Wireless sensors in medical applications

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***Abstract* - Sensor networks have the potential to greatly impact many aspects of medical care. By outfitting patients with wireless, wearable vital sign sensors, collecting detailed real-time data on physiological status can be greatly simplified. Sensor data can be integrated into electronic patient care records and retrieved for later analysis. In a wide range of clinical studies, especially those involving ambulatory or at-home monitoring, wireless sensors would permit data acquisition at higher resolution and for longer duration than existing monitoring solutions. However, there is a significant gap between existing sensor network systems and needs of medical care. In particular, medical sensor networks must support multicast routing topologies, node mobility, a wide range of data rates and high degree of reliability, and security. This paper discusses the potential application of Wireless sensors in medical care and underlying challenges.**

***Index Terms* – Active Triage Tag, Biosensors, Bluetooth, Circadian Activity Rhythms, Electrocardiograph EKG, in-network aggregation, Medics, Motes, oximeter, Oxygen saturation(SpO2), Wireless sensors, Wireless Medical Telemetry Services,**

I. Introduction

An emerging application for wireless sensor networks involves their use in medical care. In a hospital or clinic, outfitting every patient with tiny, wearable wireless sensors would allow doctors, nurses and other caregivers to continuously monitor the status of their patients.

In an emergency or disaster scenario, the same technology would enable medics to more effectively care for large number of casualties. Wireless sensor network could receive immediate notification on any changes in patient status, such as respiratory failure or cardiac arrest. Wireless sensors could augment or replace existing wired telemetry systems for many specific clinical applications, such as physical rehabilitation or long-term ambulatory monitoring.

Advances in embedded systems have led to the development of small, low power sensor nodes(often called “motes”) that consist of a simple microcontroller, a small amount of memory, a low power radio, and various sensors that are capable of collecting, processing, and transmitting sensor data over distances of 100m or more.

II. THE NEED FOR WIRELESS SENSORS IN MEDICAL APPLICATIONS

Wireless medical telemetry is not altogether new. Number of wireless medical monitors are currently on the market, including electrocardiographs (EKG), pulse oximeters, blood pressure monitors. Most of these devices use Bluetooth or the analog Wireless Medical Telemetry Services, commonly employing IEEE802.11. However, these systems are generally designed only to “cut the cord” between the sensor worn by the patients and a bedside monitor or other nearby receiving device. They are not intended to participate in a network, to relay data to multiple receiver or to scale to a large numbers of monitors in an area. In addition, few of these systems are designed to be wearable; most remain attached to the hospital bed, and the few wireless ambulatory products on the market are generally large and cumbersome[5].

The emergence of low-power, single-chip radios based on the Bluetooth and 802.15.4 standards has precipitated the design of small, wearable, truly networked medical sensors. In a mass casualty or disaster setting, medics can place tiny sensors on each patient to form an ad hoc network, relaying continuous vital sign data to multiple receiving devices (e.g. PDAs carried by physicians, or laptop base stations in ambulances)[9] . In addition to relaying vital sign data, each node can act as an “active triage tag” storing information about the wearer (identification, medical history, severity status, etc.). RF-based localization [13] can be used to track patient. Such a system can be translated directly into hospital settings where wired monitoring is cumbersome and (especially with paediatric and neonatal patients) obstructs the caregivers access to the patient.

III. CHALLENGES FOR SENSORS IN MEDICAL APPLICATION

Most sensor network are intended for deployments of stationary nodes that transmit data at relatively low data rates, with a focus on best effort data collection at a central base station, By contrast, medical monitoring requires relatively high data rates, reliable communication, and multiple receivers(e.g. PDAs carried by doctors and nurses). Moreover, unlike many sensor network applications, medical monitoring can not make use of traditional in-network aggregation[1] since it is not generally meaningful to combine data from multiple patients. The Major challenges which a medical fraternity figures out in [3],[4],[5] are as follows :

a) Development of highly robust, ad hoc multi – hop routing schemes
b) Prioritization of critical data, e.g. serious change in patient status
c) Sensor nodes are too primitive for expensive public key approaches, still must support flexible security policies
d) Calibration of receiving devices

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IV. REQUIREMENTS OF WIRELESS SENSORS IN MEDICAL APPLICATIONS

The requirements for a medical sensor network design depend greatly on the specific application and deployment environment. A sensor network designed for ad hoc deployment in an emergency situation has very different requirements than one deployed permanently in a hospital. In general, however, we can identify several characteristics that nearly all medical sensors would share[5],[6].

A. Wearable sensor platform

Medical applications generally require very small, lightweight, and wearable sensors. Existing mote platforms are good for demonstrations but has difficulty with large battery packs and protruding antennas.

B. Reliable communication

In medical settings, a great emphasis is placed on data availability. Although intermittent packet loss due to interference may be acceptable, persistent packet loss(due to congestion or node mobility) would be problematic. Depending on the sensors in use, sampling rates may range anywhere from less than 1Hz to 1000Hz or more, placing heavy demands on the wireless channel.

C. Multiple receivers

It is expected that the data from a given patient will typically be received by multiple doctors or nurses caring for the patient. This suggests that the network layer should support multicast semantics.

D. Device mobility

Both patients and care givers are mobile, requiring that the communication layer adapt rapidly to changes in link quality. For example, if multihop routing protocol is in use, it should quickly find new routes when doctor moves from room to room during rounds.

E. Security

Aside from the obvious security considerations with sensitive patient data, United States law mandates that medical devices meet the requirements of the 1996 Health Insurance Portability and Accountability Act (HIPAA). Recent work on private-key and public-key **c**ryptography schemes for sensors network is applicable here, but must be integrated into an appropriate authentication and authorization framework.

F. Real-Time Data Streaming

Since sensor networks deal with real world situations which often require a timely response (e.g., medical emergencies, vital sign reporting, tracking), it is necessary to provide real-time data streams. Due to resource limitations of both computation and communication, and unpredictability in network topology and work load, it is impractical to guarantee hard real-time constraints.

V. OVERVIEW OF RESEARCH OF WIRELESS SENSORS IN MEDICAL

Recent advances in embedded computing systems have led to the emergence of wireless sensor networks, consisting of small, battery-powered "motes" with limited computation and radio communication capabilities. Sensor networks permit data gathering and computation to be deeply embedded in the physical environment.

a) 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.[8].

b) Researcher have developed [3] a small, wearable wireless pulse oximeter and 2-lead EKG based on the sensor node platforms. These devices collect heart rate (HR), oxygen saturation (SpO2), and EKG data and relay it over a short-range (100m) wireless network to any number of receiving devices, including PDAs, laptops, or ambulance-based terminals. The data can be displayed in real time and integrated into the developing pre-hospital patient care record. The sensor devices themselves can be programmed to process the vital sign data, for example, to raise an alert condition when vital signs fall outside of normal parameters. Any adverse change in patient status can then be signaled to a nearby EMT or paramedic.

c) In collaboration with the Motion Analysis Laboratory at the Spaulding Rehabilitation Hospital, Researcher [3],[13]are developing a separate sensor board for monitoring the limb movements and muscle activity of stroke patients during rehabilitation exercise. These boards, consisting of 3-axis accelerometer, gyroscope, and electromyogram (EMG) sensors, will permit researchers to capture a rich data set of motion data for studying the effect of various rehabilitation exercises on this patient population.

d) The researcher have presented a design centered approach that created an electronic triage system for mass casualty events[9],[10]. This has resulted in a system that changed how medics interacted and how information was collected, distributed and displayed. This has facilitated communication between providers at the disaster scene, medical professional at local hospital, and specialist available for consultation from distant facilities .This uses the wearable sensors which provide four functionalities: vital signs monitoring, location tracking, medical record storage, and triage status tracking. The author has integrated two types of non – invasive sensors – a pulse oximeter and blood pressure sensor. The pulse oximeter attaches to the patient's fingers and measures heart rate(HR) and blood oxygenation level (SpO2). A cuff pressure sensor on the patient's upper arm measures systolic and diastolic blood pressure. They have also integrated two types location sensing capabilities – a GPS to provide geo location, and indoor location detection system to provide location where the GPS signal cannot be reached. The GPS sensor allows medics to track patients who are outdoors, e.g. at the scene of the emergency. The ability to track the location of the patients indoors will be very useful features for helping medics quickly locate a specific patient whose conditions have deteriorated. The authors have shown the results with all the peripheral devices turned on, the pulse and oxygenation reported every second, The GPS location reported every 5 minutes , and the blood pressure reported every 15 minutes. Software on the tablet device receives real – time patient data from the mote and processes them to detect anomalies. When an anomalies is detected in the patient vital signs, the medics software application generates an alert in the user interface. The medics can locate the patient by selecting to view a map of the disaster scene marked with the GPS location of each patient. The medics can also select "sound alert" feature that will sound a buzzer and blink an LED on the mote. Medics expect the monitoring system to be most useful for patients who have been triaged and are waiting for ambulances. They can then use this system to prioritize the patients who need to be transported by ambulances.

e) Wireless sensor networks deployed throughout an indoor environment[13] offer the opportunity for accurate location tracking of mobile users. Using radio signal information alone, it is possible to determine the location of a roaming node at close to meter-level accuracy. The research is targeted towards developing a robust, decentralized approach to RF-based location tracking. The system, called MoteTrack, is based on low-power radio transceivers coupled with a modest amount of computation and storage capabilities. MoteTrack does not rely upon any back-end server or network infrastructure: the location of each mobile node is computed using a received radio signal strength signature from numerous beacon nodes to a database of signatures that is replicated across the beacon nodes themselves. This design allows the system to function despite significant failures of the radio beacon infrastructure.

f) Virginia Medical researchers[6] have developed SolarDust, a sensor board for Mica motes. It provides the mote's microprocessor with a UART interface to a Bluetooth transceiver. This enables a body network to communicate with other commercially available sensor devices, as well as communicate with a resident's cell phone for emergency response.[7]

VI. APPLICATION AREAS

1) Reference [2] shows potential of wireless sensors in Medical application.

A. Real-time, continuous patient monitoring

(a) : This includes Pre-hospital, in-hospital, and ambulatory monitoring possible
(b) : Replace expensive and cumbersome wired telemetry systems

B. Home monitoring for chronic and elderly patients

(a) : Collect periodic or continuous data and upload to physician
(b) : Allows long-term care and trend analysis
Reduce length of hospital stay

C. Collection of long-term databases of clinical data

(a) : Correlation of biosensor readings with other patient information
(b) : Longitudinal studies across populations
(c) : Study effects of interventions and data mining

2) Examples of envisioned mission where the Wireless sensors can quickly make an impact are the following[10],[6].

A. Sleep Apnea

Every night, monitor blood oxygenation, breathing, heart rate, EEG and using on body sensors to assess severity and pattern of obstructive sleep apnea. Home network monitors agitations(movement) and stores and reports sensor data to the network alerts provider and patients if oxygenation falls below a threshold. Monitoring can continue while treatment efficacy is assessed.

B. Journaling Support

Journaling is a technique recommended for patients to help their physicians diagnose ailments like rheumatic diseases. Patients record changes in body functions (range of motion, pain, fatigue, sleep, headache, irritability, etc), and attempt to correlate them with environmental, behavioral, or pharmaceutical changes. The homecare network can aid patients by providing a time synchronized channel for recording and transmitting the journal (PC, PDA); recording environmental data or external stimuli (temperature, barometric pressure, sunlight exposure, medication schedule); and quantitatively measuring changes in symptoms(pain, heart rate, sleep disruption).

C. Cardiac Health

Cardiac arrhythmia is any change from the normal beating of the heart. Abnormal heart rhythms can cause the heart to be less efficient, and can cause symptoms such as dizziness, fainting, or fatigue. Since they are sometimes very brief, it can be difficult to properly characterize them. Cardiac stress tests attempt to to induce the event while the patient is wearing sensors in a laboratory. In a homecare setting wearable EKG sensors can monitor for the condition continuously, over days or weeks, until the event occurs. The recorded data is promptly sent to the physician for analysis. If the event is serious enough, the emergency communication channel may be used to call for help, or it may be dispatched automatically. Other sensors in the home may be able to record environmental data to help identify the cause (side effect of medicine, little sleep, etc.).

3) D. Circadian Activity Rhythms

4) CARs reveal intimate details about a person's living activities and health status. As wireless sensors grow in their capability to collect, process, and store data, personal information privacy becomes a rising concern. Reference [6] discusses about a framework to protect privacy and still support timely assistance to patients with critical health conditions.

VII. CONCLUSION

Advances in wireless sensor networking have opened up new opportunities in healthcare systems. The future will see the integration of the abundance of existing specialized medical technology with pervasive, wireless networks. Sensor node and sensor network development have the potential to revolutionize patient care by allowing continuous, real-time, non – invasive, wireless monitoring of multiple patients. Relaying this information to one or more systems that are supported by the developing medical grid could yield acute, real time triage and decision support. Examples of areas in which future medical systems can benefit the most from wireless sensor networks are in-home assistance, smart nursing homes, and clinical trial and research augmentation.

Unobtrusive, wearable sensors will allow vast amounts of data to be collected and mined for next-generation clinical trials. Data will be collected and reported automatically, reducing the cost and inconvenience of regular visits to the physician. Therefore, many more study participants may be enrolled, benefiting biological, pharmaceutical, and medical-application research.

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