Low-Cost Accelerometry-Based Posture Monitoring System for Stroke Survivors

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ABSTRACT
This paper reports a low-cost autonomous wearable accelerometry-based posture monitoring system for stroke survivors. The hardware part of the system consists of monitoring devices, each of which comprises of a three-axial accelerometer and a beeper, LED light and vibrator to provide redundant modes of inappropriate posture warnings that would hopefully trigger self-correction. The inappropriate posture data are stored in an EEPROM. The software part of the system downloads, analyzes and presents the data in graphical format to enable a carer or therapist to quickly glance at the durations, frequency and locations of inappropriate postures.

Categories and Subject Descriptors
B.4.2 [**Input/Output and Data Communications**]: Input/Output Devices – *channels and controllers*

General Terms
Design, Human Factors.

Keywords
Stroke, accelerometer, physiotherapy, rehabilitation

1. INTRODUCTION
Stroke patients are believed to benefit from good posture yet they can spend long periods in inappropriate positions, most commonly slouching and letting the arm to free fall [1]. Unfortunately these inappropriate positions can go undetected for long, which can bear some severe consequence, ranging from lengthening recovery period to further physical injury. In a study of stroke aftercare by nurses, it was found that deliberate adjustment of patients' position by nurses was a rare event as they are busy and there is little warning that the nurses can attend to [1]. This opens an opportunity for autonomous posture monitoring. The assessment of posture and movement has greatly benefited from the advancements in sensor technology, miniaturization and signal analysis. Conventional autonomous methods include wrist-worn actometers, tilt-switch transducers, mechanical pedometers, etc [2].

Single- and multi-channel accelerometry with calibrated sensors is another promising technology, especially due to the low cost and wide availability of the components. In such system, postures and patterns of movement became the basis of the evaluation of behaviors, symptoms and physiological changes. Accelerometers had been used for ambulatory monitoring [2] and assessment of gait, stability and movement disorders [3]. However, no published work had been found on the use for posture monitoring in stroke survivors with physical impairment.

This paper reports a low-cost (this prototype costs around $100 for the whole system, with the cost expected to go down exponentially with mass production) wearable device that detects inappropriate postures in stroke survivors. Even though the device can theoretically detect inappropriate postures in any persons, we focus on stroke rehabilitation as this has not been explored widely and maintaining good postures in early stroke rehabilitation seems to hold the key to full recovery [1]. In addition, there are some inappropriate postures that are specific to stroke survivors, such as pusher syndrome (a clinical disorder following left or right brain damage in which patients actively push away from the nonhemiparetic side, leading to a loss of postural balance) [4], and therefore, in this work, we focus on more general inappropriate postures as well as those postures.

2. DESIGN
The system consists of hardware and software components. The hardware component consists of ten monitoring devices. Each of these devices consists of a three-axial accelerometer to sense orientation (by detecting the pull of gravity against the sensor), a beeper (to produce warning sound when an inappropriate posture is detected), a red/green LED (the green indicates that the device has been calibrated properly and the wearer is in the 'correct' position – the LED turns red when an inappropriate posture is detected) and a vibrating motor – similar to the one used in cell phones. These three modes of warnings provide redundancy, which increase the chance of the inappropriate postures to be detected by the wearer (and therefore will hopefully trigger self-correction), especially when the wearer has sensory impairment that prevents effective registering of warning information in one form, a likely scenario for many stroke survivors.

The ten monitoring devices are placed above each knee; on each shoulder; on the top of each wrist with an extension placed on the back of the hand (this extension does not contain any LED, beeper or vibrating motor); on the back (halfway between the neck and the waistline); and on the back of the head.

All of the monitoring devices are wired to a main board that is worn in a waist-pack. This main board contains the batteries, a microprocessor, interface Integrated Circuits (ICs), a real-time clock, and non-volatile EEPROM for logging posture violation

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events. It also contains a port for In-System Programming, so the program on the microprocessor can both be initially programmed and later upgraded as needed. Finally, this main board contains an RS-232 serial communication port to allow the unit to be connected to a computer for downloading the Event Log, setting the time, and most importantly, programming the criteria for what constitute posture violations that the wearer needs to be aware of.

The microcontroller to PC interface deals with sending and receiving information via the RS-232. The interface consists of basic commands that can be used by system testers to see if the device is working properly, such as data dumping mode.

The last component of the system is the interface for use by physical therapists with minimal programming experience, and therefore this interface is GUI-based. The interface consists of:

2.1 Calibration screen

During calibration, the therapist asks the patient to wear the monitoring devices and to go through daily motions (sitting, walking, standing, etc.). During these motions, the values from the accelerometers are saved in a lookup table, which mainly consist of the ranges of good postures. The calibration screen offers the following options:

- Save to device: Save the values for the selected posture to the main board.
- Reset: Erase settings for the selected posture from the main board.
- Save to file: Save the current configuration to a file.
- Import configuration from file: Import a configuration from a pre-existing file, which can then be modified, saved to the main board, etc.
- Import configuration from device: Get the current configuration from the device.

2.2 Monitor screen

Even though the main aim of the device is to autonomously detect bad posture and warn the wearer of such event, there might be occasions where healthcare intervention might be required. Therefore, the system is equipped with monitoring mode. The monitor screen enables the physician to view the logs stored in the device. Each violation can be replayed by the therapist as a movie. Information is summarized using various plots. The monitor screen offers the following options:

- Play: The therapist can select a date, and the log of a violation on that date to replay. Whenever there is a violation on a particular location, this point on the outline image of a human body flashes red throughout the duration of the violation. Figure 1 shows an example of this function.
- Save logs to file: The logs from the devices can be exported to a file as part of a patient's record and for later retrieval.
- Import logs from file: A previous log file from a patient's records can also be imported for monitoring purposes.
- Detailed reports: Currently the following statistics are reported: the number of violations per day, percentage of posture mode per day (e.g. 10% standing, 35% sitting, 20% walking, 35% lying down etc.), the number of violations per posture (i.e. which posture was violated how many times), number of violations per location etc.

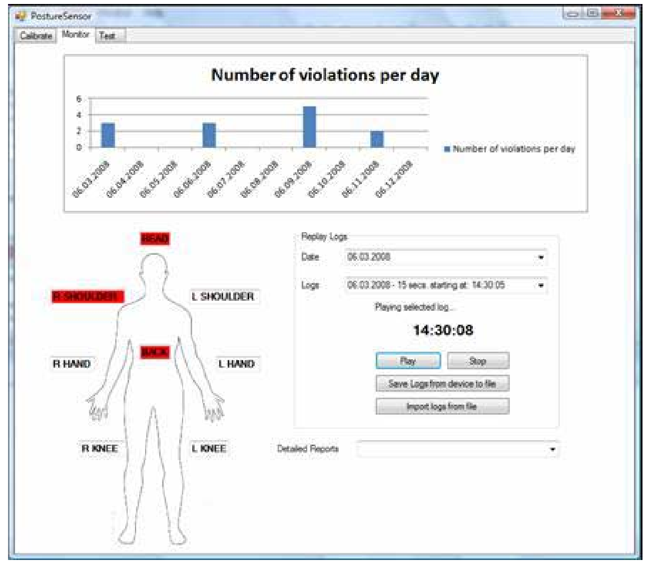

Figure 1. Example of the play function

2.3 Test Screen

The test screen is used for testing the device in real-time. Raw data (acceleration in x, y, z coordinates) from all sensors is displayed in real time. This screen can also be used to test if the devices deduce the current posture mode and detect violations correctly.

3. DEVICE TESTING

As a proof of concept that the system works, it was tested with two healthy older persons, who were asked to wear the system for 6 hours. The device was able to detect bad postures that were above the threshold set time. The two participants stated that they were satisfied with the device and that the device has some use in correcting their postures. However, they complained that the beeper that sounded when bad postures were detected was annoying (which was the aim of this device, and therefore no modification was done even though complaint was registered). When the sound was muted and warning was delivered through vibration, there were occasions that the participants did not feel it.

In summary, this system seems to be able to function as bad posture detector. However, a properly designed user experiment with stroke survivors is needed to verify the usefulness of this system.

4. REFERENCES

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