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Smart Rollator Prototype

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Abstract *– An overview of the Smart Rollator prototype is presented in this paper. The Smart Rollator utilizes an ambulatory assistive device, namely a rollator, to provide a non-obtrusive monitoring system. With the aging population, the need for technologies that support independent living, and assist in maintaining the health and well-being of older adults is growing. The Smart Rollator prototype consists of a number of subsystems including: distance/speed monitoring, tri-axial acceleration monitoring, force monitoring, seat usage monitoring, and physiological monitoring. Data are transmitted wirelessly through a local data terminal to a remote server. Using remote data terminals various people can view and perform analyses on these data (e.g. rollator user, family members, health care professionals). The Smart Rollator is intended to improve the utility of conventional rollators by enabling remote monitoring capabilities that will support on-going care and rehabilitation, as well as potentially impact rollator design and prescription.*

Keywords *– ambulatory assistive device, rollator, walker, aging, elderly, photoplethysmography*

I. INTRODUCTION

The over 65 age stratum is currently the only growing population segment [1]. The number of older adults in Canada is projected to double to approximately 10 million by 2036, where nearly 1 in 4 Canadians will have reached the age of 65 [1]. Population aging is not unique to Canada; in fact, in most other Western industrialized countries, seniors make up a larger percentage of the population than in Canada [1]. With an aging population there are a number of associated challenges, including decreased mobility/stability and increased health problems, placing a heavy demand on the health care system.

Inactivity among the elderly has been shown to be a significant cause of increased morbidity [2] and premature mortality [3]. Ambulatory assistive devices, including rollators (similar to walkers but have wheels that better support "normal" walking gait), are employed to overcome stability and safety issues, promoting health and welfare, and enable users to maintain mobility and their ability for independent living. The ability to maintain mobility and independence is an important in a person's health and well-being, as well as their quality of life [1].

In this research, we are developing a Smart Rollator, which increases the utility of conventional rollators with technology that enables remote monitoring to support ongoing care-giving/rehabilitation. The Smart Rollator will allow health care professionals to quantitatively assess patients during normal daily usage, instead of being restricted to evaluations in unrealistic constrained laboratory environments. Practitioners have expressed that even simplistic data such as frequency of usage, and walking distance/speed, would be highly beneficial for their rehabilitation practices. For example, usage data would enable them to perform adherence monitoring of treatment plans outside of therapy sessions. In addition, such monitoring would provide important insights that can assist in the prescription and design of rollators.

This paper describes the design and implementation of the initial Smart Rollator prototype focusing on a number of sensor subsystems.

II. SYSTEM DESIGN

A. System Overview

The Smart Rollator (Fig. 1) is comprised of multiple non-obtrusive monitoring systems (e.g. distance/speed, force, cardiac). A microprocessor system collects data, into local memory, which are transferred periodically to a remote data server through a local data terminal. This terminal may be located by the user's bed, enabling data transfers each night. Remote terminals enable a variety of people (e.g. rollator users, health care professionals, family members) to examine the data and to generate reports via the Internet. Reports will be custom tailored to the individual's role (e.g. reports viewed by a physiotherapist would be different than those viewed by a rollator user).

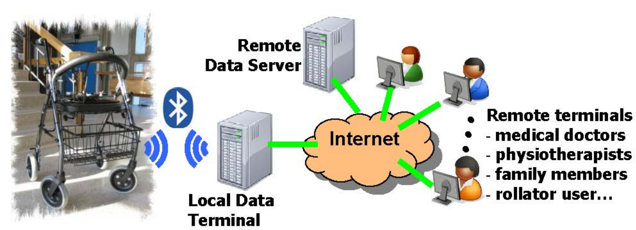

Figure 1 Smart Rollator system diagram

Automatic alarms regarding potential health problems can be issued appropriately. For example, changes in rollator loading forces may be indicative a neuromuscular disorder or injury. For persons with Parkinson's disease, postural control is diminished resulting for both static and dynamic balance (e.g. increased swaying) [4]. To compensate for stability deficiencies, significant stabilization forces are generated by the hands during rollator use [5]; it is anticipated that examination of the forces on the rollator handles can identify

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load magnitudes beyond normal ranges, asymmetries, and rhythmic patterns that can be attributed to diseases, such as Parkinson's. A health care professional can be notified to examine the changes in loading forces, as well as examine long-term trends, and follow up during the user's subsequent visits.

B. Distance/Speed Monitoring

The distance/speed of the rollator is measured using a Hall effect sensor and a series of magnets fitted on a rollator wheel, in a manner similar to a bicycle cyclometer (Fig. 2). Recorded data can be downloaded onto a server for visualization and analysis. A liquid crystal display is available on the current embedded system for development purposes; however, this is not likely to be used in operation, particularly for persons with certain compound impairments (e.g. mobility deficiency along with vision or mental deficiencies). Rather, summary data will be logged and transmitted to a remote server for off-line analysis and monitoring. Simultaneously, for other users, access to such a display may be useful for motivational purposes; similar to the use of pedometers in encouraging walking exercise.

While this monitoring is quite simplistic and can easily be retrofitted to rollators, consultations with physiotherapists indicate that it would be very useful. Quantitative measures would enable one to monitor adherence and progression in rehabilitation. It would also enable the examination of usage patterns, such as the distance traveled during a single rollator usage or the percentage of activity/inactivity within a day.

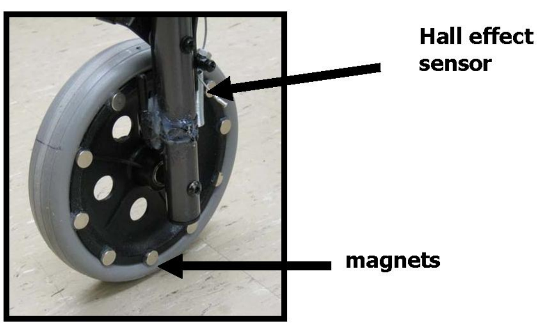

Figure 2 Sensor system for distance/speed monitoring.

C. Acceleration Monitoring

A tri-axial accelerometer (DE-ACCM3D, Dimension Engineering, Akron, OH) was used in the prototype system to measure rollator pose and acceleration. The presence of gravitational acceleration enables the system to sense surface slopes and tilting of the rollator. Observational analysis of rollator usage noted that users sometimes have difficulties going down inclines, due to the rollator "rolling away" from them. In combination with the measure of speed, it is possible that automatic active breaking could be applied appropriately to limit such difficulties, increasing user safety and decreasing falls. Large accelerations due to collisions and falls were also discernable and can be used to trigger alarms/warnings or to simply quantify such events to provide better insight in rollator design and environmental design (e.g. frequent collisions may indicate issues such as doorways being too narrow, furniture spaced too close together).

D. Force Monitoring

An initial prototype was constructed using a strain gauge to measure the rollator loading at each handle. Preliminary testing using able-bodied subjects revealed that during usage of the rollator, the time profile of the force measurements exhibited a periodic characteristic, which was related to the gait cycle. This suggests that force monitoring could have utility in gait monitoring or gait training applications with rollators. Furthermore, measurement of force is also useful for health care practitioners to evaluate rollator usage. Knowledge of applied force could help in adjusting the rollator or in prescribing an appropriate rollator to each user. Lastly, asymmetric loading or long term changes may also be indicative of existing or developing heath care issues, such as Parkinson's Disease, as described in the Section I.

We are currently investigating the utility of 6 degree-of-freedom force sensors on the handles to also determine user intent. User intent information (e.g. direction they wish to steer the rollator), combined with an obstacle detection and drop-off detection system, could be used as a means of obstacle and drop-off warning or avoidance system. This would improve the user safety, and avoid collisions and falls related to sharp changes in the floor surface (e.g. curbs, stairs). There are a number of projects related to the Smart Rollator that are working on obstacle detection/avoidance and guidance/wayfinding systems; these include the Utah State University iWalker [9], the M.I.T. Personal Aid for Mobility and Monitoring system [10], the University of Virginia assistive robotic agent [11], and Veterans Affairs Personal Adaptive Mobility Aid [12].

E. Seat Usage Monitoring

A simple binary pressure sensor placed on the rollator seat can provide information regarding seat usage. Data from this would be related to timing and duration of when the user sits on the rollator. Such usage data could be revealing in terms of usage behavior (e.g. how much rest the user needs during walks, or if the user is using the rollator more like a wheelchair).

Seat usage information could also be used as an additional safety mechanism. For example, a safety issue arises when a user sits down or rises from the rollator, without first remembering to engage the brakes. Combining the information from the accelerometers, force sensors, and seat usage sensor, it possible to determine events related to sitting and standing. An automatic breaking system could then be implemented to address such safety issues.

A more complex sensor (e.g. calibrated strain gauge) will be considered to replace the binary sensor. Differentiation between a seated user and other loads (e.g. a bag of groceries placed on the seat) may be necessary, but not possible with the binary pressure sensor.

F. Physiological Monitoring

The physiological monitoring system is comprised of a cardiac monitor and a blood oxygenation monitor. Two modalities were initially proposed for cardiac monitoring: 1. electrocardiograms (ECG) using contact-based electrodes; and 2. photoplethysmography (PPG) by monitoring the variable light absorption due to the pulsitile nature of blood flow. ECG monitoring would require two electrical contacts that span the heart, which could be accomplished with electrodes on both handles of the rollator. As illustrated in Fig. 3, PPG can be either *reflection* PPG, which measures the reflected light intensity with the source and detector adjacent to each other, or *transillumination* PPG, which measures the traversed light intensity with the source and detector facing each other on opposite sides of the sample under test [6]. Implementation of transillumination PPG typically requires a high source intensity, as it must penetrate more tissue, and is often limited to extremities that permit reasonable light intensities (e.g. finger tips, ear lobe). The transillumination PPG sensor is typically implemented in a clip, ensuring good surface contact. Reflection PPG is more appropriate for a Smart Rollator, as it requires lower power and has a less obtrusive interface (i.e. no clip is required). An external ECG system was used to validate the PPG system, however ECG was not integrated into this prototype.

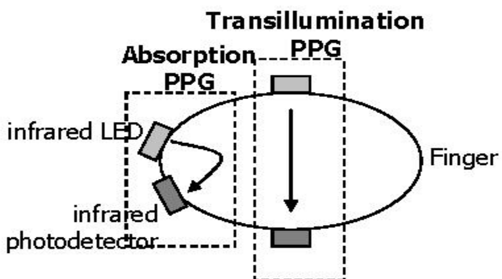

Figure 3 Cross-section of a finger, illustrating photoplethysmography.

A matched infrared emitter and phototransistor detector (λ = 950 nm) were employed in a prototype system. As we are only concerning ourselves initially with heart rate monitoring, the PPG signal was low pass filtered (Tow-Thomas filter biquad, $f_{cuttoff}$ = 5 Hz) to remove high frequency noise. It was observed that a PPG signal could be measured at various locations on the palmar surface of the hand, which is the surface of the hand that will be in contact with the rollator; however, the signal power was greatest at the pads of the fingers. Fig. 3 illustrates a PPG signal taken from the pad of a finger. While noise is clearly visible, the heart rate can easily be discerned. A multi-sensor PPG could be implemented to increase reliability of the measurement (e.g. averaging out noise across the multiple PPG signals and accounting for instances of poor sensor contact).

The PPG signal is cyclic (short term cyclostationary) and the period (reciprocal of the heart rate) can be determined via the autocorrelation of the signal; a variant on the heart rate estimator use for phonocardiograms would be applicable [6]. As measurement noise may vary the shape of the PPG pulse from beat-to-beat, autocorrelation of the signal magnitude (or square magnitude) can help reduce these effects. Denoising algorithm (e.g. wavelet denoising) would further mitigate the effects of measurement noise.

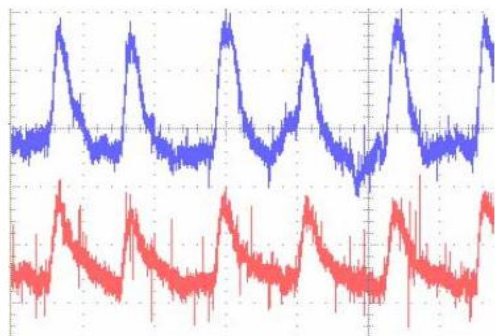

Figure 4 Photoplethomography signal. Lower trace is before filtering. Upper trace is after low pass filtering.

Blood oxygenation can be determined be pulse oximetry, which employs two wavelengths of light (typically, red light in the λ_1 = 600 - 750 nm range and near infrared light in the λ_2 = 850 - 1000 nm range) and takes advantage of the differences in absorption characteristics of oxygenated and deoxygenated hemoglobin. A pulse oximetry sensor system for pulse oximetry can be used for PPG measurements as well. Reflective pulse oximetry is more challenging than transillumination pulse oximetry but has shown to be feasible [13].

Reliable cardiac monitoring during normal use can provide important clinically relevant information (e.g. use-effort). For example, it has been shown that for patients with chronic obstructive pulmonary disease, rollator use can increase walking distance [7] and efficiency [8]. Translating such findings with real-world rollator use, via remote monitoring, can be difficult in a complex, dynamic environment (noise, movement, etc.). Employing redundant and/or multi-modal sensors provides a means of increasing the reliability of sensors systems. Related research has already demonstrated that multi-modal methods of cardiac monitoring can significantly improve signal quality [14][15].

While cardiac monitoring will be intermittent (i.e. only during rollator use), this is anticipated to be sufficient. Short-term usage data (i.e. during a single rollator use) can provide information regarding physical intensity and effort. Long-term trends, which can be related to general health and well-being, could be observed along multiple data segments.

G. Data Communications

The current Smart Rollator prototype employs a Motorola 68HC11microcontroller system, which is interfaced to a wireless Bluetooth transceiver capable of performing data transfers to an open source database (Sun Microsystems, MySQL). Bluetooth self-discovery features enables data transfers to be initiated without any user intervention, an important design issue considering the target user population of older adults; dealing with a complex user interface would be problematic for those unfamiliar with computer systems or for those with vision or mental impairments.

III. CONCLUSIONS

Certain monitoring subsystems of the Smart Rollator are more complex than others. For example, the speed/distance monitor is a relatively straightforward subsystem when compared to the physiological monitoring system, and thus has matured more quickly in the prototype; however, even simplistic monitoring can prove to be quite useful. As noted, physiotherapists are interested in having the ability to acquire usage data to track adherence and progression in rehabilitation. A prototype Smart Rollator is near completion for initial deployment to demonstrate the potential utility of this device.

This initial prototype is also intended to be used to reveal the number of design and human factors issues associated with remote monitoring systems; these include cost, transportability (e.g., weight, collapsibility), safety, ease of use, comfort, whether technological solutions are provided as a retrofit option or are fully integrated, whether remote monitoring will be used temporarily (e.g., during rehabilitation, for quantitative rollator assessments) or during all normal rollator usage, and target user population (e.g. compound impairments, including patients with visual impairments or degenerative diseases such as multiple sclerosis). Future iterations of Smart Rollator prototypes will be guided by feedback obtained from this initial prototype.

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