Abstract

e-Healthcare is a popular healthcare application of Wireless Body Area Sensor Network (WBASN). Today home monitoring of patients with movement disorders, monitoring of elderly for early fall detection are very popular applications. Our research focuses on one such important application of continuous, non-invasive, and wireless monitoring of the patients with Parkinson's disease, for preventing potential falls and injuries and recording the number of occurrences of Freezing of Gait (FoG) over single or multiple days. We propose a home based monitoring system which involves embedding of wireless sensors in the patient's vicinity, such as in his room. Analyzing the values of RSSI, which is the measure of received signal strength, from these sensor nodes we implement a robust patient's activity monitoring system for early fall determination. Multiple occurrences of FoG can also be monitored with our system, which is not possible to record at the doctor's clinic due to its relation with the degree of consciousness when a person is at the hospital. We also plan to derive different mobility patterns for a person during his/her day's activity and train the system accordingly.

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1. Introduction

Parkinson's disease (PD) is a highly prevalent, neurodegenerative disorder in the United States, which affects several thousand individuals every year. The severity of disease is manifested in the severity of expression of symptoms such as: tremors in limbs, impairment of gait, Freezing of Gait (FoG), bradykinesia (hesitation or slowness in a movement). One of the distinguishing factors to quantify the severity of PD is the degree of gait impairment. Currently doctors use a subjective measure to measure the progression of disease, known as Unified Parkinson's Disease Rating Scale (UPDRS), which is based on the doctor's observation of the severity of the symptoms during the patients visit at the hospital. The PD symptoms are highly episodic and cannot be completely studied or recorded at the doctor's clinic. As the disease progresses there are higher risks of patients’ falls due to gait instability, which can prove to be
even fatal. It is therefore extremely important to monitor the PD patients continuously at their homes so as to alert them or the medical professionals to prevent injuries by detecting early signs of falls.

We propose a potential solution of continuous, non-invasive, wireless home based monitoring of the PD patients using Wireless Body Area Sensor Networks (WBASN). WBASN has been extensively studied to provide real time monitoring of the patients. One of the major concerns in developing the monitoring system is patient's ease. Carrying sensors on patient's body will add to the level of discomfort which he is already suffering. Our solution is to deploy a fair amount of the sensors in the surrounding area of the patient such as his room, to monitor his everyday activity and alert him in case of his tendency to suffer a fall due to gait instability. We propose to study the entire mobility pattern of the patient as he goes about his daily activities. This data can then be used to train our system to predict falls when a person shows symptoms that precede a fall.

2. Background and Motivation

As discussed in the previous sections, the amount of PD progression can be measured by quantifying the gait impairment in the patient. The subsequent effect of increase of gait impairment is falls in patients. The patients exhibit different degrees of FoG in each event. So to it is very difficult for the gait center experts to reproduce the same frequency and severity of freezing in a simulated environment or in clinic, when the patients visit the doctors. Thus, the only solution to this is to monitor the patients at their homes in order to quantify and characterize the symptoms of PD, to reduce the risks of falls and injuries and also to monitor the effect of dosage changes in PD patients.

One of the earliest works on the use of Sensor Networks was in the CodeBlue project at Harvard University that involved multihop routing designed for medical monitoring [1]. Usage of wireless technology enables continuous, real-time monitoring of the elderly, without the involvement of caregivers [2]. Wireless sensors have been used to determine the extent of Parkinson's disease in a patient using wearable sensor devices [3]. These sensors can be used to determine the distinctive motion patterns of a particular individual. Lots of research is going on quantifying the symptoms of PD using wireless sensor networks. A simple and straightforward solution researched is to equip a PD patient with monitoring equipment that could indicate the current status of the patient as illustrated in Figure 1.

![Fig. 1. A patient with Parkinson’s disease with monitoring equipment.](image)

However, when such devices are attached to a patient, the individuals’ normal gait may be replaced by protective or evasive actions that do not necessarily reflect overall frequency and severity of gait impairment in the unfettered, unrestricted environment of daily life. Generally, patient monitoring systems use traditional intrusion detection mechanisms to detect the presence of patients in the vicinity. Commercial intrusion detection mechanisms such as Alarm-Net use infra-red radiation to detect the presence of an intruder and use the mobile communications backbone to send notifications to predefined entities. The Advanced Health and Disaster Aid Network (AID-N) designed at the Applied Physics
Laboratory at Johns Hopkins University uses ad-hoc wireless networks to monitor critical patients [5]. However, this system requires the patient to wear a vital sign sensor on his/her body and triage sensors so as to enable the system to effectively monitor the patient.

All of these systems require the patient to wear sensors be wearing some wireless device on his/her body so as to have effective detection of the location of the patient. While these devices may be cumbersome, they also make the patient aware of the fact that he or she is being monitored. This might result in the patient being conscious and deviate from his/her normal daily activities. Of course if the patient forgets to or does not wear the system, then the monitoring cannot be done. We propose a novel way to achieve the same objective of patient monitoring without requiring the patient to wear a device on his/her body. Our system is completely unobtrusive and the patient can be monitored over long periods of time very effectively.

The objective of this proposal is to determine the extent to which a wireless sensor network (WSN) could effectively monitor the burden of gait disability and provide early warning of follow up events that could be anticipated.

3. Methods and Experiments

We have been setting up wireless sensor devices to monitor mobility of PD patients at home by measuring RSSI (Received Signal Strength Indicator) values received by sensor motes strategically placed at different locations of the room, to measure an individual’s normal movements in a room. We propose to measure the value of the Received Signal Strength Indicator (RSSI) between two deployed sensor nodes that change when an object obstructs the Radio Frequency signal through its presence between the nodes. Our system would enable a more accurate estimation of the degree of gait disability in an individual and provide real-time input that would help in determining the course of actions to follow for a particular patient. The system is completely unobtrusive and inconspicuous to the patient. RSSI is defined as ten times the logarithm of the ratio of power of the received signal and the reference power.

\[
\text{RSSI} \propto 10 \log \frac{P}{P_{\text{REF}}} \tag{1}
\]

We know that power received from a source decreases as the point of measurement moves away and the power detected at a distance is inversely proportional to the square of the distance. Therefore, we can write the relationship of RSSI and distance as:

\[
\text{RSSI} \propto \log \left(\frac{1}{\text{distance}^2}\right) \tag{2}
\]

Hence, in general, the relationship between RSSI and distance can be written as:

\[
\text{RSSI} \propto -\log \left(\text{distance}\right) \tag{3}
\]

We can use this relationship to effectively determine the location of a person with respect to a fixed set of sensor motes.

3.1. Patient’s mobility detection using RF Signal Strength

Experiments have been carried out to provide real-time mobility detection in the form of an intrusion detection system (IDS), surveillance and control applications on a wireless sensor network [4]. RSSI is a measure in decibels, which is ten times the logarithm of the ratio of the received power (P) and the reference power (P_{REF}) as shown in equation (1). Power at the receiver (P_{RES}) is inversely proportional to the square of the distance. Therefore, through this relatively straightforward conversion, we believe that RSSI could be used as an indicator of distance with limited accuracy.

3.2. Indoor monitoring of patients with RSSI

Experiments were performed with people walking between the sensor motes and the monitoring station.
The variation of signal strength with time as the person moves about is used to determine the presence of
the person in a particular location.

Figure 2a shows that when there is obstruction in the path from the single sensor to the Base Station
there is significant drop in the signal strength and Figure 2b shows that when there is obstruction in the
path from multiple sensors to the Base Station there is also visible drop in the signal strength. The typical
raw data from sensor nodes when there is no obstruction between the node and the Base Station is shown
in Figure 3.

Experiments were performed with the scenario as depicted in Figure 4. The room was divided into two
zones (represented by two concentric circles) in order to have a better location estimate for our proposed
study. The goal is to determine the drop in RSSI values as the Radio Frequency signals are obstructed by
a person walking between the sensor motes.

The experiment involves a ring of sensors around the base station. Another set of sensors in the
periphery of the room unicasts their packets to the ring of sensors around the base station. The whole
room was divided into four regions which are labeled in the diagram as I through IV. We also divide the
entire room into two zones as discussed before. The area surrounding the base station and the ring of
sensors around it is designated as Zone 1 while the area between the sensors in the outer areas of the room
and the inner ring is designated as Zone 2. Hence each region has a quarter of each of the two zones.

From the diagram we can see that motes 5, 9 and 7 are setup to unicast to 1, 2 and 4 respectively. Mote
1 receives forwarded data from Mote 12 through mote 5 which in turn receives data from mote 8. Node 9
receives forwarded packets from Node 6 which also receives packets from Node 10. In a similar manner
Node 7 receives forwarded packets from Node 11 and 13. A detailed description of the packet forwarding
strategy is as shown in the Table 1.

The nodes that are in the vicinity of the base station and form the ring around it can directly
communicate with the base station and are responsible for forwarding their own packets as well as
packets that have been received from the other nodes. The other motes have their transmission power
turned down so that they can only forward to one of the nodes in Zone 1. This helps in segregating the
area to be monitored into different zones and reduces the power consumption of the other nodes.

All packets that are received by the nodes in the ring around the base station are forwarded to the base
station. The RSSI values between the different nodes are inversely proportional to the square of the
distance and they show up on the Listen application that is bundled with TinyOS.

RSSI was measured from all the sensor nodes every 250 milliseconds. On the receiver side of the
experiments, a sensor mote (base station) was connected via USB to a laptop which was placed in the
same level of the sensors on the ground. The sensor motes were programmed in TinyOS to send and
receive beacon signals among each other.
So, all the nodes measured the RSSI from each of its other neighbors. RSSI values were calculated from the received beacon signals according to the specification in the sensor mote’s datasheet. We denote the measured RSSI values as “Perfect Experimental Data” (PED), as it reflects the data in a perfect mobility scenario and recorded at the laptop. This was our ideal scenario. We then experimented with the behavior of RSSI with physical human mobility between the sensor motes. As shown in Figure 4 a subject was made to walk and thereby obstruct the signals between the sensor motes. The PED would now have the levels of drop in RSSI. We use this information in defining our thresholds. Once the Listen application is running we can determine the changes in the RSSI values depending on the packets received at the base station. The source and the destination addresses are used to determine where the packet originated and used to give us an estimate of the location of the person in a particular zone in the room.

For real-time data visualization we have used the Oscilloscope application bundled with TinyOS. With the application running we can see a drop in the received signal values when the signals are obstructed between two motes.

4. Conclusion

Our system would enable a more accurate estimation of the degree of gait disability in an individual and provide the doctor with more inputs and help him determine the course of actions to follow for the particular patient. The system would be completely unobtrusive and inconspicuous to the patient which would eliminate the problem of consciousness in the individual when he/she is being examined at the doctor’s clinic. Using the unicast scheme helped us in monitoring the subject’s movements in various
areas of the room. However, since the nodes near to the base station are responsible for forwarding all the packets from the rest of the network, it may lead to the energy-hole problem.

Also, the system cannot handle vast amounts of data as the Zigbee protocol was designed for low data rates. Again, since ZigBee uses a Carrier Sense Multiple Access - Collision Avoidance (CSMA-CA) mechanism, a situation is created where we cannot guarantee when a particular sensor will get an opportunity to transmit. The multiple radio signals can create noise as the dynamic-movement related signal may interfere. However, increasing the number of sensors would increase the accuracy of the system since it would add to the beneficial redundancy of the received signals.

5. Future Work

We propose to setup an indoor monitoring facility at the patients’ home or hospice through the use of low-powered static sensors placed on the walls and designed to cover a three dimensional space such as a bedroom or a living room. These sensors would send their measured RSSI values to a small base station also located in the same premises that would log the RSSI values and the time. As the patient moves around these values would change and we can create a complete model of the patients’ mobility patterns through the analysis of the data. The data at the base station can then be transmitted to the doctor over the internet or can be downloaded by the patient himself onto a portable memory stick.

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References


