2 \rightarrow k5 + k3 \rightarrow (k6 + k7 \rightarrow k13 + k8 \rightarrow k14 + k9 \rightarrow (k15 + k16 \rightarrow k20 \rightarrow k21 \rightarrow k22) + k10 \rightarrow k17 + k11 \rightarrow k18) + k4 \rightarrow k12 \rightarrow k19$

Test path

$k1 \rightarrow k2 \rightarrow k5$
 $k1 \rightarrow k3 \rightarrow k6$
 $k1 \rightarrow k3 \rightarrow k7 \rightarrow k13$
 $k1 \rightarrow k3 \rightarrow k8 \rightarrow k14$
 $k1 \rightarrow k3 \rightarrow k9 \rightarrow k15$
 $k1 \rightarrow k3 \rightarrow k9 \rightarrow k16 \rightarrow k20 \rightarrow k21 \rightarrow k22$
 $k1 \rightarrow k3 \rightarrow k10 \rightarrow k17$

$k1 \rightarrow k3 \rightarrow k11 \rightarrow k18$

$k1 \rightarrow k4 \rightarrow k12 \rightarrow k19$

FOR MODIFIED SYSTEM

Path expression

$k1 \rightarrow (k2 \rightarrow k5 + k3 \rightarrow (k6 + k7 \rightarrow k14 + k8 \rightarrow k15 + k9 \rightarrow k16 + k10 \rightarrow (k17 + k18 \rightarrow k23 \rightarrow k25 \rightarrow k26) + k11 \rightarrow k19 + k12 \rightarrow k20) + k4 \rightarrow k13 \rightarrow (k21 + k22 \rightarrow k24)$

Test path

$k1 \rightarrow k2 \rightarrow k5$

$k1 \rightarrow k3 \rightarrow k6$

$k1 \rightarrow k3 \rightarrow k7 \rightarrow k14$

$k1 \rightarrow k3 \rightarrow k8 \rightarrow k15$

$k1 \rightarrow k3 \rightarrow k9 \rightarrow k16$

$k1 \rightarrow k3 \rightarrow k10 \rightarrow k17$

$k1 \rightarrow k3 \rightarrow k10 \rightarrow k18 \rightarrow k23 \rightarrow k25 \rightarrow k26$

$k1 \rightarrow k3 \rightarrow k11 \rightarrow k19$

$k1 \rightarrow k3 \rightarrow k12 \rightarrow k20$

$k1 \rightarrow k4 \rightarrow k13 \rightarrow k21$

$k1 \rightarrow k4 \rightarrow k13 \rightarrow k22 \rightarrow k24$

In our approach we identify test cases in the existing test suite on which the original and modified programs may produce different outputs. If a test case does not execute any modified statement, it need not be re-run. After applying the proposed method, we noticed that the EDG affects the size of the test suite T' ; i.e., greater the number of connections of a node, more number of test cases have to be selected for the set T' . For example, consider figure 6 and figure 7, change occurs when a student can only login if he/she has submitted the fees. The test cases of original system are 35 and for modified system are 24. We note that the selected test cases are much less than the original test cases, thus enabling selection of test cases for regression testing web applications finally reducing the test set size. The percentage of selected test cases differs depending on the importance of the changed component.

Test cases in original system: 35

Test cases in modified system: 20

No of test cases eliminated: 15

Percentage reduction in test cases:

$(15/35) \times 100\% = 41.4\%$

Finally, the result shows that the proposed approach leads to reduction in the number of test cases to be rerun; on average 41.4% of the test cases were selected. However, the reduced set of test cases still

covers affected and potentially affected components that can be determined by the program change.

VI.

CONCLUSION

Web applications undergo changes in the maintenance phase, and this calls for retesting changed programs. To retest a program after changes, regression testing techniques enable selection of an adequate subset of the whole test suite on the condition that the selected subset will give confidence about covering the changes. Realizing this objective, in this paper we proposed a new paradigm that exploits regression testing to be used by web applications. This event-driven technique relies on the creation of event-dependency graph for the original and modified web application, then converting the both graphs into event test tree facilitation removal of redundancy, improving scalability and easing the test process. Both the trees are compared to identify for affected and potentially affected nodes, as we intend to select test cases for regression testing web applications finally reducing the test set size. A web application, Simple Web Student Login System was developed in J2EE and the results analyzed to demonstrate the usefulness & effectiveness of the proposed work. The proposed approach is only executed on predefined and assumed test cases, automatic test cases generation is a potential future direction.

REFERENCES

- [1] Alalfi, M.H., Cordy, J.R., Dean, T.R. (2009). Modelling methods for web application verification and testing: state of the art. *Software Testing, Verification, Reliability*, pp. 265-296.
- [2] Theodore S. Norvell. (2003). Automating regression testing of java programs the JSnoopy way. *Newfoundland Electrical and Computer Engineering Conference*.
- [3] Tarhini, A., Ismail, Z., Mansour, N. (2008). Regression Testing Web Applications. *International Conference on Advanced Computer Theory and Engineering*, pp. 902-906.
- [4] Xu, L., Xu, B., Jixiang, J. (2005). Testing Web Applications Focusing on Their Specialties. *ACM SIGSOFT Software Engineering Notes*, 30(1), pp. 10-16.
- [5] Xu, L., Xu, B., Chen, Z., Jixiang, J. and H. Chen. (2003). Regression Testing for Web Applications Based on Slicing. *Proceedings of the 27th Annual Int. Computer Software and Applications Conference*, 3(6), pp. 652-656.
- [6] Ricca, F., Tonnella, P. (2001). Analysis and testing of Web applications. *International Conference on Software Engineering Proceedings of the 23rd International Conference on Software Engineering*. IEEE Computer Society, pp. 25-34.
- [7] Tarhini, A., Fouchal, H., Mansour, N. (2006). Regression Testing Web Services-based Applications, *ACS/IEEE International Conference on Computer Systems and Applications*, pp. 163-170.
- [8] Qian, Z., Miao, H., Zeng, H. (2007). A Practical Web Testing Model for Web Application Testing, *Third International IEEE Conference on SignalImage Technologies and InternetBased System*, pp. 434-441.

Experimental studies for the role of piston rings' face profiles on performance of a diesel engine fueled with diesel and jatropha based biodiesel

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This study presents performance behaviors of a commercial diesel engine fueled with diesel and Jatropha based biodiesel (B100) at various loads (up to 100%) using standard (conventional) and three new face profile designs (I, II & III) of piston rings. Face profiles of piston rings had considerable impact on engine's brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and mass flow rate, irrespective of fuels used. BTE of engine fueled with diesel increases 2-8% with new face profile design (III) of piston rings in comparison to standard (conventional) piston rings. BTE enhances 8-16% when engine is fueled with biodiesel using face profile design (III) on piston rings. Corresponding to increase in BTE, recorded reduction in BSFC (biodiesel) is 28-34%. Industrial application of the results of present study may be useful in saving of fuels.

Keywords: Biodiesel, Diesel, Engine performance, Face profiles, Fuel consumption, Piston rings

Introduction

Fossil fuels are depleting rapidly due to exhaustive uses in industrial, transportation, agriculture and domestic sectors. Biodiesel¹⁻⁹ is being explored as a sustainable energy source to substitute diesel. Also, mechanical losses at various interfaces in engines are being minimized for improving fuel economy and reducing exhaust emissions. Friction losses (30-50%) in internal combustion (IC) engines occur at the interfaces of piston-cylinder, piston ring-cylinder, and piston-piston ring¹⁰⁻¹⁴. Even small reduction in friction at piston ring-cylinder liner interface may contribute in significant fuel saving and reduction in emissions¹⁵. Design of top compression piston ring has a significant impact on lubricating oil consumption in addition to engines' overall performance¹⁶⁻¹⁸. This study compares performance parameters of a commercial diesel engine fueled with diesel and Jatropha based biodiesel (B100) and assesses performance of diesel engine with both fuels using standard (conventional) and three different face profile designs (I, II & III) of piston rings.

Experimental Section

Development of New Face Profiles of Piston Rings

A fixture (Fig. 1) was developed to hold piston rings for micro machining the face profiles. In this fixture, a circular groove (outer diam, 102 mm; inner diam, 94 mm; and depth, 1.5 mm) is fabricated for holding piston ring during machining. Piston rings of three different designs (I, II & III) are based on mathematical modeling¹⁷ of hydrodynamically lubricated interface formed between piston ring and cylinder liner.

Experimentation

Experiments were carried out on a single cylinder (vertical), 4-stroke, and water-cooled commercial diesel engine with following specifications: rated brake power, 7.4 kW; rated speed, 1500 rpm; bore x stroke, 102 mm x 116 mm; displacement volume, 948 cc; compression ratio, 17.5:1; SFC at rated HP/1500 rpm, 251 g/kWh; lubricating oil consumption, 1.0% (max.) of SFC; lubricating oil sump capacity, 3.75 l; fuel tank capacity, 11.5 l; fuel tank refilling time period, every 5 h engine running at rated speed; engine weight without flywheel, 127 kg; weight of flywheel, 64 kg; starting, hand start with cranking handle (optional: 12v electric start); direction of crank rotation from side of flywheel, clockwise; fuel system, gravity feed fuel system with efficient paper element

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Fig. 1—Fixture with a clamped piston ring

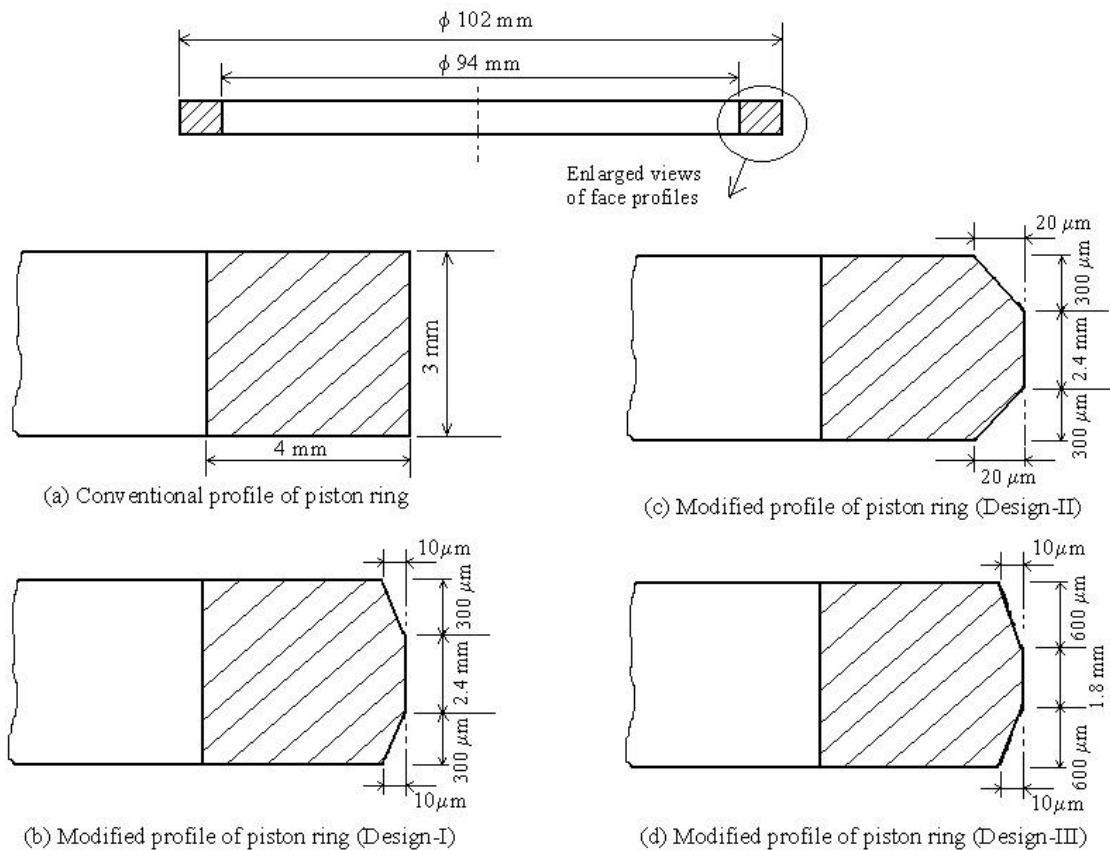


Fig. 2—Schematic diagrams of standard (conventional) and three new face profiles of piston rings

filter; and lubrication system, forced feed. A fuel-measuring unit stopwatch for time. Engine was run for each set of rings, at no load condition for 1 h. Thereafter, test engine was loaded gradually keeping the speed within

permissible limits while recording readings pertaining to different parameters. Engine performance tests were carried out using a standard (conventional) face profile for piston rings. Both diesel and Jatropha based biodiesel

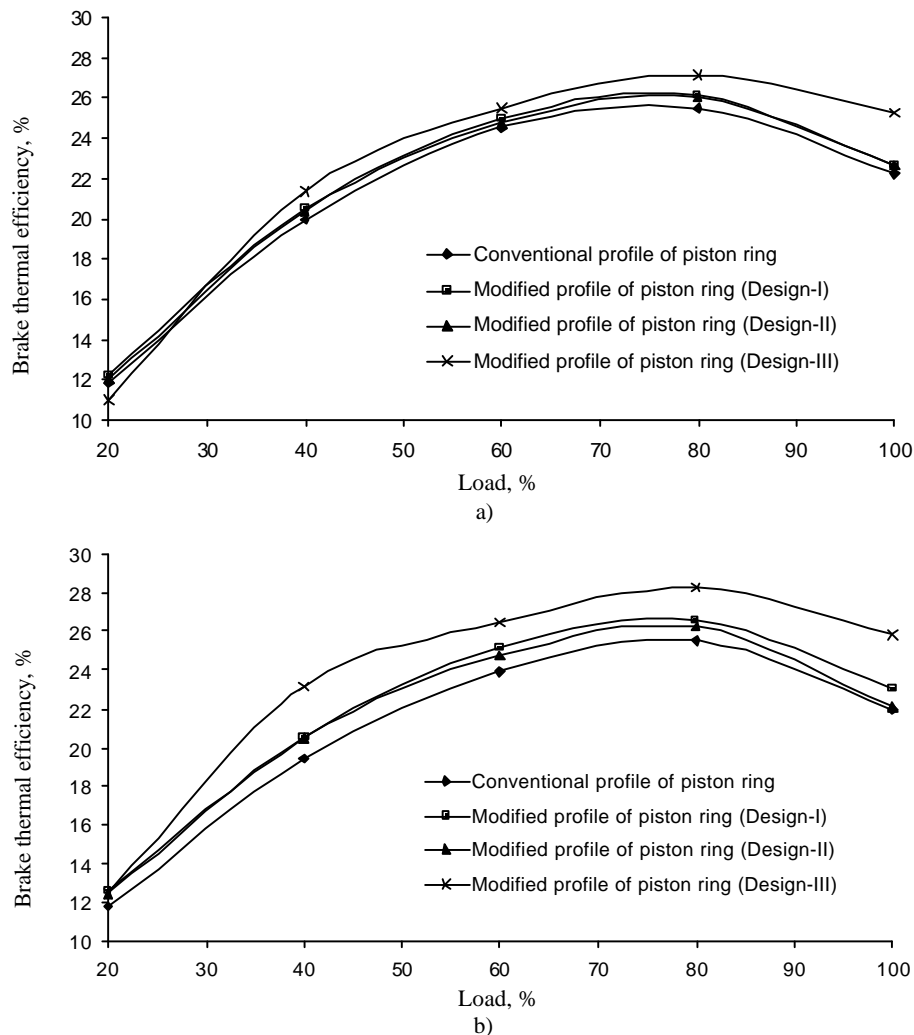


Fig. 3—Variation of brake thermal efficiency (BTE) with load for: a) diesel; and b) biodiesel

fuels were used for generating base line data. Thereafter, performance parameters' readings were recorded with new face profile designs (I, II & III) of piston rings using both diesel and biodiesel fuels.

Results and Discussion

Some physicochemical properties were measured in laboratory well before the commencement of experiments of diesel and Jatropa based biodiesel (B100), respectively and are as follows: flash point, 76, 162°C; kinematic viscosity^{40°C}, 3.21, 4.12 cSt; sulfur, 340, 8 ppm; cetane number, 47.2, 49; carbon, 87, 77% by wt; hydrogen, 13, 12% by wt; and oxygen by difference, negligible, 11% wt. Jatropa biodiesel (B100) has higher flash point and kinematic viscosity in comparison to neat diesel. Biodiesel has traces of sulphur whereas diesel has substantial content of sulphur. Cetane number of

biodiesel is higher than diesel. Biodiesel contains oxygen (11%) whereas diesel contain any oxygen.

Brake Thermal Efficiency (BTE)

Marginal differences in BTE are recorded with both fuels (Fig. 3) when standard piston ring sets are used. Highest thermal efficiencies recorded at 80% of maximum load with diesel and biodiesel (25.56%). BTE decreases at higher loads (> 80%) due to poor combustion of fuels, a normal trend in IC engines. A significant improvement in BTE has been achieved when piston rings of new face profile design (III) is used in engines fueled with diesel (27.16%) and biodiesel (28.29%) are relatively high on these rings. Increase in BTE happens due to effective lubrication with new face profile design (III) of piston rings. Better lubrication reduces mechanical losses at the interface of cylinder liner and piston rings,

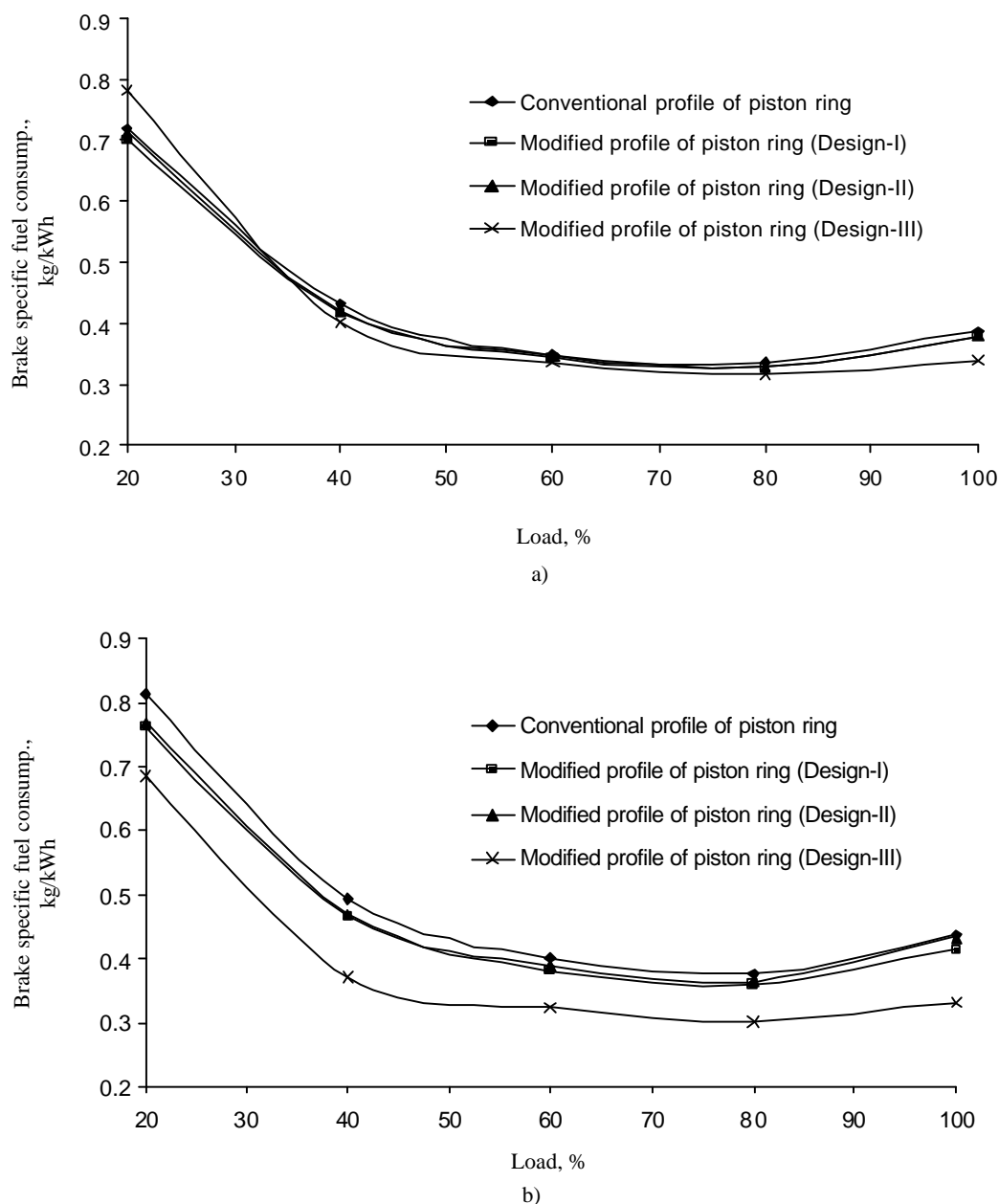


Fig. 4—Variation of brake specific fuel consumption (BSFC) with load for: a) diesel; and b) biodiesel

enhancing engine efficiency. BTEs of engine increase with diesel (2-8%) and biodiesel (8-10%), with new face profile design (III) of piston rings in comparison to standard (conventional) piston rings. Better BTE with biodiesel may be attributed to high cetane number resulting in better combustion of fuel.

Brake Specific Fuel Consumption (BSFC)

BSFC reduces continuously with increase in applied load of test engine (Fig. 4). It reduces considerably

(28-34%) for the combination of new face profile design (III) of piston ring and biodiesel, attributed to effective lubrication causing reduction of interface friction.

Mass Flow Rate (MFR)

MFR increases continuously with increase in applied load of test engine (Fig. 5). It reduces significantly (28-34%) for the combination of new face profile design (III) of piston ring and biodiesel, may be due to effective lubrication that causes reduction in interfacial friction

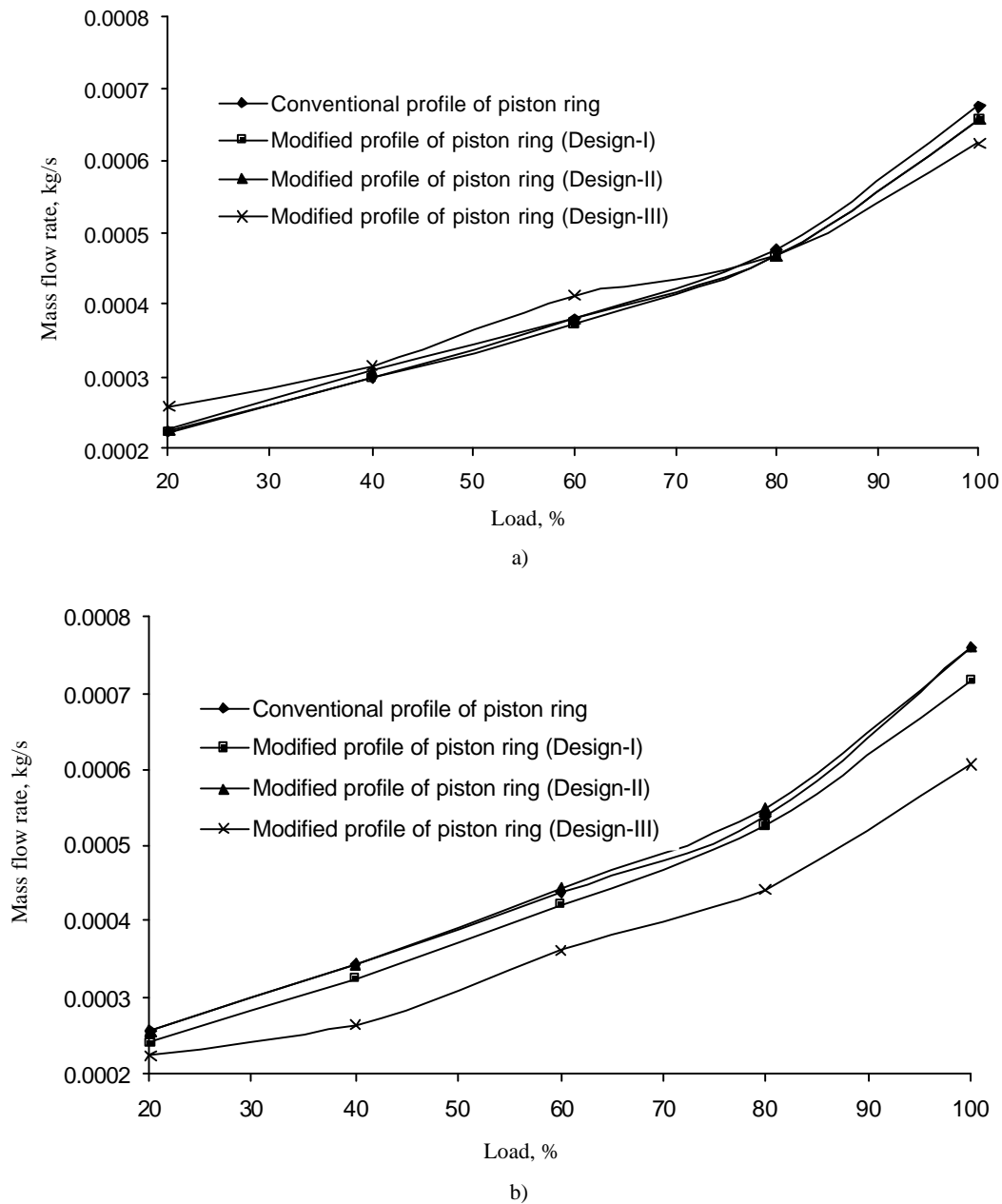


Fig. 5—Variation of mass flow rate (MFR) of biodiesel with load for: a) diesel; and b) biodiesel

and better combustion of biodiesel due to high cetane number.

Conclusions

BTE of engine with piston rings of new face profile design (III) increases when fueled with: diesel, 2-8; and biodiesel, 8-16%. BSFC reduces (28-34%) for the combination of piston rings of new face profile design (III) and biodiesel. BSFC of biodiesel may be due to

better combustion, high cetane number and inbuilt oxygen in biodiesel. Thus industrial application of results of this study may be useful in saving of fuels.

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References

- 1 Agarwal A K & Das L M, Biodiesel development and characterization for use as a fuel in compression ignition engine, *ASME Trans, J Eng Gas Turb Power*, **123** (2001) 440-447.
- 2 Ramadhas A S & Jayaraj S, Biodiesel production from high FFA rubber seed oil, *Renew Ener*, **29** (2004) 727-742.
- 3 Reddy J N & Ramesh A, Parametric studies for improving the performance of Jatropha oil fuelled compression ignition engine, *Renew Ener*, **31** (2006) 1994-2016.
- 4 Agarwal D, Sinha S & Agarwal A K, Experimental investigation of control of NO_x emissions in bio-diesel fueled compression emissions engine, *Renew Ener*, **31** (2006) 2356-2369.
- 5 Sarma A K, Sarmah J K, Barbora L, Kalita P, Chatterjee S *et al*, Recent inventions in bio-diesel production and processing-a review, *Rec Pat Eng*, **2** (2008) 47-58.
- 6 Basha S A, Gopal K R & Jebaraj S, A review on biodiesel production, combustion, emission, and performance, *Renew Sustain Ener Rev*, **13** (2009) 1628-1634.
- 7 Sharma Y C & Singh B, Development of biodiesel: current scenario, *Renew Sustain Ener Rev*, **13** (2009) 1646-1651.
- 8 Jain S & Sharma M P, Prospects of bio-diesel from Jatropha in India: a review, *Renew Sustain Ener Rev*, **14** (2010) 763-771.
- 9 Jauaun J & Ellis N, Perspectives on bio-diesel as a sustainable fuel, *Renew Sustain Ener Rev*, **14** (2010) 1312-1320.
- 10 Knoll G D & Peeken H J, Hydrodynamic lubrication of piston skirts, *ASME Trans, J Lub Tech*, **104** (1982) 504-509.
- 11 Mitsuru H & Yasukazu B, A study of piston friction force in an internal combustion engine, *ASLE Trans*, **30** (1987) 444-451.
- 12 Takiguchi M, Machida K & Furuham S, Piston friction force of a small high-speed gasoline engine, *ASME Trans, J Tribol*, **110** (1988) 112-118.
- 13 Nakada M, Trends in engine technology and tribology, *Tribol Int*, **27**(1994) 3-8.
- 14 Tung S C & McMillan M L, Automotive tribology overview of current advances and challenges for the future, *Tribol Int*, **37**(2004) 517-536.
- 15 Andersson P, Tamminier J & Sandstron C E, Piston ring tribology – a literature survey, *VTT Res Notes* 2178, 2002.
- 16 Rabute R & Tian T, Challenges involved in piston top ring designs for modern SI engines, *ASME Trans, J Eng Gas Turb Power*, **123** (2001) 448-459.
- 17 Pandey R K, Tandon N & Sharma A, Lubrication studies with some new piston ring profiles, in *Proc 4th World Tribol Congress* (Kyoto, Japan) 6-11 September-2009.
- 18 Pandey R K, Tandon N & Chaudhary R, Effect of top compression piston ring profile on the fuel efficiency of IC engine, in *Proc Tribo-India Conf* (IIT Delhi, India) 11-12 December2009.

Identification of Type-2 Fuzzy Models for Time-series Forecasting using Particle Swarm Optimization

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Abstract—This paper presents the fuzzy model identification framework, where Particle Swarm Optimization (PSO) algorithm has been used as an optimization engine for building Type-2 fuzzy models from the available chaotic Mackey–Glass time-series data. The presented framework is capable of evolving the Membership Functions parameters, Footprint of Uncertainty (FOU) and the rule set to obtain an optimized Type-2 fuzzy model. Four experiments are reported for differently corrupted chaotic time-series data sets. Root Mean square error (RMSE), between the outputs of the designed T2 FLS and the target is used as the performance criterion to rate the quality of solutions and hence demonstrate the performance of the proposed framework.

Keywords—Type-2 Fuzzy Logic System; Particle Swarm Optimization; Footprint of Uncertainty, Mackey-Glass time-series data

I. INTRODUCTION

Designing models of complex systems is an important topic in many disciplines of engineering. Models are generally used for simulation, identification of system behavior as well as for the prediction and control purposes. There has been a drastic growth of successful applications in science and engineering that have adopted the use of fuzzy models, which are known for their capabilities to handle ambiguous or vague concepts of human perception for complex systems problems, where it is extremely difficult to describe the system models mathematically. While Type-1 fuzzy logic has been the most popular form of fuzzy logic so far, recently there has been a significant increase in interest towards more complex form of fuzzy logic, viz. Type-2 fuzzy logic. This transition from Type-1 to Type-2 fuzzy logic has been largely inspired by the realization that Type-1 Fuzzy Sets (T1FSs) offer limited capability for modeling uncertainty and cannot handle the high levels of uncertainties, which are usually present in real-world applications [1]. In 1975, Zadeh [2] recognized this limitation and introduced the concept of generalized FSs, now termed as Type-2 FSs (T2 FSs), as an extension to T1 FSs. In such T2 FSs the membership grade for a crisp input is not a crisp value but another T1 FS. Therefore, T2 FLSs, which use T2 FSs, characterized by fuzzy MFs, have an additional third dimension. This third dimension and footprint of uncertainty (FOU) provide an additional degree

of freedom for T2 FLSs to directly model and handle uncertainties [3]. But at the same time, this additional dimension makes T2 FLSs computationally much more complex.

Due to the computational complexities associated with the general T2 FLSs, almost all applications use only Interval Type-2 (IT2) FSs in the FLS, the result being an IT2 FLS. IT2 is a special case of a general T2 FS where all the secondary membership grades equal one. The computations for an IT2 FS are very manageable, which makes an IT2 FLS quite practical [4]. IT2 FLSs have been successfully applied in many areas, like signal processing [5]–[9] and control [10], [11], in which they outperform their type-1 counterparts.

Design of fuzzy models is the task of finding the parameters of fuzzy model so as to get the desired behavior. Two principally different approaches are used for the design of FLSs: heuristic-based or knowledge-based design and model-based design. In the first approach, the design is created based on the expert(s) knowledge, while in the second, the input-output training data set is used for building model. The heuristics-based design lacks systematic approach and is very difficult to apply to multi-input/multi-output problems that represent the largest part of industrial process control application. These difficulties of the heuristics-based approach have lead to more interest in the model-based design. Some popular techniques for model-based design are Genetic Algorithms (GAs), Ant Colony Optimization (ACO), PSO, Fuzzy c-means (FCM) clustering, Artificial Neural Networks (ANN) that have been used for the identification of T1 FLSs [12]. Some of these techniques have also been used for creating T2 fuzzy models. Al-Jaafreh and Al-Jumaily [13] trained T2 FLS using PSO for a biomedical application with single input and single output, whereas Park and Kwang [14] have used GA for designing T2 FLS from *Mackey-Glass Time-Series* data.

In this paper, we have presented the use of PSO algorithm for identification of IT2 fuzzy models from the available data. The proposed design approach has been applied to the benchmark problem of *Mackey-Glass Time-Series* forecasting. Four sets of experiments are conducted under four different SNRs i.e. 15dB, 20dB, 25dB, and 30dB.

The paper is organized as follows. In Section 2, a brief overview of T2 FLSs is presented. Section 3 describes the methodology for the identification of IT2 fuzzy models from *Mackey-Glass Time-Series* data using PSO. A brief description about this time-series data is also presented in this Section. Simulation results from several experiments using differently corrupted data sets are presented in Section 4. Finally, conclusions are drawn in Section 5.

II. OVERVIEW OF T2 FLSs

A. Generalized T2 FSs and T2 FLSs

A T2 FS can be informally defined as a fuzzy set that is characterized by a fuzzy or non-crisp membership function. This means there is uncertainty in the primary membership grades of a T2 MF, which introduces a third dimension to the MF, defined by the secondary membership grades [15, 16].

Such a T2 FS, denoted by \tilde{A} can be expressed mathematically in the following form as in (1)

$$\tilde{A} = \{(x, u), \mu_{\tilde{A}}(x, u) | \forall x \in X, J_x \subseteq [0, 1]\} \quad (1)$$

Where, $\mu_{\tilde{A}}(x, u)$ is the T2 MF, x , the *primary variable*, has domain X ; $u \in U$, the *secondary variable*, has domain J_x at each $x \in X$; J_x is called the *primary membership* of x and $u \in J_x \subseteq [0, 1]$. Uncertainty in the primary memberships of a T2 FS consists of a bounded region which is called the footprint of uncertainty (FOU). It is the union of all primary memberships, [15] as in (2)

$$FOU(\tilde{A}) = \bigcup_{x \in X} J_x \quad (2)$$

All the embedded FSs of FOU are T1 FSs and their union covers the entire FOU. General T2 FLSs that use general T2 FSs are computationally complex.

B. Interval T2 FSs and IT2 FLSs

IT2 FSs are the most widely used T2 FSs to date, used in almost all applications because all calculations are easy to perform. IT2 is a special case of a T2 FS where all the secondary membership grades equal one. IT2 FS is completely characterized by its 2-D FOU that is bound by a Lower MF (LMF) and an Upper MF (UMF), $\underline{\mu}_{\tilde{A}}(x)$ and $\overline{\mu}_{\tilde{A}}(x)$, respectively, both of which are T1 MFs. The FOU of an IT2 FS is described in terms of these MFs, as in (3).

$$FOU(\tilde{A}) = \bigcup_{x \in X} [\underline{\mu}_{\tilde{A}}(x), \overline{\mu}_{\tilde{A}}(x)] \quad (3)$$

For the IT2 FLS considered in this paper, *Left MF*, *Right MF* approach is used. For example, given a symmetrical Triangular shaped Principle T1 FS with MF parameters defined by left support point (x^l), right support point (x^r) and FOU as shown in Fig. 1. From this, the parameters of Left and Right FSs can be worked out as shown in the Fig. 2 and hence the corresponding IT2 FLS. Considering the Triangular Principle T1 FS to be symmetrical, the middle point (x^c) of the FS will be the average of the left and right support points. Hence an IT2 FS can be completely

characterized by three parameters viz. left (x^l) support point, right support point (x^r) and FOU.

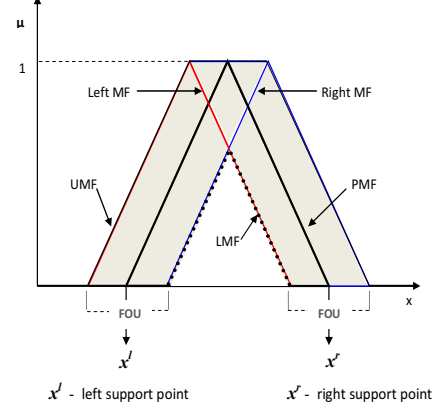


Figure 1. IT2 FSs

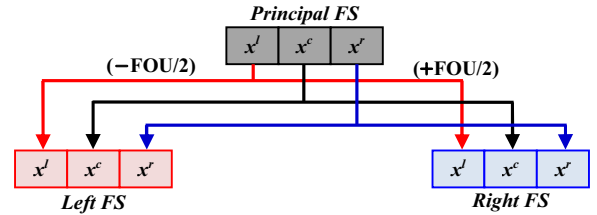


Figure 2. Mechanism for obtaining Left and Right FSs

III. IT2 FUZZY MODEL IDENTIFICATION THROUGH PSO

A. Fuzzy Model Identification Problem

Generally, the problem of fuzzy model identification includes the issues like identifying: the type of fuzzy model, the input and output variables, number and types of MFs for the input and output variables, number of fuzzy rules, parameters of antecedent and consequent membership functions, fuzzy rule-base, performance criteria for evaluating fuzzy models [12][17].

The design of fuzzy systems or fuzzy models identification can be formulated as a search and optimization problem in the high-dimensional search space, where each point corresponds to a fuzzy model. Given some objective function, the system performance forms a hypersurface and finding the optimal fuzzy model parameters is equivalent to finding the optimal location on this hypersurface that is generally infinitely larger, nondifferentiable, complex, noisy, multimodal and deceptive [18]. These traits of hypersurface make evolutionary algorithms good candidates than the traditional gradient-based methods. PSO algorithms have the capability to find optimal or near optimal solution in a defined search space and can be used to evolve the parameters of fuzzy models. Most promising advantage of PSO over GAs is its algorithmic simplicity.

In the present work, the number and shapes of MFs for the input and output variables, and the number of rules in the

rule-base are fixed. The parameters of the MFs, and the antecedents and consequents of the rule-base are tuned through PSO.

B. Mackey-Glass Time Series data

The proposed approach of designing IT2 FLS using PSO algorithm has been demonstrated by applying it to the noisy time-series data set. Time series forecasting is the use of a model to forecast future events based on known past events and to predict data points before they are measured. An example of time-series forecasting is predicting the opening price of a stock based on its past performance. FLSs designing for forecasting of Mackey-Glass time-series [19] is a benchmark problem. Mackey-Glass chaotic time-series can be represented mathematically as in (4)

$$\frac{ds(t)}{dt} = \frac{0.2s(t-\tau)}{1+s^{10}(t-\tau)} - 0.1s(t) \quad (4)$$

Such a system with $\tau \leq 17$ is known to demonstrate deterministic/periodic behavior that turns chaotic with $\tau > 17$. For the purpose of simulation of (4), it is required to be converted to discrete-time system through Euler's method represented in (5).

$$\begin{aligned} f(s, n) &= \frac{0.2s(n-\tau)}{1+s^{10}(n-\tau)} - 0.1s(n) \\ s(n+1) &= s(n) + hf(s, n) \end{aligned} \quad (5)$$

where h is a small number and the initial values of $s(n) \forall n \leq \tau$ are set randomly. In our experiments, $h=1$ and $\tau=30$ were used. Fig. 3 shows sample data sets, each consisting of 600 points and corrupted with different noise levels. In all our experiments, first 400 points (corrupted) were used for training and the next 200 points (noise-free) for testing.

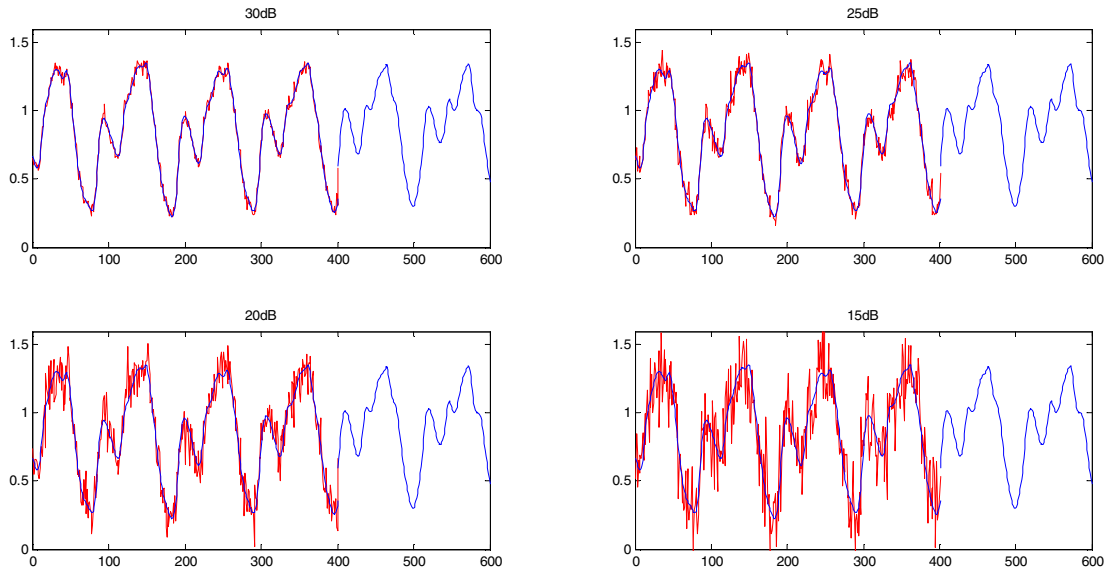


Figure 3. Mackey-Glass time-series data sets with different noise levels

C. PSO Algorithm

PSO is a population based stochastic optimization technique developed by Eberhart and Kennedy in 1995 [20], inspired by social behavior of bird flocking or fish schooling. The pseudo-code for the identification of IT2 fuzzy model through PSO algorithm is listed below:

Pseudo-code

```

{
  Define PSO parameters viz. Swarm Size, Iterations,  $\phi_1$ , etc.
  Iteration = 0;
  Generate random swarm of particles
  While Iteration  $\leq$  Number of Iterations or Fitness value = 0 or
    No fitness improvements up to 500 iterations
  {
    Limit Swarm;
    Build IT2 fuzzy model for each particle;
    Evaluate each fuzzy model and calculate RMSE;
    Update all the particles position and velocity;
    Iteration=Iteration+1;
  }
End
}

```

The first step in the optimization is to pick up the variables to be optimized and define the respective Universe of Discourse (UOD). It is important to define a set of constraints for the particles to be optimized. Solutions that do not satisfy constraints are invalid solutions and hence not acceptable. The fitness function represents the quality of each solution and also provides a link between the optimization algorithm and the problem under consideration. The goal of the optimization is to find out the values of the variables that satisfy the defined constraints that maximizes or minimizes the fitness function.

hbest PSO model, which is the hybrid of *gbest* and *lbest* models, has been used in our experiments, where each particle belongs to a sub-swarm and feels collective attraction towards its present *pbest* particle, p_i , the *lbest* particle, p_l , and the *gbest* particle, p_g , as expressed mathematically,

$$v_{id}^{n+1} = \chi(\omega v_{id}^n + \phi_1 r_1^n (p_{id}^n - x_{id}^n) + \phi_2 r_2^n (p_{gd}^n - x_{id}^n) + \phi_3 r_3^n (p_{ld}^n - x_{id}^n)) \quad (6)$$

$$x_{id}^{n+1} = x_{id}^n + v_{id}^{n+1} \quad (7)$$

where

χ	Constriction factor
ϕ_1	Cognitive Acceleration
ϕ_2	Social Acceleration
ϕ_3	Local Acceleration
r_1, r_2, r_3	Random numbers uniformly distributed in the range (0,1)

Fig. 4 depicts the position update of a particle for a two-dimensional search space. Infact, this update is carried out as per (6) and (7) for each particle of swarm for each of the d -dimensions in d -dimensional search space.

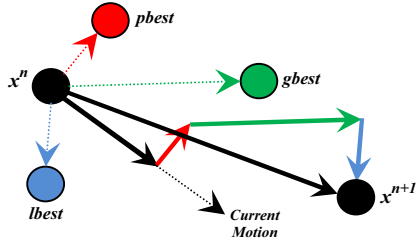


Figure 4. Position update for *hbest* PSO model for 2-D search space

RMSE between the evolved IT2 FLSs outputs and the targets has been used as the fitness function for the PSO run. Mathematically,

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (c_i - t)^2} \quad (8)$$

where

c_i	actual computed output of the designed IT2 fuzzy model
t	Target output
N	Total number of data points

D. Encoding of IT2 FLS

For evolving fuzzy models through PSO, a very important consideration is to completely represent a fuzzy system by a particle, and for this, all the needed information about the rule-base and MFs is required to be specified through some encoding mechanism. Also the MFs and the rule-base must be evolved simultaneously, since they are codependent in a fuzzy system [18].

Encoding IT2 FSs:

An IT2 FS can be characterized by means of 3-tuple (x_k^l, x_k^r, FOU_k) . Therefore, particle carrying details about the parameters of the MFs of all the input and output variables can be represented as follows:

$$x_1^l, x_1^r, FOU_1, x_2^l, x_2^r, FOU_2, \dots, x_n^l, x_n^r, FOU_n, x_{n+1}^l, x_{n+1}^r, FOU_{n+1} \quad (9)$$

The index $n+1$ is associated with the MFs of the output variable.

The dimensions of the particle representing IT2 fuzzy model can be worked out from Fig. 5, which represents one IT2 FS for the input/output variables. Thus, three dimensions viz. x_k^l , x_k^r and FOU_k are required for each FS, which are to be modified during PSO run. The representation can be generalized to following form:

$$\text{Particle Size} = 3m_i \quad (10)$$

Thus the particle size for representing all the IT2 FSs of input and output variables for IT2 fuzzy model is represented as

$$\text{Particle Size (IT2 FSs)} = \sum_{i=1}^{n+1} 3m_i \quad (11)$$

where,

n - number of input variables

m_i - number of IT2 FSs for the i^{th} input, and the index $n+1$ corresponds to the FSs of the output variable.

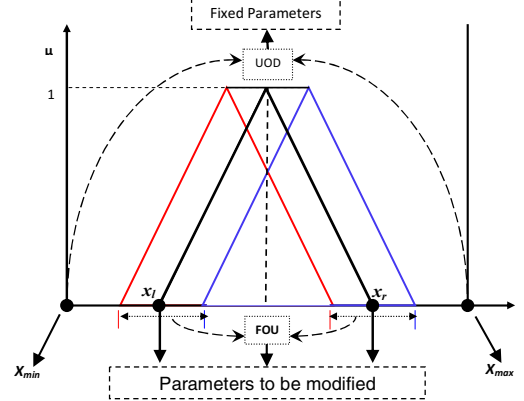


Figure 5. Representation of parameters of IT2 FS to be evolved through PSO

Encoding Fuzzy Rule-Base:

Considering r number of rules in the rule base, the particle size required for its representation is given as

$$\text{Particle Size (for rule base with } r \text{ rules)} = r(n+1) \quad (12)$$

Thus, the particle size required for representing the complete IT2 fuzzy model can be obtained by adding (11) and (12).

$$\text{Particle Size (complete IT2 fuzzy model)} = \sum_{i=1}^{n+1} 3m_i + r(n+1) \quad (13)$$

IV. EXPERIMENTS AND SIMULATION RESULTS

In all our experiments corresponding to the evolutionary design of IT2 FLS for forecasting of *Mackey-Glass time-series*, the following were used:

- Four antecedents per rule, viz., $x(k-3)$, $x(k-2)$, $x(k-1)$ and $x(k)$ to predict one consequent $x(k+1)$.

- ii. Five Triangular IT2 FSs for each antecedent and consequent
- iii. Ten fuzzy rules

Mamdani inference has been used for IT2 FLSs with MIN t -norm, MAX s -norm, Centroid type-reduction, and Centroid defuzzification. Following constraints have been defined for each FS of input and output variables and the rulebase:

- Left support point < Right Support point i.e. $x_{nk}^l < x_{nk}^r$
- FS support points are confined within the respective UOD, i.e. $X_{min} < FS \text{ Parameters} < X_{max}$

The particle size for this problem worked out from (13) is 125. A particle representing an IT2 fuzzy model of dimensions 125, whose FS parameters of input/output variables and rule-base can be modified through PSO algorithm is shown in Fig. 6. For the purpose of clarity in presentation, two scripts have been attached with the parameters of the IT2 FSs and FOUs so as to associate them with different input and output variables. For example, the three parameters for the second IT2 FS of the first input variable can be represented as $(x_{12}^l, x_{12}^r, FOU_{12}^i)$. PSO parameters corresponding to the experiments reported in this paper are listed in Table I.

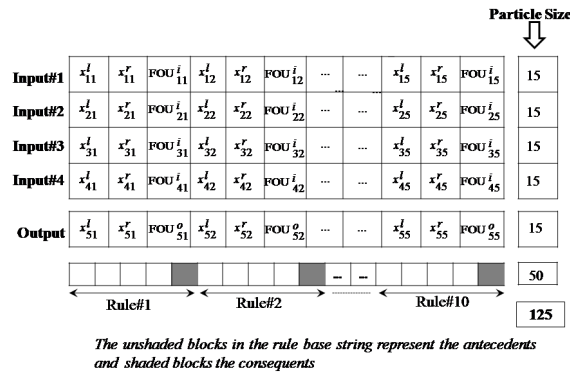


Figure 6. Representation of IT2 fuzzy model by a particle

TABLE I. PSO PARAMETERS FOR REPORTED EXPERIMENTS

PSO Model	hbest
Neighborhood Topology	Ring
Neighborhood Size	1
Swarm Size	20
Iterations (Maximum)	1000
Constriction Factor (γ)	0.729
Acceleration Parameters	$\phi_1 = \phi_2 = \phi_3 = 2$
Inertia Weight	1 (Fixed)
Termination Criteria	Either of the following three <ul style="list-style-type: none"> • No fitness improvement up to 500 iterations • Fitness value=0 • Iterations=1000

Implementation of the proposed design is done in MATLAB and GFS Toolbox¹. MATLAB functions were written for initializing random population, limiting the solutions within the defined constraints, converting each validated particle into IT2 fuzzy structure format required for GFS Toolbox, evaluating objective function, and for updating the position and velocity of particles. Each IT2 fuzzy structure was evaluated for the training data using GFS Toolbox. Four IT2 FLSs were evolved from four differently corrupted data sets. Convergence plots for all four experiments are shown in Fig. 7 and the corresponding RMSEs have been reported in Table II. Simulation time for each experiment was about 23 hours and 50 minutes.

TABLE II. SIMULATION RESULTS OF ALL FOUR EXPERIMENTS

Experiment No.	SNR	RMSE
1	30dB	0.0724
2	25dB	0.1032
3	20dB	0.1420
4	15dB	0.1908

V. CONCLUSIONS AND FUTURE WORK

In this paper, evolutionary design of IT2 FLS from the benchmark *Mackey-Glass Time Series* data is presented. Simulation results for four different experiments for differently corrupted chaotic time-series data sets are reported that illustrate the viability and efficiency of the used framework. The design framework presented here is very generic and can be extended to evolve the parameters like number and types of FSs that were kept fixed in experiments reported here. It is a well recognized fact that the performance of evolutionary algorithms to a great extent depends on the choice of appropriate strategy/operating parameters. For all the experiments here, the PSO operating parameters were kept fixed and *hbest* PSO model has been followed. It would be worthwhile to investigate the influence of PSO operating parameters and trying other PSO variants to achieve better accuracy and/or convergence.

The parallel nature of evolutionary algorithms requires lot of computational efforts, which is evident from the simulation time reported in this paper. Thus, the use of high performance computing resources becomes a key to accelerate the experiments. One way to achieve this is through cluster computing that uses a group of independent computers working as single, integrated computing resource. Recently there has been a major shift towards GPU computing to provide large performance speedups for general-purpose applications that are harnessed through programming languages such as CUDA and OpenCL. Thus, it would be a challenge to map these experiments on cluster and GPU for speedup.

One of the future directions could be employing hybrid framework for fuzzy modeling where PSO can be integrated with other learning techniques. Another direction for the future work could be applying this methodology for other field and applications.

¹ <http://sourceforge.net/projects/gfstool/>

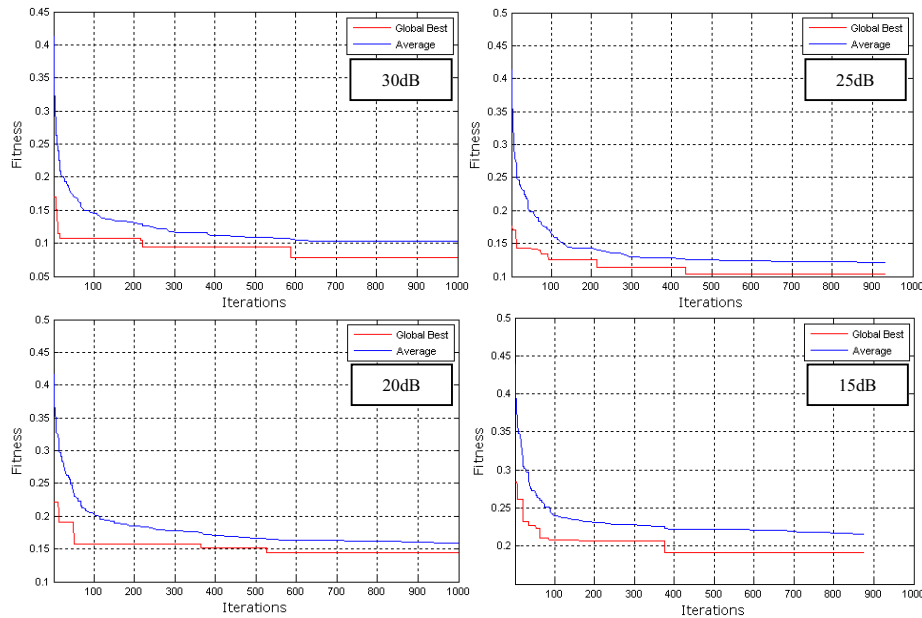


Figure 7. Convergence plots for all four experiments

REFERENCES

- [1] N. N. Karnik, J. M. Mendel, and Q. Liang, "Type-2 Fuzzy Logic Systems," *IEEE Trans. Fuzzy Syst.*, vol. 7, pp. 643–658, 1999.
- [2] L. A. Zadeh, "The Concept of a Linguistic Variable and Its Application to Approximate Reasoning - 1," *Information Sciences*, Vol. 8, pp 199–249, 1975.
- [3] P. Melin and O. Castillo, "A New Method for Adaptive Control of Nonlinear Plants using Type-2 Fuzzy Logic and Neural Networks," *J. Gen. Syst.*, vol. 33, pp. 289–304, 2004.
- [4] C. Hwang and F. C.-H. Rhee, "Uncertain Fuzzy Clustering: Interval Type-2 Fuzzy Approach to C-means," *IEEE Trans. Fuzzy Syst.*, vol. 15, no. 1, pp. 107–120, 2007.
- [5] Q. Liang and J. M. Mendel, "Equalization of nonlinear time-varying channels using type-2 fuzzy adaptive filters," *IEEE Trans. Fuzzy Syst.*, vol. 8, no. 5, pp. 551–563, 2000.
- [6] Q. Liang and J. M. Mendel, "MPEG VBR video traffic modeling and classification using fuzzy technique," *IEEE Trans. Fuzzy Syst.*, vol. 9, no. 1, pp. 183–193, 2001.
- [7] H. B. Mitchell, "Pattern recognition using Type-II fuzzy sets," *Information Sciences*, vol. 170, pp. 409–418, 2005.
- [8] J. Zeng and Z. Q. Liu, "Type-2 fuzzy hidden Markov models and their application to speech recognition," *IEEE Trans. Fuzzy Syst.*, vol. 14, no. 3, pp. 454–467, 2006.
- [9] C. Hwang and F. C.-H. Rhee, "Uncertain fuzzy clustering: Interval type-2 fuzzy approach to C-means," *IEEE Trans. Fuzzy Syst.*, vol. 15, no. 1, pp. 107–120, 2007.
- [10] P. Melin and O. Castillo, "A new method for adaptive control of nonlinear plants using type-2 fuzzy logic and neural networks," *J. Gen. Syst.*, vol. 33, no. 2/3, pp. 289–304, 2004.
- [11] H. Hagras, "A hierarchical type-2 fuzzy logic control architecture for autonomous mobile robots," *IEEE Trans. Fuzzy Syst.*, vol. 12, no. 4, pp. 524–539, 2004.
- [12] H. Hellendoorn and D. Driankov (Eds.), *Fuzzy Model Identification – Selected Approaches*, Springer-Verlag, 1997.
- [13] M. Al-Jaafreh, and A. Al-Jumaily, "Training type-2 fuzzy system by particle swarm optimization. Proc. IEEE Congress on Evolutionary Computation (CEC 2007), 2007, pp 3442–3446.
- [14] S. Park and H. Lee-Kwang, "A designing method for type-2 fuzzy logic systems using genetic algorithms," in *Proc. Joint 9th IFSA World Congress 20th NAFIPS Int. Conf.*, Vancouver, BC, Canada, July 2001, pp. 2567–2572.
- [15] J. M. Mendel and R. I. John. "Type-2 Fuzzy Sets Made Simple". *IEEE Transactions on Fuzzy Systems*, Vol. 10, No. 2, pp. 117–127, 2002.
- [16] Q. Liang and J. M. Mendel. "Interval Type-2 Fuzzy Logic Systems: Theory and Design". *IEEE Transactions on Fuzzy Systems*, Vol. 8, No. 5, pp.535–550, 2000.
- [17] J. Yen and R. Langari, *Fuzzy Logic – Intelligence Control and Information*, Pearson Education, 2003.
- [18] Y. Shi, R. Eberhart and Y. Chen, "Implementation of Evolutionary Fuzzy Systems," *IEEE Transactions on Fuzzy Systems*, Vol 7, No. 5, pp.109–119, 1999.
- [19] M.C. Mackey and Glass, "Oscillation and Chaos in Physiological Control Systems," *Science*, pp. 287–289, 1977.
- [20] J. Kennedy and R. Eberhart, "Particle Swarm Optimization," *Proc. IEEE Conference on Neural Networks*, Perth, Australia, 1995, pp. 1942–1948.

Nanostructured platform for the detection of *Neisseria gonorrhoeae* using electrochemical impedance spectroscopy and differential pulse voltammetry

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Abstract We report on a nanocomposite based genosensor for the detection of *Neisseria gonorrhoeae*, a bacterium causing the sexually transmitted disease gonorrhoea. Amino-labeled probe DNA was covalently immobilized on electrochemically prepared polyaniline and iron oxide (PANI-Fe₃O₄) nanocomposite film on an indium tin oxide (ITO) electrode. Scanning electron microscopy, transmission electron microscopy, electrochemical impedance spectroscopy (EIS) and differential pulse voltammetry (DPV) techniques have been employed to characterize surface of the modified electrode. The genosensor has detection limits of 1×10^{-15} M and 1×10^{-17} M, respectively, using the EIS and DPV techniques.

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This biosensor can discriminate a complementary sequence from a single-base mismatch and from non-complementary DNA, and has been utilized for detection of DNA extracted from *N. gonorrhoeae* culture, and from patient samples with *N. gonorrhoeae*. It is found to exhibit good specificity for *N. gonorrhoeae* species and shows no response towards non-gonorrhoeae type of *Neisseria* species (NgNs) and other gram-negative bacterias (GNBs). The affinity constant for hybridization calculated using the Langmuir adsorption isotherm model is found to be $3.39 \times 10^8 \text{ M}^{-1}$.

Keywords *Neisseria gonorrhoeae* · Sexually transmitted disease · Polyaniline-Fe₃O₄ nanocomposite · Electrochemical DNA sensor · Impedance spectroscopy

Introduction

There is increased interest towards tailoring of the micro and nanostructured materials for fabrication of advanced micro and nanobiodevices [1]. In this context, conducting polymers (CPs) are an excellent choice because of their robustness, flexibility, cost-effectiveness, ease-of-synthesis and fast electron transferring properties due to their conjugated structure [2]. Among the various CPs, polyaniline (PANI) is one of the most extensively studied CP due to its electrical conductivity, thermal and environmental stability, ease-of-preparation and electrochemical properties [3–8]. In spite of these interesting characteristics, PANI has found limited biosensing applications till date since it is not electrochemically active in neutral solution, and exhibits redox characteristics only in an acidic medium (pH < 3) [9]. In order to obtain improved conductivity, attempts have been made to prepare PANI-CNT composites [10].

The hybrid of PANI and metal oxide nanoparticles has attracted much attention. Among the various metal oxide nanoparticles, Fe_3O_4 is an interesting material because of its unique electrical and magnetic properties [11] with excellent biological compatibility [12, 13]. The hybrid of PANI and Fe_3O_4 nanoparticles have been prepared using different techniques such as chemical precipitation method, chemical oxidative polymerization for the different applications in electrical-magnetic shields, electrochemical display devices and microwave absorbing materials [14–16]. The inclusion of Fe_3O_4 nanoparticles may perhaps enhance the performance of a desired biosensor in terms of high catalytic activity, enhanced conductivity, improved sensitivity and selectivity. The excellent biological compatibility as well as large surface area due to a small granular diameter has made these nanoparticles promising material for immobilization of desired biomolecules and to retain their biological activities for a longer time. The optical, piezoelectric or electrochemical techniques are often used in DNA biosensors as transducers [17–19]. The electrochemical methods, in particular, provide sensitive, cost-effective and rapid way of analysis [20, 21]. The detection is accomplished by immobilization of single stranded DNA onto electrode surface and hybridization of a target DNA sequence present in the sample. The method is known to be very efficient and specific, because DNA sensor may detect an analyte even in the presence of a mixture of many different nucleic acid fragments [22]. Indirect method for electrochemical DNA hybridization detection is based on the determination of electroactive indicators whose interactions and binding affinity with double-stranded and single-stranded DNAs are quite different. The indirect methods measure response of a redox active molecule or an intercalator (metal complex, antibody, redox active organic dye etc.) electrochemical signal [23–27]. In the present case electrochemical properties of nanostructured PANI and Fe_3O_4 have been utilized to fabricate an electrochemical biosensor.

Electrochemical impedance spectroscopy (EIS) is a sensitive tool for label free DNA hybridization detection [28–31]. This interesting technique allows analysis of interfacial changes originating from biorecognition events at electrode surfaces. Rodríguez et al. have reported a gold surface modified with a self-assembled monolayer of 11-amino-1-undecanethiol for covalent immobilization of oxidized single-walled carbon nanotubes. The EIS measurements have been performed to follow the DNA hybridization process by using redox couple $[\text{Fe}(\text{CN})_6]^{3-/4-}$ as a marker ion [32]. Zhou et al. have reported a polyaniline nanofiber/carbon paste matrix (PANI/CPE), prepared by doping carbon paste with PANI, nanogold and carbon nanotubes have been bound on the surface of the PANI/CPE for sequence-specific DNA detection of phosphinothricin acetyltransferase (PAT) gene having the detection limit of 5.6×10^{-13} mol/L from

1.0×10^{-12} mol/L to 1.0×10^{-6} mol/L dynamic range [33].

We report results of the studies relating to electrochemical preparation of PANI- Fe_3O_4 nanocomposite films onto ITO surface that may serve as an excellent affinity interface for the immobilization of DNA. A sensitive genosensor based on this nanocomposite has been fabricated for label free detection of *N. gonorrhoeae* bacteria causing sexually transmitted disease (STD, gonorrhoea) that may lead to 2–5 folds increased chances of HIV acquisition if not diagnosed or treated at early stages. The sequence-specific DNA of the *opa*, a multicopy gene, has been taken and detected using EIS and DPV method. The results reveal that PANI- Fe_3O_4 nanocomposite may provide an excellent platform for the fabrication of genosensor.

Experimental section

Chemicals and reagents

Iron-oxide (Fe_3O_4) nanoparticles, aniline, potassium monohydrogen phosphate, potassium dihydrogen phosphate, potassium ferrocyanide $[\text{K}_4\text{Fe}(\text{CN})_6]$, potassium ferricyanide $[\text{K}_3\text{Fe}(\text{CN})_6]$, tris base, ethylene diamine tetra acetic acid (EDTA), Methylene blue (MB) and glutaraldehyde (Glu) have been procured from Sigma-Aldrich, USA. Indium-tin-oxide (ITO) coated glass plates (0.25 cm^2) have been obtained from Balzers, UK. All other chemicals are of analytical grade. All the solutions and glassware are autoclaved prior to being used. Deionized water (resistance $18.2 \text{ M}\Omega\cdot\text{cm}$) obtained from the Millipore water purification system has been utilized for the preparation of desired aqueous solutions.

Procurement of artificial DNA sequences

Probe DNA for specific label free detection of *N. gonorrhoeae* has been identified from the *opa* gene (a multi-copy gene) of *N. gonorrhoeae*. All oligonucleotide sequences have been procured from Sigma-Aldrich, USA. The Probe DNA used for immobilization in these studies are as follows.

Probe: aDNA or Amino-(GenBank Accession No: PUID 9716119 snum 2705)	
Oligonucleotide	Sequence
Probe DNA: Amino/aDNA	5'-CCGGTGCTTCATCACCTTAG-3'
Complementary target DNA (c-DNA)	5'-CTAAGGTGATGAAGCACCGG-3'
One-base mismatch DNA (oDNA)	5'-CTAAGTTGATGAAGCACCGG-3'
Non-complementary DNA (nDNA)	5'-GTATGGTGATCAAGCTCCCG-3'

The procedures for DNA Isolation from culture, DNA extraction from urethral and endocervical swab patient samples,

Preparation of urethral and endocervical swab patient samples for direct detection of complementary target DNA have been with given supplementary data S1, S2, S3.

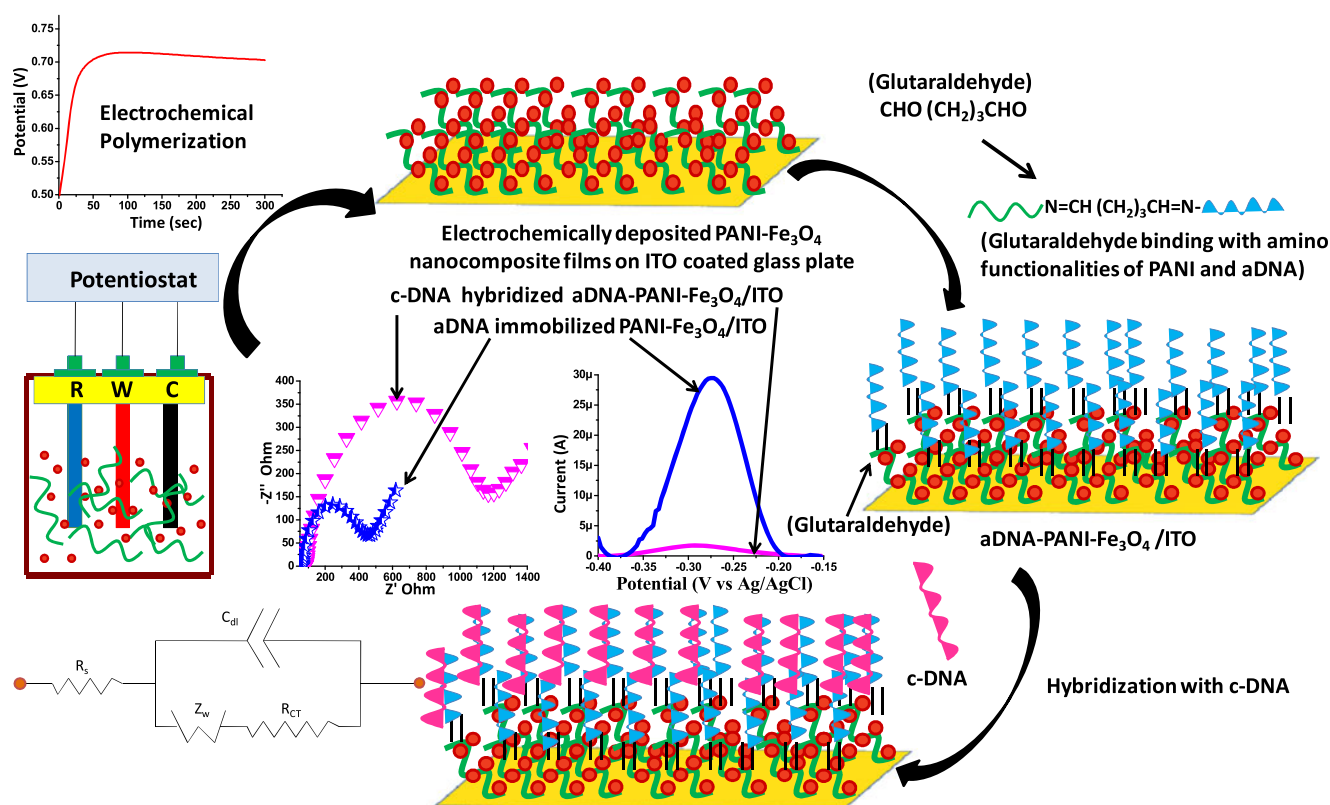
Electrochemical polymerization of PANI-Fe₃O₄ nanocomposite onto ITO electrode

The ITO plates are pre-cleaned with acetone, ethanol, and a copious amount of deionized water. To obtain the uniformly distributed OH groups on ITO surface, ITO plates are immersed in a solution of H₂O₂/NH₄OH/H₂O (1:1:5, v/v) for 30 min at 353 K for hydrolysis, after which these are rinsed thoroughly with deionized water and dried. The PANI-Fe₃O₄ nano-composite is prepared by electrochemical polymerization of aniline in the presence of iron oxide nanoparticles. Fe₃O₄ nanoparticles are dispersed in 1 M HCl that turns yellow after solubilization and it is ready to use. 1 mL of Fe₃O₄ nanoparticles dispersed in 1 M HCl is mixed with acidic solution (0.1 M HCl) of 10 mL of 0.2 M aniline and used for electrochemical polymerization onto ITO coated glass plate (0.25 cm²) using a three-electrodes electrochemical cell. The polymerization is performed chronopotentiometrically at 150 μ A for 900 s (via intermittent washing using autoclaved Millipore water after every 300 s of polymerization). The resulting composite films are washed with the background

electrolyte solution to exclude any residual monomer from the electrode. The electrode is dried under vacuum at room temperature (298 K) for about 24 h to obtain PANI-Fe₃O₄/ITO nanoelectrode. This nanocomposite has been characterized using X-ray diffraction (XRD, Supplementary data S6 and Supplementary Fig. 1).

Fabrication of amino labeled DNA functionalized PANI-Fe₃O₄/ITO nanobioelectrode

DNA is immobilized onto the electrochemically deposited PANI-Fe₃O₄/ITO nanoelectrode using Glu as a cross-linker under optimized conditions. For this purpose, firstly the PANI-Fe₃O₄/ITO nanoelectrode is dipped in 1.0% Glu for about 4 h followed by treatment with 10 μ l of aDNA (1.0 μ M) in a humid chamber at 298 K for 1 h. The incubation of aDNA solution on Glu-PANI-Fe₃O₄/ITO nanobioelectrode results in covalent bond formation between amine groups of aDNA and aldehyde group of Glu (Scheme 1). This fabricated aDNA-PANI-Fe₃O₄/ITO nanobioelectrode has been characterized using scanning electron microscopy (SEM, LEO 440), high resolution transmission electron microscopy (HRTEM, Model Tecnai G2 F30 STWIN, supported with field emission electron gun source operated at the electron accelerating voltage of 300 kV), contact angle (CA, Model OCA ISEC,



Scheme 1 Schematic representation of preparation of PANI-Fe₃O₄/ITO nanoelectrode and DNA immobilization

Dataphysics instruments GmbH, Germany), Fourier transform infrared spectroscopy (FT-IR, Perkin Elmer, Spectrum BX II), EIS, DPV, cyclic voltammetry (CV) (Potentiostat/Galvanostat, Autolab Eco Chemie, Netherlands) techniques. The results of EIS measurements and instrumentation are given in supplementary data (S4 and S5). All the CV and DPV measurements are provided in the supplementary information (Supplementary data S7, S8 and Supplementary figure 2, 3).

Results and discussion

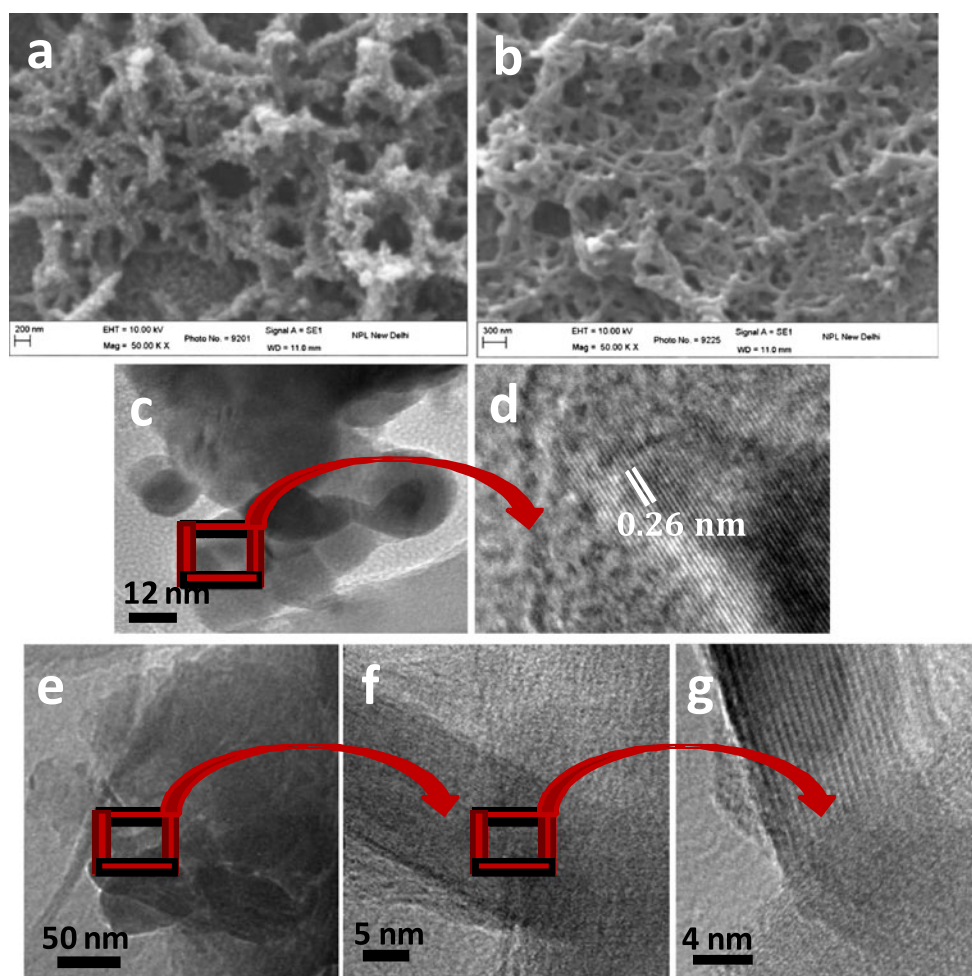
Scanning electron and high resolution transmission electron microscopic studies

SEM has been used to conduct the surface morphological studies on PANI-Fe₃O₄/ITO nanoelectrode (a) and aDNA-PANI-Fe₃O₄/ITO nanobioelectrode (b) and the results are shown in Fig. 1a, b. A thin coating of gold is sputtered on the desired samples prior to the SEM studies for better resolution of the microstructures. The PANI-Fe₃O₄/ITO nanoelectrode shows physical entrapment of granular nanoparticles of

Fe₃O₄ inside the network like structure of polyaniline nanotubes (Fig. 1a). Figure 1b shows SEM image of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode. The presence of dense network like structure onto the surface of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode is attributed to the immobilization of DNA molecules (Fig. 1b).

HRTEM has been employed to characterize PANI-Fe₃O₄ and aDNA immobilized PANI-Fe₃O₄ nanocomposite. The observations of PANI-Fe₃O₄ nanocomposite reveal that the Fe₃O₄ nanoparticles with size from 20 to 50 nm are present in the PANI matrix (Fig. 1c). Figure 1d shows that Fe₃O₄ nanoparticles are trapped in the PANI matrix. The interface between PANI and Fe₃O₄ nanoparticle is quite distinct without any microstructural inhomogeneity and porosity. Moreover, stacking of lattice planes with interplanar spacing of about 0.26 nm can be seen in structure of the nanoparticles. The corresponding spacing (0.26 nm) relates to the crystal structure of Fe₃O₄ nanoparticles with cubic (fcc, s.g. $Fd\bar{3}m$, $a=0.838$ nm) of hkl: 311. Figure 1e shows the immobilization of probe DNA onto PANI-Fe₃O₄ nanocomposite. In Fig. 1f, probe DNA immobilized onto PANI-Fe₃O₄ nanocomposite can be distinctly resolved. The diameter of all the

Fig. 1 SEM image of (a) PANI-Fe₃O₄/ITO nanoelectrode, (b) aDNA-PANI-Fe₃O₄/ITO nanobioelectrode and HRTEM of (c) PANI-Fe₃O₄ nanocomposite (d) PANI-Fe₃O₄ nanocomposite at higher magnification (e) aDNA-PANI-Fe₃O₄ nanobiocomposite (f) aDNA-PANI-Fe₃O₄ nanobiocomposite at high resolution (g) aDNA-PANI-Fe₃O₄ nanobiocomposite at higher resolution



DNA strands varies from 10 to 15 nm with length up to 500 nm. Figure 1g elucidates a higher magnification image of a DNA strand linked with PANI-Fe₃O₄ nanocomposite. The image reveals a set of multiples stripes generated along the diameter of individual DNA with almost uniform width of approximately 1.5 nm oriented along the longitudinal direction of the structure of DNA.

Contact angle and Fourier transform infrared (FTIR) spectroscopic studies

Contact angle studies have been carried out to obtain information relating to the immobilization of DNA onto the electrode surface (Fig. 2a). The change in the contact angle value is related to the immobilization of DNA molecules. The contact angle value of the PANI-Fe₃O₄/ITO nanoelectrode (Fig. 2a(i)) is found to be 54.9°, and decreases to 39.1° after the immobilization of aDNA (Fig. 2a(ii)). The decrease in the contact angle values can be attributed to the presence of NH₂ and OH groups of DNA, which helps to lower the contact angle values [34]. The change in contact angle values after immobilization indicates successful binding of the DNA.

Figure 2b shows the FT-IR spectra of PANI-Fe₃O₄/ITO nanoelectrode (curve i) and aDNA-PANI-Fe₃O₄/ITO nanobioelectrode (curve ii). It is found that PANI-Fe₃O₄/ITO nanoelectrode exhibits characteristic peaks at around 3234 cm⁻¹ (N–H stretching), 1582 cm⁻¹, 1493 cm⁻¹ (C=C stretching

deformation of quinoid and benzenoid ring, respectively), 1300 cm⁻¹ (C–N stretching of secondary aromatic amine), 1140 cm⁻¹, and 822 cm⁻¹ (out-of-plane deformation of C–H in the 1,4-disubstituted benzene ring) (Fig. 2b curve i) [35]. The peak seen at about 580 cm⁻¹ is attributed to the presence of Fe₃O₄ nanoparticles [36, 37]. In the FT-IR spectrum of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode, vibration bands observed at 1067 and 1243 cm⁻¹ are due to the asymmetric stretching of P–O–C vibration and stretching vibration of P=O of the phosphoric acid group, respectively. The peaks found at 1492 and 1606 cm⁻¹ are associated with the carbonyl stretching vibration and C=C bonds in the purine and pyrimidine rings (curve ii) [38–40]. The peaks observed at 1690 cm⁻¹ (C=N stretching), 1360 cm⁻¹ (C–N stretching) and 1034 cm⁻¹ (O–N stretching) reveal bonding vibrations present in the nitrogenous bases indicating immobilization of DNA.

Immobilization studies

The bioelectrodes have been characterized at each step of modification using EIS measurements. Figure 3a shows the Nyquist plots obtained for PANI-Fe₃O₄/ITO nanoelectrode (i), Glu-PANI-Fe₃O₄/ITO nanobioelectrode (ii) and for the aDNA-PANI-Fe₃O₄/ITO nanobioelectrode (iii). The R_{CT} is found to increase from 105.1 Ω to 170.5 Ω after Glu modification of PANI-Fe₃O₄/ITO nanoelectrode, due to the insulating nature of the Glu layer. The increment obtained in the R_{CT} value (461.3 Ω) after aDNA immobilization [41] can be attributed to electrostatic repulsion between the negatively charged phosphate backbone of aDNA and redox couple ([Fe(CN)₆]^{3-/4-}) present in the solution.

Figure 3b shows the Nyquist plots obtained for different concentrations of aDNA immobilized onto Glu-PANI-Fe₃O₄/ITO nanobioelectrode to investigate the optimum concentration. Continuous increase in the R_{CT} is observed with increasing concentrations of aDNA upto concentration of 1.0 × 10⁻⁶ M. It may be noted that we have observed negligible change in the R_{CT} value beyond 1.0 × 10⁻⁶ M concentration. Hence, 1.0 × 10⁻⁶ M concentration of aDNA has been used for all the experiments.

Specificity studies

The performance of this nanobioelectrode has been investigated by checking aDNA-PANI-Fe₃O₄/ITO nanobioelectrode hybridization with DNA extracted from *N. gonorrhoeae* culture isolate, pus sample spiked with *N. gonorrhoeae* and *N. gonorrhoeae* positive male patient. The specificity of the bioelectrode has been studied by incubating the probe DNA immobilized electrode with DNA extracted from other NgNs as well as other GNBs. Figure 3c shows EIS response of the STD sensor to DNA extracted from *N. gonorrhoeae* culture isolate, pus sample spiked with *N. gonorrhoeae* and *N.*

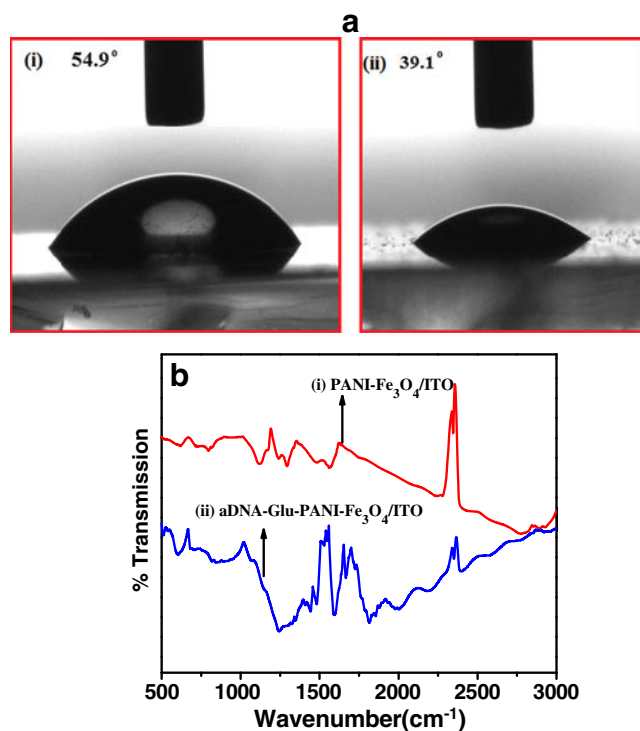
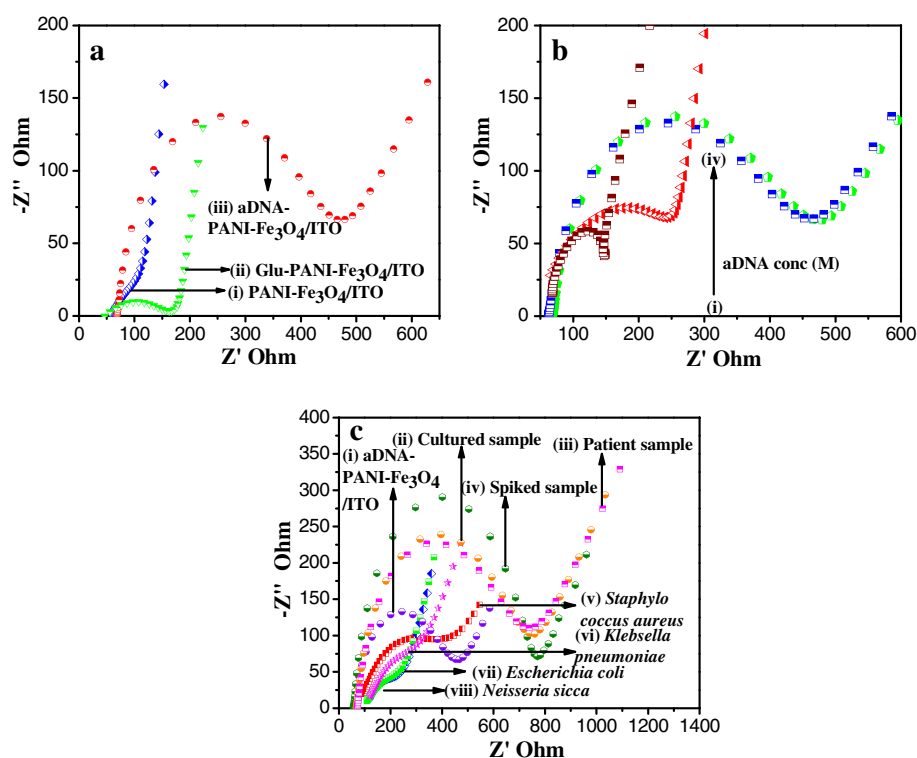


Fig. 2 Contact angle images (a) and FTIR spectra (b) of (i) PANI-Fe₃O₄/ITO nanoelectrode, (ii) aDNA-PANI-Fe₃O₄/ITO nanobioelectrode

Fig. 3 Nyquist diagrams of (a) Immobilization studies (i) PANI-Fe₃O₄/ITO nanoelectrode, (ii) Glu-PANI-Fe₃O₄/ITO nanobioelectrode and (iii) aDNA-PANI-Fe₃O₄/ITO nanobioelectrode (b) Effect of aDNA concentration onto Glu-PANI-Fe₃O₄/ITO nanobioelectrode (i) 1.0×10^{-8} M (ii) 1.0×10^{-7} M (iii) 1.0×10^{-6} M (iv) 1.0×10^{-5} M (c) Specificity studies of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode after treating with *Neisseria gonorrhoeae* culture, spiked sample, patient sample and other NgNs as well as other GNBs in 0.05 M PBS of pH 7.0 containing 5 mM [Fe(CN)₆]^{3-/4-}



gonorrhoeae positive male patient and cultures of denatured and fragmented *Klebsella pneumoniae*, *Staphylococcus aureus*, *Escherichia coli* and a clinical strain of *N. sicca*. The observed significant increase in the EIS signal shows that the nanobioelectrode (aDNA-PANI-Fe₃O₄/ITO) is highly specific for *N. gonorrhoeae*. However, no significant increase in the signal is obtained in presence of *K. pneumoniae*, *S. aureus*, *E. coli* and *N. sicca* DNA indicating the specificity of probe DNA for *N. gonorrhoeae* detection.

Response studies

DNA hybridization [42–44] has been investigated by monitoring change in the charge transfer resistance (R_{CT}) after

incubation of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode for about 15 min in different complementary DNA concentrations. The response of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode has been investigated by treating aDNA-PANI-Fe₃O₄/ITO nanobioelectrode by artificial DNA (c-DNA, nDNA, oDNA) (Fig. 4a). Enhancement in the R_{CT} (1083.9 Ω) is found after hybridization of c-DNA with the probe DNA onto aDNA-PANI-Fe₃O₄/ITO nanobioelectrode as a result of increase in the negative charge due to double-stranded DNA formation. However, negligible change in R_{CT} (461.3 Ω , 461.9 Ω) is found with nDNA and oDNA, respectively. The results of immobilization studies conducted using CV are given as supplementary data S7 and supplementary Fig. 2. The impedance spectra of the electrode has been recorded in phosphate buffer

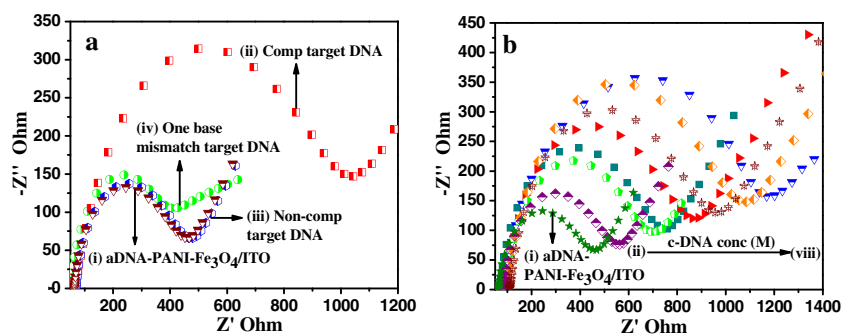


Fig. 4 Nyquist diagrams of (a) Hybridization studies (i) aDNA-PANI-Fe₃O₄/ITO nanobioelectrode after treatment with (ii) c-DNA, (iii) nDNA, (iv) oDNA, (b) Nyquist diagrams recorded at aDNA-PANI-Fe₃O₄/ITO nanobioelectrode (i) and after hybridization reaction with different

concentrations of c-DNA: (ii) 1.0×10^{-16} M, (iii) 1.0×10^{-15} M, (iv) 1.0×10^{-14} M, (v) 1.0×10^{-12} M, (vi) 1.0×10^{-10} M and (vii) 1.0×10^{-8} M (viii) 1.0×10^{-6} M in 0.05 M PBS of pH 7.0 containing 5 mM [Fe(CN)₆]^{3-/4-}

Table 1 Characteristics of aDNA-PANI-Fe₃O₄/ITO nanobio-electrode along with those reported in literature

S. No.	Electrode	Biosensing element	Method of immobilization	Detection Range	Detection limit	Stability	Binding constant	Clinical studies	Reference
1.	11-Amino-1-undecanethiol modified Au surface, covalently immobilized with oxidized single-walled carbon nanotubes	DNA	Covalent immobilization via EDC-sulfo NHS	250 nM to 1000 nM using EIS	-	-	-	-	[32]
2	Nanogold and CNT hybrid coated on the polyaniline nanofibers –modified carbon paste electrode	Sequence-specific DNA of the PAT gene and PCR amplification of the NOS gene from transgenically modified beans	Physical adsorption	1.0×10 ⁻¹² mol/L to 1.0×10 ⁻⁶ mol/L using EIS	5.6×10 ⁻¹³ mol/L	-	-	-	[33]
3	Polyaniline/polyacrylate-modified boron-doped diamond electrode	DNA	Covalent immobilization via EDC-NHS	2.0×10 ⁻⁷ to 5.0×10 ⁻⁸ M using EIS	2×10 ⁻⁸ M	Yes	-	-	[42]
4	Self-assembly of two dimensional 3-mercaptopropyltrimethoxy silane containing colloidal Ag nanoparticles onto Au electrode surface	DNA	HS-ssDNA binding to the Ag nanoparticles	8.0×10 ⁻⁹ to 1.0×10 ⁻⁶ M using EIS	4.0×10 ⁻⁹ M	Yes	-	-	[43]
5	PANI modified ITO electrode	Sequence-specific DNA of the <i>opa</i> gene from <i>N. gonorrhoeae</i>	Avidin-biotin coupling	1×10 ⁻¹⁶ M to 1×10 ⁻⁶ M using DPV	0.5×10 ⁻¹⁵ M	60 days	-	Yes	[44]
6.	PANI-CNT modified ITO electrode	Sequence-specific DNA of the <i>opa</i> gene from <i>N. gonorrhoeae</i>	Cross-linking (Glutaraldehyde)	1×10 ⁻¹⁷ M to 1×10 ⁻⁶ M using DPV	1.2×10 ⁻¹⁷ M	75 days	9.16×10 ⁹ M ⁻¹	Yes	[10]
7	PANI-Fe ₃ O ₄ modified ITO nanoelectrode	Sequence-specific DNA of the <i>opa</i> gene from <i>N. gonorrhoeae</i>	Cross-linking (Glutaraldehyde)	1×10 ⁻¹⁶ M to 1×10 ⁻⁶ M using EIS	1×10 ⁻¹⁵ M	120 days	3.39×10 ⁸ M ⁻¹	Yes	Present work
				1×10 ⁻¹⁸ M to 1×10 ⁻⁶ M using DPV	1×10 ⁻¹⁷ M				

saline (PBS) solution of pH 7.0 containing 5 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$ solution and the results are shown in Fig. 4. The continuous increase in R_{CT} is observed with increasing concentrations of c-DNA due to enhanced hybridization [45]. Figure 4b shows variation in R_{CT} as a function of c-DNA concentration ranging from 1.0×10^{-16} M to 1.0×10^{-6} M with detection limit of 1.0×10^{-15} M. It is found to be higher than that of the other DNA biosensors reported in literature (Table 1). However, the detection limit of this system is lower than that of the PANI-CNT system reported earlier [10]. The R_{CT} value increases linearly with logarithm of the c-DNA concentration. The linear regression of the plot follows Eq. 1

$$R_{CT} = 27.3 \log C + 1030.9 \quad (1)$$

The regression coefficient for linear regression is 0.9876.

Supplementary data S8 describes DPV response of the aDNA-PANI- Fe_3O_4 /ITO nanobioelectrode after hybridization with c-DNA concentration ranging from 1×10^{-18} M to 1×10^{-6} M exhibiting 1×10^{-17} M as the detection limit (Supplementary Fig. 3).

Stability and reproducibility of the DNA sensor

It has been found that this DNA sensor can be regenerated when it is immersed in 0.5 M NaOH for 2 min. The experiments show that it can be used for 14 times without losing its sensitivity. This DNA sensor has good stability for about 120 days perhaps due to the interaction between PANI backbone and Fe_3O_4 and hence could be used for repetitive detection.

Surface coverage calculation

The fraction of the occupied binding sites or surface coverage (Θ) of c-DNA can be calculated using Eq. 2: [46]

$$\Theta = 1 - \frac{R_M}{R_C} \quad (2)$$

where, R_M is the charge transfer resistance for aDNA-PANI- Fe_3O_4 /ITO nanobioelectrode and R_C is the charge

transfer resistance obtained for different concentrations of the c-DNA hybridized onto aDNA-PANI- Fe_3O_4 /ITO nanobioelectrode.

Figure 5a shows a plot of Θ as a function of concentration of c-DNA onto aDNA-PANI- Fe_3O_4 /ITO nanobioelectrode. The value of Θ increases with increasing c-DNA concentration and is found to be ~ 0.629 (62.9%) for 10^{-6} M c-DNA. However, the value of surface coverage of aDNA ($1.0 \mu\text{M}$) onto the PANI- Fe_3O_4 /ITO nanoelectrode is 63% (calculated from R_{CT} values obtained in Fig. 3b).

Binding constant calculation using Langmuir adsorption isotherm

The binding constant of the hybridization of target DNA to the probe DNA has been investigated using Langmuir adsorption isotherm, which is based on the assumption that there is negligible intermolecular interaction between the adsorbed c-DNA molecules and there are uniform binding sites, having equal binding energy, on the surface. The Langmuir model is widely used to study the protein and DNA interactions and to determine the binding affinities. The high value of binding constant indicates better affinity of c-DNA towards immobilized aDNA. According to Langmuir adsorption model a plot of C_o/R_{CT} as a function of C_o in Eq. 3 yields a straight line.

$$R_{CT} = \frac{(R_{CT})_{\max} C_o K_A}{1 + C_o K_A} \quad (3)$$

where C_o is concentration of c-DNA and R_{CT} is the corresponding charge transfer resistance. Figure 5b shows the plot of C_o/R_{CT} as a function of C_o for c-DNA-aDNA-PANI- Fe_3O_4 /ITO nanobioelectrode. The straight line obtained indicates applicability of the Langmuir model onto the aDNA-PANI- Fe_3O_4 /ITO system. Equation 3 is further used to calculate the value of binding constant. The ratio of slope to intercept yields the value of K_A as $3.39 \times 10^8 \text{ M}^{-1}$. The value of binding constant for PANI-CNT system is found to be as $9.16 \times 10^9 \text{ M}^{-1}$ (data not shown) that perhaps may be reason of the higher detection limit of the PANI-CNT system due to the higher electrical conductivity of CNT.

Fig. 5 Plot of surface coverage with different c-DNA concentrations (a) Langmuir adsorption isotherm plot for adsorption of c-DNA onto aDNA-PANI- Fe_3O_4 /ITO nanobioelectrode (b)

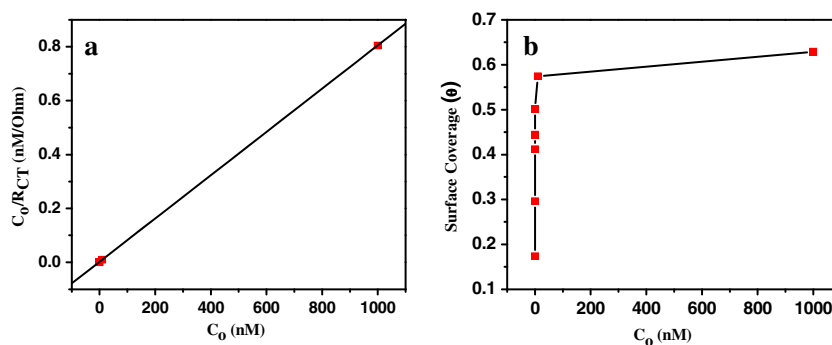


Table 1 shows characteristics of the DNA biosensor based on aDNA-PANI-Fe₃O₄/ITO nanobioelectrode along with those of the other DNA biosensors reported in literature.

Conclusions

The electrochemically prepared PANI-Fe₃O₄ nanocomposite, onto ITO glass plate, immobilized with aDNA has been used as a genosensor for application to label free detection of *N. gonorrhoeae* bacteria causing sexually transmitted disease. The aDNA-PANI-Fe₃O₄/ITO nanobioelectrode is capable of detecting the DNA hybridization process by monitoring changes in the charge transfer resistance obtained from diameter of the semicircle of the Nyquist plot. The results of DNA hybridization with the c-DNA exhibit an increase in the R_{CT} values in comparison to that of the aDNA modified bioelectrode due to repulsion between the negative charge of the DNA phosphate groups and the negative charge of the [Fe(CN)₆]^{3-/4-} ions. The response studies of aDNA-PANI-Fe₃O₄/ITO nanobioelectrode reveal wider detection range of DNA concentration. The sequence-specific DNA of the *opa* gene from *N. gonorrhoeae* has been detected by this genosensor. aDNA-PANI-Fe₃O₄/ITO nanobioelectrode exhibits specificity toward *N. gonorrhoeae* species and shows negative response with NgNs and other GNBs. The value of binding constant estimated using Langmuir adsorption isotherm is found to be $3.39 \times 10^8 \text{ M}^{-1}$. Efforts should be made to improve electrical conductivity of PANI composite by using AuNPs, AgNPs, CNT and graphene. Besides this, it should be interesting to fabricate ordered molecular assemblies [47] based on PANI-Fe₃O₄ nanocomposite for application to nucleic acid sensor.

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References

- Zhang L, Wan M, Wei Y (2005) Polyaniline/TiO₂ microspheres prepared by a template free method. *Synth Met* 151:1–5
- Zhang Z, Wan M (2002) Composite films of nanostructured polyaniline with poly(vinyl alcohol). *Synth Met* 128:83–89
- Malinauskas A (2004) Self doped polyanilines. *J Power Sources* 126:214–220
- Chandrasekhar P (1999) Conducting polymers, fundamentals and applications: a practical approach, 1st edn. Kluwer Academic Publishers, London
- Olmedo L, Hourquebie P, Jousse F (1997) Handbook of Organic Conductive Molecules and Polymers (Ed.: H. S. Nalwa), John Wiley and Sons Ltd, Chichester.
- MacDiarmid AG (2002) Synthetic metals: a novel role for organic polymers. *Synth Met* 125:11–22
- Tran HD, Kaner RB (2006) A general synthetic route to nanofibers of polyaniline Derivatives. *Chem Commun* 3915–3917.
- Skotheim JR, Elsenbaumer RL, Reynolds JR (1998) Handbook of conducting polymers. Marcel Dekker, New York
- Diaz AF, Logan JA (1980) Electroactive polyaniline films. *J Electroanal Chem* 111:111–14
- Singh R, Dhand C, Sumana G, Verma R, Sood S, Gupta RK, Malhotra BD (2010) Polyaniline/carbon nanotubes platform for sexually transmitted disease detection. *J Mol Recognit* 23:472–479
- Dormann JL (1991) Fioranim D magnetic properties of fine particles. North-Holland, Amsterdam, pp 309–423
- Ankamwar B, Lai TC, Huang JH, Liu RS, siao MH, Chen CH, Hwu YK (2010) Biocompatibility of Fe₃O₄ nanoparticles evaluated by in vitro cytotoxicity assays using normal, glia and breast cancer cells. *Nanotechnology* 21:075102 (9 pp).
- Sun J, Zhou S, Hou P, Yang Y, Weng J, Li X, Li M (2007) Synthesis and characterization of biocompatible Fe₃O₄ nanoparticles. *J Biomed Mater Res A* 80A:333–34
- Lu X, Yu Y, Chen L, Mao H, Zhang W, Wei Y (2004) Preparation and characterization of polyaniline microwires containing CdS nanoparticles. *Chem Commun* 1522–1523.
- Lu X, Yu Y, Chen L, Mao H, Gao H, Wang J, Zhang W, Wei Y (2005) Aniline dimer-COOH assisted preparation of well-dispersed polyaniline-Fe₃O₄ nanoparticles. *Nanotechnology* 16:1660–1665
- Ahmad R, Kumar R (2010) Conducting polyaniline/iron oxide composite: a novel adsorbent for the removal of amido black 10B. *J Chem Eng Data* 55:3489
- Watterson J, Piuino PAE, Krull UJ (2002) Practical physical aspects of interfacial nucleic acid oligomer hybridization for biosensor design. *Anal Chim Acta* 469:115–127
- Yang M, McGovern ME, Thompson M (1997) Genosensor technology and the detection of interfacial nucleic acid chemistry. *Anal Chim Acta* 346:259–275
- Arotiba OA, Ignaszak A, Malgas R, Al-Ahmad A, Baker PGL, Mapolie SF, Iwuoha I (2007) An electrochemical DNA biosensor developed on novel multinuclear nickel (II) salicylaldehyde metal-lodendrimer platform. *Electrochim Acta* 53:1689–1696
- de-los Santos-Alvarez P, Lobo-Castanon MJ, Miranda-Ordieres AJ, Tunon-Blanco P (2004) Current strategies for electrochemical detection of DNA with solid electrodes. *Anal Bioanal Chem* 378:104–118
- Sun X, He P, Liu S, Ye L, Fang Y (1998) Immobilization of single-stranded deoxyribonucleic acid on gold electrode with self-assembled aminoethanethiol monolayer for DNA electrochemical sensor applications. *Talanta* 47:487–495
- Ge C, Miao W, Ji M, Gu N (2005) Glutaraldehyde-modified electrode for nonlabeling voltammetric detection of p16^{INK4A} gene. *Anal Bioanal Chem* 383:651–659
- Drummond TG, Hill MG, Barton JK (2003) Electrochemical DNA sensors. *Nat Biotechnol* 21:1192–1199
- Christopoulos TK (1999) Nucleic acid analysis. *Anal Chem* 71:425R–438R
- Farabullini F, Lucarelli F, Palchetti I, Marrazza G, Mascini M (2007) Disposable electrochemical genosensor for simultaneous analysis of different bacterial food contaminants. *Biosens Bioelectron* 22:1544–1549

26. Bagni G, Osella D, Sturchio E, Mascini M (2006) Deoxyribonucleic acid (DNA) biosensors for environmental risk assessment and drug studies. *Anal Chim Acta* 573:81–89
27. Odenthal KJ, Gooding JJ (2007) An introduction to electrochemical DNA biosensors. *Analyst* 132:603–610
28. Kafka J, Pänke O, Abendroth B, Lisdat F (2008) A label-free DNA sensor based on impedance spectroscopy. *Electrochim Acta* 53:7467–7474
29. Keighley SD, Li P, Estrela P, Migliorato P (2008) Optimization of DNA immobilization on gold electrodes for label-free detection by electrochemical impedance spectroscopy. *Biosens Bioelectron* 23:1291–1297
30. Suni II (2008) Impedance methods for electrochemical sensors using nanomaterials. *Trends Anal Chem* 27:604–611
31. Ricci F, Plaxco KW (2008) E-DNA sensors for convenient, label-free electrochemical detection of hybridization. *Microchimica Acta* 163:149–155
32. Rodríguez LS, Pomales GS, Cabrera CR (2010) Single-walled carbon nanotubes modified gold electrodes as an impedimetric DNA sensor. *Electroanalysis* 22:399–405
33. Zhou N, Yang T, Jiang C, Du M, Jiao K (2009) Highly sensitive electrochemical impedance spectroscopic detection of DNA hybridization based on Au(nano)-CNT/PAN(nano) films. *Talanta* 77:1021–1026
34. Solanki PR, Arya SK, Nishimura Y, Iwamoto M, Malhotra BD (2007) Cholesterol biosensor based on aminoundecanethiol self-assembled monolayer using surface plasmon resonance technique. *Langmuir* 23:7398–7403
35. Chen SA, Lee HT (1995) Structure and properties of poly(acrylic acid)-doped polyaniline. *Macromolecules* 28:2858–2866
36. Cornell RM, Schwertmann U (1996) The iron oxide. VCH, New York
37. Kryszewski M, Jeszka JK (1998) Nanostructured conducting polymer composites - superparamagnetic particles in conducting polymers. *Synth Met* 94:99–104
38. Neault JF, Naoui M, Manfait M, Tajmir-Riahi HA (1996) Aspirin-DNA interaction studied by FTIR and laser Raman difference spectroscopy. *FEBS Lett* 382:26–30
39. Kanakis CD, Tarantilis PA, Polissiou MG (2006) Interaction of antioxidant flavonoids with tRNA: intercalation or external binding and comparison with flavonoid-DNA adducts. *DNA Cell Biol* 25:116–123
40. Prabhakar N, Arora K, Singh SP, Pandey MK, Singh H, Malhotra BD (2007) Polypyrrole-polyvinyl sulphonate film based disposable nucleic acid biosensor. *Analytica Chimica Acta* 589:6–13
41. Caliskan A, Erdem A, Karadeniz H (2009) Direct DNA hybridization on the single-walled carbon nanotubes modified sensors detected by voltammetry and electrochemical impedance spectroscopy. *Electroanalysis* 21:2116–2124
42. Gu H, Su XD, Loh KP (2005) Electrochemical impedance sensing of DNA hybridization on conducting polymer film-modified diamond. *J Phys Chem B* 109:13611–13618
43. Fu Z, Yuan R, Xu L, Chai Y, Liu Y, Tang D, Zhang Y (2005) Electrochemical impedance behavior of DNA biosensor based on colloidal Ag and bilayer two-dimensional sol-gel as matrices. *J Biochem Biophys Methods* 62:163–174
44. Singh R, Prasad R, Sumana G, Arora K, Sood S, Gupta RK, Malhotra BD (2009) STD sensor based on nucleic acid functionalized nanostructured polyaniline. *Biosens Bioelectron* 24:2232–2238
45. Katz E, Willner I (2003) Probing biomolecular interactions at conductive and semiconductive surfaces by impedance spectroscopy: routes to impedimetric immunosensors, DNA-sensors, and enzyme biosensors. *Electroanalysis* 15:913–947
46. Szymańska I, Radecka H, Radecki J, Kaliszan R (2007) Electrochemical impedance spectroscopy for study of amyloid beta-peptide interactions with (–) nicotine ditartrate and (–) cotinine. *Biosens Bioelectron* 22:1955–1960
47. Matharu Z, Bandodkar AJ, Gupta V, Malhotra BD (2012) Fundamentals and application of ordered molecular assemblies to affinity biosensing. *Chem Soc Rev* 41:1363–1402

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Noise Analysis of Gate Electrode Work function Engineered Recessed Channel (GEWE-RC) MOSFET

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Abstract. This paper discusses the noise assessment, using ATLAS device simulation software, of a gate electrode work function engineered recessed channel (GEWE-RC) MOSFET involving an RC and GEWE design integrated onto a conventional MOSFET. Furthermore, the behaviour of GEWE-RC MOSFET is compared with that of a conventional MOSFET having the same device parameters. This paper thus optimizes and predicts the feasibility of a novel design, i.e., GEWE-RC MOSFET for high-performance applications where device and noise reduction is a major concern. The noise metrics taken into consideration are: minimum noise figure and optimum source impedance. The statistical tools auto correlation and cross correlation are also analysed owing to the random nature of noise.

1. Introduction

To achieve higher speeds and packing densities, the world has witnessed the miniaturization of the basic MOS device structure. Today, CMOS technology has an established place in the design of multi-gigahertz communication circuits. This is due to the continuing down-scaling of MOS devices, which improves their RF performance characteristics. As the MOSFET is shrunk, some unwanted effects are observed such as punchthrough, hot carrier injection, noise in RF range, and dependence of threshold voltage on channel dimensions, DIBL and other short channel effect (SCEs) which affect the performance of the device in a negative manner. As MOSFET device sizes and signal levels are aggressively scaled down, the low-frequency noise (LFN) properties become increasingly important. This is because the signals are no longer significantly higher than the LFN, especially since the LFN level increases significantly as the device's size is scaled down[1,2]. As the issue of noise becomes increasingly important in deep-submicron MOSFETs, it is necessary to be able to accurately measure and model the noise parameters of MOSFET to fully characterize its noise performance.

Concave MOSFETs are known to alleviate many of the SCEs [3,4]. This has been achieved by separating the source and drain (S/D) regions by a groove. Several studies have reported that the potential barrier formed at each concave corner is responsible for suppressing the SCEs, hot-carrier

effects and punch-through. It is also responsible for the degradation of current driving capability and threshold voltage. The recess MOSFET, however, in conjunction with dual material gate (DMG) architecture [5,6], named as Gate electrode work function engineered recessed channel (GEWE-RC) MOSFET, as shown in figure 1, enhances drain current characteristics (shown in figure 2), average carrier velocity and suppresses SCEs, thereby proving superior to the conventional MOSFET. With DMG architecture, the step potential profile, due to different work functions of two metal gates, ensures reduction of SCEs and screening of the channel region under gate 1 from drain potential variations. Thus, the average electric field in the channel is enhanced, improving the electron velocity near the source and, hence, the carrier transport efficiency. Some past works on this device such as RF analysis[7] and linearity analysis[8] have been done before and they suggest the feasibility[9] of this model. The work has been compiled in Chaujar *et al.* The GEWE-RC MOSFET [10,11] (figure 1) considered in this study also integrates the potential benefits of concave MOSFETs with DMG architecture for enhancing the noise performance of scaled devices in comparison to the conventional MOSFET.

For the purpose of the above mentioned noise analysis, structural design parameters, such as gate length, junction depth, substrate doping, gate metal work function and thickness of the oxide layer are tuned in GEWE-RC MOSFET to attain the best performance. The noise parameters examined are the minimum noise figure[12], NF_{min} , and optimum source admittance, Y_{opt} , or impedance, Z_{opt} , as they are important in the design of low noise RF circuits such as low noise amplifiers (LNA)[13] and mixers[14]. The statistical tools auto correlation and cross correlation are also analysed owing to the random nature of noise.

All simulations have been performed using ATLAS device simulation software. The models activated in simulation comprise the inversion layer Lombardi CVT mobility model along with the Shockley–Read–Hall (SRH) and Auger recombination models for minority carrier recombination. Furthermore, we adopt the hydrodynamic energy transport model which includes the continuity equations, momentum transport equations, energy balance equations of the carriers and Poisson’s equation [12]. It can model the non-local transport phenomenon, and hence presents a higher accuracy than the drift–diffusion method. The quantum corrections have not been taken into account because the quantum mechanical effects become significant when the gate oxide thickness is below 30 Å or 3 nm. In our study, since the gate oxide thickness is 3 nm, the quantum corrections are ignored [15]. The specifications of the device are given in Table 1.

Table 1. Design Parameters for GEWE-RC MOSFET
used in the analysis

Design Parameters	
Effective Channel Length	96nm
Groove Depth	70nm
Source/Drain Junction Depth	50nm
Negative Junction Depth	20nm
Substrate Doping	$1 \times 10^{17} \text{ cm}^{-3}$
Source/Drain Doping	$1 \times 10^{20} \text{ cm}^{-3}$
Physical Oxide Thickness	3nm
Permittivity Of Oxide	3.9
Work Function Of Gates	Of gate1=4.77eV Of gate2=4.1eV

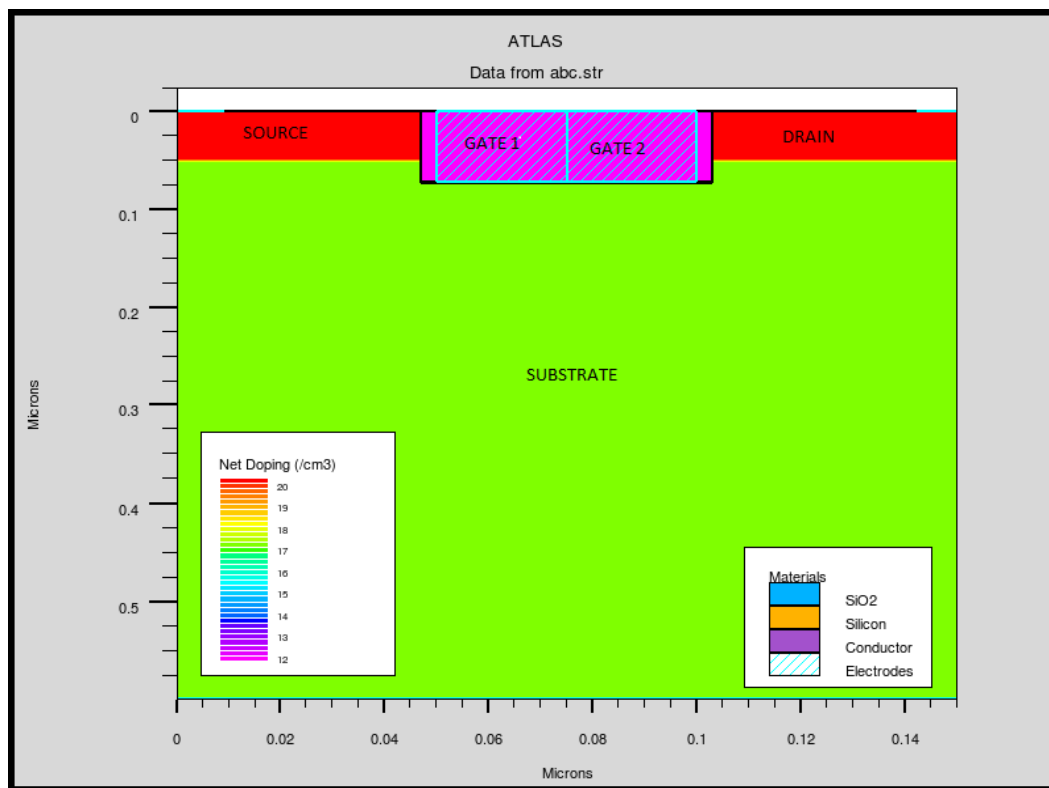


Figure 1. The architecture of GEWE-RC MOSFET.

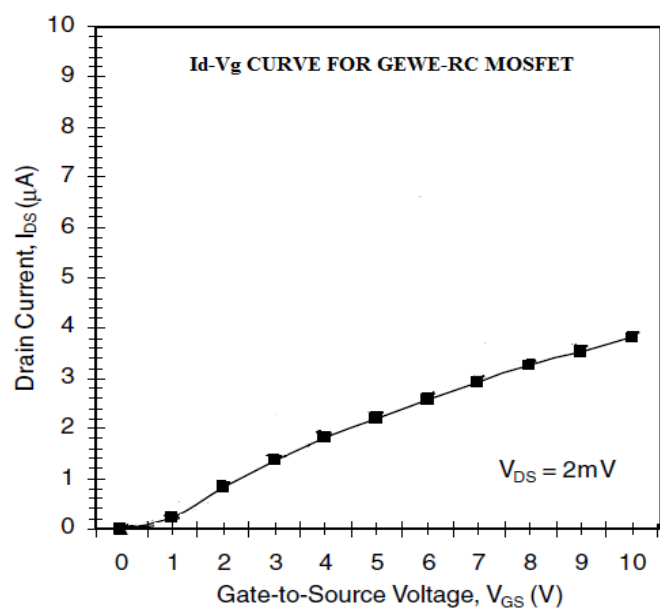


Figure 2. Id-Vg characteristics of GEWE-RC MOSFET.

2. Noise Analysis

Noise performance of a modern small-area MOS devices is dominated by random telegraph signal (RTS) fluctuations[7,12]. Their origin is the capture and subsequent emission of charge carriers at discrete trap levels near the Si-SiO₂ interface[16,17]. For deep-submicrometer devices, the number of traps with energy within a few kT close to the surface Fermi level is small[2]. Both, the number of traps and their position over the channel are random variables[16,18]. Traps located in the gate oxide near the interface to the silicon capture and reemit some of the carriers responsible for the current flowing between the source and the drain of the device[18]. Hence, the carrier transport efficiency is hampered.

2.1. Results and Discussion

2.1.1. Minimum Noise Figure. The Figure 3 explains the effect of frequency on the noise behavior of GEWE-RC MOSFET and the Conventional MOSFET designs (with the same specifications), in terms of minimum noise figure. Results clearly reveal that noise figure for the conventional MOSFET decreases with the increasing frequency but that of GEWE-RC MOSFET increases with the increasing frequency. Although, it is noteworthy that the noise figure for the conventional MOSFET and GEWE-RC MOSFET at 1000Hz is 67.6643dB and 0.000212794dB respectively. Also, it is vital to observe that the lowest noise figure shown by the conventional MOSFET is 9.18454dB only. This observation can be mainly attributed to the work function difference of the gates in the GEWE-RC architecture, due to which a step-potential is introduced in the channel[19]. There exists a screening of the channel region from the drain induced variations due to which the number of carriers entering the channel remains comparatively less varied[19]. Also, the vertical electric field is reduced due to which the trapping of the carriers near the Si-SiO₂ reduces, which results in the improved carrier transport efficiency[20].

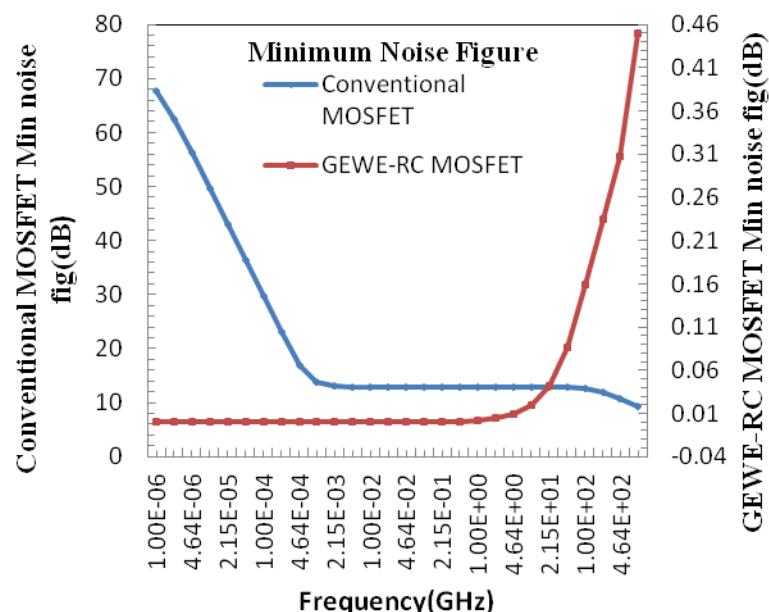


Figure 3. Minimum Noise Figure as a function of frequency.

2.1.2. Optimum Source Impedance. The Figure 4 gives the behavior of optimum source impedance ($Z_{OPT}=R_{OPT}+jX_{OPT}$) with respect to frequency. Because the oxide layer acts as a dielectric, there is essentially never any current between the gate and the channel during any part of the signal cycle[21]. As the oxide thickness is being continuously shrunk due to the scaling of the MOSFET, the MOSFET should have a large source impedance to avoid destruction by electrostatic charges. In the Figure 3 it can be vividly seen that optimum impedance for GEWE-RC MOSFET is much higher than that of the Conventional MOSFET.

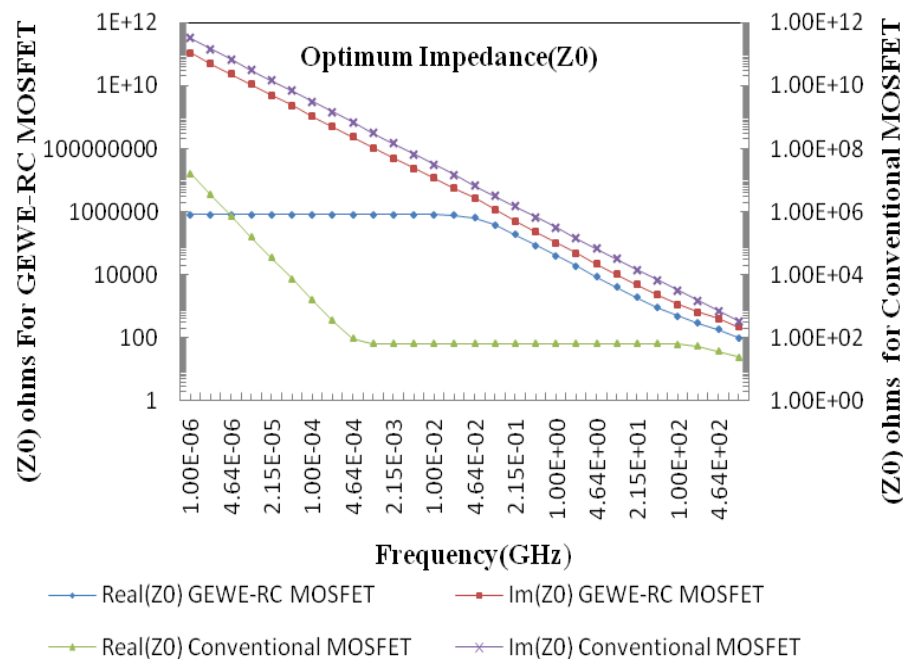


Figure 4. Optimum Source Impedance as a function of frequency.

2.1.3. Auto Correlation and Cross Correlation. The MOSFET is considered as a two port device (Figure 5) i.e. the noise induced at the gate is separated from the MOSFET and is depicted by V1 and the noise received at the output is replaced by a voltage V2[22]. Since noise is a random phenomenon, some statistical analysis is indispensable for this research. Thus, the autocorrelation and cross correlation of the voltages at the two ports of the devices are compared. From the above analysis it can be inferred that surface scattering with the Si-SiO₂ gate interface is noticeably reduced in the GEWE-RC MOSFET because of a lower vertical electric field. Therefore, isotropic scatterings present a reduced prevalence in this device[23]. Thus it can be concluded that the mean free path (λ) of carriers crossing the channel as a function of the frequency is much larger than in the conventional transistor[19]. This reduced influence of isotropic scatterings implies that the scattering mechanisms are not so effective in breaking the correlation between gate and drain current, which leads to higher cross correlation (i.e. $V1.V2^*$) between them[23]. Figure 6 depicts such behaviour. In Figure 6, the imaginary part of cross correlation for GEWE-RC MOSFET is abruptly ending as the y axis has a log scale and log is undefined for negative values. It is notable though that the values of Imaginary part of cross correlation for GEWE-RC MOSFET abruptly finishes at 1GHz; this is due to the fact that the y axis of the graph has a log scale and the results for the $Im(V1.V2^*)$ comes out to be negative. Thus, as log is undefined for negative values, the graph for $Im(V1.V2^*)$ abruptly ends at 1GHz. Auto correlation is the cross correlation of a signal with itself. As can be seen by Figure 7, there is higher

auto correlation between the input (i.e. $V_1.V_1^*$) and output voltages (i.e. $V_2.V_2^*$) in GEWE-RC MOSFET than the conventional MOSFET depicting lesser intrinsic noise in the former than the latter.

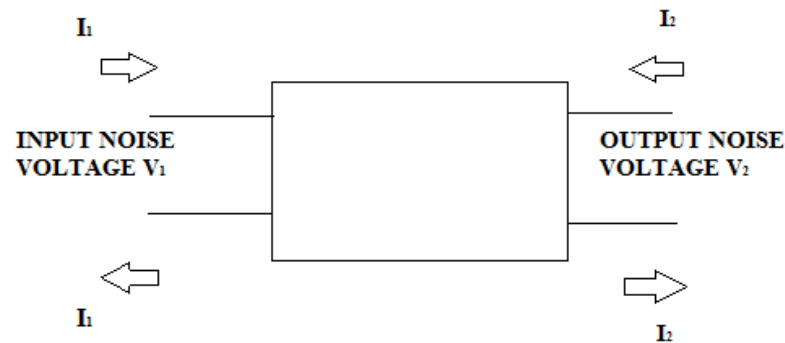


Figure 5. MOSFET as a two port device where the input noise is replaced by a voltage V_1 and the noise received at the output is replaced by V_2 .

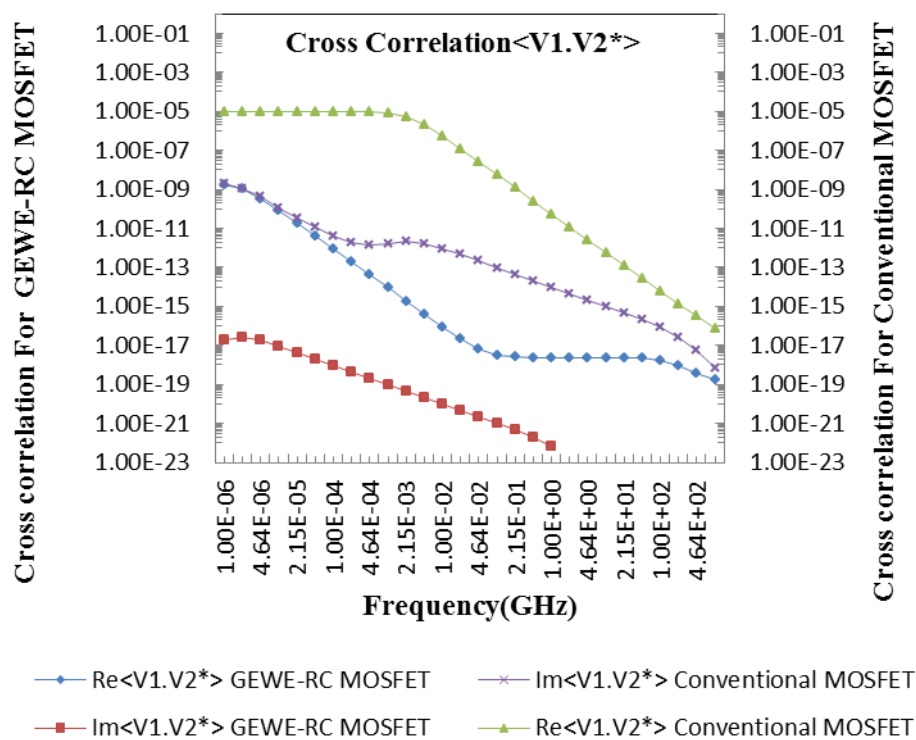


Figure 6. Cross correlation as a function of frequency.

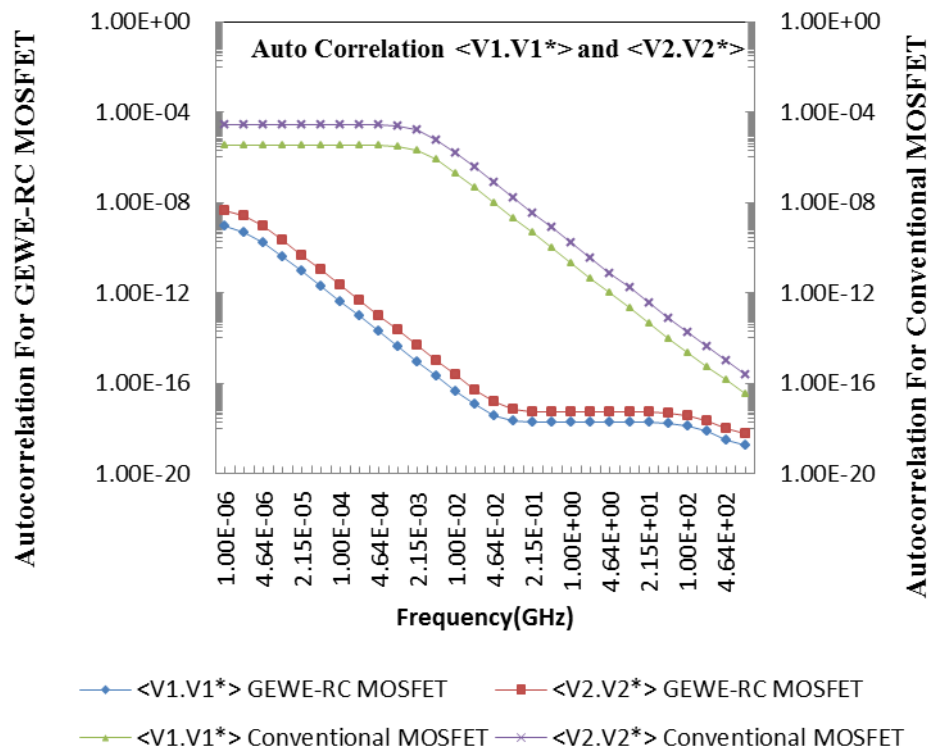


Figure 7. Auto correlation as a function of frequency.

3. Conclusion

As shown in this work, from the analysis of the microscopic noise sources and dynamic performance of the devices; GEWE-RC MOSFET exhibits superior noise performance in comparison to its conventional counterpart. It can be concluded that the reduced induced gate noise and stronger cross correlation are responsible for the noticeable improvements observed in the intrinsic minimum noise figure. Hence, proving its potency for low power, low noise and low supply voltage applications. Lower noise figure and higher optimum source impedance pertained by the GEWE-RC architecture strengthens the idea of using it for such applications, thereby giving a new opening for usage in RF applications.

4. References

- [1] Brederlow R, Weber W, Schmitt-Landsidel D, and Thewes R 1999 Fluctuations of the low frequency noise of MOS transistors and their modeling in analog and RF-circuit *IEDM Tech. Dig.* 159.
- [2] Sánden M, Marinov O, Deen M J, and Ostling M 2002 A new model for the low-frequency noise and the noise level variation in polysilicon emitter BJTs *IEEE Trans. Electron Devices* **49** 514.
- [3] Takeda E, Kume H and Asai S 1983 New grooved-gate MOSFET with drain separated from channel implanted region (DSC) *IEEE Trans. Electron Devices* **30** 448.
- [4] Sreelal S, Lau C K and Samudra G S 2002 Parasitic capacitance characteristics of deep sub micrometer grooved gate MOSFETs *Semicond. Sci. Technol.* **17** 179.
- [5] Long W and Chin K K 1997 Dual material gate field effect transistor (DMGFET) *IEDM Tech. Dig.* 549.
- [6] Zhou X 2000 Exploring the novel characteristics of hetero-material gate field-effect transistors

- (HMGFET's) with gate-material engineering *IEEE Trans. Electron Devices* **47** 113.
- [7] Chaujar R, Kaur R, Saxena M, Gupta M and Gupta R S 2008 GEWE-RC MOSFET: A solution to CMOS technology for RFIC design based on the concept of intercept point; *International Conference on Recent Advances in Microwave Theory and Applications*, 2008 661.
- [8] Rishu Chaujar, Ravneet Kaur, Manoj Saxena, Mridula Gupta and R. S. Gupta 2008 Intermodulation Distortion and Linearity Performance Assessment of 50-nm gate length L-DUMGAC MOSFET for RFIC Design, *Superlattices and Microstructures* **44** 143.
- [9] Chaujar R, Kaur R, Saxena M, Gupta M and Gupta R S 2007 On-state and switching performance investigation of sub-50nm L-DUMGAC MOSFET design for high-speed logic applications *Semiconductor Device Research Symposium, International* 2007 1.
- [10] Chaujar R, Kaur R, Saxena M, Gupta M and Gupta R S 2008 Laterally amalgamated Dual material Gate concave (L-DUMGAC) MOSFET for ULSI *Microelectron. Eng.* **85** 566.
- [11] Chaujar R, Kaur R, Saxena M, Gupta M and Gupta R S 2007 RF-Distortion in Sub-100 nm L-DUMGAC MOSFET *14th Int. Workshop on the Physics of Semiconductor Devices (IWPSD-2007)* (Mumbai) 168.
- [12] ATLAS Device Simulator, SILVACO International 2011.
- [13] Shaeffer D K and Lee T H 1997 A 1.5 V, 1.5 GHz CMOS low noise amplifier *IEEE J. Solid-State Circuits* **32** 745.
- [14] Karanicolas A N Dec. 1996 A 2.7-V 900-MHz CMOS LNA and mixer *IEEE J. Solid-State Circuits* **31** 1939.
- [15] Lo S H, Buchanan D A, Taur Y and Wang W 1997 Quantum-mechanical modeling of electron tunnelling current from the inversion layer of ultra-thin-oxide nMOSFET's *IEEE Electron Device Lett.* **18** 209.
- [16] Boutchacha T and Ghibaudo G 1998 Low frequency noise characterization of 0.18 μm Si CMOS transistors *Phys. Status Solidi, A* **167** 261.
- [17] Simoen E, Dierickx B, Clayes C L, and Declercq G J 1992 Explaining the amplitude of RTS noise in submicrometer MOSFETs *IEEE Trans. Electron Devices* **39** 419.
- [18] Kirton M J and Uren M J 1989 Noise in solid-state microstructures: A new perspective on individual defects, interface states and low-frequency ($1/f$) noise *Adv. Phys.* **38** 367.
- [19] Chaujar R, Kaur R, Saxena M, Gupta M and Gupta R S 2008 TCAD Assessment of Gate Electrode Workfunction Engineered Recessed Channel (GEWE-RC) MOSFET and Its Multilayered Gate Architecture—Part I: Hot-Carrier-Reliability Evaluation, *IEEE Trans on Electron Devices* 2008 **55** 2602.
- [20] Hou F C, Bosman G, and Law M E 2003 Simulation of oxide trapping noise in submicron n-channel MOSFETs, *IEEE Trans. Electron Devices*, **50** 846.
- [21] Ribes G, Mitard J, Denais M, Bruyere S, Monsieur F, Parthasarathy C, Vincent E, and Ghibaudo G 2005 Review on high-k dielectrics reliability issues *IEEE Trans. Device Mater. Rel.* **5** 5.
- [22] Belostotski L and Haslett J W 2008 Two-port noise figure optimization of source-degenerated cascode CMOS LNAs, *Analog Integr. Circuits Signal Process.* **55** 125.
- [23] Rengel R and Martín M J 2010 Electronic transport in laterally asymmetric channel MOSFET for RF analog applications *IEEE Trans. Electron Devices* **57** 2448.