CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 SUMMARY OF CONTRIBUTIONS

This thesis focused on three important areas of remote patient monitoring of viz., i) post-operative patients in a hospital environment, ii) elderly patients in a home environment, and iii) patients affected by COPD and PD in ambulatory environments. This thesis also proposed a wireless sensor grid architecture for monitoring different group of patients’ health status.

In the first study, an architecture for remote monitoring of post-operative patients in a hospital environment using wireless sensor networks was proposed to enhance patient care by integrating smart sensors, wireless communication and network technologies. This thesis evaluated the suitability of wireless sensor networks for monitoring vital signs such as the heart rate, electrocardiogram, and body temperature in post-operative patients. This thesis also presents the preliminary data from this system, which was tested on a group of normal volunteers as they underwent a range of activities similar to those of post-operative patients during the recovery period. Our architecture demonstrated the potential suitability of an ear-worn sensor for the monitoring of post-operative patients to perform their daily activities without being hindered. The ear-worn sensor device may be able to quantify the mobility of a recovering patient, thereby determining his/her rate of recovery over a period of time following surgery. This has clinical importance because if a patient is not recovering adequately following surgery, he/she can be selected to receive a more tailored intervention such as chest and
mobilization physiotherapy. The threshold-based algorithm analyzes the data from the patients through the base station and automatically alerts the physicians and emergency department personnel, when an abnormality occurs. The threshold levels for the physiological signals are included in the algorithm. The central server collects the physiological signal data and transmits it through the internet in real-time to support the need for multiple parties to share information about the patients' status and locations. It displays the basic information of all patients currently being linked to central servers and also through a secured web server. The benefits of the system are that, it identifies those at risk and intervenes to prevent complications by alerting the physicians and emergency department personnel through e-mail and SMS services and it has the potential to reduce the cost of patient care by reducing the need for further rehospitalisation.

The second study presents the architecture for monitoring elderly patients using Wireless Sensor Networks in a home environment without disturbing their daily activities and improving the quality of life of elderly persons at low cost. The wearable sensors make the detection of physiological signals relevant to the motion / visual pattern of the elderly patients at home. The In-Network data aggregation implemented in our system is used to increase the energy efficiency of wireless sensor nodes at the same time avoid packet losses and high storage capacity servers in compared to other monitoring systems without aggregation technique. These sensor nodes are programmed to awaken the node whenever abnormal signals are detected and transmit the data to the server and then return to the sleep mode. When an abnormality is detected in the sensor node, it automatically turns on and transmits the signal to the central server and simultaneously alerts the caretaker near the patients. The analysis is done using the software moteView, a built-in library for data acquisition, processing, analysis, and display.

The central server has been programmed with two algorithms. The first is the threshold-based algorithm, which attempts to identify the
physiological parameter values that are potentially harmful or indicative of immediate danger to the patients. The second is the inactivity detection algorithm in which change in angles in conjunction with a crossing of a set acceleration threshold within the same time interval for detecting rapid or lack of movement of elder patients from accelerator output. The sensor node is programmed through the central server in such a way that if lack of movement/action is detected, it awakens the Imote2 device connected to the 3-D camera fixed in that specific room to send the status of the elder patient to the central server. The central server dispatches the critical events detected by the sensor nodes and alerts physicians, caregivers and healthcare professionals via e-mail and short message services (SMS).

The third study of the thesis presents the architecture for monitoring patients affected by Chronic Obstructive Pulmonary Disease (COPD), patients with Parkinson’s disease (PD) during their rehabilitation period in an ambulatory environment. The sensor node kit placed on the body is responsible for collecting physiological data and movement data from the sensors, compress it using a simple data compression technique, and transmit it to the data collector node in an energy-efficient manner, which in turn transmits it to the central server. The central server has been programmed with an algorithm for analyzing ECG signals, which detect similar sequential patterns in a set of data series. The algorithm will be useful for finding significant subsequences that are likely to characterize a set of non-uniform time series. The real time data are compared with the reference template in the databases to identify the abnormality of the signal and alert the physicians and emergency department personnel for further follow-ups. Our system of monitoring of COPD and PD patients during walking in the smart ground would potentially improve compliance with exercise, aid in the clinical assessment of improvements toward the baseline, and ultimately decrease the length of stay in the hospital.

This thesis also presents the sensor grid architecture whose advantage when compared to the centralized telemedicine techniques is to
facilitate a secure and seamless sharing of databases and to support the acquisition and analysis of ECG databases to combat major diseases on an individual basis. The Alchemi is chosen to implement Grid middleware functions. The architecture designed and tested for remote monitoring of post-operative patients in hospitals, monitoring of elderly patients at home, and in an ambulatory environment, provides a platform for physicians and researchers to share information with a distributed database and computational resources to facilitate ECG analysis and alert when life threatening event occurs. The sensor grid developed, creates an environment where ECG data’s are stored at the distributed databases and less time consuming for analyzing the ECG signal. The data’s are also made easily available to the different actors of healthcare, the physicians, the healthcare centres and administrations, and of course the citizens. Such a facility is not available in a centralized telemedicine technique. Information from the distributed databases is made available over the internet to provide remote access to physicians and emergency department personnel to closely monitor the patients.

7.2 PATIENTS SAFETY

Proper application of wireless technology has the potential to increase effectiveness, decrease costs, and generally improve the quality of healthcare. Wireless devices should be designed and produced in a way that ensures that the device will not compromise the clinical condition or safety of a patient, or the safety and health of the user or any other person, when the device is used on a patient. Also any risks associated with the use of the device should be acceptable risks when weighed against the intended benefit to the patient and compatible with a high level of protection of health and safety.

The benefits of wireless communication systems in healthcare applications are
1. Healthcare workers rely on a constant flow of information in order to manage their patients effectively. In the past, this information may have been delivered to each ward through a single computer station, which is cumbersome, time-consuming, and takes valuable time away from monitoring and caring for patients. Real-time access to patient charts, laboratory results, and medical histories can be made available through wireless devices at the bedside. There are also benefits in reducing paperwork and needless human traffic. Less time is required inputting notes and more time available to spend with patients.

2. Connecting patients to monitors and monitors to local area networks requires a large number of cables. This wiring is generally inconvenient and particularly troublesome if a patient needs to be mobile or a patient is stationary but the layout of equipment (operating table, anesthesia equipment and monitors) is rearranged.

Uncertainty and concern with regard to EMI have acted as major obstacles to the full deployment of wireless technology in many facilities. However observation of the following separation distances should not cause significant EMI to medical equipment:

1. Two wireless Mode kits / Two-way radios / walkie talkies (security/ maintenance personnel)—6–8 m;
2. GSM1800 and CDMA phones—0.5 m,
3. GSM900 phones—2 m; and
4. Wireless LANS/Bluetooth—1 m.

7.3 LIMITATIONS OF OUR SYSTEMS

All technologies have limitations, and cannot provide their benefits under all circumstances. When new technology is introduced into the
emergency response arena, it is important to note its limitations as well as its capabilities. Due to the chaotic nature of emergencies, our system faces the challenge of operating in situations that challenge instrumentation designed for use in the controlled environment of a clinical situation.

The wireless patient monitoring feature will not be useful in all situations. In a mass casualty disaster, when the medics must triage many casualties quickly, they will not have time to respond to alerts until all patients have been triaged. Medics expect the monitoring system to be most useful for patients who have been triaged and are waiting for ambulances. They can then use our system to prioritize the patients who need to be transported by ambulance.

The other limitations of the proposed method are

1. Skin connectivity with the electrodes can be a problem.
2. The electrodes pull away from the skin after a while.

7.4 CONCLUSION

Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power, multifunctional wireless sensor nodes that are small in size and communicate untethered in short distances. These tiny wireless sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks based on the collaborative effort of a large number of nodes. The efficiency of hospital staff is increased by using some of these newly available applications and tools. In the healthcare field, issues such as long-term patient care in hospitals, support for elderly people at home and in an ambulatory environment are being discussed in the realm of wireless sensor networks.
This thesis has presented a remote patient monitoring system architecture using wireless sensor nodes capable of monitoring several different environments: hospitals, home, and ambulatory. The system implemented is a real-time patient monitoring system, which enables medical doctors to watch their patients on a remote site, to monitor their vital signs and to give them some advice for first-aid treatments.

The system developed has the following facilities added to have a positive impact on time-saving and cost effectiveness by preventing the patients from re-hospitalization and monitoring multiple patients’ health status simultaneously.

1. The data are available for review on the central server, and can be accessed remotely by means of a standard web browser. This secured web server exploits the interactive possibilities of the Internet to combine the integration of diverse types of clinical information with facilitation of patient-provider communication, raising the prospect of achieving higher levels of patient care.

2. The In-Network data aggregation technique implemented in our architecture attempts to collect the most critical data from the sensors and transmit it to the base station in an energy-efficient manner with minimum data latency. “In-network” means sending partially aggregated values rather than raw values, thereby reducing power consumption.

3. The fall detection algorithm implemented, observes a change in angles in conjunction with a crossing of a set acceleration threshold within the same time interval. The large acceleration along with the change of angle with respect to the initial position within the same time frame is labeled as a fall. The
results showed that the algorithm has the potential to distinguish between a fall and daily routine activities.

4. The sequential time series analysis scheme uses a simple sampling method to compare two subsequences that are of different lengths. Our results show that the algorithm developed has better accuracy in locating anomalies in the ECG signals of the patients.

5. The system developed automatically alerts the physicians, emergency department personnel and caregivers when an anomaly is detected through email and SMS services.

The sensor grid architecture is designed and tested for monitoring different groups of patients: Remote monitoring of post-operative patients in hospitals, elderly patients at home and patients affected by COPD and PD in an ambulatory environment to enable real-time sensor data collection and the sharing of computational and storage resources for sensor data processing and management. The medical server in our system developed has the following facilities to provide seamless access to a wide variety of resources in a pervasive manner.

1. To store the data collected by the sensor nodes.

2. To facilitate analysis with the help of connected executor’s computation powers and predicts the disease with the available databases.

3. To alert the physicians, emergency departments and caretakers through e-mail and SMS services when anomaly occurs.

With its potential use in the hospitals and home healthcare fields, wireless sensor networks have an important role in improving the lives of
patients. Besides bringing comfort to patients, there are large commercial benefits in the area of reducing costs, rehospitalisation, and improving equipment and patient management.

7.5 SCOPE FOR FUTURE WORK

Wireless sensor networks, a well-known technology consist of small, battery-powered "motes" with limited computation and radio communication capabilities. This technology has the potential to impact the delivery and study of resuscitative care by allowing vital signs to be automatically collected and fully integrated into the patient care record and used for real-time triage, correlation with hospital records, and long-term observation. This network technology provides a better solution for remote monitoring of post-operative patients in a hospital, elderly patients at home and patients affected by COPD and PD during their rehabilitation period in ambulatory environments. There are many other extensions possible to the current work that can be studied further. The direct extension is to use artificial intelligence in wireless sensor networks to explore simple parallel-distributed computation, distributed storage, data robustness and auto-classification of sensor readings to help the physicians in the early interpretation of diseases.

With sensor networks on the verge of deployment, security issues pertaining to the sensor networks are in the limelight. Due to the sensitiveness of medical data, austere privacy and security are inevitable for all parts of healthcare systems. The second extension of this work is to include security protocols to provide security in sensor networks, with an emphasis on authentication, key management and distribution, secure routing, and methods for intrusion detection.
Many “standard” and proprietary protocols use the media-access controller (MAC) and the physical circuits (PHY) associated with IEEE 802.15.4 radios. Those protocols use their own arrangements of bits and bytes to transfer information between nodes, but none of them use the Internet Protocol (IP). So they cannot directly communicate with Internet-based devices and Web servers/browsers. The IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) standard offers an alternative because it employs the IPv6 protocol and can operate equally well over wireless and wired connections. The third extension is to include 6LoWPAN communications which don't require a complete rewrite of an IEEE 802.15.4 radio stack. Instead, 6LoWPAN adds an adaptation layer that lets the radio stack and IPv6 communications operate together.

Wireless Sensor Actor Networks (WSANs) are emerging as a new generation of sensor networks. In Wireless Sensor Actor Networks, sensors gather information about the physical world, while actors take decisions and then perform appropriate actions upon the environment, which allows remote, automated interaction with the environment. The presence of a single actuator in sensor networks eliminates the need for coordination and communication between actuators and a sparsely connected network eliminates the need for location management. The fourth extension is to include WSANs in remote monitoring of patients to automatically actuate the devices such as the defibrillator, drug delivery system, muscle stimulator, etc., when life threatening events occur. Our current work can also extend further to monitor sports personalities and patients affected by other specific diseases during their normal routine activities.