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Metrics from in-home sensor data to assess gait change due to weighted vest therapy☆

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ABSTRACT

A set of metrics and a methodology were developed to characterize a subject's ability to ambulate. These metrics use the movement of the subject's centroid as detected by an inexpensive depth camera system. The centroid is chosen as it is less sensitive to cluttered environments typically found in a person's home. Three classes of metrics focusing on three major categories of motion were developed. The first class measures fundamental characteristics of movement in three directions. The second class focuses on measuring the walk's entropy. The third class uses periodicity in the subject's motion to deduce temporal gait parameters including stride length. Metrics are validated and compared to existing Fall Risk Assessments (FRA's). While results show strong correlation to many FRA's, not every subject has the same relationships between metrics and FRA's suggesting a unique "fingerprint" of metrics associated with a subject and/or their condition.

The methodology was tested using a group of subjects undergoing Balance Wear Therapy targeting sensory inputs to improve balance control. The ability of the metrics to detect changes in the subject's ambulation when the vest is either put on, or taken off was also explored. Results show sufficient sensitivity to detect changes when the vest is donned and doffed. Many effects are not seen immediately, but over 2–4 h following donning or doffing the vest. Results also demonstrate the ability, using the size of the analysis window, to focus on the time required for the effects of each metric to change.

1. Introduction

More than one third of older adults fall each year (Kannus et al., 1999; Lord, Ward, Williams, & Anstey, 1993; Sattin et al., 1990; Scuffham, Chaplin, & Legood, 2003). Of these falls, 10% to 20% cause moderate to severe injuries. Of these falls, about three percent will result in a fracture of some kind (Nevitt, Cummings, Kidd & Black, 1989). According to the United States Centers for Disease Control and Prevention, in 2012, the direct medical cost of falls among older adults, adjusted for inflation, was over $30 billion (Costs of Falls Among Older Adults | Home and Recreational Safety | CDC Injury Center, n.d.).

Beyond the physical and immediate financial cost of falls, there are longer term costs, psychological, physical and financial, that

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result from falling. Howland reported that the fear of falling may, in fact, affect social interaction regardless of actual fall risk (Howland et al., 1993). Nevitt found that approximately one quarter of falls cause the subject to limit their normal activities, usually because of injury, but often simply due to the fear of falling again (Nevitt et al., 1989). Reducing the occurrence of falls, then, can go a long way in reducing the direct and indirect costs of falls. Not only will the patient's life be extended, and direct hospitalization costs be reduced, but more patients will be able to maintain their functional independence longer, delaying or eliminating their dependency on family, friends, or the healthcare system as a whole. This will lead to a higher quality of life.

To better monitor the population of older adults in order to identify the potential of falling before it happens or between exams, a set of metrics was developed that can be used to study the effects of therapies and monitor a subject's gait as the subject carries out their typical day to day activities. Since the target is the home environment, we focused on using inexpensive depth cameras, such as the Microsoft Kinect®.

In order to test these algorithms and metrics, we chose to use BalanceWear Therapy. BalanceWear Therapy (BWT) consists of strategically placing sensory inputs (small ¼ to ½ pound weights) at various locations on the trunk. BWT is currently being utilized to treat patients with Multiple Sclerosis, Parkinson's disease, traumatic brain injury, vestibular issues, and ataxia. The BalanceWear® vest, produced by Motion Therapeutics in Oxnard, CA, consists of a vest, worn on the torso with Velcro areas where small, light weights are attached to the inside of the vest. The physical therapist performed a BalanceWear assessment to identify directional imbalance of a subject and strategically placed ¼ to ½ pound increments of weight in specific locations on the vest to improve directional balance and postural control. The patient was then instructed to wear the vest for several hours once or twice during the day. Studies conducted have focused on the clinical effects of the vest (Gibson-Horn, 2008; Widener, Allen, & Gibson-Horn, 2009a, 2009b) but have not investigated how the vest specifically impacts the patient's ambulation beyond gait speed.

A brief discussion of background and related work is included in Section 2. The Methods section describes how the data were collected and analyzed. The Metrics section discusses how each metric is computed. The Results and Discussion sections highlight the findings.

2. Related work

2.1. Fall risk assessments

2.1.1. Timed Up-and-Go

The "Timed Up and Go" (TUG) test is a modification of the "Get Up and Go" test developed by Mathias et al. (1986) to add a temporal component to the assessment (Podsiadlo & Richardson, 1991). Their research has shown that the TUG test is reliable, correlates well with the Berg Balance Scale, Gait Speed, and Barthel Index of "Activity of Daily Living", and appears to predict the patient's ability to go outside alone safely (Podsiadlo & Richardson, 1991). Other researchers have arrived at similar conclusions (Kristensen, Ekdahl, Kehlet, & Bandholm, 2010; Steffen, Hacker, & Mollinger, 2002).

The TUG is a timed test requiring the subject to rise from a chair, walk 3 m, turn around, return to the chair, and sit back down. Morris, Morris, and Iansek (2001) investigated the reliability of this measure in people with Parkinson's disease. The TUG has been studied with other pathological conditions as well, including amyotrophic lateral sclerosis (Montes et al., 2007), post stroke (Walker, Brouwer, & Culham, 2000), and orthopedic disturbances (Arnold & Faulkner, 2007; Kristensen, Foss, & Kehlet, 2009).

2.1.2. Habitual gait speed

Habitual gait speed (HGS) has been studied as a means to detect a significant change in a person's gait (Bohannon, 1997; Kuo, Leveille, Yu, & Milberg, 2006; Li et al., 2012) which is a predictor of falls. To measure, the subject is asked to walk at a comfortable, habitual speed for a specified distance (20 feet is typical). The walk is timed and the average speed is computed. Bohannon found gait speed to be highly reliable (Bohannon, 1997). This FRA was also shown to be moderately correlated with the subject's age (-0.558; $p < 0.001$), and minimally correlated with height and several mechanical aspects of gait (ankle dorsiflexion strength, hip flexion strength, and hip abduction strength). Knee extension strength was found to be strongly correlated with HGS. Bohannon also published height normalized means and standard deviations for Habitual Gait Speed and Maximum Gait Speed (Bohannon, 1997).

2.1.3. Functional reach

A third common fall risk instrument is the Functional Reach Assessment. This test guides the patient through a series of reach tasks designed to gauge not only the flexibility, but also the ability of the patient to balance sufficiently to reach. This instrument was published in 1990 by Duncan, Weiner, Chandler, and Studenski (1990). The instrument measures the difference between the arm's length and the maximum forward reach using a fixed base of support.

2.1.4. Berg Balance Scale

The Berg Balance Scale (BBS) is a test of 14 different items and is used to monitor fall risk principally relying on assessment of the patient's balance. The 14 activities that comprise the instrument evaluate the subject's balance, ability to rise from and sit on a chair, walking, turning, and balance while walking. In this instrument, all 14 items are rated on a scale of 0 to 4 corresponding from no ability to full ability. The final score is simply the total of each rating out of a total of 56 with each item being equally weighted (Berg, 1989).