Internet-of-Things Management of Medical Chairs and Wheelchairs

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Abstract: In this paper, we describe the application of the technologies of the Internet-of-Things (IoT) to the management of wheelchairs and medical chairs such as geriatric (Geri) chairs or treatment chairs. Specifically, it seeks to monitor the status of high-risk or physically-weakened patients in hospitals or care facilities as they rest on wheelchairs or await treatment on medical chairs with sensor data collected by embedded pressure and motion sensors, and provide real-time alerts to the medical staff. The potential for injuries from high-risk individuals attempting to stand and falling is very serious. The injuries often result in additional complications to the underlying health condition requiring the use of the wheelchair or treatment. The proposed IoT wheelchair and medical chair management system will alert the staff immediately when a susceptible individual stands or attempt to stand, and allow them to take immediate remedial action. The motion data from the network of sensors is further processed by machine learning models which predict occupant intent regarding sit-to-stand transition, providing preventive alerts to the staff. The research consists of two parts. The first part created IoT-connected sensors and devices used to capture the occupant's motion on the chair and send the data to a central server. The second part developed the staff alert application that runs on mobile phones and consoles located in the nurses' stations, that receive the information from the server.

1 INTRODUCTION

In a hospital or care facility, one of the roles of the staff is to ensure the safety of patients as they rest or wait for treatment. Internet of Things (IoT) allows for real-time remote collection and interpretation of data, and immediate feedback of monitored status based on the collected data. In medical applications, IoT enables the collection of medical data of patients in a hospital and the dissemination of the patients' status to the medical staff immediately. This allows the medical staff to assess the condition of those in their care, and take appropriate actions to prevent or mitigate worsening medical conditions or additional complications and injuries.

In this research, we developed a real-time wheelchair and medical chair monitoring system based on IoT-connected pressure and motion sensors. Here, wheelchairs and medical chairs are equipped with IoT pressure and motion sensors that detect whether or not the occupant has moved to a standing position, or is attempting to stand. The devices transmit the data of the motion or change in pressure in real-time to a central server. Computational intelligence based on the sensor data can be provided on the chairs to detect and/or predict occupant status or intent. The server processes and interprets the data, then updates to a mobile application running on the staff's mobile devices, alerting them if a high-risk occupant stands or is attempting to stand. It can also alert the nurses in the nurses' station via a dedicated console, or be integrated into the facility's patient management system.

Further work includes the measurement of the patient's lower body strength during recovery or rehabilitation. Current tests include the 30-second chair stand test (30CST) and 5 times sit-to-stand test (5xSTS) are used to assess lower-body strength (Zhang, 2018). Chairs equipped with pressure sensors and motion sensors will be able to capture the dynamic weight distribution and motion of the seat as the patients perform the test, and provide more data regarding the area of performance improvement and strengthening.

2 SIT-TO-STAND EVENT MANAGEMENT

The elderly population, patients who are physically weakened due to medical conditions, and patients whose medication impairs physical control are

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particularly susceptible to falls in injury. This is especially problematic when individuals move from a sitting position to a standing position (Pozaic, 2016). In addition, patients with cognitive and memory impairment may attempt to stand and leave while resting in a sitting position, risking both falls and becoming lost by wandering. Our project aims to solve these issues by introducing a monitoring system designed to supervise the movement of those occupants while sitting in a wheelchair, geriatric (Geri) chair, or other treatment chairs. This allows the care staff the ability to react promptly and take appropriate remedial actions to the high-risk individual standing or attempting to stand. The idea of putting Geri chair alarms to alert nurses and care staff of occupant movement has been implemented before in existing products (alzstore.com). In previous works, chair alarms have been employed to signal occupants leaving the chair with a co-located, integrated alarm. These chair alarms consist of a chord attached to an occupant's clothing. If an occupant stands, the cord pulls out a magnetic contact sensor which produces an audible alarm, alerting the caregivers of the situation. A pressure-sensitive pad that rests on the seating area of the chair has also been developed to sound an audible alarm if the occupant stands, reducing the pressure on the pad.

However, in a hospital or care facility, this is likely to disturb the other individuals in the vicinity of the alarm. For our project, we aim to remove the audio aspect of these alarms. By enabling the sensors to send notifications to the staff via an IoT network the disturbance created by the audio alarm is eliminated. The staff must be alerted in case of an alarm whenever they are on duty. Therefore, this system sends alerts directly to the mobile phones of the on-duty medical or care staff.

In our previous work, we integrated a pressure sensor to hospital beds with IoT to alert nurses when a bed-rest patient vacates their bed and risking falls and injuries (Yeh, 2021). Another work incorporates gesture recognition of data from a sensor array mounted on patient chairs that provide an audio alarm to the staff and PC notification (Knight, 2008).

3 COMPONENTS

The embedded IoT medical system consists of the following elements:

1) Network of pressure sensors and motion sensors suitable for wheelchair or medical chair use;
2) Internet-capable processing devices co-located and connected to the chair absence sensors, which collect, interpret, and transmit the sensor data
3) An algorithm or set of algorithms, running on the processing device and/or server, to determine if the occupant has stood up or is in the process of standing up. The algorithms can also include machine learning models for occupant intention-to-stand prediction
4) A WiFi, 5G, or other suitable and secure network accessible from inside the facility or environment
5) A data collection server that receives the chair status data for the facility or the sector of the facility which it is monitoring
6) Mobile devices or cellular phones that is normally carried by the staff during their shift, running the mobile application that displays the status of the chairs that the staff is attending to or responsible for

3.1 Sensors

Pressure sensors such as pressure pads are commercially available and easy to obtain. These devices sense pressure through the distribution of the occupant weight among the pad and sensors. In this system, the pressure pad is connected to a Wi-Fi module. The purpose of the module is to read real-time occupant data from the sensors and relay the information to the data analysis server.

Also, motion sensors or accelerometers are readily available to measure the movement on the chair. Here, occupant motion can be monitored to determine if a sit-to-stand event is occurring. In addition, the accelerometer may be able to determine the quality of rest that the occupant is experiencing. We would like to emphasize that the accelerometer is to be mounted on the chair, and not worn on the wrist of the patient/user. This minimizes patient discomfort and the workload on the care staff by reducing bodily attachments, as the patient may already have various monitoring devices and intravenous tubes attached to their bodies.

In addition to pressure and motion sensors, it is also possible to utilize other sensing technology to assist in the monitoring of wheelchairs or medical chairs. Heat sensors can also be deployed on the chair to monitor the temperature of the chair as the occupant is sitting on the chair. This temperature will not be an accurate reading of the occupant's body temperature, due to the lack of direct contact between the sensor and the occupant's body (shielded by gown, sheets, etc.). However, it does provide a relative difference in temperature when the occupant is on the chair versus not on the chair.

3.2 Microcontroller

The sensors will be connected via a suitable interface to a computing device (microcontroller). Depending on the computing and power requirements, the microcontroller can also perform computation on the collected data. For example, if the algorithm is simple enough for the sensing modality, the microcontroller would be able to directly determine if a sit-to-stand transition has occurred.

The microcontroller must be equipped with networking capabilities, preferably wireless, which will be used to transmit the collected data to a server. Ideally, the microcontroller will be powered via an AC power adaptor. This provides a constant source of power delivered by the facility. Since many treatment chairs are typically already powered, using AC power should be an option in a hospital environment. However, for wheelchairs AC power is usually not available because of their mobility, and rechargeable batteries must be deployed. Even if AC power is available, rechargeable batteries may be advantageous to provide backup power to the microcontroller and sensing devices in case of a power failure.

3.3 Algorithm and Machine Learning

From the data collected by the sensors, one or more algorithms are used to determine the status of the occupant on the chair. Several types of algorithms can be developed and deployed in the system, and can be dynamically changed in response to clinical or patient requirements. The proposed algorithm types are as follows:

1) Simple chair vacancy algorithm
   Determines whether the person has left the chair
2) Sit-to-stand transition algorithm
   Determine in real-time what stage of the sit-to-stand transition is being executed, from fully seated, to weight shifting, to weight transfer, to fully standing.
   It will also determine if a sit-to-stand attempt has failed.
3) Predictive sit-to-stand algorithm
   Predicts from the movement on the sensors the probability that the person is intending or begins to attempt to stand
4) Lower body strength algorithm
   Measures the dynamic movement of the patient as they perform sit-to-stand transitions, and determines rehabilitation progress and relative strength and weakness during stages of movement

With a pressure pad under the seating area, the algorithm to determine if the occupant has vacated the chair is relatively simple to implement a type 1 algorithm. Either a lower threshold pressure level has been crossed, or a sudden decrease in pressure level can be used to trigger an alert. With additional pressure sensors, located on the four corners of the seat, the weight distribution of the person can be measured, allowing dynamic measurement of the person's motion to implement a type 2 algorithm. This can be further enhanced by motion sensors situated around the chair to implement type 3 or 4 algorithms.

Simple algorithms such as types 1 and 2 that do not require much computing power can be implemented directly in the microcontroller. This would lower the data transmission on the requirements on the network, and reduce the computation load on the server. The microcontroller can simply transmit the computed state of the person.

For more complex algorithms, if the microcontroller lacks the necessary processing power, it can simply transmit the received data to the server for execution. However, with the capabilities of modern microcontrollers, we expect more types of algorithms to be executable locally on the chair.

We are planning the use of machine learning models to predict the individual's sit-to-stand intention from the motion collected from the sensor network. It is possible to use supervised learning to train the model, with the researchers labeling the intention of the seated individual prior to a sit-to-stand event or no transition event. However, because the time series data before an actual sit-to-stand event is captured, this data can be used for unsupervised learning, dramatically lowering the training cost of the human labeling process. Although the training will be done on the server, the pre-trained machine learning model can potentially run on the microcontroller.

3.4 Network

The hospital or care facility must provide a network that the microcontrollers deployed on the chairs can connect to. WiFi is the most prevalent wireless networking system deployed in most modern environments. The network must provide adequate security against data interception and data breaches, and WiFi provides this capability. It must be highly reliable (transmitted data is not lost or corrupted) and have low latency (transmitted data is received immediately). Bandwidth requirements are low for the IoT chairs, as only a small amount of data is transmitted per second per chair.

Other data networking systems may be used, provided that the facility or environment possesses such a system or is willing to invest in such a system, and the system provides the necessary security. Wireless systems include 5G cellular networks. Wired systems that can be considered are ethernet, powerline communication, coaxial, or telephone networking.

3.5 Server

The role of the central server is to receive the data sent by the microcontroller from sensors attached to the IoT chairs. When a microcontroller or algorithm running the server determines/predicts a sit-to-stand event, it will send an alert to the mobile device or cell phone carried by the responsible caretaker and/or the console at the nurses' station.

It is often the case that there are multiple nurses or care staff in the facility, each attending to a set of chairs, some with high-risk or physically-weakened individuals, and some without.

The configuration of the assignment of the chairs to each caretaker must be simple and straightforward. Also, the chair alert must be able to be turned on or off for each chair depending on whether a high-risk individual has been placed on the chair, and if the occupant has been removed from the chair (by the staff) for reasons such as return to bed or treatment sessions.

3.6 Mobile Devices and Mobile Application

The mobile application that notifies and alerts the responsible nurses or care staff of sit-to-stand transition will run on a mobile device that the staff member carries. For caretakers with facility-issued or personal mobile phones that they carry on their persons during their shift, the mobile application can be installed and provisioned on these devices by the IT staff. Dedicated devices can also be developed that connect to the facility's network and alert the caretakers of risky sit-to-stand events.

As a high-risk or physically-weakened individual is placed on a particular IoT chair, the nurse will be able to scan a barcode or QR code, or connect via Bluetooth or RFID, and turn on the alert for that chair. Similarly, the alert is turned off for the chair prior to when the occupant is removed from the chair.

The facility management or IT staff will be able to assign the set of chairs to each particular mobile device/caretaker from the central server, or on the mobile devices.

The mobile device can provide alerts in the form of (1) visible notification on the screen, (2) vibration of the device, and/or (3) one-time or periodic audible beep or alarm.

4 INITIAL SYSTEM

For the initial presence sensing system development, we created a test system from the following components.

The microcontroller was chosen to be the ESP32 because it is powerful, low cost, and, most importantly, has integrated WiFi capabilities (espressive.com). It is compatible with the Arduino Integrated Development Environment, a widely used open-source development system that uses the C++ coding language, making it simple for programming and updating. The ESP32 platform features a built-in dual-core CPU with WiFi connectivity, a wide operating temperature range from -40°C to 125°C. This development board is low-cost and usually operates at 160MHz with 4MB of flash memory and 8MB of PSRAM.

WiFi networks are ubiquitous and secured with WPA2 (IEEE, 2016). The IoT devices will be connected over a 2.4GHz WiFi band because it is more secure and has a longer range compared to the 5.0GHz band.

For this initial development, we chose the Blynk cloud-based server. Blynk is an IoT platform that allows machine learning and data analytics on mobile apps and runs over the HTTPS API. Blynk (blynk.io) operates with the concept of a virtual pin, which enables data to be exchanged from a device to the server easily via the cloud.

Similarly, we used the commercially available Blynk application for the application that runs on mobile devices. It operates on both iOS and Android. The Blynk mobile application uses a drag-and-drop interface, allowing for a simple and user-friendly design.

We are investigating and building the different types of algorithms that will process the sensor data. We are building the machine learning models using TensorFlow (Abadi, 2016), and are investigating the use of TensorFlow Lite Micro (David, 2020) to run the pre-training model on the ESP32.

For future development, we plan to migrate to more secure and robust servers and mobile devices. Cloud-based servers include Amazon Web Services (Amazon 2015), Google Cloud (Gonzales, 2015), and Microsoft Azure (Copeland, 2015). Also, a variety of software solutions exist if the facility plans to host the servers in-house.

The React Native environment is being planned for the development of the mobile application. It supports both the Android and iOS operating systems. React Native (facebook.github.io) is built on JavaScript while rendering in the platform's native user interface, enabling cross-platform sharing of code from a single codebase.

Figure 1 shows the screenshot of the chair management mobile application on the iOS environment. Here, alerts for Chair 1 and Chair 4 are active. Chair 2 and Chair 3 are turned off because no high-risk individuals are occupying the chairs. Chair 1 is showing green, meaning the occupant is in the chair. Chair 4 is showing red, meaning the occupant has stood up and an alarm is raised.

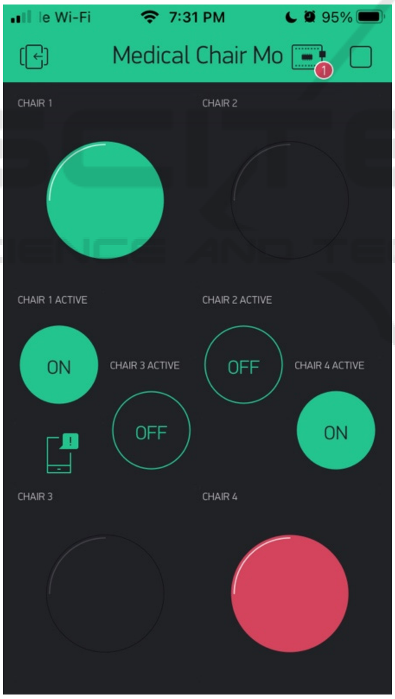

Figure 1: Alarms; Chair alert on/off.

Figure 2 shows the screenshot of the mobile notification alert in real-time as the occupant on Chair 4 stands up.

Figure 3 shows the screenshot of the alert on the lock screen of the iOS device in real-time as the occupant on Chair 4 stands up.

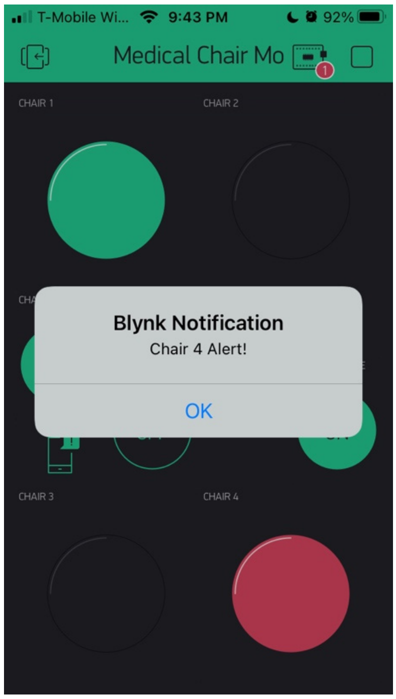

Figure 2: Notification on the application screen.

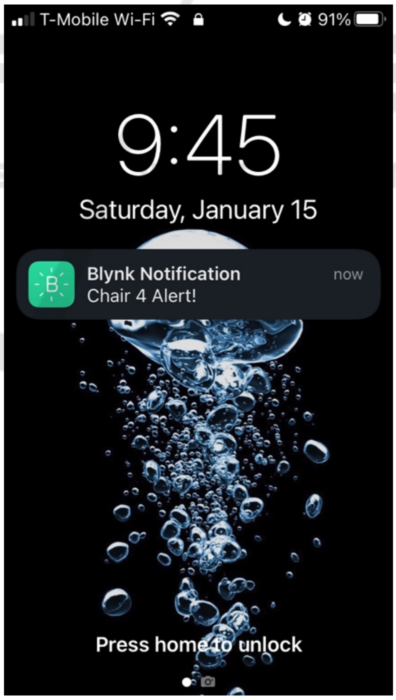

Figure 3: Notification on the lock screen.

Figure 4 shows a commercially available pressure sensing pad (nationalcallsystems.com) used to monitor occupant presence on the chair.

Figure 5 shows a semiconductor motion sensor (InvenSense MPU-6050 accelerometer + gyroscope) (InvenSense, 2020) module and a strain gauge weight sensor (sparkfun.com).

Figure 4: Pressure sensing pad.

Figure 5: Motion and weight sensor modules.

5 CONCLUSION AND FUTURE WORK

We have created a novel IoT-based wheelchair and medical chair management system that uses integrated sensors (pressure and motion sensors), WIFI-connected microcontrollers, algorithms, cloud-based servers, and mobile applications. This alerts the nurses and care staff immediately of sit-to-stand events that may lead to falls and serious injuries, and take mitigating actions to prevent such injuries and complications.

We propose the integration of additional sensors and algorithms to the medical chairs that enable the dynamic assessment of patient rehabilitation and recovery in each phase of the sit-to-stand transition, and identify areas of strengthening and weakening.

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