Supporting rehabilitation prescription compliance with an IoT-augmented four-legged walker

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Abstract

Four legged walkers enable mobility for elderly people, and can be an important component for rehabilitation after trauma. At the same time, the benefits of using a walker are contingent on its correct use, that sometimes requires some effort from the patient. Incorrect use might delay rehabilitation and can even lead to accidents and injuries. In this paper we present the hardware and software design for a IoT-augmented walker with features specifically targeted towards improving compliance with prescriptions for rehabilitation. The software of the walker autonomously processes sensor readings, identifies problems with prescription following and detects dangerous situations. The walker can provide feedback to the user helping with prescription conformance and alerts him/her for danger. The software agent also logs the data to a central database for later processing. Experiments with a prototype show that the walker can help the user comply better with the prescription.

1 Introduction

More than 1.5 million people in the United States use four legged walkers. Older adults use them on a long-term basis to assist with activities of daily living. Walkers are also prescribed as part of the rehabilitation treatment after trauma, to allow patients to re-acquire mobility.

Walkers provide two distinct benefits, concerning weight bearing and balance, respectively. By using the walker, the patient can decrease the weight bearing on one or both legs, alleviating pain from injury (such as leg or hip fracture) or from chronic conditions such as arthritis. Walkers can also help in the case of weakness or loss of control of lower limbs, such as in certain strokes.

A different benefit of walkers is concerning the balance of the patient: by extending the base of support to the area that includes the rectangle delineated by the four legs, the walker can help with conditions involving poor balance control.

The use of walkers, however, also presents challenges and creates risks. For instance, it is known that there is a relationship between the use of mobility aids like walkers and increased risk of falling and related injuries. At least some of these risks are caused by the improper use of the walkers, such as asymmetric loading of the walker legs, taking steps that are too long or not ensuring the stability of the walker before using it as a support. Another risk associated with the use of walkers for rehabilitation after a trauma is that the patient can use the walker to achieve mobility without exercising the injured foot, delaying the rehabilitation.

Physiotherapists instruct the patients in the correct use of the walker. For purposes of rehabilitation, they also specify the relative weight distribution the patient should apply to the legs. However, they cannot keep the patient under constant surveillance, and patients often do not follow these instructions on a day-by-day basis. For more complex instructions involving relative weight distributions, the muscle memory and self-examination ability of patients is unreliable with regards to relative force levels to be applied to the legs of walker.

In this paper we describe an Internet-of-Things (IoT) augmented walker that collected and analizes data from weight and proxity sensors to provide the user with feedback to help with prescription compliance.

2 Related Work

A walker or a wheeled walker is often used as an aid to promote activity and improve balance and mobility of elderly people [Bateni and Maki, 2005; Salminen *et al.*, 2009] or in the recovery phase for after stroke or injuries [Graafmans *et al.*, 2003]. Several research projects aimed to develop technologically augmented "smart" walkers for applications such as guidance and health monitoring [Dubowsky *et al.*, 2000; Schraft *et al.*, 1998; Lacey and Dawson-Howe, 1998; Chuy *et al.*, 2005].

Applications which allow remote monitoring by collected data of physical rehabilitation sessions are useful, because by analyzing them, they can contribute dramatically to improve the life quality of patients [Postolache *et al.*, 2015]. Furthermore, they can provide instant feedback by monitoring unbalance and instability conditions. In order to have such applications we need different kind of sensors to gather information from the environment. Interface pressure sensing technologies and force sensing resistors are the most promising sensing technologies in the field of physiotherapy treatments.

[Martins *et al.*, 2012] proposed an augmented four wheeled walker design that lets the user control and move the walker through a joystick interface. The project aimed both to provide an easy to use interface as well as the means to collect data and provide feedback to the medical staff.

[Postolache *et al.*, 2011] developed a smart walker architecture based on a 24GHz FMCW Doppler radar, a MEMS accelerometer, piezoresistive force sensors augmented with a Bluetooth communication module. In contrast to our work, the system used two sensors embedded in the handles rather than in the four legs of the walker. Also, the system was not designed to give instant feedback to the patient but to provide the physiotherapist with the information about the progress of the patient.

[Wang *et al.*, 2014] presents a wheeled walker (rollator) equipped with encoders and inertial sensors, used for gait analysis and health monitoring. By using motion capture encoders and a 3D accelerometer/gyrometer the device enables the experimenter to calculate gait parameters and obtain trajectories of the user, and then compare it with a reference trajectory obtained in a training session. By requiring the user to be tagged with motion detect dots to allow full body motion capture, this is targeted towards laboratory settings. In contrast with this work, we designed a legged rather than wheeled walker, and we are targeting the home use by the patient rather than a laboratory setting.

In this paper we propose a walker design with a simple user interface that gives visual feedback to the user based on the physiotherapist's prescription and is able to collect data either by itself without connecting to a server or based on a server-client architecture.

3 Hardware and software implementation of the IoT augmented walker

The IoT-augmented walker starts with an off-the-shelf four-legged walker that had been augmented with sensors, computing devices and user interface components. Other than a slight increase in weight, there is no change in the functionality of the walker.

The weight distribution applied to the four legs of the walker is captured by 4 pressure sensors, each connected to a HX711 breakout board. The proximity of the user to the sensor is measured using the VL53L0X time-of-flight laster ranging module. Finally, orientation data is provided by the Adafruit BNO005 absolute orientation sensor which combines a MEMS accelerometer, magnetometer and gyroscope on a single die with an ARM Cortex-M0 processor.

The sensor data is collected by a Raspberry Pi-based main computer housed in a custom 3D-printed housing. The top of the box serves as a display that provides feedback to the patient using the device. The computer can connect to available WiFi networks for real-time data upload (this is not necessary for normal operation). The physiotherapist can configure the device for the device either through WiFi or through a keyboard attached to the USB port. The patient does not need to perform any other interaction with the device except turning it on and off, and recharging the battery with a standard charger. Our tests suggest that while the software is running the battery holds its charge for 12+ hours.

The software running on the IoT-augmented walker must perform several distinct functions. In the background, it initializes the sensors, and continuously collects data from them, performs initial filtering, stores and (if required) uploads it to a centralized web service. The web service is running on a dedicated server or the cloud and is implemented using the Django Python-based web framework. This functionality is performed in the background and does not require user interaction.

The user interacts with the IoT-augmented walker through a simple visual user interface that provides continuous real-time feedback to the user about whether it is using the walker correctly and whether it follows the prescription. The design objective of this interface was to keep the visual look simple to avoid additional cognitive load. The user should be to determine with a single glance whether it is following the prescription and the necessary corrective action. The user interface is built on top of the Kivy library, often used to implement simple games on various platforms.

The user interface contains no text elements, and uses only graphical representations and color to describe the state of the walker (Figure 2, top). The colored progress bar on the left side of the screen illustrate the distance of the user from the walker, as measured by the proximity sensor. The progress bar varies in the normal (green) range during the normal use of the walker. The bars turn red when the user gets too close or too far from the walker, which might be an indication that the user is taking steps that are too long.

The middle and right part of the display is occupied by four circular, dynamic graphs that correspond to the current weight and the prescription weight load on the corresponding legs of the walker. The green disks represent the desired weight which is set by the physiotherapist. These change only over the span of days or weeks tracking the progress of rehabilitation. The red circles change their size function of the weight applied to each leg. When the patient raised the walker to make a step, these circles shrink to zero, and they expand again when the walker is placed on the floor and the patient applies weight to them to step closer. The walker is used correctly if the measurement of the maximum weight point matches the target red circles. Depending on the type of the trauma, the patient is recovering from, these weights might be asymmetrical.

The same display is used to warn the user of a dangerous situation. To present a stable support, the walker needs to have all four legs on the ground before load is being applied. If the sensor processing detects that load is increasing only on 3 or 2 legs, the display turns the indicator for the leg which is not on the ground red, and also warns the user with a vibration signal.

4 Experiments

There can be many reasons why a user might not follow the prescription: forgetting, inconvenience, lack of trust in the efficiency of the prescription and so on. However, for a prescription including the specific use of a walker, we conjecture that a significant factor might be the fact that the prescription relies on the muscle memory of the user, maybe coupled with the verbal or textual instructions of the physiotherapist.

Figure 1: The IoT augmented walker from the point of view of the user (left) and a close-up of the screen (right). The user is applying more weight to the left side of the walker.

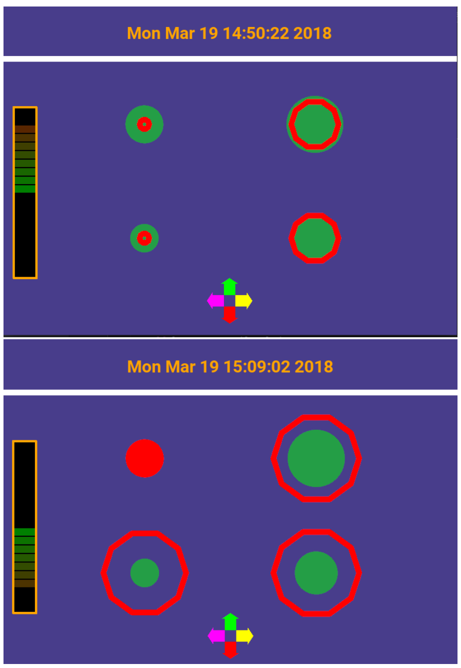

Figure 2: The user interface of the IoT-augmented walker. Top: the user is too close to the walker, the load on the right side is approximately correct, but it is too low on the left size. Bottom: dangerous situation, the left forward leg is dangling in the air, while the other three legs are loaded.

The hypothesis we aim to verify is as follows: the muscle memory of the walker user is not sufficient to follow the prescription to a sufficient precision, and the feedback from the proposed user interface can significantly improve conformance to the prescription.

For these preliminary experiments we used a healthy subject, one of the co-authors of the paper. (More extensive experiments will be performed on future iterations of the walker on the target population of patients). The experimental procedure extended over two days. In the first day, the subject familiarized himself with the operation of the UI, was presented with the prescription and given the opportunity to practice it. The prescription involved a requirement involving an asymmetric load on the walker - such prescriptions are typically given for situations where the walker is used to rehabilitation after trauma or surgery. The requirement was that the subject should apply 1.5 times more pressure on right side of the walker compared with the left side and 1.3 times more pressure on front legs compared to the rear legs.

On the second day, the subject was tested on the ability to conform to the prescription. The subject was directed to traverse a trajectory in the lab twice: first time with the user interface covered, while second time with the user interface visible to the subject. In both cases, the sensors and computer of the walker were active and recording the weight trajectories. As the subject was aware that compliance is tested and was reminded of the prescription, this experiment only measures the difference provided by the user interface.

Figure 3 shows the collected results, together with the prescription target. An ideal behavior represents one where the maximum load represented by the locations where the step shape bottoms out is aligned to the target values.

The left side of the graph shows the user trying to follow the prescription based on his muscle memory and the remembered verbal instructions. Indeed, the graph confirms that the user does try to follow the prescription, for instance by putting more weight on the right side than on the left. However, the actual weight distribution is erratic - this is especially visible on the front and rear left leg. Furthermore, there is a systematic bias - while the user was asked to put 1.3 times more pressure to the front legs versus the rear, the actual measured values are often more than 5 times larger. On the right side plots, recorded with the user interface feedback visible to the user, the prescription was followed more closely (although occasional spikes of weight load still exits).

5 Conclusions

In this paper we described the design of an IoT-augmented four-legged walker that can provide feedback to the user about the current and prescribed weight distribution. Preliminary experiments show that even healthy users in optimal situations have difficulty complying with the prescription and the feedback offered by the walker can help with prescription compliance. Nevertheless, future work is necessary to validate these findings on larger populations of patients and over

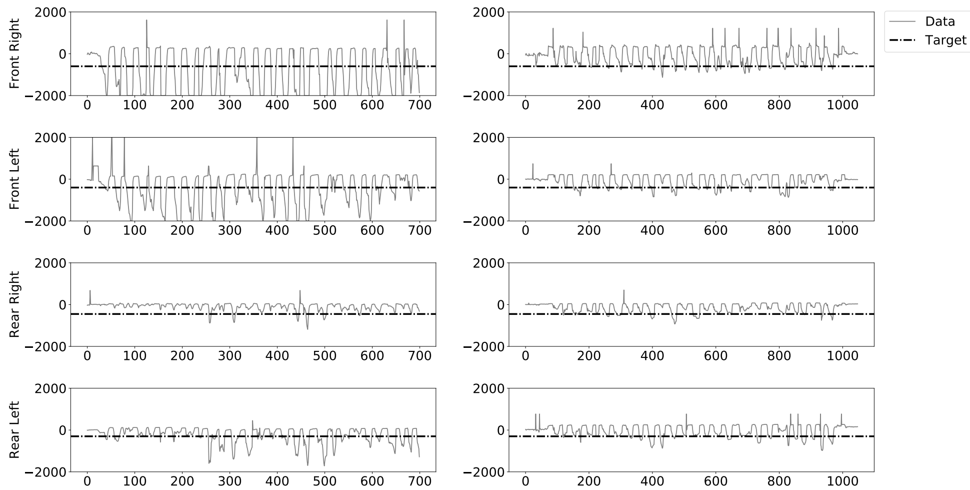

Figure 3: Filtered results of second-day compliance with the weight distribution prescription without the user interface feedback (left) and with the user interface feedback (right).

longer periods of time. We are also working on improved user interaction techniques that can reduce the cognitive load and minimize distraction required by the weight distribution compliance.

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