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Toward A Hi-Fi Wireless Sensor Network for Rehabilitation Supervision

B.SarathkumaR[*1], **Ms. Ruchi Sawal**[2]
[*1] II M.Tech Embedded Systems, [2] Assistant Professor, Department of electronics and instrumentation, Karunya University, Coimbatore, India
Sarathkumar.b389@gmail.com

Abstract

Habitually a sensor for rehabilitation is a custom field in a medical applications, wireless sensors is fetching a great interest in medical applications for handling abundance work in the field of biomedical and for further research. To handle this, there have been numerous solutions suggested with minimum cost, flexible and unobtrusive systems for rehabilitation supervision. The various solutions proposed focus on the aspects like sensor/hardware design, architecture design and signal processing algorithms. The objective is to design and the employment of a new light-weight and user-friendly wireless sensor for high-fidelity rehabilitation supervision. To be exact, it has a protocol with efficient communication that fulfills the requirements for the supervision of rehabilitation. The goal is to collect information that boost engineers and computer scientists to work together in this field to tackle the rising challenges.

Keywords: WSN, Rehabilitation, communication protocols.

Introduction

Rehabilitation is an exercises process with the goal of accomplishing a physical functioning level that allows patients to return to their initial body condition after an accident or a surgery. Studies show an enormous increase in functional recovery of patients with increased amount of exercises through rehabilitation [1]. However, intensive exercises process has to be done with continuous supervision of patients and increase the load for psychotherapists. Advances of wireless technology and inertial sensors such as gyroscopes and accelerometers have improved wireless sensor networks for rehabilitation supervision. Wireless sensor networks can collect relevant information about persons behavior and deliver feedback to the user in real time. They make promising growth of low cost, less weight, unobtrusive and easy to handle monitoring solutions for rehabilitation supervision. There has been mass of research works on WSN for rehabilitation supervision. Here the design and implementation of WSN for high-fidelity rehabilitation supervision. In addition, we discourse the challenge of forecasting a fault-tolerant energy-efficient communication protocol that meets the medical requirements of our application. The communication protocol minimizes collisions even though several sensor nodes stream their data at high rate. First, it offers a review of surviving wireless sensor networks for rehabilitation. Second, the design and implementation of a wireless sensor network prototype for high-resolution rehabilitation monitoring is presented. Third, it propose a new fault tolerant communication protocol for supervising rehabilitation process is built on the top of the IEEE 802.15.4 standard, while meeting the QoS requirements of the rehabilitation supervision applications. In the next section a review existing wireless sensor networks for rehabilitation supervision. In section 3, the architecture and the hardware of prototype are described. In section4, we outline our communication protocol. Section 5 specifics the implementation of our protocol on the top of this Standard. We evaluate our solution in section 6 and give some concluding remarks and directions for future works in the section 7.

Related Works

There has been a mass of research mechanisms on wireless sensor networks for rehabilitation. These researches have focused on three main areas:

Sensor node design: To attain comfortable and non-invasive continuous supervision of rehabilitation process, wireless sensor nodes should fulfill the following requirements: minimal weight, miniature form factor, Wearability and unobtrusive-ness. Meeting these requirements is mainly obtained by decreasing the size of components in sensor nodes. In [2], the design of a small sensor unit with gyroscope and accelerometer sensors to shape a simplified, cheap and wearable sensor network for gait evaluation. But , this miniature form factor sensors are linked with wires which may bound the patient's movement and level of comfort and thus negatively influence the obtained results. Lim et al. in [3] present a wireless sensor network used in upper arm rehabilitation for stroke patients. Their work have attention on decreasing the size of components in sensor nodes. However, reduction of component size puts a strong constraints on hardware designers and reduces available resources. Their work have attention on the design of a wearable, compact and low cost sensing module able to measure the arm movement with accuracy. Even though data is wirelessly sent to the base station, sampling frequency is restricted to 25 Hz and motion analysis is performed offline because of challenges in wireless transmission. The iNODE presented in [4] is a miniaturized sensor node with a Force Sensitive Sensor (FSR) and a Respiratory Inactive Plethysmography (RIP) sensors. INODE measures the locomotive and respiratory signals and assesses the coordination between them. In a separate work [5], authors developed a communication protocol to interconnect the iNODE sensors. However, this communication protocol does not support mesh topologies and has a very less communication range. Signal processing algorithms: The growth of efficient signal processing algorithms able to process a high volume of sensors data. These algorithms must handle data and deliver valuable feedback in real time. However, data from a single sensor node may not be sufficient to extract relevant information. So, further signals have to be combined to produce significant information that evolve into medical knowledge. In [6], authors practice a wearable sensor system that measures reaction force and detects eight dissimilar gait phases. This system is placed on a motion analysis system and a gait phase detection algorithm. To deal with sensor errors and calibration, they practice an intelligent calibration process that fuses accelerometer and gyroscope signals. Zhou et al. in [7] design an arm movement tracking system for rehabilitation of stroke patients. The system is based on a weighted least squares filtering method that eliminates the errors whose Euclidean distance is larger than a threshold. There has been much efforts in designing easily deployable wireless sensor networks for rehabilitation supervision. Mercury [8] is a wearable wireless sensor network platform for motion analysis of patients who undergo from Parkinson's disease, epilepsy and stroke. It is centered on a flexible programming interface allowing clinicians to implement dissimilar policies following the application requirements. Kifayat et al. in [9] present a framework that combines wireless sensor network technology and gaming to support rehabilitation of patients with physical disabilities. While the patient uses the game, data is collected in real-time by the wireless sensor network and forage into a control service permitting the patient to monitor its virtual demonstration by physically moving his body. RehabSPOT proposed in [10] is a highly customizable wireless sensor network for rehabilitation built on the top of SunSPOT sensors. The system is based on a software architecture which allows dynamic network construction and sensor management at runtime. Most of earlier surveyed wireless sensor networks have a little concern to communication protocols. They supposed that existing communication protocols developed for WSN's are also suitable to rehabilitation monitoring applications. However, these applications have two specific features that heavily influence the network performance and cannot be passed over. On one hand, the positioning of various adjacent sensor nodes on the body may cause serious intervention problems. On the other hand, sensor nodes need to continuously stream bulks of data to a receiver at a resolute rate over a long period. In [11], authors develop a telerehabilitation system that has both, a wearable sensor network and a video conferencing system. One objective of this work is to study the impact of the various sensor nodes and the sampling rate on the reliability of the radio transmission. However, the recommended communication protocol has no fault acceptance capabilities and the system must be physically restarted at every loss of link. Authors investigate using ANT networking technology [13] to collect data from sensor modules to the receiver. However, this method presents significant disadvantages such as limited transmission range and limited packet size.

System Architecture

In this paper, we recommend a low cost, easy to use an unobtrusive WSN for high fidelity rehabilitation supervision. Our system have four major components: a set of motion sensor nodes, a base station, a communication protocol and a system manager software. The motion sensor nodes are worn by the patient and measure motion data (acceleration and angular velocity) as the patient moves his limbs. Data collected by motion sensor nodes is wirelessly sent to the base station using our new energy efficient, fault tolerant communication protocol. The base station forms a star topology with the motion sensor nodes and relays received data to the system manager running on a laptop. It is also responsible for a number of functions such as node management, node synchronization and commands dissemination. The system manager processes, saves and displays the received data at real-time. We use elastic bracelets for easy sensor nodes fixing. These bracelets can be easily fixed with no or minimal help. Each motion sensor node has an accelerometer and a gyroscope to measure patient's limb movements. We developed a TinyOS application to sample sensors at high frequency and to send the collected motion data (acceleration and angular velocity in three axis) to the base station. In order to reduce communication overhead and meet high frequency data sampling, we store collected samples in a buffer with a specified capacity and bundles several samples into a single message when sending them to the base station. The data that we get from sensors sampling represents the voltage value of the sensor output at the moment of measurement. We should transform this value into acceleration or angular velocity before feeding it into a back office software that helps in patient control by doctors. In order to reduce energy consumption of sensor nodes, we suggest a sensor nodes that send the raw data to the system manager which processes it into useful information. After processing, the manager stores the data in a clinical database for further signal processing and medical analysis. This data is used by doctors to check the patients' physical performance for the purpose of assessing the best therapies suitable for the patient. Since doctors may have no networking knowledge, we developed a simple user-friendly Java Graphical User Interface for the system manager application. The GUI enables doctors to easily start/stop/resume data collection, plot and filter downloaded data at real-time and access to previously recorded data for offline analysis.

A. Hardware

To make our wireless sensor network appropriate for body worn clinical and in-home applications, we decided to use the light weight and low power consumption . In our prototype, a motion sensor node and on-board 2 Gbytes Micro SD flash. The core component named ARDUINO UNO has ATmega328 Microcontroller (16MHz, 2 Kbyte SRAM, 32 Kbyte flash, 14 ADC channels). We use 6 ADC channels to capture the accelerometer and the gyroscope sensors data (1channel per axis). Motion sensor nodes have a low-power MPU-6050 Six-Axis (Gyro & Accelerometer) MEMS Motion Tracking Devices. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyro full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*.

Communi Cation Protocol

A WSN for rehabilitation supervision gathers information about patient activity and feeds it into a bio-mechanical model for gesture evaluation. To be able to generate an accurate report and feedback, the bio-mechanical model needs some information (acceleration, angular velocity) from several nodes in real time. Therefore, the sensor sampling and data transmission should be performed at high frequency. Our design objective is to build a WSN that meets those requirements.

A. Access to the Medium

Existing WSNs use the contention-based CSMA-CA access method to access to the channel and to send their data. Before sending a packet, a node using CSMA-CA has to listen to the channel to determine whether or not another node is transmitting. If the channel is found to be idle, then the node begins the transmission. Otherwise, the node postpones its transmission for a random period of time (back off time) before trying to access the channel again. Our protocol adopts a star network topology where the base station has a major role. It periodically sends a control message to synchronize network's nodes and to advertise the network for new nodes willing to join it. The time between two control messages is organized into a time division multiple access (TDMA) period and a CSMA-CA period (see figure 2). The TDMA period is a contention free period exclusively reserved for the HRP traffic in order to minimize collisions. The CSMA/CA period is used to transmit the LRA traffic. Figure 1 illustrates the different steps that the node C performs to join a network of a base station having two nodes already connected (node A and node B).

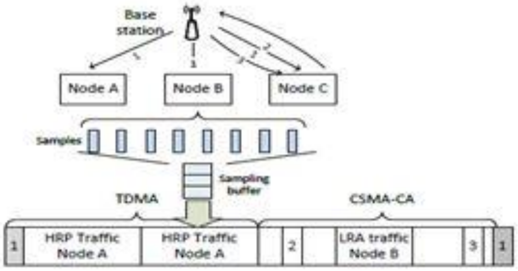

Fig.1 Communication Protocol

Upon receiving the control message, the node C sends a join request to the base station and waits for an acknowledgement. If needed, the node C specifies that it needs a timeslot from the TDMA period for its HRP traffic. Messages 1, 2 and 3 in figure 1 represent respectively the control message, the join request and the join acknowledgment messages. However, access probability and delivery ratio sharply decrease when the packet size or the network size increase[14][15] The control message also defines the exact moment at which each node is expected to send the data to avoid collisions during the TDMA period.

B. Fault Tolerance

Scheming a fault-tolerant and reliable communication protocol is of a primary goal and is a key challenge in medical wireless sensor networks. Consider a patient executing its rehabilitation exercises going beyond the communication range of the base station for a long time. It is not acceptable to lose the data collected by sensors during disconnection or failure periods. To tackle this challenge, we have established and executed a fault tolerant mechanism based on the delay tolerant network concept. This mechanism exploits the Micro SD flash memory for local data storage in case device loses connection with the base station. When a device stops receiving control messages from the base station, it enters in the DTN mode and stores collected data on the Micro SD flash memory. If a connection to the base station is available again, the node resumes sending fresh collected data during its TDMA slot. In addition, it benefits from the CSMA-CA period to progressively send the data backed on the flash memory. If no connection to the base station becomes available again before the end of the rehabilitation session, the backed data will be automatically transferred to the clinical database once the device docked for charging. This data is then added to the corresponding rehabilitation session information for further off-line analysis. The two gigabyte Micro SD flash memory of our motion sensor nodes makes possible to store samples for ten days at 100 Hz frequency.

A WSN Communication Archite Cture For Rehabilitation: Implementation

In order to encounter the specific requirements of this application, we have established an energy efficient, fault tolerant communication protocol which minimizes collisions. We have implemented our protocol on the top of the IEEE 802.15.4 standard running in the beacon enabled mode. Our protocol adopts a star network topology where the base station is the devices which use the CAP period (CSMA-CA) for sending their LRA traffic and the CFP period (GTS) for sending their HRP traffic.

A. Network Joining Implementation

In our protocol, the first action that a node does is to join the network by sending a request message to the base station. Upon receiving this join request, the base station allocates a timeslot for this device and acknowledges the success of the operation. The application running on the node initiates an association procedure with the PAN coordinator (i.e. the base station) and waits for the result of the operation. If the association succeeds, and if the node has HRP traffic to send, the application initiates a GTS allocation to reserve a timeslot for this device. The figure.2 details messages sent and action performed during the join mechanism.

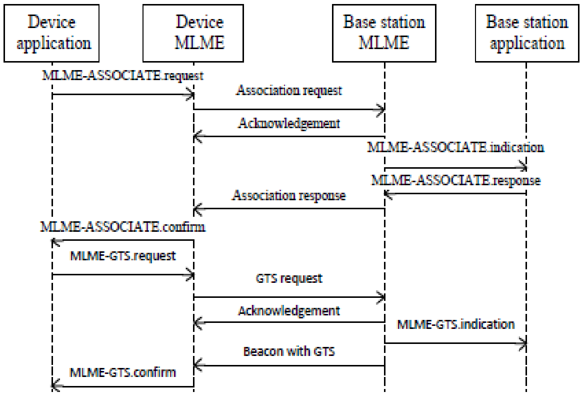

Fig.2 Message sequence chart for network joining

B. Data Transmission Implementation

In the 802.15.4 beacon enabled mode, the network coordinator sends periodically a beacon frame to synchronize devices and describes the structure of the current super frame. Each times a device receives this beacon, the MLME service triggers the MLME-BEACON. Indication event. We have implemented a MLME BEACON. indication event handler in which the device prepares packets to send ready data to the base station. The handler takes available samples in the sampling buffer and creates several packets. Once a packet is ready, the handler forwards it to the MCPS service and requests to send it to the base station during the GTS allocated for this device. The MCPS service handles the timely transmission of this data frame and indicates the result of transmission to the application. The application deletes the sent samples from the sampling buffer just after the frame transmission. The figure.3 describes services and actions involved in data transmission phase. In order to reduce energy and bandwidth consumption, our protocol does not use acknowledgements when sending HRP traffic. This does not decrease transmission reliability since data is sent in GTSs which guarantees exclusive channel access.

C. Fault Tolerance Implementation

In order to implement our fault tolerance mechanism, we have written a handler for the MLME-SYNC-LOSS indication event. This handler starts the

DTN mode in which the application stores all sampled sensor signals on the Micro SD flash memory instead of sending them to the base station. Once the connection established, the device returns to the online mode and resumes wireless data transmission to the base station. When a device stops receiving control messages from the base station, it enters in the DTN mode and stores collected data on the Micro SD flash memory.

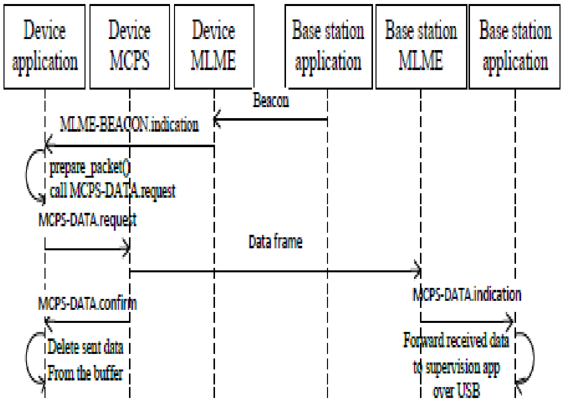

Fig.3 Message sequence chart for data transmission

Performance Evaluation

In order to evaluate our solution, we have conducted intensive real-world experiments and simulations. During real world experiments, motion sensor nodes were worn by a person while performing different tasks (walking, running, seating, writing, swinging the arm) during several hours. This wide range activity levels and session duration are similar to real rehabilitation conditions Figure.4 shows the error rate for the communication protocol which is been obtained during transmission has been plotted in the system manager at real time. In order to investigate the efficiency of our communication protocol, we have computed the average transmission-error rate while varying the network size from one to five nodes and the sensors sampling frequency from 50 to 100, 200 or 400 Hz. During each experience, transmission-error rate was computed from a set of 100000 samples transmission. . We have performed the same experiments using the TinyOS communication protocol defined for the CC2420 chip on [16] to compare our protocol with. For instance, the transmission-error rate is 55% when only three nodes sample their sensors at 400 Hz. Figure.5 shows the prototype model of the supervision process our protocol. We notice that our protocol performance is not impacted by the sampling frequency .

Conclusion

In this paper we have presented the design and the implementation of a new WSN for high-fidelity rehabilitation supervision. This system is a light-weight easy-to-use monitoring system that can be used in-home or within a hospital

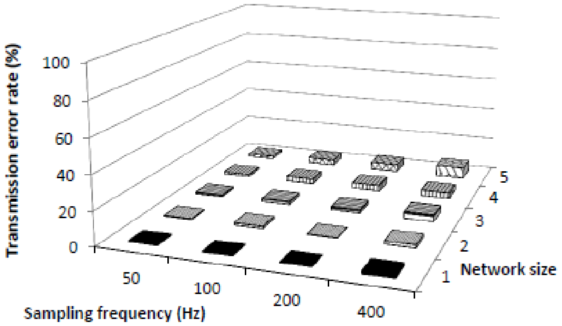

Fig.4 Transmission error rate for communication protocol

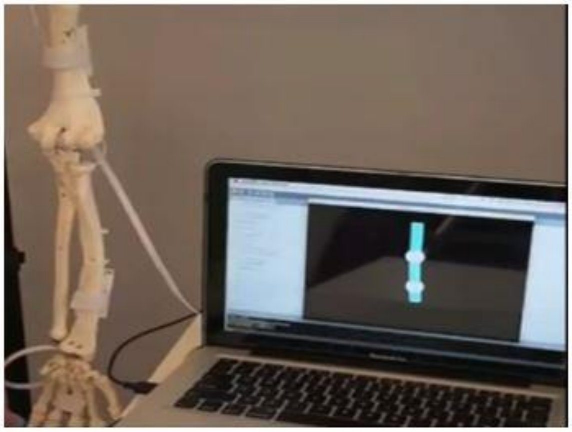

Fig.5 Prototype Model

Contrary to existing WSNs for rehabilitation that we surveyed, our solution has a fault-tolerant, energy-efficient communication protocol that meets the clinical requirements of rehabilitation supervision in terms of data quality and data rate. We have conducted several simulation and real world experimentations that showed the high data delivery ratio of our communication protocol with all tested configurations. Our project is a work in progress and much still remains to be done. In particular, we will replace the laptop by a lightweight PDA. This will bring an important added value to our solution and improve the mobility and flexibility. Also, we plan to conduct more comprehensive tests in cooperation with doctors and physical therapists to provide a better evaluation of our solution. Finally, we need to tackle new challenges in order to incorporate our solution into a complete clinical information system.

References

[1]. G. K. et al., "Effects of augmented exercise therapy time after stroke: A Meta-Analysis," Stroke, vol. 35, no. 11, pp. 2529–2539, Nov. 2004.A Meta-Analysis," Stroke, vol. 35, no. 11, pp. 2529– 2539, Nov. 2004.

[2]. H. Saito, T. Watanabe, and A. Arifin, "Ankle and knee joint angle measurements during gait with wearable sensor system for rehabilitation," in World Congress on Medical Physics and Biomedical Engineering, September 7-12, 2009, Munich, Germany, 2009, p. 506509.

[3]. C. K. Lim, I. Chen, Z. Luo, and S. H. Yeo, "A low cost wearable wireless sensing system for upper limb home rehabilitation," in 2010 IEEE Conference on Robotics, Automation and Mechatronics, Singapore,2010, pp. 1–8.

[4]. M.Schiek, "Distributed intelligent sensor network for neurological rehabilitation research," in 4th European Conference of the International Federation for Medical and Biological Engineering, 2009, pp. 1714–1717.

[5]. M. Schloesser, A. Schnitzer, H. Ying, C. Silex, and M. Schiek, "iSANLA: intelligent sensor and actuator network for life science applications," in 30th EMBS, 2008, pp. 2369–2372.

[6]. T. Liu, Y. Inoue, K. Shibata, and R. Zheng, "Measurement of human lower limb orientations and ground reaction forces using wearable sensor systems," in IEEE/ASME international conference on Advanced intelligent mechatronics, 2007, p. 16.

[7]. H. Zhou, H. Hu, and N. Harris, "Application of wearable inertial sensors in stroke rehabilitation," in 27th EMBS, 2006, pp. 6825–6828.

[8]. K. Lorincz, B. Chen, G. W. Challen, A. R. Chowdhury, S. Patel, P. Bonato, and M. Welsh, "Mercury: A wearable sensor network platform for high-fidelity motion analysis," in Proceedings of the 7th Conference on Embedded Networked Sensor Systems, 2009, pp. 183–196.

[9]. K. Kifayat, P. Fergus, S. Cooper, and M. Merabti, "Body area networks for movement analysis in physiotherapy treatments," in 24th IEEE International Conference on Advanced Information Networking and Applications Workshops, 2010, pp. 866–872.

[10]. M. Zhang and A. A. Sawchuk, "A customizable framework of body area sensor network for rehabilitation," in 2nd International Symposium on Applied Sciences in Biomedical and Communication Technologies, Bratislava, Slovakia, 2009, pp. 1–6.

[11]. M. Hamel, R. Fontaine, and P. Boissy, "In-home telerehabilitation for geriatric patients," Engineering in Medicine and Biology Magazine, IEEE, vol. 27, no. 4, pp. 29–37, 2008.

[12]. M. Soini, J. Nummela, P. Oksa, L. Ukkonen, and L. Syd\nheimo, "Wireless body area network for hip rehabilitation system," Ubiquitous Computing and Communication Journal, vol. 3, p. 7, 2008.

[13]. [Online]. Available: www.thisisant.com

[14]. C. Buratti, "Performance analysis of IEEE 802.15. 4 Beacon-Enabled mode," IEEE Trans. Veh. Technol., vol. 59, no. 4, pp. 2031–2045, 2010.

[15]. C. Buratti and R. Verdone, "Performance analysis of IEEE 802.15. 4non beacon-enabled mode," IEEE Trans. Veh. Technol., vol. 58, no. 7, pp. 3480–3493, 2009.

[16]. TEP 126 : CC2420 Radio Stack, Std. [Online]. Available:http://www.tinyos.net/tinyos-.x/doc/html/tep126.htm.