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Analysis of Commode Grab Bar Usage for the Monitoring of Older Adults in the Smart Home Environment

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***Abstract*—The occurrence of falls inside the home is a common yet potentially hazardous issue for adults as they age. Even with the installation of physical aids such as grab bars, weight transfers on and off a toilet or bathtub can become increasingly difficult as a person's level of physical mobility and sense of balance deteriorate. Detecting this deterioration becomes an important goal in fall prevention within a smart home. This paper develops an unobtrusive method of analyzing the usage of toilet grab bars using pressure sensors embedded into the arm rests of a commode. Clinical parameters are successfully extracted automatically from a series of stand-to-sit (StSi) and sit-to-stand (SiSt) transfers performed by a trial group of young and older adults. A preliminary comparison of the parameters indicates differences between the two groups, and aligns well with published characteristics obtained using accelerometers worn on the body. The unobtrusive nature of this method provides a useful tool to be incorporated into a system of continuous monitoring of older adults within the smart home environment.**

I. Introduction

As the age of our general population increases, the need for secure and responsive living environments for older adults becomes increasingly evident and imperative. It is estimated that by the year 2021 adults over the age of 65 will represent 18% of Canada's population [1]. In preparation for this, multi-disciplinary partnerships have been formed to provide solutions to the health and technological needs that will develop. The work presented here is the result of an ongoing partnership between universities within the research group Technology Assisted Friendly Environment for the Third Age (TAFETA) [2]. The goal of this group is to develop smart home technology that will allow older adults to live safe and independent lives.

A common and potentially hazardous issue for older adults is the occurrence of falls inside the home. One in three adults over the age of 65 will experience at least one fall every year [3]. A high correlation has been found between the risk of falling and the mechanics of postural transitions such as stand-to-sit (StSi) and sit-to-stand (SiSt) [4]. Recent work has provided insight into the detection and classification of these transitions using accelerometers worn on the body [5] [6].

The bathroom is a common place for falls to occur, especially during transfers to and from the bathtub or toilet. To aid in these transfers, the Canadian Standards Association recommends the use of grab bars affixed to the wall or in the form of toilet commodes. However, the relevant literature lacks quantitative analysis regarding how they are actually being used. Furthermore, it is not known how toilet bar use changes over time or with changing health. This paper develops a method for analyzing the usage of commode grab bars by automatically extracting clinical parameters which characterize their loading patterns over time. Information regarding the usage by populations with different physical characteristics could lead to fall prevention by an improvement in their design, configuration and implementation. Incorporating these characteristics into a single-occupancy smart home monitoring system could lead to fall prevention by alerting caregivers of a decrease in strength or a gradual loss of balance before a hazardous fall occurs.

This paper begins by defining the clinical parameters under consideration in the analysis of commode grab bar usage in Section II. Sections III and IV describe the instrumentation and data collection performed to extract location and force sequences from the grab bars. Section V begins by verifying a sample collected from a younger test subject. It then proceeds to a sequence recorded by an older adult, where it depicts the automated extraction of the defined clinical parameters. Observations comparing the preliminary results of the older adults to the younger test subjects are made before concluding the paper in Section VI.

II. Clinical parameters

In collaboration with the clinical team, several parameters of interest were chosen to describe the loading pattern on

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each commode grab bar during weight transfers from both StSi and SiSt:

1) *Transfer time:* duration of time over which the grab bars are used by the participant for weight transfer

2) *Maximum position:* location of applied force which is closest to the back of the commode, also termed the most posterior position

3) *Time to maximum position:* time taken to reach the most posterior position

4) *Position range:* absolute distance along the bar covered by the applied force during transfer

5) *Maximum force:* maximum force exerted on the bar

6) *Time to maximum force:* time taken to reach the maximum force exerted on the bar

7) *Force range:* absolute difference in force applied to the bar during transfer.

III. Instrumentation

A. Laboratory Setup

The test laboratory for the toilet commode grab bar project was located in the Faculty of Health Sciences, University of Ottawa, Canada. Simulating a typical bathroom found in a private home, it was equipped with a standard sink, bathtub and toilet. Affixed to the toilet was a standard-sized commode with the dimensions shown in Figure 1.

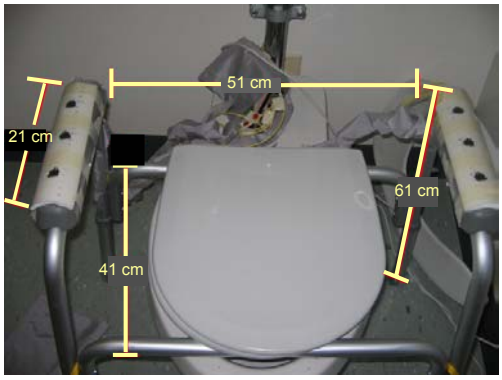

Fig. 1. Commode grab bars instrumented with embedded pressure sensors

B. Commode Bar Instrumentation

Pressure sensing has been shown to provide a valuable yet unobtrusive method of data collection regarding a smart home occupant's interactions with their surroundings [7] [8]. Three Kinotex® pressure sensors manufactured by Tactex Controls Inc. were embedded in polyethylene foam and placed on each of the two commode bars as shown in Figure 1. The sensors had a diameter of 1 cm and were equally spaced 6 cm apart such that a hand would activate at least one sensor during contact with the bar. Their placement began at 5 cm from the front end of each bar and covered the full length of the arm rests, with locations of 5 cm, 11 cm and 17 cm. The bars were then wrapped in a semi-rigid plastic membrane to allow applied forces to be distributed over the neighboring sensors. Though individually each sensor measures the pressure exerted directly on it, their small contact area compared to the spatial resolution over the length of the bar allows them to act as force sensors. The three sensors from each bar were input into a converter box and connected to a desktop computer, where the outputs were recorded at a sampling rate of 10 Hz. Finally, the entire set up and all associated wires were covered in a gray cloth to avoid any visual bias by the participants.

IV. Data Collection

A. Participant Recruitment

Ten young adults aged 19 to 26 years were recruited for initial calibration and testing of the equipment set-up and 11 older adults aged 60 to 80 years participated in the study. The young adults were students or employees of the Ottawa Health Sciences Center and the older adults were recruited from organizations from within the Ottawa area. All participants were in good overall health and were capable of executing a transfer on and off the commode independently.

B. Transfer Recordings

Participants attended a briefing where they were informed of the study objectives and signed the appropriate consent forms. They then proceeded to the lab where they were asked to begin standing with their back to the commode. They were instructed to use the grab bars to sit down on the commode, to remain seated without touching the bars for five seconds, to stand up using the grab bars and remain standing until instructed to repeat the sequence. This sequence was repeated five times with breaks in between when necessary. The pressure sensor outputs were recorded for the entire length of all trials and stored for subsequent analysis.

V. Results

A. Location and Force Estimate Sequences

When a force was applied at any point along the bar, the three sensors each responded with a corresponding output voltage reflecting their measured pressure. The location and force exerted on the bar were determined using the artificial neural network-based algorithms developed in [9] and [10]. Figure 2(a) contains the three sensor outputs recorded from a trial of StSi and SiSt transfers performed by a young test participant. Figure 2(b) and 2(c) contain the resulting sequences of location and force estimates. At around 2.5 s, the three sensors were activated as the participant used the grab bar to sit down. After about one additional second the pressure was released and remained off while the participant was seated. At around 8.5 s the sensors were activated once again as the participant returned to a standing position. The contribution of each sensor output in Figure 2(a) can be seen

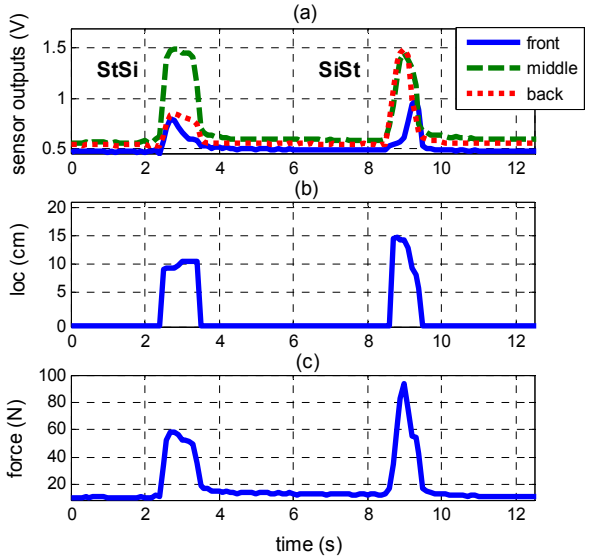

Fig. 2. Data sequence of (a) sensor outputs, (b) location estimates and (c) force estimates for a stand-to-sit (StSi) and a sit-to-stand (SiSt) performed by a young test participant

in the estimates of Figures 2(b) and 2(c). During the StSi transfer, the middle sensor was considerably higher than that of both the front and back ends. This is reflected in the location estimate at that time being just under 10 cm, corresponding to the user applying force on the middle of the 21 cm grab bar. A picture of the bar with the direction of increasing location is found in Figure 3. Throughout the StSi transfer the back sensor remained fairly constant whereas the front sensor began to decrease slightly, causing the contact location estimate to increase to just over 10 cm by the end of the sit. This represents the participant releasing their hand in a forward sliding motion once seated. The force estimates of Figure 2(c) also followed these loading and unloading patterns closely. During the SiSt, the middle and back sensor outputs began equally high resulting in a location estimate of about 14 cm, which is the middle point between these two sensor locations. Towards the end of the SiSt the front sensor quickly increased its contribution, resulting in a quick decrease in estimated contact location. The location estimates conformed to expectations, as the StSi transfer is accompanied by a backward motion limited by the back of the seat, whereas the SiSt transfer was accompanied by a forward motion with no limitations. The force estimates during the SiSt reflected a shorter duration of applied force than during the StSi. This behavior was also expected, since one must release their grip on the bar to reach a full standing position.

B. *Parameter Extraction*

A sample of location and force sequences collected from an older adult are displayed in Figure 4. While the overall pattern is similar to the younger sample in Figure 2, differences can be seen in transfer times as well as in maximum location and applied forces. The clinical parameters identified in Section II were extracted from the

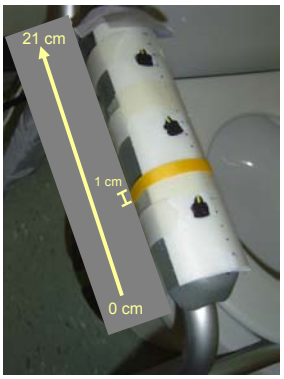

Fig. 3. Direction of increasing location along the grab bar

location and force sequences by an automated algorithm. To define the start and end of the transfers, a lower threshold was set on the force output past which the action was considered to have begun. A sample of the parameter extraction for the StSi transfer of the sequence is depicted in Figure 5. The associated clinical parameter results are included in Table I.

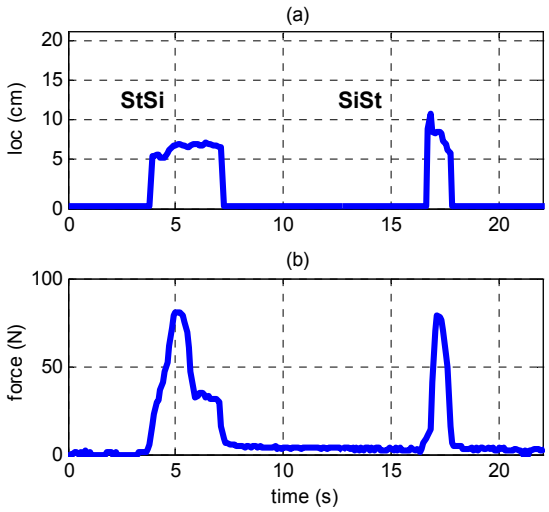

Fig. 4. Data sequence of (a) location estimates and (b) force estimates for a stand-to-sit (StSi) and a sit-to-stand (SiSt) performed by an older adult

C. *Preliminary Observations of Grab Bar Usage*

The clinical parameters were extracted for both the StSi and SiSt trials of all participants. The average StSi time for the young adults (1.24 s) compared well to the average StSi time for the healthy group (1.2 s) measured using accelerometers in [5]. The average SiSt time for the young adults (1.0 s) compared well to the average SiSt time for the healthy subjects (0.95 s) measured using accelerometers in [6]. Older adults generally produced longer transfer times for both the StSi (1.81 s) and SiSt (1.35 s) transfers than the young adults. Older adults also generally exerted less force on the bars. The younger adults tended to make contact with the bar at a position closer to the back of the commode. While the position range was larger in older adults than in

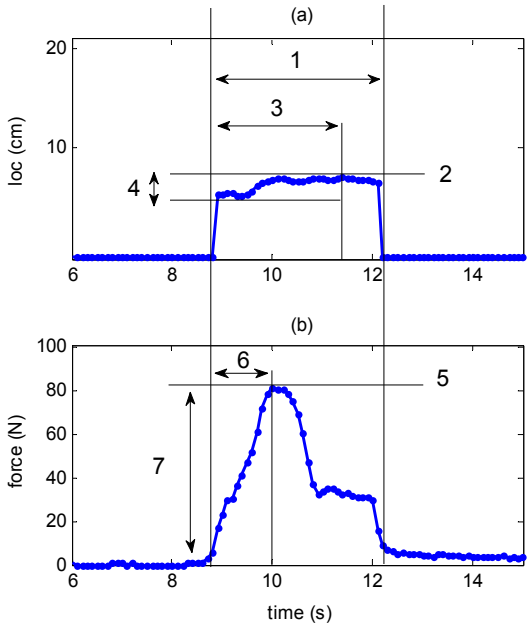

Fig. 5. Parameter extraction from the sequences of (a) location estimates and (b) force estimates for the stand-to-sit (StSi) transfer of an older adult

TABLE I
CLINICAL PARAMETERS EXTRACTED FROM THE STAND-TO-SIT TRANSFER OF AN OLDER ADULT

Number	Parameter Name	Value
1	Transfer time	3.4 s
2	Maximum position	7.1 cm
3	Time to maximum position	2.6 s
4	Position range	1.9 cm
5	Maximum force	81.0 N
6	Time to maximum force	1.2 s
7	Force range	75.2 N

young adults during the StSi transfer, the reverse was true during the SiSt.

VI. CONCLUSIONS

Clinical information was obtained regarding the usage of grab bars during transfers on and off a toilet commode using embedded pressure sensors. The contact location and force applied to the bar during StSi and SiSt transfers were estimated from the pressure sensor outputs. Clinical parameters such as transfer length, maximum force and range of contact location were successfully extracted to characterize the sequences. The enhanced knowledge of grab bar usage over varying populations could contribute to the optimization of their design and implementation, which could be beneficial in the prevention of falls. It could also be focused towards the detection of deterioration in the strength or mobility of an individual over time. The unobtrusive nature of this work contributes a useful tool which can be incorporated into a larger system of continuous monitoring of older adults within the smart home environment.

VII. FUTURE WORK

The next stages of this project will involve the study of grab bars with different lengths, orientations and configurations. Pressure sensors will be used to instrument horizontal, vertical and diagonal bars as well as offset support rails. Additional trials will compare grab bar usage between individuals with different levels of physical mobility such as older adults who have suffered a hip fracture as well as post-stroke patients. Continuous monitoring of individuals with lower mobility will also be performed to detect changes related to the progress of rehabilitation.

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