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A Feasibility Study of Wireless Sussex MK4 System for Electrical Impedance Mammography

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Abstract

Electrical Impedance Mammography has been the field of interest in recent years in the area of breast care monitoring. This paper proposes a wireless planar array EIM data acquisition system ensuring low cost, reliable, accurate and efficient system. The proposed wireless planar array EIM system consists of wireless nodes, a gateway and a computer. This proposed system could not only reduces the noise interference from the conventional wired data acquisition system, which is one of the most talked about issues as well as increases the number of independent measurements which are very important for data acquisition and image reconstruction. The current planar EIM system's limitation of using fixed number of electrodes can be improved by increasing the number of electrodes to improve the quality of information. Practical difficulty of applying large number of electrodes to the current system includes space limitation due the sealed synthetic covering comprising of driving circuitry and the programmable switching network. By the use of wireless nodes for transmitting and receiving the measurements, acquisition and the digital circuitry will be isolated from the system receiving and transmitting the measurements and the control signals through a radio link. Preliminary investigation has demonstrated that the system is successful; accurate and optimized for the current planar EIM system.

Keywords: electrical impedance mammography, wireless sensor network, electrical impedance tomography, breast cancer detection, data acquisition system, planar array system.

INTRODUCTION

Electrical Impedance Tomography (EIT) is a biomedical imaging technique for probing the impedance distribution of human tissues. It was established since early 1980s [3]. It uses surface measurements to evaluate the electrical impedance of any object [4]. It involves controlled injection of electrical currents due to specific conductivity and permittivity of regions of the object. EIT measurements are normally achieved by injecting small currents through electrodes around the region to be imaged with the resulting potentials measured among pairs of electrodes. These potentials are then used to reconstruct the conductivity of the imaged region. With a prior knowledge of the conductivity of various components comprising the image region, the composition of the structure can be determined. It is possible to apply this new technique on human beings because the electrical impedance of different body tissues varies widely from 0.65 Ω.m for cerebrospinal fluid to 150 Ω.m for bone. Cole and Cole delivered the primary model of tissue impedance features in 1941 [9]. This Cole-Cole model is still extensively currently used. The first impedance image obtained with the modern EIT technique was published by Henderson and Webster [19]. They produced trans-thoracic impedance images of the thorax rather than real tomography images. The designers of the very first imaging EIT system were Barber and Brown of the University of Sheffield (UK) in 1982 [3]. This was for the first time a real two-dimensional impedance image display by an impedance measurement system, which employed 16 electrodes in its data collection system and used a back projection based image reconstruction algorithm. The data collection was performed in real time at a speed of 10 frames per second. It was a serial configuration with 16 current drivers and 16 voltage receivers acquiring at a frequency of 50 kHz. The overall accuracy of the data collection system was about 1% [3, 4].

Since electric currents applied to the body depend on the tissue's conductivity distribution, organ interior images can be reconstructed from the data acquired on the surface of the body. Higher conductivity and permittivity in comparison to the healthy breast tissue [18, 21, 15]. Consequently a highly conductive region may require further investigation as it could possibly indicate a serious health concern. EIT has been used in clinical imaging for number of modalities not limiting to thorax [26, 39] breast [16, 17, 8, 35] and brain [20, 33, 23, 13].

Electrical impedance mammography (EIM) is an imaging procedure using electrical impedance tomography (EIT) to identify breast cancer. It reconstructs the internal impedance distribution of the breast under investigation, by utilizing an opportune image reconstruction algorithm and a modest number of surface quantifications [12]. As malignant tumours have significantly higher conductivity or/and permittivity than the circumventing mundane tissue, an aberrantly high conductivity or/and permittivity in the reconstructed image may be a denotement of a breast cancer. Several EIM systems are presently carrying out research to improve the detection and diagnosis of early breast cancer detection uses electrodes for sensing and injecting the potentials are structured in either ring or a planar electrode array formation.

Until now, most published clinical results are based on TS2000 (Israel) [22], MEIK (Moscow) [24] consist of planar electrode array in square pattern and the first generation electrical impedance spectroscopy (EIS) (Dartmouth) [16-17]. Sussex MK4 system also has electrodes structured in hexagonally planar pattern [37, 38]. When applying the EIM technique to clinical diagnosis, a major problem is the limitation of its poor spatial resolution. The image quality is mainly related to two factors: 1) the accuracy of the data collection system and 2) the image reconstruction technique.

Studies have shown that the ring electrode array is insensitive to the regions off and in the center of the electrode plane and the planar electrode array is insensitive to the region remote from the electrode plane. Clinical trials indicate that EIM is a realistic method for breast cancer detection; however, the challenges for the current systems are significant which including image quality, image reconstruction and system performance.

The correct information from the data collection system is determined not only by the number of electrodes used and electrode configuration but also the applied current patterns and voltage measurement strategy [2]. In particular, the numbers of electrodes are very paramount for data acquisition and image reconstruction. The number of independent quantification are very paramount for data acquisition and image reconstruction [7]. Noise interference from the conventional wired data acquisition system increasing the one of the most talked about issue Signal to noise ratio (SNR). Additionally, image reconstruction is much more difficult than that of other modalities such as X-ray. In EIM, the reconstruction algorithm uses erudition of the applied current patterns and the quantified electrode voltages to solve the inverse quandary, computing the electrical impedance distributions of the breast. Furthermore the inverse problem is said to be ill posed as noticeable changes in impedance distribution in the interior of the object can result in only small voltage changes at the surface. However, some new algorithms such as genetic algorithms to improve the spatial resolution of EIT images are under study and have revealed relatively good performance.

Electrical Impedance Mammography (EIM) provides a new solution to break through the current limitation for early cancer detection. Several studies have addressed the possible factors affecting the system performance and signal quality. Possible factors are characterized on the basis of external and internal sources of possible errors along with predictable and unpredictable noise sources. External sources of error artefacts introduced by the patients and their movements while scanning are most likely to affect the image reconstruction. Predictable and unpredictable causes may introduce frequency dependent noise whereas internal sources which can be also classified as systematic errors, degrade system performance due to electronic circuit design, configuration and stray capacitance and cable connections. Three main distinct measures compromised are signal to noise ratio (SNR), roll-off and artefacts. Potential errors in the Sussex Planar Array EIM system are classified into three broad categories on the basis of noise, external and systematic (non-linearity errors caused by the hardware and image reconstruction, sensors, control etc.) errors [5, 6, 30].

In order to overcome the above mentioned problems and challenges wireless technology is proposed to be used with the existing EIM system. Current developments in technology have integrated various different fields together. Hence the emergence of the medical engineering field is no exception. Therefore, in today's world medical equipment comprises of many advanced electronic based medical devices such as portable vital sign monitors for measuring blood pressure, body temperature measurement that can also track a patient's status and location updates [10], ECG monitors for analysing heart activity and electronic infusion pumps, to name few [27]. Due to advancements and the increasing number of devices there is a need to diversify from infrastructure based approaches towards infrastructure-less networks, so that device control, monitoring and resource sharing can be achieved smartly. Networks have shifted from homogeneous to heterogeneous networks and future networks will be a composite of interconnected networks. The current need is to have an infrastructure-less network, which has many advantages over infrastructure based networks. In infrastructure-less networks there is low cost, easy implementation and hierarchical distributed networks (Zhao, Win Lab) whereas infrastructure based networks have higher implementation cost are more complex and a higher level of expertise needed to implement them [29]. Hence, to facilitate communication and device operability, various wireless communication standards have been developed such as IEEE 802.11 for wireless local area networks (WLAN), IEEE 802.15 for specifying wireless personal area networks

(WPAN) which further extends to IEEE 802.15.1 for Bluetooth; IEEE 802.15.2 addresses co-existence of WPAN with other wireless devices operating on different standards like 802.11; the IEEE 802.15.3 task group is for high rate wireless personal area networks; the IEEE 802.15.4 standard specifies low rate wireless personal area networks (LR-WPAN) and is the basis for many other wireless protocols like ZigBee , WirelessHart, IPv6 over low power personal area network (6LoWPAN), to name a few. Similarly, the Wireless Sensor Network works on the IEEE 802.15.4 standard. It has been integrated into a wide range of applications including military [24], agriculture [28], industrial automation [11], environment monitoring [1] and health care [25]. WSN consists of inexpensive low power sensor nodes that are small in size. It helps in organizing an application topology into various types. Usually, sensor nodes in WSN are data centric. In this paper we propose the use of wireless nodes for EIM detection resulting in the replacement of conventional wired EIM recorders into wireless EIM recorders. For this purpose jitter, MAC delay and throughput is analysed at two different wireless communication standards namely IEEE802.11 and 802.15.4. The proposed wireless scheme is studied on the basis of reducing or eliminating the major contributing sources of artefacts limiting the system performance and image quality in clinic. These factors affecting the systems include artefacts introduce by the patient while scanning, internally and externally introduced frequency dependent noise, contact impedance and hardware limitations degrading system performance due to cable connections. The results shows that all these sources of errors are removed once the wireless technology is introduced in the system

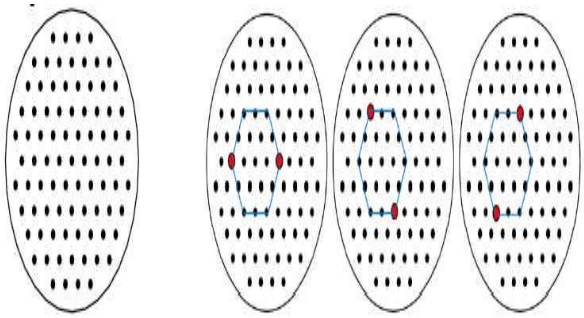
The rest of the paper discusses the background of MK4 system in section 2, followed by a discussion over conventional data acquisition system in section 3. Section 4 contains a description of the proposed wireless system followed by simulation parameters in section 5. Results and conclusions are given in section 6 and 7 respectively.

SUSSEX MK4 EIM SYSTEM

The Sussex MK4 EIM system is a 3D imaging system for breast cancer detection. Using impedance distribution of the breast, image is produced for the inner tissues to be investigated. The Sussex MK4 has an 85 planar array electrode setup comprising of multi frequency 3D EIM system [19, 4, 5, 20] for breast examination. The breast to be examined is introduced into a scanner head containing saline liquid of the same temperature as that of the human body as shown in Figure-1(a) [5, 6]. Breast to be scanned is partially pressed by the plate arranged with 85 electrodes hexagonally. The electrode plate is adjustable according to different breast sizes indicated in Figure-1(b).

(a) (b)

Figure 1. (a) Sussex MK4 EIM system (b) The planer electrodes.



(a) (b) (c) (d)

Figure 2. 85 electrodes planar array (a), (b), (c) and (d). Driving electrodes frame [14, 38].

The current excitation and voltage measurements are only focused and achieved in a small hexagonal area shown in Figure-2. In each measurement frame area, there are a maximum of 3 excitation events at 0°, 60° and 120° (Figure-2(a)-(c)). In each excitation, there are maximum of 12 voltage measurements, which are collected strictly parallel to the driving pair. With this special type of electrode configuration method, there are 123 excitation events corresponding to 1416 measurements. In Figure-2, the red dots indicate the excitation pair and the blue line hexagon indicates the measuring frame [14, 30].

TRADITIONAL MK4 DATA ACQUISITION SYSTEM

A complete MK4 EIM data acquisition comprises of hexagonally arranged planar electrodes, power source, data acquisition circuit and the data processing software. The independent measurements recorded are used to reconstruct image. One of the major factor affecting the resultant image is the accuracy of raw data. In order to obtain the improved and increased number of independent measurements, we needed to get the value of the electrical signal as accurately as possible. This was also the intent of design about each kind of data acquisition system.

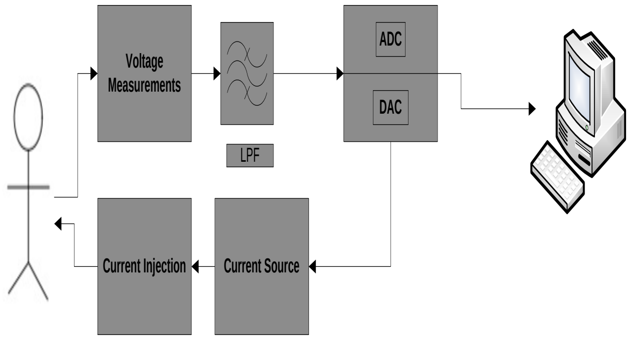


Figure 3. Traditional Sussex MK4 wired system.

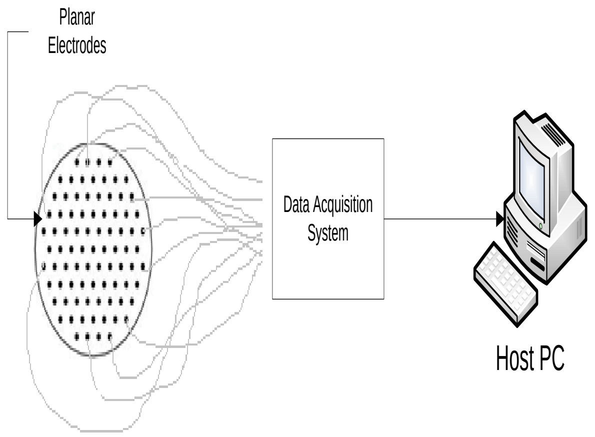


Figure 4. Traditional Sussex MK4 wired system using planar electrodes.

In the wired acquisition system shown in Figure-3, the noise interference was mainly generated when signal transferred between the electrodes and data acquisition system. Signal calibration circuits are placed in close proximity to the sensing electrodes as possible. The acquired data would to be transformed to the digital signal, which was not susceptible to be interrupted. After the digital transformation, software calibration is used before reconstructing the signal.

Unwanted threshold levels introduced could be minimized adequately in the data acquisition system. In [14, 31] the system performance and possible factors affecting the signal measurements are addressed. It was shown that the system performance depends upon the number of factors including system generated glitches and artefacts caused by patient movement during acquisition etc. Systematic inaccuracies include frequencies dependent unwanted threshold noise levels generated by the electronic circuitry and the surrounding environment. In this research proposed more than a few conventional and novel calibration techniques used to minimize frequency dependent noise level introduced due to the few of these artifacts in the acquired signals in advance to image reconstruction. It was accomplished that the post calibrated signal quality is able to generate images for the breast cancer detection. Figure-4 shows the wire connections of the traditional systems with the planar electrodes.

MODEL FOR WIRELESS SUSSEX MK4 DATA ACQUISITION SYSTEM

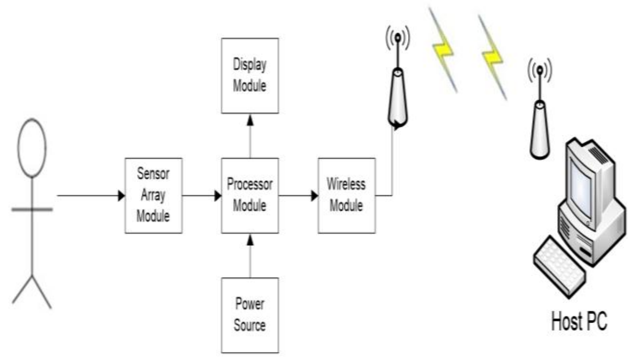


Figure 5. Wireless Sussex MK4 proposed.

As stated above, the complicated circuit model of traditional wired system was derived from the hardware space limitation. At the same time, this system model also caused the complicated work for installing the equipment. In this case, the technology of wireless sensor network could solve all the problems at a stroke. We might set the wireless device close to the electrode to collect the output signal with a simplified, low-cost and efficient signal conditioning circuit and send the data to the receiving end through the radio link, limiting the noise from the wired transmission circuitry.

As the upgrading of the traditional system, this paper presented the wireless Sussex MK4 data acquisition system. With the help of WSN technology, the imaging system may perhaps avoid designing quite a lot filters to restrict the unwanted threshold levels resulting in improving the system acquisition accuracy and reducing cost. The model for system could be showed as Figure-5. With the model showed in Figure-5, all of the nodes could be switched between injection and measurement mode at any time. Also, each node has respective signal conditioning circuit for collecting the voltage signal.

Signal injection and the independent measurements can be carried out by the assigned nodes manually or automatic. When the receiving nodes have com electrical signal, it would filter the noise at first.

SIMULATION PARAMETERS

OMNET++ was used for the simulation of IEEE802.11 and IEEE 802.15.4. This simulator is based on discrete events with the primary use being to simulate distributed systems and communication networks. Therefore, we have used OMNET++ for a comprehensive analysis of wireless communication standards for our prescribed application. As EIM recorders have multiple sensor electrodes for recording, in the prescribed topology we have used 85 sensor nodes with an access point as a main coordinator. Keeping the topology constant, jitter, mac delay and throughput is calculated by simulating the two IEEE 802.11 and IEEE 802.15.4 standards. The parameters used for the simulation are listed as follows in Table-1 and Table-2 for the two standards.

Table-1. IEEE 802.11 parameters.

IEEE 802.11 Physical Layer Parameters	
Simulation Area	400m
Physical Layer	2.4GHz
Radio Medium Path Loss	Free Space Path loss
Number of Nodes	12
Node Authentication timeout	5s
Node Association timeout	5s
Mobility Parameters	
Mobility speed	10ms
Mobility Update Interval	100ms
Node mobility radius	100m
Mac Layer Parameters	
Mac Threshold bytes limit	2304bytes
Mac maximum retry	5
Contention window size	20
Node Mac slot time	9us
Access Point Mac slot time	9us
Data Parameter	
Message Frame size	2304byte

Table-2. IEEE 802.15.4 parameters.

IEEE 802.15.4 Physical Layer Parameters	
Simulation Area	400m
Physical Layer	2.4GHz
Radio Medium Path Loss	Free Space Path loss
Number of Nodes	12
Node Authentication timeout	2.5s
Node Association timeout	2.5s
Mobility Parameters	
Mobility speed	10ms
Mobility Update Interval	100ms
Node mobility radius	100m
Mac Layer Parameters	
Mac Threshold bytes limit	127 bytes
Mac maximum retry	5
Contention window size	2
Node Mac slot time	4.5us
Access Point Mac slot time	4.5us

RESULTS AND DISCUSSION

Jitters

In a wireless network, jitter usually refers to a variation of packet arrival time at a node. There are various reasons for jitter such as network congestion, time drifting or change of route. Jitter is one of the significant parameters for a network performance evaluation. In our prescribed topology, we observed higher than average jitter with the IEEE 802.11 standard as compared to IEEE 802.15.4 as shown in Figure-6. Average jitter for this standard is 0.0367 seconds. For the IEEE 802.154 standard, highest jitter was observed for the constant speed mobility pattern of 0.01569 seconds. While, linear mobility has less jitter with 0.01563 seconds.

$$\text{Average jitter} = \frac{\sum_0^{80} \text{Jitter at Individual Node}}{\text{Total Number Of Nodes}} \qquad (1)$$

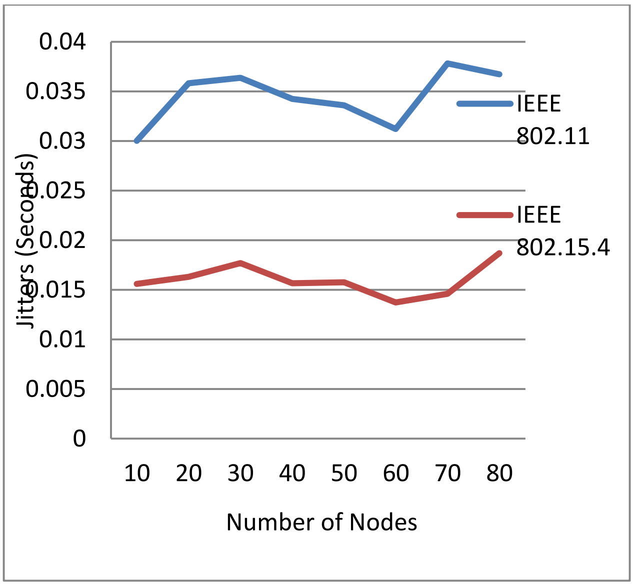


Figure 6. Comparison of jitters between IEEE 802.11 and IEEE 802.15.4.

Mac Delay

When the IEEE 802.11 standard was used, MAC delay at every individual node was different. The average MAC delay of all nodes is 0.075 seconds for the IEEE 802.11 standard. However, Mac delay when using the IEEE 802.15.4 standard is relatively less, averaging 0.0121 seconds. The comparative graphs are shown in Figure-7. The following formula has been used for average MAC delay calculation:

$$\text{Average mac delay} = \frac{\sum_{0}^{80} \text{Mac Delay at Individual Node}}{\text{Total Number Of Nodes}} \quad (2)$$

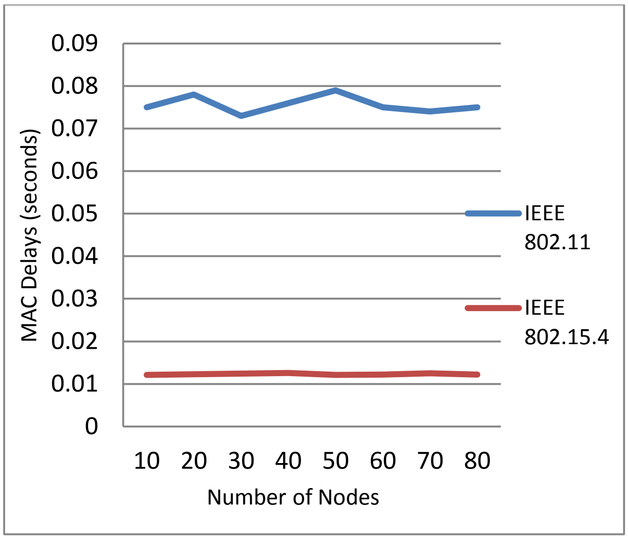


Figure 7. Comparison of MAC delays between IEEE 802.11 and IEEE 802.15.4.

Throughput

When using IEEE 802.11 parameters for 85 sensor nodes, the throughput value is around 70% to 80%. Whereas, for IEEE 802.15.4 simulated parameters, the throughput is between 85%-90%. The results are presented in Figure-8. Hence, the use of 802.15.4 yields higher throughput for higher number of nodes and is more suitable to be used in wireless EIM application.

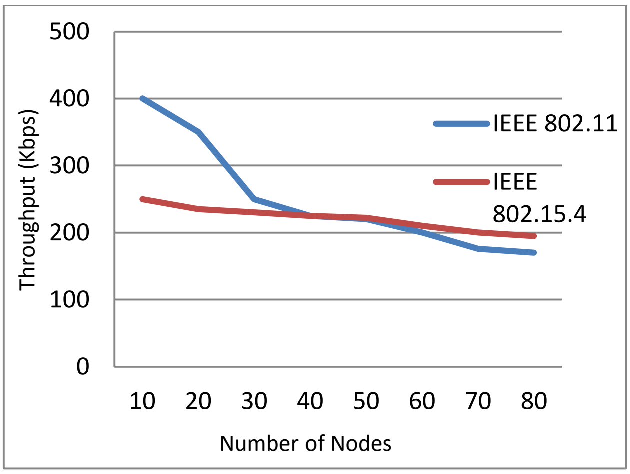


Figure 8. Comparison of throughput between IEEE 802.11 and IEEE 802.15.4.

CONCLUSION

In this paper we proposed wireless EIM methodology to remove system generated noise and make the system much for fast; accurate and scalable. The proposed use of wireless nodes for the EIM recorder is presented, for which the feasibility is derived by calculating the jitter, MAC delay and throughput for two commonly used wireless standards: IEEE 802.11 and 802.15.4, respectively. The application requires reliability and robustness so that not even a minor recording event remains undetected. The result shows that the wireless system is feasible to be deployed.

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