31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Objective real-time assessment of walking and turning in elderly adults

Zoran Škrba, *Member IEEE,* Brian O'Mullane, *Member IEEE*, Barry R. Greene, *Member IEEE*, Cliodhna Ni Scanaill, *Member IEEE,* Chie Wei Fan, Aaron Quigley, *Senior Member IEEE*, Paddy Nixon, *Senior Member IEEE*

***Abstract*—Recent research suggests that falls are the most common cause of injury and disability in older persons. Invasive systems or body worn sensors can be employed in controlled clinical and laboratory settings to determine clinical measures of gait and stability. This study by contrast aims to explore how video technology, can be employed to unobtrusively determine the same measures. Data from 63 elderly subjects, recruited through a research clinic was analyzed. The derived parameters include: the walk time, the number of steps of the TUG test and stability out of the turn. The results show that video analysis can be used to automate current clinical measures of gait and stability as well as to inform future automated interventions.**

I. Introduction

FALLS are the most common cause of injury and hospitalization and one of the principal causes of *death* and *disability* in older persons. With 30% of community dwelling elderly people over 65 years of age falling each year and 12% of these falling at least twice [1, 2]. Incidence increases further with age and frailty [1]. The principal difference is in the resultant consequences.

Various mechanisms for maintaining dynamic postural stability are lost with the process of ageing [3]. Poor muscle strength, vestibular dysfunction and neurological diseases that affect the feedback loop can all contribute to loss of postural stability [3]. The loss of postural stability in an older person results in falling especially during turning [4]. Turning requires postural control to maintain the centre of mass within the base of stability.

Recent research has found that older persons who are prone to falls have unsteady and slower turns [4]. This study aims to provide quantitative objective assessment of elderly people in walking and turning using automated video analysis.

Manuscript received April 7, 2009.

Zoran Škrba, TRIL Centre, University College Dublin, Ireland (e-mail: zoran.skrba@ucd.ie).

Brian O'Mullane, TRIL Centre, University College Dublin, Ireland (e-mail: brian.omullane@ucd.ie).

Barry R. Greene, Intel Digital Health Group, Leixlip, Co. Kildare, Ireland and the TRIL Centre (e-mail: barry.r.greene@intel.com).

Cliodhna Ni Scanaill, Intel Digital Health Group, Leixlip, Co. Kildare, Ireland and the TRIL centre (e-mail: cliodhna.ni.scanaill@intel.com).

Chie Wei Fan, St James's hospital and the TRIL centre, Dublin, Ireland (e-mail: cfan@stjames.ie).

Aaron Quigley, University College Dublin, Ireland (e-mail: aquigley@ucd.ie).

Paddy Nixon, University College Dublin, Ireland and the TRIL Centre (e-mail: paddy.nixon@ucd.ie).

A. Get Up and Go

The Get Up and Go test (also known as the Timed Up and Go test (TUG)) was developed by Mathias and Nayak as a tool to screen for balance problems in the older population [5]. The test involves rising from a chair, walking 3 meters, turning, and returning to the chair. The subject is visually graded on a scale of 1 to 5, with 1 being normal and 5 being severely abnormal. A score of 3 or higher indicates an increased risk of a fall [5].

Other researchers [6] have modified this test by adding a time component; it was found that neurologically intact adults (non-fallers) are able to complete the task in less than 10 seconds [1]. Shumway-Cook further modified the test by adding a cognitive task (counting backward by threes) and a manual task (carrying a cup of water) to the original test. Demura et al has extended the walk to 5 m with inclusion of overcoming obstacle and reported that fallers took longer to complete the task than non-fallers [7]. All authors suggest that the TUG test is one of the most powerful tools for predicting which elders may fall in the future.

B. Dite Turn Test

Dite et al [4] have identified certain turn measures that discriminate between groups of healthy and prone to falling older adults and have good sensitivity for identifying multiple fallers. They were: the time taken to accomplish the turn, the number of steps taken during the turn, being steady throughout the turn, and being non-hesitant with fluid movement between turn and walk when exiting the turn. The maintenance of balance during turning is a key measure of stability [8, 9].

The TUG and Dite tests are typically administered by a clinical staff in a controlled clinical environment. This is an unnatural setting and is time and resource consuming. Furthermore these tests are subjectively based and require the presence of trained medical personnel. This study aims to show how technologies such as digital video cameras can be used to extract parameters derived from the TUG and Dite tests.

II. Methods

A. Inclusion Criteria

Older persons age 60 and over, able to walk independently with or without aid with an MMSE 20 or over.

B. Data Set

Data from 63 patients was included in the study; however data from 11subjects was excluded due to occlusion of one or both camera lenses. Thus the data analyzed consisted of 29 subjects with history of falls and 23 without. The mean age is 70.9, the mean weight 74.2kg, and there are 36 females and 18 males. This data set is a part of larger data set (600 subjects) gathered by our research clinic.

C. Test Protocol

TUG is performed as follows: the participant is asked to get up from a 46cm high chair, walk three meters, turn at a designated spot on the mat, return to the seat and sit down. The time taken to complete the task is recorded by the clinician. The time is measured from the moment the clinician says ‘go’ to the moment the participant sits back on the chair.

In Figure 1 our research clinic Gait Analysis Platform [10], is shown. It utilizes BioMOBIUS™ for real-time data acquisition from multiple data streams: the video cameras, Tactex® floormat and body worn devices (Shimmer®) [11]. The application contains controls for starting and stopping data acquisition during the gait and TUG analysis trials as well as text fields for the clinician to enter any relevant additional comments pertaining to the trial recording; these comments are stored in the SQL database.

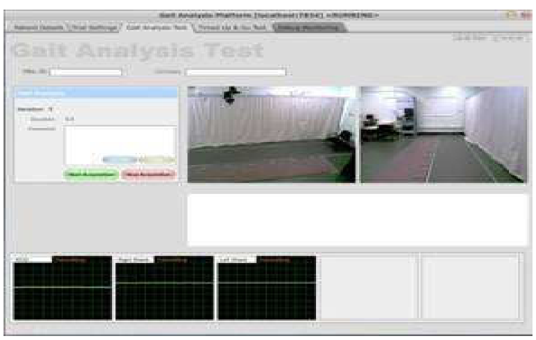

Figure 1: BioMOBIUS based video data acquisition application.

Two webcams with large view angle for video capture were set up. They capture the side and back view as the subject is performing the test. Microsoft LifeCam VX-6000 cameras were chosen as they had a reliable fast capture rate (30fps), gave good clear images (no blurring) as well as a wide field of view necessary to capture a 3m walk. The clinicians used a stop watch for recording the TUG time.

One of the benefits of using BioMOBIUS™ for this application is that all of the data from a single test is synchronously acquired and stored in a single data file.

D. Parameters Required

This study aims to both compare the manual assessment with the automated measurements, and evaluate predictive value of automated measurements. Three categories of parameters were calculated from the video data, including:

- Time of the walk for the TUG test. Defined as the time taken for the subject to rise from the chair and to sit back down.
- Number of steps taken during the TUG test.
- Stability into and out of the turn

E. Video analysis and parameter extraction

The walk time and the number of steps parameters will be extracted using the video from the side camera and the stability is calculated using the back camera video. The top two right hand side windows in Fig. 1 show the two camera views. The cameras are positioned in such a way so as to capture the whole 3m TUG test.

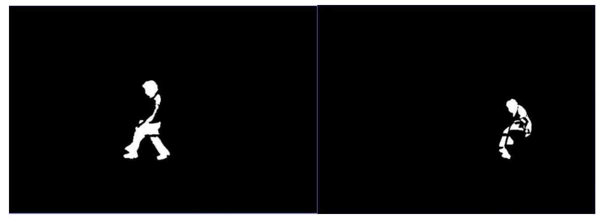

Figure 2: Silhouette of subject sitting and walking (while performing TUG test) derived automatically from video data using BioMOBIUS based application.

F. The Walk Time

To extract the time taken to complete the walk part of the TUG test moments when the subject stands up and sits down need to be captured. First the subject’s silhouette is extracted from the video. Background subtraction is used. A background image of the room without any subject present is taken. This is then subtracted from every subsequent frame. The difference is a silhouette of the subject. To remove some artifacts (e.g. single pixel noise) a median filtering and threshold operations are performed, Figure 2 shows the result of this. To detect the moment the subject stands up the position of the head of the subject is considered. The baricenter of the silhouette head is extracted and its X and Y coordinates noted. When the baricenter of the head crosses a horizontal threshold the person is assumed to be standing, the baricenter position is then tracked until it falls back below the threshold and the person is assumed to be seated again; this is shown in Figure 3. Figure 4 displays baricenter tracking of X coordinate vs. time.

Figure 3: TUG walk data extraction, the baricenter of the head is shown by a white dot (side and back camera views)

The task of automating the extraction of the walk time is complicated by extra people (i.e. clinicians) appearing in the field of view before and after the TUG trial. This was one of the reasons for declaring some of the data unusable.

The walk time is measured from the moment the subject stands up to the moment they sit down. This time is extracted from the baricenter's X coordinate position data, shown in Figure 4. As the subject walks towards the left side of the camera view the X coordinate value decreases until the turn point is reached after which the X coordinate starts increasing again. X coordinate value is zero when the subject is sitting (is below the threshold line). To extract the walk time:

1) First all the local minima and maxima of the X coordinate position are found.

2) For each local minimum that is in the range of the turning point the maxima either side of it are considered, shown in Figure 4. The time at the local minimum is recorded as the walk turn time.

3) If these maxima are in the region of the chair and of similar amplitude and a similar distance from the midpoint, the "*M"* shape is considered to be valid.

4) The time between the two local maxima is taken as the time of the walk (max points are noted in Figure 4). The times of maxima are also recorded as the walk start time and the end time.

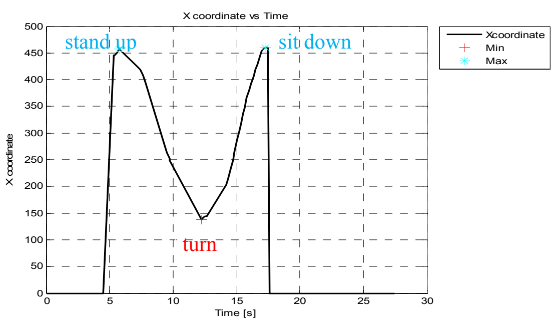

Figure 4: Baricenter tracking. The "M" shape describes the profile of the subject's head during the TUG. The other data shows additional movement in the field of view of the camera.

G. The Number of Steps

To calculate the number of steps taken in the course of the TUG test we first look at detecting a single step. Similarly to the method described above, we first get a silhouette of the subject and then look at the movement of the feet. We can calculate a step by looking the movement of the leading foot. Namely, we look at the foot's acceleration. As the subject starts to move, the foot will first accelerate and then decelerate until it touches the ground. When the rate of change of the foot's displacement is small (near zero); the foot has stopped moving, and a foot fall is assumed to have occurred.

H. The Stability Out of the Turn

Dite et al [4] noted that the fallers are unsteady, less fluent and their movement more hesitant when coming out of the turn and returning to the chair. Furthermore the direction out of the turn was deemed pertinent to stability and balance. The inverted pendulum model [12] explains that the head undergoes a larger displacement than the trunk during lateral movement of the body. The position of the head was easier to extract and track using video based analysis due to partial occlusion of the subject during the walk. To calculate the "stability/fluency" factor, four parameters were examined between the exit of the turn and return to chair:

- The total amount the subject's head veered in one direction from the direct path to the chair
- The magnitude of the lateral motion of the head during the walk to the chair
- The quantity of 'veer' of the subject's head from the direct path over the first half of the walk to the chair
- The maximum displacement of the head from the norm over the duration of the walk

A camera positioned behind the subject was used; the camera was positioned over the left shoulder of the subject when they are seated. A silhouette is, again, extracted and the stumble is tracked by the position of the baricenter of the head. The field of view of the camera (Figure 3) is large enough to take in the subject's head both when they are seated and during the entire walk. A background extraction method similar to the one used to extract the walk time is used to extract the silhouette and its head position. As only the head position is of interest to us, all other portions of the image are blocked out. The X and Y coordinates of the head's baricenter are used for the analysis.

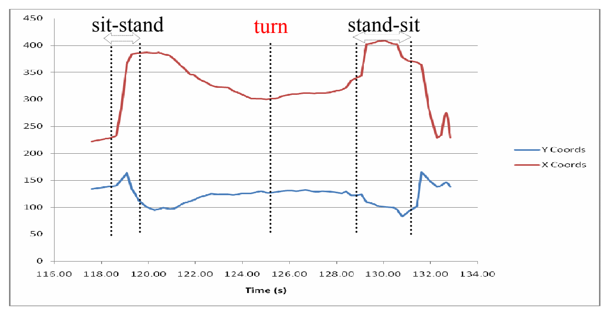

Figure 5: X and Y position of the baricenter of the head from the rear camera during the TUG trial.

The position of the head as seen from a camera behind the subject is tracked during the trial. Figure 5 shows the X and Y coordinates of the subjects head baricenter as viewed from the back camera. Because of the angle of the camera, as a subject walks towards the mark, the X position tends to the left which results in a lower X value. As they return to the chair the X value increases again. It is this section of the data we are interested in. The movement characteristic should be roughly linear with small variation due to each step. The variation from the norm gives us a measure of how much the subject deviated from their course.

Figure 5 shows that the movement in to the turn (the local minima) is relatively linear. But from the turn to the local max, it deviates quite significantly, corresponding to a large veer to the subject's right.

V. Data Analysis

A Wilcoxon Rank Sum test was used to determine how well a given parameter can distinguish between fallers and non-fallers (a p-value $p<0.05$ was considered significant).

The automatically derived timed up and go (automatic TUG) was compared against the TUG values measured manually in the clinic. The manual value was recorded upon completion of the test, i.e. the time measured by the clinician using a stopwatch.

When comparing the automatic to the manual values we did see a large error in the case of the TUG time. On average the automatic TUG time (walk time) values were 2.5s less than the manually measured ones. This can be explained due to the fact that the manual time is recorded from the time the clinician manually initiates timing to the time the clinician judges that the subject has sat back down and stops timing. In contrast, the automated walk time is measured from the time the subject's head crosses the trigger point as the person stands up and then crosses the same point when they sit down. Thus the walk time does not correspond exactly to the manually recorded TUG time.

VI. RESULTS

Numerical results for each of the parameters derived automatically from the video files are tabulated in Table 1. Results of this study show that clinically useful parameters can be derived automatically from routinely recorded digital video footage. Out of the eight reported parameters, two (Automated walk time and the difference between the End Time and the Turn Time) are shown to provide significant discrimination between fallers and the non-fallers. Figure 6 shows class specific histograms of the two parameters. One that showed significant differences between faller and non-fallers populations (End Time – Turn Time) and one that did not (manual; TUG time).

VII. DISCUSSION

The automated walk time was shown to be a better predictor of falls than the manual TUG time. This is assumed to be because of both the objective nature of the automated process and the removal of communication time lag between the clinician and the subject. The total variation in the position of the head out of the turn back to the chair is also shown to be as significant as the manual TUG.

This study showed how pervasive technologies can be used to extract a number of movement features from video data. The features were inspired by clinical tests used to identify elderly people at risk of falls. Our eventual aims and improvements to the system include:

- Develop a fully automated, clinically relevant TUG and Dite inspired test
- Deploy in non controlled environments
- Automate extraction of gait and other parameters for prediction of falling

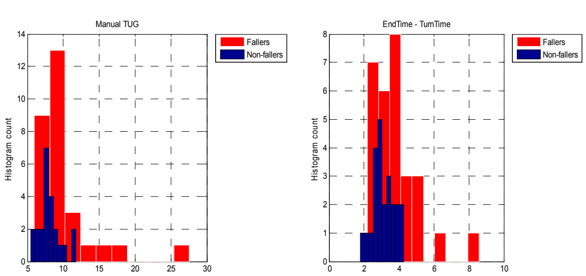

Figure 6: Histograms of manually recorded time of TUG and the [Walk End Time - Walk Turn Time] variable for the faller and non-faller groups.

TABLE I. VIDEO DERIVED PARAMETERS FOR THE FALLERS AND NON-FALLERS GROUPS. *STATISTICALLY SIGNIFICANT DIFFERENCE BETWEEN FALLER AND NON-FALLER GROUPS.

	Fallers (n=29) Mean±Std	Non-fallers (n=23) Mean±Std	Rank sum	p- value
Manual TUG [s]	9.88±4.21	8.10±1.60	509	0.07
Automated walk time [s]	7.44±3.54	5.92±1.31	497	0.04*
No. of steps	10.1±2.53	9.09±2.54	533.5	0.16
TurnTime-StartTime [s]	3.61±2.31	2.77±0.72	514	0.08
EndTime-TurnTime [s]	3.83±1.3	3.15±0.64	494	0.03*
Total variation (of head from the norm)	-6.94±1052.11	-391.87±1511.51	436	0.07
Max Veer (first half of walk back)	13.06±18.89	7.83±9.94	453	0.15
Max Deviation (over the walk)	28.43±30.53	26.24±36.05	488	0.46
Veer	469.12±937.37	566.65±1451.84	471	0.28

VIII. ACKNOWLEDGMENT

This study has been significantly accelerated and delivered as a result of funding from the TRIL Centre. The TRIL Centre is an active research collaboration between industry and academic partners including Intel, Trinity College Dublin, University College Dublin, and the National University of Ireland, Galway. The Centre has created dedicated laboratories at Intel and in each of the universities involved and is driving bi-directional knowledge and technology transfer through the collective work of a multidisciplinary team. (www.trilcentre.org)

IX. REFERENCES

[1] Shumway-Cook et al. "Predicting the probablity for falls in community-dwelling older adults using the timed up and go test", Phys Ther 2000; 80 (9): 896-903.

[2] Kent S, and Fildes B; "Injury hospitalisationa and deaths, in: Hazard, Melbourne", Monash University Accident Centre, 1994;19:11-13.

[3] Grannata K. P., and Lockhart E. T., "Dynamic stability differences in fall prone and healthy adults", Journal of Electromyography and Kinesiology 2008: 172-178.

[4] Dite W, Temple VA. Development of a clinical measure of turning for older adults. Am J Phys Med Rehabil 2002;81(11):857-66; quiz 867-8.

[5] Mathias S, Nayak USL, Isaacs B, "Balance in elderly patients: The "get up and go" test", Arch Phys Med and Rehabilitation 1986; 67:387-9

[6] Podsiadlo D, Richardson S. "The timed ''Up & Go'': a test of basic functional mobility for frail elderly persons", J Am Geriatr Soc. 1991;39:142–8

[7] Demura S, Uchiyama M. "Proper assessment of the falling risk in the elderly by a physical mobility test with an obstacle", Tohoku J Exp Med 2007;212(1):13-20.

[8] Paquette C., Paquet N., and Fung J. "Aging affects of rapid head motions with trunk and pelvis movements during standing and walking", Gait and Posture 2006;24(1):62-69

[9] T.E. Shubert et al. "Are Scores on Balance Screening Tests Associated with Mobility in Older Adults?", Journal of Geriatric Physical Therapy Vol.29;1:06

[10] O'Donovan K., Dishongh T., Foran T., Leahy D., Ni Scanaill C., "The development of a clinical gait analysis system" ICAMPAM, Rotterdam, Netherlands, May 21-24, 2008

[11] http://www.biomobius.org/

[12] Gage W ., "Kinematic and kinetic validity of the inverted pendulum model in quiet standing", Gait and Posture;19 (2):124-132.