Ubiquitous Sensor Network-based Rehabilitation Center

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Abstract—This paper discusses the implementation of a rehabilitation center based on a ubiquitous sensor network. This paper discusses the implementation of a rehabilitation center based on a ubiquitous sensor network. We recognize that certain mild conditions requiring rehabilitation may be treated with minimal human supervision. In place of this constant human supervision, a variety of sensors are used to monitor the patient and rehabilitation progress. These sensors send data through a wireless Zigbee network to a server which stores the data and makes it available to a rehabilitation expert for analysis. This rehabilitation expert also issues rehabilitation prescriptions which are created based on the expert's determination of the patient's condition. By having the ability to control the rehabilitation equipment used, strictly enforce the assigned prescription, and constantly monitor the patient for any warning signs, the system ensures a safe and optimal rehabilitation session.

Index Terms—Ubiquitous sensor network, Zigbee, Wireless communication, Rehabilitation.

I. INTRODUCTION

A. Motivation

In this paper we describe a rehabilitation center management system based on ubiquitous network technology. In recent years, there has been a steady increase in sports-related and other injuries which has, in turn, placed greater stress on traditional rehabilitation centers[1]. In this context, a rehabilitation center based on a ubiquitous sensor network offers many advantages.

This rehabilitation center system augments existing rehabilitation machines with sensors that measure work being done at that machine. Sensors are also placed on the patient which are used to measure vital statistics such as heart rate and breathing. All of these sensors are securely connected to a server via an ad-hoc wireless networking system known as Zigbee. At the center of this system is a rehabilitation expert. This individual gives patients 'rehabilitation prescriptions' which the patients then carry out with as little supervision as necessary. Sensors keep track of a patient's rehabilitation session, and when the current prescription is satisfied, a device notifies the patient to stop and directs them to their next session. When a patient finishes their prescription, all data is logged to the server, allowing the rehabilitation expert to analyze the data to find ways of optimizing the patient's rehabilitation. This data may also be output via the internet to other rehabilitation centers or to the patients themselves.

This system has many advantages over traditional rehabilitation centers. Because it accurately measures and logs all pertinent data, it allows experts to keep track of a patient's progress and identify any areas of concern. Patients may also access their own data which empowers them to take a greater role in their rehabilitation. Seeing their session-to-session progress and being able to compare their results to other patients through the internet significantly motivates patients. This data may be accessible from anywhere via a secure website, thus is available to loved ones or other experts. This data may also be transferred to other facilities in the event of patient relocation.

In order to facilitate a safe and optimum rehabilitation session, rehabilitation experts, via prescriptions, have the ability to control machine parameters. Machine parameters may also be adjusted real-time depending on the patient's current condition. This system also allows for off-site rehabilitation with the use of remote sensors with data logging capabilities.

B. Scope

This rehabilitation system supports rehabilitation with minimal supervision as show in in Fig. 1. Therefore, it is most applicable to cases where the patient's condition is not overly severe. Severe cases may still make use of the monitoring features of this system; however they will still require that the patient's rehabilitation session be supervised. Whether supervised or not, collecting detailed and consistent data over the course of a patient's rehabilitation will allow experts to optimize their patient's rehabilitation while decreasing the usage of rehabilitation center resources.

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II. SYSTEM COMPONENTS

A. Rehabilitation Expert

While this system is heavily automated, the human element is essential for ensuring that patients are expertly guided through the rehabilitation process. This system does not attempt to remove rehabilitation experts from the rehabilitation process, but rather empower them with information allowing them to better understand and optimize a patient's rehabilitation regimen. This rehabilitation expert is responsible for determining an appropriate rehabilitation schedule, analyzing data generated by this system, and, if necessary, altering the patient's regimen based on the data collected. This is all accomplished through the 'rehabilitation prescription' system where the expert assigns rehabilitation tasks for the patient to perform using a simple user-interface on the server application. When the patient is ready to start his or her session, the rehabilitation server sends this prescription data to the patient's personal node and configures the appropriate machine with the patient's requirements. The rehabilitation expert has the power to control the time a patient spends at a rehabilitation machine, the resistance or level a machine is to be set at and danger thresholds for vital signs such as heart rate.

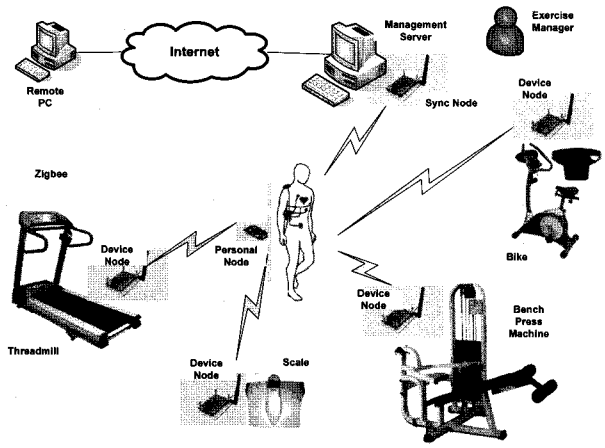

Fig. 1 Overview of USN rehabilitation center

B. Nodes

In the context of this USN-based rehabilitation center, nodes are small Zigbee-based devices that provide an interface with sensors, rehabilitation machines, and the server. They also log the data that they receive and communicate to the patient via light emitting diodes. In this system there are three types of nodes.

1) Personal Note

Each patient carries with them a personal sensor node. This personal sensor node performs a variety of functions that play a role in the patient's rehabilitation. The personal node may be connected to a variety of sensors which measure a patient's vital statistics. These readings are then logged for future analysis. If a patient's vital statistics exceed expected levels, an alarm will sound and the rehabilitation session will be terminated. The personal node is also responsible for receiving the prescription from the server, as well as sending the results of the session back to the server for storage and analysis. Finally, the personal node notifies the patient when a patient completes a rehabilitation prescription.

2) Device Note

Each rehabilitation machine is fitted with a device node. This node interfaces with machines via a serial interface (for computerized machines), or through sensors that track a machine's activity. These sensors log machine activity and send this data to the server via the patient's personal node. The device node does not directly interface with the server.

3) Synch Note

This node is connected to the server and provides the ability to interface with all Personal Nodes in the rehabilitation center. This node receives all rehabilitation data and passes it to the server.

C. Sensor

A variety of sensors may be used with this system. Rehabilitation equipment that is not electronic may be outfitted with magnetic sensors which allow the node to record frequency data as shown in Fig. 2. Sensors may also be attached to the patient to keep track of their vital signs. The most common types of sensor that may be used in this application are sensors that measure breathing and pulse. If other vital statistics need to be monitored, additional sensors may be added to the system with little effort.

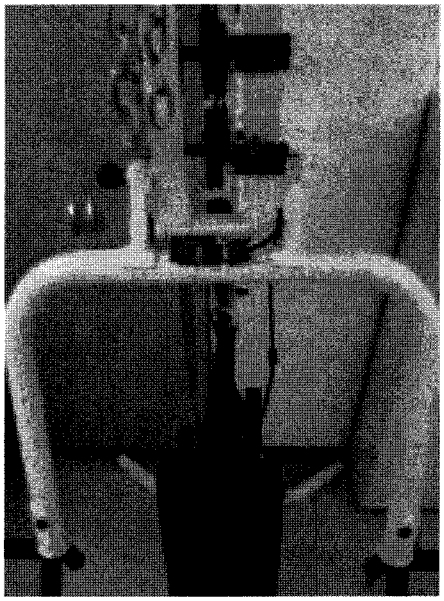

Fig. 2 Rehabilitation weight machine fitted with sensors and Zigbee device node

D. Rehabilitation Center

The types of machines that can be used with this

system vary greatly. If a machine has an electronic interface, such as modern treadmills and exercise bicycles, a device node can be programmed to connect directly to the machine via a RS232C interface. If a machine does not have an electronic interface, magnetic sensors may be fitted to the machine in order to provide the system with time (frequency, repetitions, duration) and effort (weight, resistance) metrics. We have successfully tested a rehabilitation-cycle with an electronic interface as shown in Fig. 3 and Fig. 4, along with a bench press fitted with magnetic sensors.

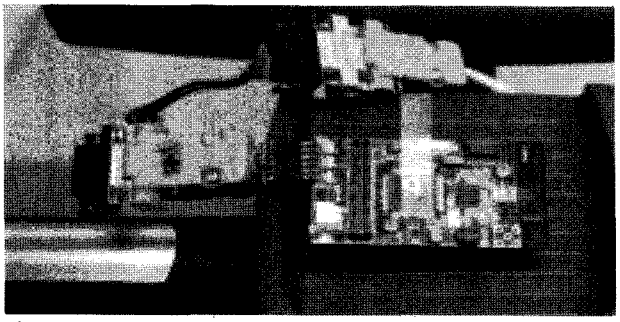

Fig. 3 Zigbee device node connected to a rehabilitation-cycle machine via RS-232C

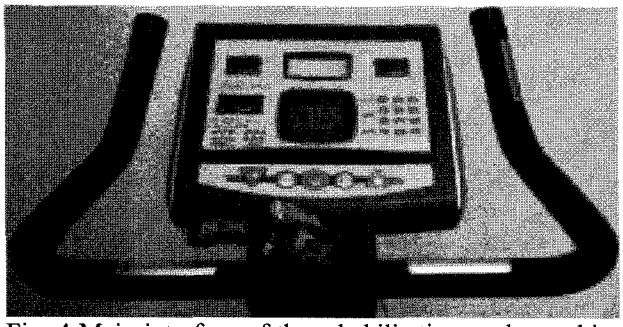

Fig. 4 Main interface of the rehabilitation cycle machine with device node

III. MANAGEMENT SERVER

The management server provides several important functions to the rehabilitation system. The server is the main point of contact for the rehabilitation expert to the system. Through its user interface, the expert can view patient data, update patient information, create rehabilitation prescriptions, and perform user management functions. The server also interfaces with all of the personal nodes in the system. When starting a rehabilitation session, the server uploads the prescription to the patient's personal node. This will then allow the personal node to configure the applicable device node and notify the patient when the prescription has been satisfied. When a patient completes a rehabilitation session, the personal node sends the server all of the data that has been collected. The server uses a MySQL database to store all received data as illustrated in Fig. 5.

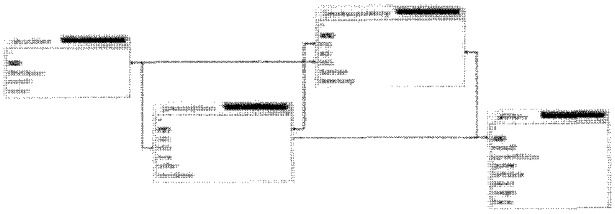

Fig. 5 Database schema

When a patient wishes to begin a rehabilitation session, they must first log-in to the system by providing the server with a username and password. The server then authenticates the patient and assigns the patient a personal node. In order to commence or continue a rehabilitation prescription, the patient must step on a scale that is connected to the server. At this point, the server also records the patient's weight. Fig. 6 shows an example of athlete management view.

A. Website

A major component of this system is the ability to access rehabilitation data remotely via the internet. This will allow the patients to play a role in their rehabilitation. Not only are they able to track their progress, they are also able to compare their results with others using the same system. This gives the patients a competitive spirit which helps greatly with motivation.

Rehabilitation data is stored in a MySQL database. The website is developed with PHP and HTML in order to provide a dynamic and easy to use experience. Given the sensitive nature of rehabilitation data, security is of paramount importance[2,3].

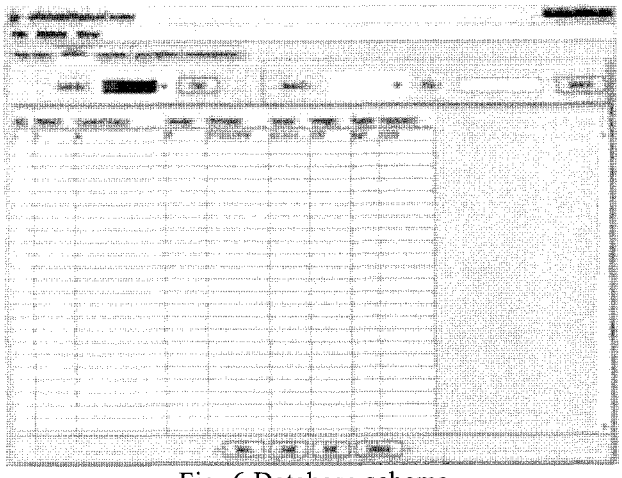

Fig. 6 Database schema

B. Zigbee

Each node incorporates a Zigbee module to provide wireless connectivity and an interface to the sensors. While there are many standards that provide wireless connectivity, Zigbee is the ideal choice for this application[4,5]. Zigbee is an open standard based on IEEE 802.15.4 and incorporates ad-hoc networking/routing, security, low power consumption (up to

years), and is able to interface with many different types of sensors and machines. The main alternatives to Zigbee are Bluetooth and WiFi. Zigbee's range is greater than that of Bluetooth, which only has a 10 meter range. The high bandwidth (and consequently complexity and high power draw) of WiFi are not required for this application.

Zigbee is flexible enough to support the ad/hoc nature of the rehabilitation center where patients log in and out as needed. The 50 meter range that Zigbee supports is more than adequate for the rehabilitation center. Greater ranges can be achieved by using Zigbee modules that act as repeaters. Since Zigbee uses a fully handshaked protocol and incorporates AES-128 security, data transmission is both reliable and secure\cite{http2}. Zigbee is a wireless networking standard that promises to reshape the way many companies create the infrastructures that their business and processes are built on. It will enable reliable, cost-effective, and low-power wireless monitoring and control products based on open standards. The Zigbee specifications are designed to accommodate sensing and control networks with a wide variety of devices, a large number of devices, low active duty cycles, small data packets, and very long battery life. Using frequency ranges of 868 MHz, 902-928 MHz, and the 2.4 GHz band, Zigbee operates at data rates of 20 Kbit/sec to 250 Kbit/sec depending on the band in use. Ranges of 10-100 meters between devices are obtainable, and when multiple devices are joined into a meshed network, the range can be greatly extended through the relaying of packets from one node to another. Unlike networks designed for more static configurations, Zigbee allows devices to join a network very quickly (typically $<$ 30 ms) and supports very quick wakeup data transmission (typically $<$ 15 ms). The ability to form a meshed network allows for multiple paths for data within the network and allows extended coverage far beyond the radio range of a single device. Due to the ad-hoc nature of Zigbee networks, additional routers can be easily added to an existing network without shutting down or restarting to provide new network paths quickly and easily. A few strategically positioned routers can greatly improve the network infrastructure of a Zigbee network and can be easily added at any time.

Security is an important aspect of Zigbee. Wireless networks offer flexibly, but often at the cost of reduced data security. Zigbee supports a variety of security strategies ranging from the IEEE 802.15.4 security for single hop transmissions all the way to Advanced Encryption Standard (AES). The AES standard uses a core encryption algorithm to support confidentially, integrity, and authenticity of transmitted data across the entire network. With security built into Zigbee right from onset, Zigbee helps to ensure that data gets to its intended destination and only its intended destination.

IV. SAMPLE REHABILITATION WORKFLOW

- New patients entering the rehabilitation center must provide some personal details for new user registration. This process is generally performed with the assistance of an administrator.
- A rehabilitation expert performs a diagnosis and assigns treatment in the form of a 'rehabilitation prescription'. This prescription consists of one or more tasks for the patient to perform.
- The patient must then log-in to the system. This is done by selecting their user name and entering a password. The system then assigns the patient a personal node, which the patient must then wear for the duration of the session.
- In order to commence the session, the patient must step on an electronic scale connected to the server. This measures and records the patient's weight and causes the patient's prescription to be sent from the server to the patient's personal node. The patient is then free to proceed to the machine indicated by the personal node.
- When the patient approaches the machine, the personal node programs the machine via its device node with all the applicable setting contained in the prescription. The patient's only requirement is to start using the machine and continue until the prescription is finished.
- When a patient satisfies a prescription, the personal node transfers all collected data back to the server. If there are any further prescriptions assigned to the patient, the next consecutive one will be automatically sent to the personal node. The patient may continue the rehabilitation session at this point.
- When the patients finish their session, they go back to the electronic scale. The scale measures and records their weight, transfers any remaining data from the personal node to the server, and deregisters the personal node so that other patients may use it. The system then automatically logs the patient out of the system.
- The patient and other authorized parties may then review the results of the session though the website.

IV. CONCLOUSIONS

This paper discusses the creation of a rehabilitation center based on ubiquitous sensor network technology. We feel that utilizing this technology greatly benefits both patients and the rehabilitation centers. The data that is generated while a patient is on a rehabilitation program can be used by experts to optimize that patient's treatment, minimizing rehabilitation time and the use of rehabilitation center resources. Sensors also ensure that the treatment is safe by constantly monitoring vital signs while treatment is in progress. Patients can be motivated by comparing their results to others with similar conditions and

being involved in internet support communities facilitated by optional web-access to some of the patient's data. Zigbee is used to facilitate wireless communication and provide an interface to the sensors. A MySQL 5.0 database is used to store patient's rehabilitation data. PHP/HTML were used to create the website and access the data stored in the database. JDK 1.5.0_06 was used to develop the server application.

In the future, we would like to work more closely with rehabilitation experts to further optimize the system and better meet their needs. We would particularly like to incorporate more specialized sensors which may be used for specific conditions. We would also like to develop the website further to provide a more interactive community-based rehabilitation experience.

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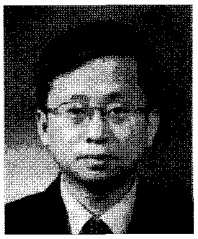

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