Analyzing Center of Pressure Progression During Bed Exits

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***Abstract*—This paper presents a new approach for analyzing center of pressure (COP) progression using pressure data collected from a pressure-sensitive array placed under the bed mattress. Pressure data were collected from a young female participant who was healthy and an older 78 year old female participant who had a history of falls. Information relevant to movement direction, time, path trajectory, magnitude and frequency was presented in three dimensional plots and color differentiated displays. When tested on data collected from an older participant who experienced a fall, this method of analyzing COP was able to illustrate distinct differences in bed exit patterns used pre and post fall episode. This analysis approach shows the potential to detect changes in bed exit patterns indicative of a critical health event. Future applications include home monitoring to assist with early intervention in the event of bed mobility decline.**

I. Introduction

There is a growing interest in technologies that have the potential to remotely monitor aspects of an individual's evolving mobility status, so that critical changes may be detected early and more serious health problems prevented [1-3].

Sensor technology is being developed as part of home monitoring systems [1, 3]. For example, pressure sensors have been used to monitor force distribution related to grab bar use [2] as well as breathing patterns related to sleep apnea [4]. One such technology, under mattress sensor technology provides a relatively unobtrusive way to monitor bed mobility in a continuous fashion [5]. Getting out of bed is an activity performed by most people on a daily basis and also one that can be easily monitored using under mattress sensor technology. Difficulty with this common activity may be an important marker of physical decline since it clearly differentiates older adults living independently with those living in institutions [6].

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Under mattress pressure sensor technology has been used to monitor various aspects of bed mobility including sit-to-stand time [5, 7, 8], bouncing [9], symmetry [7], classification of bed movements [10] and bed occupancy [11]. Center of pressure information represents another important dimension of how an individual gets out of bed, which has not yet been studied with under mattress pressure sensor technology in the home context.

Various techniques have been described for analyzing COP information relevant to postural control of standing and walking [12-15]. Poor postural control is associated with a higher risk of falling, which can lead to hospitalization, particularly among older adults [16]. Techniques for analyzing COP are lacking in relation to the study of bed mobility. Since postural control is also important for being able to rise independently [17], it follows that the development of techniques for analyzing COP related to getting out of bed are important to the development of home monitoring systems.

COP analysis approaches in the past have been restricted to examining movement direction [10] rather than considering movement direction in relation to time, frequency and magnitude of movement patterns. This paper describes an advanced approach for analyzing COP information relevant to bed mobility which incorporates information on movement direction as well as time, frequency and magnitude of movement patterns. The key contribution is that it provides a method for monitoring and analyzing postural control data which has relevance to an older population at risk of falling.

II. Data Collection

The technology used in this study consisted of a pressure sensitive mat array composed of 72 fiber optic pressure sensors with high sensitivity [8]. The pressure sensors were equally distributed in a grid structure and the entire mat covered an area of approximately 80 by 90 centimeters.

The pressure sensitive mat array was placed under the middle third of a bed mattress and connected to a transmitter box which collected and transmitted information to a computer via Bluetooth connection. Both transmitter box and computer were placed under the bed. We designated the pressure sensitive mat's X axis to correspond with bed width while the mat's Y axis corresponded with bed length. This orientation scheme is illustrated in Fig. 1.

The system was installed in the home of a 78 year old woman living independently, who volunteered to participate in the study. The system was also tested in a laboratory setting on a young healthy female volunteer. In the case of our older participant, the system was left in place for 8 months with data on bed mobility being collected on a continuous basis. Data were collected at a frequency of 20Hz and auto-saved as CSV

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files every hour such that each day 24 files were collected. The older participant was asked to record falls that she experienced over this period. She was visited monthly by a research physiotherapist who collected data generated by the pressure sensors as well as fall reports and clinical measures of physical function.

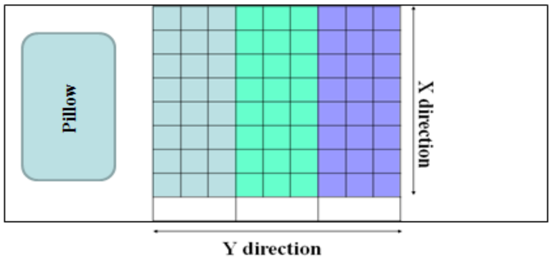

Figure 1. Bed array install graph

III. METHODOLOGY

An algorithm was written in MATLAB to process the CSV files collected and to analyze information relevant to COP. Data were sampled at a frequency of 10Hz when there was no movement on the bed and at 20 Hz when there was movement in order to optimize processing efficiency. A threshold level was set for each sensor to determine whether it was loaded or not (i.e. whether an individual was in the bed). Sensors detected pressure exerted by the overlying mattress and therefore produced a pressure value even when participants were absent from bed. These unloaded pressure values were not taken into account by the algorithm which considered sensors to be loaded when producing pressure values above the set threshold. The algorithm then calculated the number of loaded sensors, added loaded sensors' pressure values together, and divided by loaded sensors number to get average pressure (AvePre) at every sample, as in (1).

As mentioned previously, coordinate X was considered to correspond to bed width while coordinate Y corresponded with bed length. The pressure sensitive mat had 8 sensors at every line in the X direction and 9 sensors at every line in the Y direction. The algorithm designated each column in the X direction with numbers from 1 to 8 and each row in the Y direction with numbers from 1 to 9. In order to calculate COP location, sensors were summed in both X and Y directions as seen in (2) and (3). x and y represents a number of an active sensor from X direction and Y direction separately. The summed numbers were divided by the loaded sensors number. Combining results from both sets of coordinates produced a COP location on the mat area. Using this information we were able to plot a three dimensional (3-D) graph showing (X, Y) location trajectory over time which corresponded to a sample taken every 0.05 seconds. We could also create a movement frequency and magnitude plot, which shows the magnitude of Y direction movements by different colors and frequency of movements on an X-time graph or vice versa.

Fig. 2 is an example of a COP plot generated with data collected from the young healthy participant. From this plot, we can see there are 5 distinct stages of movement labeled S1 to S5. These points and the paths represent the following sequence of movements: S1=sitting on edge of bed; S1 to S2 path=lying down; S2=supine lying in stable position; S2 to S3 path = rolling to side of bed where previously sitting; S3= stable side lying position; S4=sitting on edge of bed but closer to foot of bed than S1 starting position; S4 to S5 path=getting out of bed, S5=out of bed. One can see from the graph that the largest movement on the Y axis is lying down whereas rolling and going from sit to stand occur mainly in the X-direction.

Information on COP magnitude and frequency is plotted in Fig. 3. This figure is associated with the same movement sequence as performed by our young participant and shown in Fig. 2. From Fig. 3, we can see in the first 60 time samples that the participant produced a large Y value represented by dark red followed by smaller Y value represented by yellow. The color change from dark red to yellow indicates there was a large magnitude COP movement in the Y direction for the given time period which corresponded to her position change from sitting to supine lying.

The rest of her sequence movements had a smaller magnitude than the initial change from S1 to S2. From S2 to S3 (i.e. supine lying to side lying) there was a comparably smaller magnitude movement which is represented by the change from light blue to dark blue and back to light blue around the 250 time mark. In essence, this plot uses color contrasts ranging from dark blue to dark red to represent whether a movement was large or small in magnitude at any given time in the movement sequence. The width of a color band within a time coordinate time shows how long the participant stays in a posture.

$$AvePre = \frac{\sum Active\ Sensors\ Value}{Total\ Number} \quad (1)$$

$$X_{location} = \frac{\sum x_{active\ sensor}}{Total\ Number} \quad (2)$$

$$Y_{location} = \frac{\sum y_{active\ sensor}}{Total\ Number} \quad (3)$$

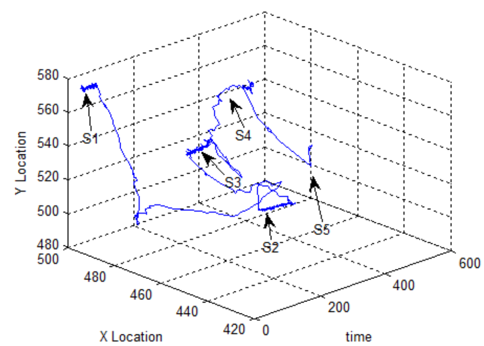

Figure 2. Example COP plot

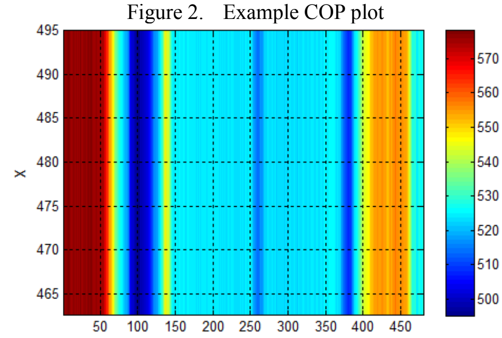

Figure 3. Magnitude and frequency of movement in Y direction

IV. COMPARING RESULTS

Using this algorithm, we analyzed COP bed exit data collected from our older participant in relation to a fall she experienced. The participant recorded the date of this fall on a calendar collected by the researcher. The COP pattern was analyzed for all bed exits which occurred a week before and a week after she fell (approximately 40 exits in total). Fig. 4 and Fig. 5 illustrate a typical pattern of her first morning bed exit. This particular transfer was chosen to represent her typical pattern since the timing corresponded to her average monthly bed exit sit-to-stand time as measured by a previously developed algorithm [8]. The time period sampled in Figure 4 was about 1 hour to include a period of quiet lying prior to the bed exit.

In Fig. 4, the COP path indicates that she normally rolled to one side from supine lying and then got into a stable sitting position. The trace shows that she leaned slightly to the left while exiting the bed. The color contrasts in Fig. 5 illustrate the magnitude of COP movement in the Y direction with time. The narrow band of red shows where the greatest magnitude of movement occurred during the sequence.

Fig. 6 and 7 illustrate COP bed exit pattern the first morning after the participant fell. The path in Fig. 6 does not display a period of quiet lying or a side rolling pattern as did the previous plot. Furthermore there is a much larger area of COP movement in both X and Y directions prior to her bed exit. The relatively high degree of color contrast in Fig. 7 throughout the sampled time period indicates that higher magnitude COP movements occurred throughout this bed exit over a longer period of time. These differences may have been due to greater pain, instability or restlessness following the fall.

Fig. 8 and 9 illustrate COP movement 4 days after the participant's fall. The Fig. 8 COP path trajectory is much closer to the participant's typical pattern. There is a period of stability prior to the roll into side lying. Before her bed exit, there is also less COP movement indicating greater stability. The Fig. 9 color plot shows that initially there was no movement as indicated by the large area of solid color. Following this, there is a small band of high color contrast including yellow, green and red. This high contrast color band indicates higher magnitude movements were performed in a relatively short period of time. This pattern is much closer to the typical pattern in Fig. 4 and 5 suggesting that the participant altered the way she got out of bed after falling but returned to her regular pattern 4 days later.

In this paper X, Y axis interval values are slightly different among plots since the size of COP movements are different. We have used the MATLAB function to adjust X, Y interval values for each set of data in order to optimize plot clarity.

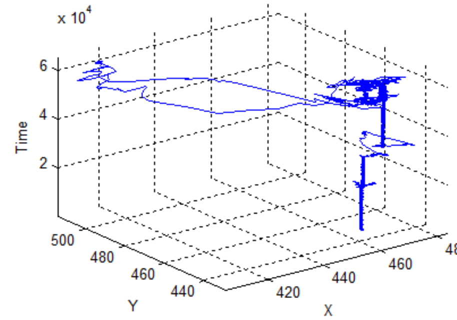

Figure 4. Morning exit of four days before the fall

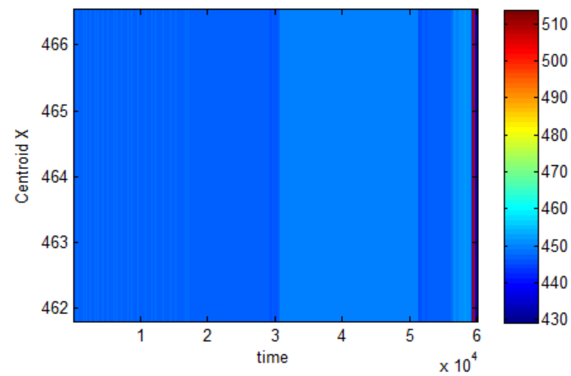

Figure 5. Frequency and magnitude of movement in Y direction four days before the fall

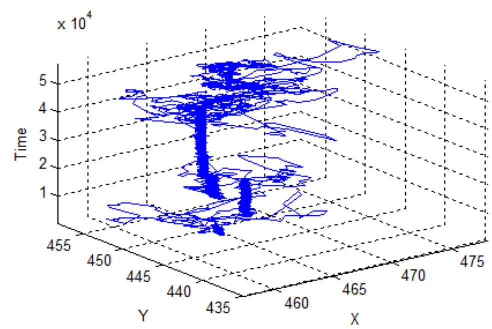

Figure 6. The next morning exit after the fall

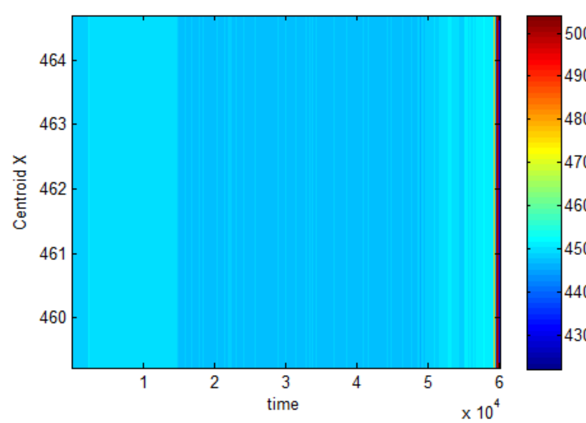

Figure 7. Frequency and magnitude of movement in Y direction of the next morning exit after the fall

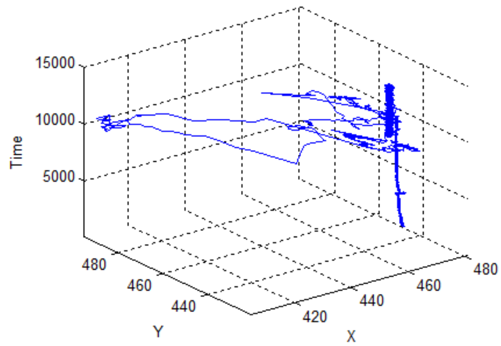

Figure 8. Morning exit four days after the fall

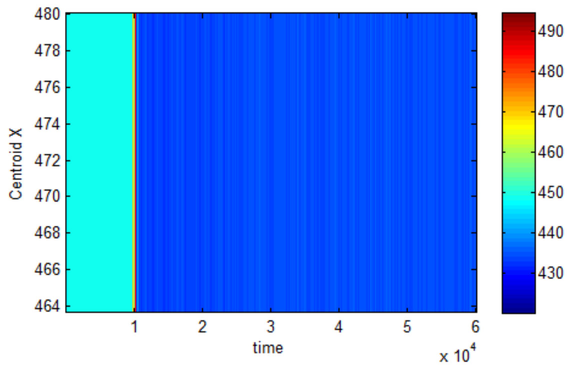

Figure 9. Frequency and magnitude of movement in Y direction of the morning exit four days after the fall

V. CONCLUSION

This paper provides a novel approach for analyzing COP information that has relevance for monitoring bed mobility over time. Using this approach we have produced visual displays of COP data which incorporate movement in X and Y directions over time thereby producing a movement trajectory that can be interpreted as a sequence. Furthermore we have produced visual color contrast displays that convey additional information regarding the magnitude and frequency of COP movement. When tested on data collected from an older participant who experienced a fall, this method of analyzing COP was able illustrate distinct differences in bed exit patterns used pre and post fall episode. The approach, therefore shows promise in terms of being able to detect critical mobility changes and is worthy of ongoing development.

VI. FUTURE WORK

In the future, we plan to refine the algorithm by increasing the processing speed and making visual displays clearer and easier to interpret for health care providers. We will also explore the use of a filter for this algorithm which may help to reduce the work of interpreting a large amount of visual information on COP movement. Although the high sampling rate produced a sensitive and accurate picture of COP movement, all of the small movements displayed may not be essential to interpreting the plots. The results of this paper reflect patterns observed in a single older individual. Future work must address whether similar patterns are viewed in a larger sample of older participants and also whether these patterns are distinct from other age groups.

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