In-Home Fall Risk Assessment and Detection Sensor System

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ABSTRACT

Falls are a major problem in older adults. A continuous, unobtrusive, environmentally mounted (i.e., embedded into the environment and not worn by the individual), in-home monitoring system that automatically detects when falls have occurred or when the risk of falling is increasing could alert health care providers and family members to intervene to improve physical function or manage illnesses that may precipitate falls. Researchers at the University of Missouri Center for Eldercare and Rehabilitation Technology are testing such sensor systems for fall risk assessment (FRA) and detection in older adults' apartments in a senior living community. Initial results comparing ground truth (validated measures) of FRA data and GAITRite System parameters with data captured from Microsoft® Kinect and pulse-Doppler radar are reported. [*Journal of Gerontological Nursing, 39*(7), 18-22.]

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Falls are a major problem in older adults. One in every three people 65 and older falls each year and 2 million are treated in emergency departments for fall-related injuries (Centers for Disease Control and Prevention, 2013). Researchers have studied falls, fall risk assessment (FRA), and interventions to prevent falls. However, their methods require that research staff or clinicians complete multifactorial FRAs (Perell et al., 2001), or that people maintain logs of falls, wear devices that measure changes in positions that could indicate a fall (Boissy, Choquette, Hamel, & Noury, 2007), or activate an alarm when they need assistance (Curry, Tinoco, & Wardle, 2003). A continuous, unobtrusive, environmentally mounted, in-home monitoring system that automatically detects when falls have occurred or when the risk of falling is increasing could alert health care providers and family members so they could intervene to improve physical function or manage illnesses that may precipitate falls. Researchers at the University of Missouri (MU) Center for Eldercare and Rehabilitation Technology are testing sensor systems for FRA and fall detection in older adults' apartments in a senior living community.

FALL SENSOR SYSTEM OVERVIEW

FRA sensor systems have been installed in apartments of older adults at TigerPlace, an independent senior living community in Missouri (Rantz et al., 2011). The FRA sensor system consists of a pulse-Doppler range control radar (developed by General Electric® [GE]), a Microsoft® Kinect (developed for a gaming system), and two web cameras. The radar unit is installed in a decorative wooden box next to the front door of the apartment. The Kinect is located on a small shelf over the front door, near the ceiling. To preserve the privacy of the resident, only the depth image (i.e., an image where the value of each pixel depends

on its distance from the camera) from the Kinect and the radar data are continuously captured. Gait parameters are calculated on a daily basis from the Kinect data. The first system was installed in June 2011, providing more than 1.5 years of continuous data for system development and improvement.

The radar unit and Kinect were integrated into data collection systems and tested in an MU engineering research laboratory before being deployed in the independent living setting. Gait parameters are extracted from the radar and Kinect systems using sophisticated algorithms developed by engineering research team members. Gait algorithms for the radar system were created by collaborators at GE Global Research Laboratories (Yardibi et al., 2011); MU researchers created algorithms for the Kinect. For testing of the sensor systems, a Vicon® optical motion capture system was used as "ground truth" to compare results to simultaneous validated measurement of gait and falls. The Vicon system uses infrared markers worn by test participants and a system of cameras to precisely measure limb and torso movements.

METHOD

Sample for Laboratory Development of the Systems

Fifteen test individuals (8 women, 7 men) ranging in age from 23 to 67 (mean age = 56.5, *SD* = 11.5 years) performed a series of walks (fast, slow, normal) and fall risk measures in the laboratory. The radar estimated the velocity, stride length, and stride variability; these measures accurately compared to estimates from the Vicon with the exception of a shuffled walk to simulate a post-stroke patient (Yardibi et al., 2011). In addition, the Kinect validation using the Vicon system demonstrated good agreement among gait parameters of stride time, stride length, and velocity (Stone & Skubic, 2011).

Sample for Field Testing in Apartments of Older Adults

After initial development and testing in the laboratory, the FRA sensor system was deployed in the residents' apartments at TigerPlace to test the system in a real-world environment. To maintain a continuous sample in 10 apartments, the

TABLE 1

CORRELATIONS BETWEEN GAITRITE VELOCITY AND FUNCTIONAL AMBULATION PROFILE (FAP) AND FALL RISK ASSESSMENTS (FRAS) (N = 15[a])

	Pearson Correlation Coefficient (p Value)						
	FRA						
GAITRite	FR	BBS-SF	TUG	SPPB	SLS (Eyes Open)	SLS (Eyes Closed)	HGS
Velocity	0.41 (0.13)	0.52 (0.045)	–0.77 (0.0008)	0.74 (0.0015)	0.15 (0.59)	–0.0073 (0.99)	–0.76 (0.0010)
FAP	0.58 (0.025)	0.60 (0.018)	–0.80 (0.0003)	0.59 (0.019)	0.32 (0.24)	0.10 (0.71)	–0.55 (0.034)

Note. FR = Multidimensional Functional Reach; BBS-SF = Berg Balance Scale; TUG = Timed Up & Go; SPPB = Short Performance Physical Battery; SLS = Single Leg Stance; HGS = Habitual Gait Speed.
[a] Unique older adult participants living in TigerPlace (not laboratory participants) during 18-month field study.

TABLE 2

CORRELATIONS BETWEEN FALL RISK ASSESSMENTS (FRAS) AND KINECT AND RADAR VARIABLES (N = 102 READINGS [15 UNIQUE PARTICIPANTS[a]])

	Pearson Correlation Coefficient (p Value)				
FRAs	Kinect Stride Time	Kinect Stride Length	Kinect Velocity	Radar Stride Time	Radar Velocity
FR	–0.18 (0.07)	0.53 (<0.0001)	0.43 (<0.0001)	–0.30 (0.002)	0.46 (<0.0001)
BBS-SF	–0.39 (<0.0001)	0.64 (<0.0001)	0.61 (<0.0001)	–0.31 (0.002)	0.42 (<0.0001)
TUG	0.59 (<0.0001)	–0.61(<0.0001)	–0.70 (<0.0001)	0.32 (0.001)	–0.55 (<0.0001)
SPPB	–0.46 (<0.0001)	0.62 (<0.0001)	0.65 (<0.0001)	–0.26 (0.008)	0.52 (<0.0001)
SLS (eyes open)	–0.34 (0.0004)	0.61 (<0.0001)	0.59 (<0.0001)	–0.15 (0.13)	0.26 (0.009)
SLS (eyes closed)	–0.16 (0.12)	0.30 (0.0021)	0.26 (0.0074)	–0.18 (0.078)	0.31 (0.0018)
HGS	0.36 (0.0002)	–0.61 (<0.0001)	–0.58 (<0.0001)	0.30 (0.0026)	–0.46 (<0.0001)

Note. FR = Multidimensional Functional Reach; BBS-SF = Berg Balance Scale; TUG = Timed Up & Go; SPPB = Short Performance Physical Battery; SLS = Single Leg Stance; HGS = Habitual Gait Speed.
[a] Unique older adult participants living in TigerPlace (not laboratory participants) during 18-month field study.

sensor system has been installed in 14 apartments. Seventeen individuals (10 women, 7 men) have consented and are monitored, including 3 couples. The age of the study participants ranges from 67 to 98 (mean age = 87.5, *SD* = 7.9 years). Six people have been discharged during the first 1.5 years of deployment for the following reasons: 1 person died, 1 moved to a nursing home, 1 couple withdrew for personal reasons, and 1 couple moved to an assisted living facility. Eleven individuals, including 1 couple, remain in the study.

Field Testing of Fall Sensor Systems

To validate and improve the sensor system, each study participant completes a monthly FRA commonly used by health care providers. The FRA is comprised of six fall risk measures that are valid and reliable: Habitual Gait Speed (HGS) (Bohannon, 1997; Fransen, Crosbie, & Edmonds, 1997); Timed Up & Go (TUG) (Podsiadlo & Richardson, 1991; Shumway-Cook, Brauer, & Woollacott, 2000); Multidimensional Functional Reach (FR) (Newton, 2001); Short Performance Physical Battery (SPPB) (Guralnik et al., 1994); Berg Balance Scale-Short Form (BBS-SF) (Berg, Wood-Dauphinee, Williams, & Maki, 1992); and the Single Leg Stance (SLS) (Vellas et al., 1997). A research assistant scores and records the fall risk measures.

In addition to the FRAs, a stunt actor completes a series of falls in each participant's apartment. To protect study participants from harm, trained stunt actors fall on mats in the apartments each month. The stunt actor falls are necessary

TABLE 3

CORRELATIONS BETWEEN GAITRITE VELOCITY AND FUNCTIONAL AMBULATION PROFILE (FAP) AND KINECT AND RADAR VARIABLES (*N* = 15[a])

	Pearson Correlation Coefficient (*p* Value)				
GAITRite	Kinect Stride Time	Kinect Stride Length	Kinect Velocity	Radar Stride Time	Radar Velocity
Velocity	–0.19 (0.49)	0.46 (0.087)	0.46 (0.087)	–0.43 (0.11)	0.44 (0.10)
FAP	–0.22 (0.44)	0.48 (0.070)	0.45 (0.089)	–0.59 (0.020)	0.57 (0.027)

[a] *Unique older adult participants living in TigerPlace (not laboratory participants) during 18-month field study.*

TABLE 4

CORRELATIONS BETWEEN RADAR AND KINECT VARIABLES (*N* = 102 READINGS [15 UNIQUE PARTICIPANTS[a]])

	Pearson Correlation Coeffici ent (*p* Value)		
Radar	Kinect Stride Time	Kinect Stride Length	Kinect Velocity
Stride time	0.19 (0.062)	–0.21 (0.031)	–0.18 (0.066)
Velocity	–0.26 (0.0096)	0.38 (<0.0001)	0.35 (0.0003)

[a] *Unique older adult participants living in TigerPlace (not laboratory participants) during 18-month field study.*

because data from actual falls are essential to develop and test computer algorithms for fall detection. The use of stunt actors provides information about how accurate the systems are in detecting actual falls. If the fall detection sensor system is to be widely adopted, it must accurately detect when falls occur.

Another FRA validation is GAITRite data collection (http://www.gaitrite.com). The GAITRite electronic walkway measures temporal and spatial gait parameters, such as cadence, step length, velocity, and the functional ambulation profile (FAP). The study participant simply walks the length of the electronic walkway, and the GAITRite system automatically calculates the gait parameters. The FAP is a summary score that can be used as ground truth for FRA (range 0 to 100) that quantifies the gait based on temporal and spatial parameters (Nelson, 1974). GAITRite data are collected every 6 months; these data are used as ground truth and are periodically compared with the other clinical FRA measures.

Data Analysis

A data set was constructed of all monthly clinical FRAs for all field study participants (*N* = 17) over 18 months of data collection (*N* = 159 completed FRAs for all clinical measures) and merged with Kinect gait data and radar gait measures for the same dates of the FRAs; this merging resulted in a final sample of 15 participants with 105 FRAs. Three types of correlations were computed using the GAITRite variables of velocity and FAP as ground truth. To account for replicate measurements over time, the Bland-Altman approach (Bland & Altman, 1994) and a method suggested by Hamlett, Ryan, Serrano-Trespalacios, and Wolfinger (2003) were used in addition to Pearson's correlation coefficient.

RESULTS

As a first analytic step, scores for velocity and FAP from the GAITRite were used as ground truth (the most accurate validated measurement of gait and fall risk) and correlations were estimated with the FRAs (*N* = 15). Correlations are in the expected direction for each FRA measure as shown in **Table 1**. Both velocity and the FAP scores are highly correlated (in the expected direction) for the BBS-SF, TUG, SPPB, SLS (eyes open), and HGS.

As the second analytic step, the FRAs were used as ground truth and correlations were estimated with the automated Kinect and radar gait measures that were developed for continuous FRA (**Table 2**). Results show the variables from the Kinect and radar, collected simultaneously during the FRAs, have correlations consistently in the expected direction, with most being statistically significant.

As a third step, the GAITRite was used as ground truth and was correlated with Kinect and radar data collected at approximately the same time, but not simultaneously. Measures from each were collected within a 2-month time frame. **Table 3** displays the correlations of gait parameters of velocity and FAP calculated from the GAITRite; stride time, stride length, and velocity calculated from the Kinect data; and velocity and stride time from the radar. Although correlations are in the expected direction, none reached statistical significance. This is likely due to the small sample size ($N = 15$). As a final step, correlations were estimated among the Kinect and radar gait parameters ($N = 102$ readings [15 participants]). As anticipated, these are correlated in the expected directions and most are statistically significant (**Table 4**).

DISCUSSION AND IMPLICATIONS

Data from this study provide preliminary evidence that work to develop an automated, continuous, unobtrusive, environmentally mounted, in-home monitoring system for FRA is possible and has potential for success. Based on the preliminary findings of this study, normal daily activities in the home can provide measures to detect changes in fall risk that are correlated with commonly used FRA measures. The results from both the Kinect and Doppler radar automated algorithms are correlated with ground truth measures of the GAITRite electronic walkway and FRA measures commonly used by health care providers.

The FRA sensor system deployed at TigerPlace has the potential to revolutionize fall prevention by measuring fall risk as individuals go about normal daily living. The system can be refined to send automated "alerts" that fall risk is increasing or provide much needed encouragement that strength training or other exercise-based interventions are actually reducing one's risk for falls. This system also has potential to keep family members and health care providers informed about changes in falls or fall risk affecting an older adult.

This study is also examining environmentally mounted (i.e., embedded into the environment and not worn by the individual) sensors for fall detection; data collection and analyses are still underway. Non-wearable fall detection would be invaluable in long-term care, hospitals, and congregate senior housing where falls are a major risk. Automatic fall detection would facilitate discovery that a person has fallen, which is crucial to survival and recovery after falls with injuries, thus enabling older adults to stay healthier longer.

Limitations of this study include the single housing site for sample recruitment, the relatively small deployment in 10 apartments, and the limited 6-month interval for GAITRite ground truth data collection. Although monthly data collection of FRAs provides an adequate source for ground truth and overcomes the limited availability of the GAITRite data, future work can include more frequent GAITRite data collection.

CONCLUSION

The effort to develop automated technology for in-home FRA and detection sensor systems is advancing new ways to help older adults remain independent as long as possible, an important goal of this population and their families. In addition, this technology has the potential to reduce costly hospitalization and nursing home stays.

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