Real-time Early Cancer Detection and Prognostic Systems Using Emerging Technologies

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***Abstract*- Cancer diseases are controllable, if detected, diagnosed and treated properly at an early stage. The early symptoms are often vague and are common to other illnesses. Annual health examination by specialists (e.g., Urologist, Gastroenterologist, and Gynaecologists) helps detect and diagnose cancer at an early stage. Following the diagnosis of cancer, patients are referred to Oncologists for treatment. It is known that early detection of the disease is one of the most important tools for successful treatments. This paper outlines an early cancer detection tool and provides an analysis of its performance using emerging technologies (such as RFID - Radio Frequency Identification and Sensor) and prognostic tool with a multi-layer architecture for intelligent real-time early cancer detection and prognostic systems (RECDPS). This paper gives network analysis of RECDPS system. Performance analysis of a network shows that database entry and response times are acceptable.**

Keywords*- *RFID; Security; OPNET; Prognostic Tool and RECDPS

I. INTRODUCTION

Cancer has a major impact on both developed and developing countries worldwide. For example, one in three men and one in four women in Australia develop cancer by the age of 75. There were over 93,000 new cases of cancer in Australia in 2003, almost 38,000 deaths due to cancer [1]. Similarly, in developing countries like India, there are 2.5-3 million estimated cancer cases at any point of time. Additionally, about one million new cases are detected each year and almost 0.6 million cancer deaths each year. 70 – 80% cancer cases were detected at the late stage where the treatment was not possible [2].

The current research shows that about twenty five million people living with various types of cancer worldwide. More than seven million people die due to cancer and about eleven million new cases are diagnosed every year. More people die (12.5% of all deaths) from cancer than from AIDS, malaria and tuberculosis. The most widespread cancers in the developed world are prostate, lung and colorectal cancers for men and breast, colorectal, and lung cancers for women [1, 2].

Current research also demonstrates that the prostate and colorectal cancer (also known as bowel cancer) is among the ten most common leading cancers by incidence and mortality in Australia and an increased prevalence of colorectal cancer incidence in the developing world [3, 4]. Around 4,680 men are diagnosed with prostate cancer, more than 3,500 people (both men and women) are diagnosed with colorectal cancer, and 150 women are diagnosed with cervical cancer each year in the state of Victoria alone. Prostate cancer is the most common cancer in men in Europe and the United States. It is the second most common cause of death in the United States [5]. Screening methods such as the prostate specific antigen (PSA) blood test for prostate cancer, colonoscopy for colorectal cancer and Pap smear for cervical cancer are reliable, but these methods are far from ideal. For example, colonoscopy is invasive and extremely unpleasant to the patient [2, 6].

At present, most of the cancer diagnostic techniques based on MRI (Magnetic Resonance Imaging) and PET (Positron Emission Tomography) images are done and recorded manually through visual inspection and analysis of thousands of recorded images. Diagnostic techniques used in cervical cancer are usually performed in two main steps. In the first step, doctors establish the presence/absence of a cancer. This is relatively simple by several tests. In the second step, doctors estimate the volume and the spread of cervical cancer. This step is complex and is often based on imprecise information.

Our existing cervical cancer database has numerous data elements such as clinical examination results, radiotherapy, toxicity, etc. The current system is that the doctor decides the stage of the cancer based on information from medical tests and then stores it in a database. The problem with the current system is the difficulty of patients' information retrieval based on statistical analysis. Doctors can only find patients who have the same as the International Federation of Gynaecology and Obstetrics (FIGO) classified stage, but not those with similar features. This is because of inconveniences of query language to retrieve information of patients to compare with each input case, and limitations of the user interface [7].

However, early detection of cancer is possible and as it offers one of the best chances to cure the disease**,** information systems can play a vital role in developing an effective approach and facilitate real-time patients' biological information (such as a raised PSA level can indicate prostate cancer**,** breath analysis for colorectal cancer, and abnormal cervical/vaginal cytology for cervical cancer) to address these threats. General practitioners or oncologists can record patients' information such as their regular visits, scanning details, findings etc. onto their PDA or electronic device, then wirelessly transmit to the remote server for central database, so that any other concerned staff can access for the further analysis. Such interconnect of a wireless devices and server can be facilitated by the use of emerging wireless technologies such as RFID and a set of sensor technologies. Then with an interactive application like RECDPS, staff can automate data collection, detection and diagnosis.

In this paper, we integrate RFID and Sensor technology with a multi-layer architecture for RECDPS via wireless network to enhance cancer diagnosis systems. This paper is structured as follows: Section II outlines the RFID-sensor model used for developing RECDPS. Section III illustrates the multi-layer architecture for RECDPS. Section IV demonstrates the RECDPS application. Section V illustrates the security of RFID sensor-based RECDPS application.

Section VI outlines the performance analysis of interconnectivity of end users to the server. Section VII concludes the paper.

II. RFID SENSOR MODEL FOR RECDPS

RFID is used to track, identify, collect and transfer patients' confidential information such as patient ID (or UR#), location, etc. wirelessly. The sensor is used to sense and collect symptomatic cancer data (patients' biological data such as raised PSA, abnormal cervical/vaginal cytology). These emerging wireless technologies can provide an optimum solution, and help healthcare providers identify the patient data accurately, detect and diagnose cancer at an early stage. Today's advanced technology is capable of uniting RFID tags and remote sensing data processing into a single integrated system [8].

In this paper, we interconnect RFID Sensor technology and prognostic tool with a multi-layer architecture for intelligent cancer early detection and diagnosis systems. An RFID sensor model/system is designed and developed to detect and monitor vital signs (biological data) of cancer. The main components of the system are outlined in Fig. 1. It mainly consists of patient tags (tiny RFID chips), smart phones and/or RFID readers embedded Personal Digital Assistant (PDA) or iPhone, various sensors and RECDPS [8]. Each tag transmits not only its unique patient ID and location, but also the cancer symptomatic data through the sensor. A nano-electronic sensor is used to detect prostate cancer. This enables the cancer specialists (e.g., oncologists) to remotely detect and monitor the prostate cancer symptomatic real-time data.

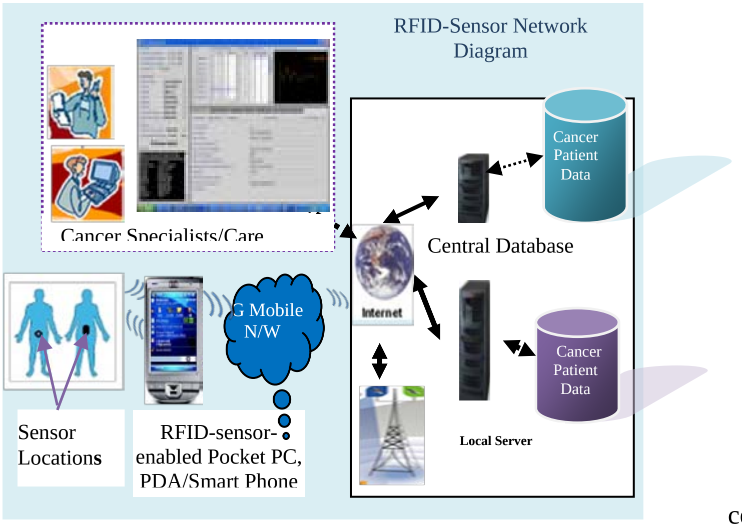

Fig. 1 Main component of RFID sensor model

Each unique patient tag can be passive, semi-passive, or active. Passive patient tags can be used for both reading and writing capabilities by the reader and do not need internal power. They get energized by the reader through radio waves and have a read range from 10mm to almost 10 meters. Passive tags are cheap, ranging from AUD 0.25c to AUD 0.40c each and life expectancy is unlimited. We suggest the use of passive patient tags (13.56 MHz ISO 15693 tag) with the read range of half a meter, a nano-sensor, and iPad, iPhone/Next G Smart Phone RFID readers for the real-time RECDPS application.

The passive patient tag antenna picks up radio-waves or electromagnetic energy beamed at it from an RFID reader device and enables the chip to transmit patient's unique ID and other information to the reader device, allowing the patient to be remotely identified. The reader converts the radio waves reflected back from the patient tag (wristband) into digital information then pass onto RECDPS system for processing.

The captured patients data and symptomatic cancer data (biological information) are then passed onto the RECDPS for processing. This PDA/iPhone-based cancer detection system integrates both RFID and sensor data, then transfers and stores in the back-end server (local and central) over a wireless network (e.g., Bluetooth, WiFi, 3G) for further processing. Analyzing and accessing these data help cancer specialists to detect early treatment of prostate cancer.

III. MULTI-LAYER ARCHITECTURE FOR RECDPS

As health organizations (e.g., Cancer Institute, Oncology Department, etc.) face data integration issues, the RFID-enabled system is a challenge while deploying RFID devices in their cancer management units (e.g., Oncology). Multi-layer RFID and nano-sensor architecture establishes an infrastructure to address such a challenge, to automate and simplify the functionality for building RFID-based solutions in the cancer care system. These five integration layers are physicaldevice layer, middleware layer, Health IT infrastructure management layer, data layer and graphical user interface layers as shown in Fig. 2. The physical device layer consists of the actual RFID hardware component (such as readers and patient tags) that integrates with the RECDPS for capturing data automatically.

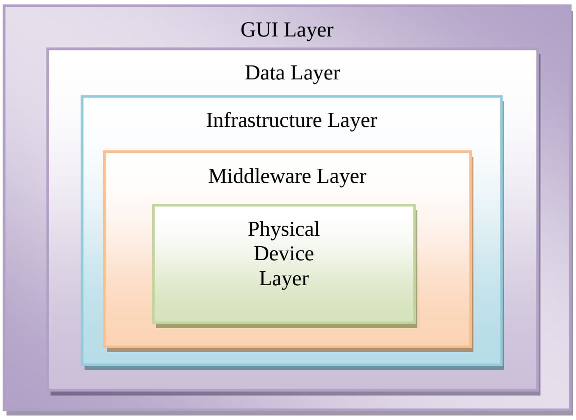

Fig. 2 Multi-layer architecture for RECDPS

The middleware layer or framework is viewed as the central system from the health system perspective. It acts as the standard mechanism to get rapid connectivity between patient detection tags, nano-sensor and PDA-based RECDPS as shown in RFID and Sensor model in Fig. 1.

The IT infrastructure management layer is responsible for managing and controlling the local healthcare organization's IT components such as computers, back-end servers, networks, and printers. In addition, this layer enables data mapping, formatting, business rule execution and the service interactions with back-end databases.

The data layer composed of Relational Database Management System (RDMS) interacts with a back-end database (SQL server) and includes a data query/loading approach using structured query Language (SQL) that supports high volumes of RFID data into a custom designed RFID database schema.

Finally, the graphical user interface (GUI) layer is comprised of an extensible GUI, which is responsible for detecting, monitoring, and managing cancer symptomatic data (e.g., PSA). The GUI also helps in managing the information, generating various cancer reports and analyzing the information at various stages in the entire value chain.

IV. RFID AND SENSOR-BASED RECDPS APPLICATION

Fig. 3(a) and 3(b) show the integration of RFID with sensor data for capturing cancer symptomatic data automatically and wirelessly. The system is developed in Microsoft Visual C#.net 2008 environment. The RFID sensor-based cancer patient identification and prognostic systems application issues a unique tag ID to every patient with a wristband at registration/admission in cancer institute or hospital. The RFID then uses the tag ID as a key to the information and perhaps other information (e.g. name, DOB, drug allergies, blood group, etc.) stored in the health providers back-end databases (SQL server).

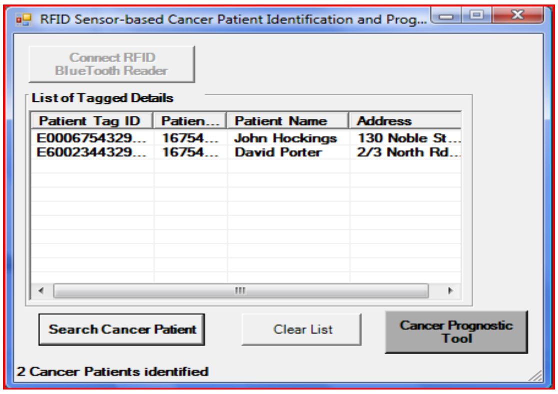

Fig. 3(a) Automatic cancer patient identification interface

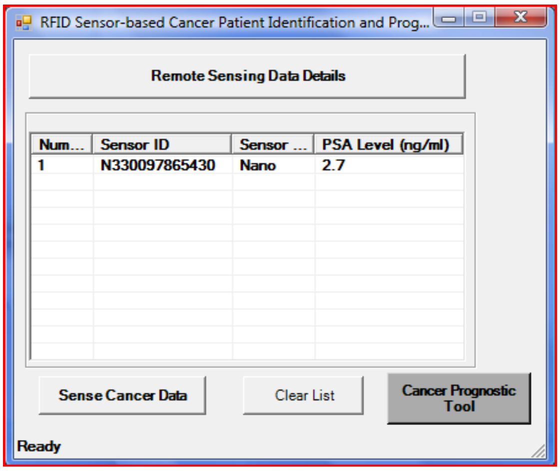

Fig. 3(b) Automatic cancer data collection interface

The wristband is used to identify patients all the cause of observation, data collection, and prognosis to discharge while in cancer care facilities. For example, an RFID patient tag only contains a unique tag ID, which a RECDPS application uses to retrieve a patient record stored in the database.

When a patient appears with a wristband within a (i.e., placed in Oncology wards, or cancer institute) read range, the application identifies the patient and the information automatically as shown in Fig. 3(a). Similarly, the sensor senses the cancer symptomatic data (e.g., PSA level for prostate cancer) and displays the captured data as shown in Fig 3(b). The RECDPS application then analyses the sensor data and predict cancer status – *positive* or *negative*. Once both RFID and sensor data are captured/collected, the RECDPS application then transfers them to the backend via wireless network for further processing. The RFID patient tag (wristband) can be removed from the patient on discharge from the cancer facilities and the available wristband from such a patient can be reused for a same patient later.

If the patient's cancer status is positive, the integrated automated prognostic tool can be used to access stored biological data from backend server and analysed for proper and accurate diagnosis of cancer patients [9]. The prognostic graphical user interface is also used to retrieve the existing patient's information (such as history, predictions, treatment and outcome of the treatment) based on statistical analysis and compare them with new patients [10, 11]. This interface presents diagnosis results graphically on the screen as shown in Fig. 3(c). In this research, we have only used 450 patients' cancer information for statistical analysis.

Fig. 3(c) Cancer prognostic interface

The integrated automated prognostic system is used to access patients' biological data from backend server and analyse them for proper and accurate diagnosis of cancer patients as shown in Fig. 3(c). A real-time RECDPS can be implemented in any hospital (Oncology units), and cancer facilities for better detection and diagnosis of cancer worldwide. At present, we are in discussion with one of the largest cancer institute in Melbourne, Australia to install a RECDPS.

V. SECURITY OF RFID AND SENSOR-BASED RECDPS

While RFID provides promising benefits such as automation of cancer data collection process, some significant challenges (e.g., security, and process and management of RFID and sensor data) need to be addressed before these benefits can be realized. To overcome these challenges, appropriate security measures are needed. Without security, illegal activities that cheat RFID systems are easy because of the air interface between patient tags and RFID readers, between nano-sensor and RECDPS, and between RFID readers and the back-end database system (SQL server). In addition, user privacy is also a big issue, since anyone can intercept communication between the patient tags and readers (RFID), between readers and back-end system, and obtain information about a patient tag holder. To remove security vulnerabilities and protect cancer patient privacy, a number of existing RFID security systems have considered and adopted as a measure of security.

In our cancer management system (RECDPS) communications between patient tags and readers, readers and back-ends are one way. Our patient tags are passive, inexpensive, shorter read range (50 cm) and have a minimum amount of memory (less than 1 kb). We are keeping very little information in the patient tag e.g., Patient ID only. In the worst situation, if an intruder intercepts and gets the tag ID, he/she gains nothing because the tag does not contain any additional information.

As patient tags are ISO standard, the RFID reader support and communicate with these (ISO 15693) tags. If more than one cancer patient tag answers a query sent by a RFID reader, it detects a collision. An anti-collision is performed to address this issue if multiple instances of patient tags are in an energizing field. For the secure transfer of patient data from a RFID reader to back-end database (SQL server), we are using a Hash Function-based Mutual Authentication Scheme [12-13]. This scheme, utilizing a hash function, is widely used for secure communication between readers and back-end SQL servers in a RFID-based environment.

VI. PERFORMANCE ANALYSIS OF RECDPS

In this paper, performance analysis of the Wireless RECDPS networks through simulation has been attempted using packet tracer and OPNET [14] as simulating tools. For RECDPS networks, the metrics like delay, throughput, and inter-networking performance has been investigated and tested. Cancer symptomatic information collected by RECDPS being fed to the server through networking devices for further processing is displayed in Fig. 4.

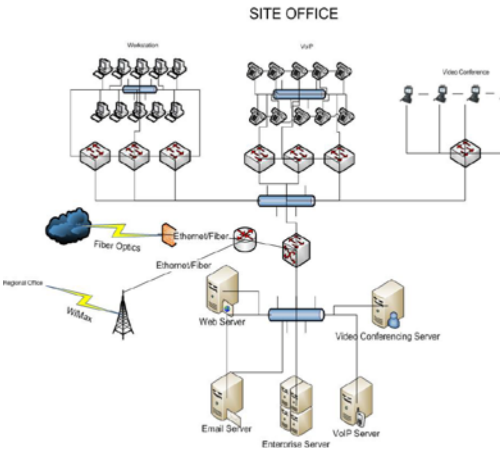

Fig. 4 Site office server farm

Server farm consists of enterprise server (with database), email server for secured email communication between oncologists (or doctors), web server for secured remote connection from any remote device to the central system, VOIP and video conferencing server for viewing patients conditions live through internet. Server site network is as shown in Fig. 4.

The network setting consists of single subnets with multiple 24-port Ethernet switches, local area network (LAN) with 100 in main server site office connected via the 10baseT link, and five sever, each running single applications is connected through a 24-port Ethernet switch via the 10baseT link. Subnets are connected to a subnet centrally placed with a server using a 100baseT link. Server farm also consists of a web server (that supports Web-browsing), a FTP server (that supports FTP and file print services), a VoIP server and a Video Conferencing server.

Network devices configuration has been tested on packet tracer as shown in Fig. 5. For the purpose of configuration, end devices are phones (VOIP), scanner, PCs and laptops. All the patient data are stored on the server through network. Inter-networking devices used are switches, routers, wireless routers and cloud as an Internet Service Provider (ISP).

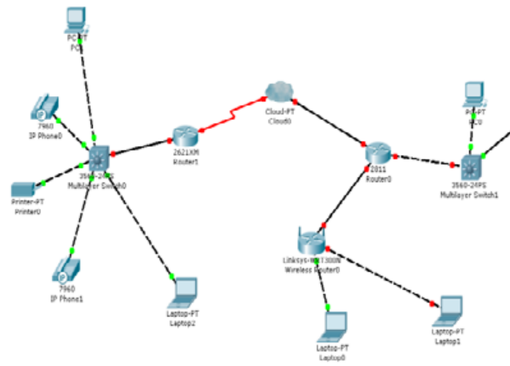

Fig. 5 Configuration of interconnectivity

For the purpose of simulation, wired router model CISCO 2811, wireless router model switch model CISCO871W, switch model 2560 24 port multilayer switch are used. Fig. 4 shows part of the network used for simulation. It is scalable, such as inter-networking devices and end devices can be added easily.

RFID sensor network system has been simulated using OPNET IT GURU professional version as shown in Fig. 6(a) and 6(b). Server applications used for simulation are database, web (http) and Voice over IP (VoIP). The performance is analysed for database entry, database query and web in terms of response time and traffic received time. These factors are important in health care system, as patients' data will be entered from remote hand held devices and retrieved from database server whenever needs.

Fig. 6(a) Interconnectivity of remote devices within world

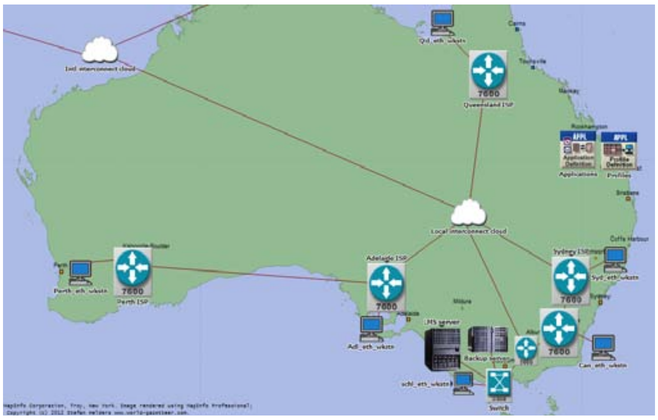

Fig. 6(b) Interconnectivity of remote devices within Australia

The Fig. 7 shows the graph of these performance analyses. This figure shows that database query and response times are less than 0.04 sec, data received as a 1.5 packets/sec and web traffic is 24kbps. These figures indicate that network is acceptable for real time data entry and response from central server from remote end of the network.

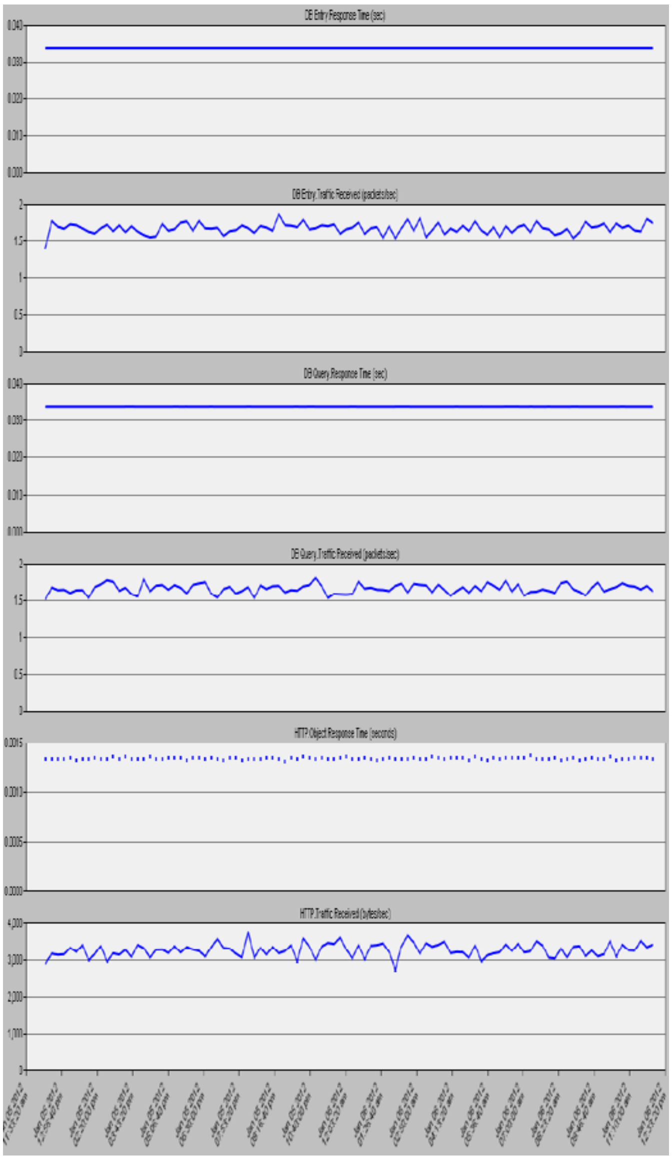

Fig. 7 Performance graphs

VII. CONCLUSIONS AND FUTURE WORK

The early stages of cancer especially prostate cancer are often asymptomatic, so the disease often goes undetected until the patient has a routine physical examination. The proposed real-time RECDPS will help cancer specialists in both developed and developing countries with fast and accurate patient identification and detection, automatic data collection and storage, and prognosis of cancer patient in real-time through wireless communication. Automated prognostic tools and the display of data from similar cancer patients in a user friendly manner would help many oncologists and researchers worldwide. Efforts are being made to develop the complete system for use in medical practice.

In the future version of RECDPS, we will explore the functionality to construct 3D MRI image and retrieval of volume and spread cancer tumour. Network can be used to simulate video streaming in the future. One of the important factors in the proposed system is RFID security. Our future research will investigate the RFID security concerns and minimisation techniques.

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Savitri has more than 22 years of teaching and research experience in Engineering and Information Technology (IT) disciplines. She has worked in the IT industry as a manager for more than 10 years. She has demonstrated continuing scholarly and professional involvement in both learning and teaching and research by publishing a number of books and research papers nationally and internationally. She has obtained several industry grants and supervised many research students and research associates. She has chaired a number of conferences in multi-disciplinary areas and edited their proceedings. Currently she is working as an Associate Professor of Engineering at Melbourne Institute of Technology, Melbourne, Australia.

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