

Quantitative Analysis of 180 Degree Turns for Fall Risk Assessment Using Video Sensors

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Abstract—In this paper, we present a method for quantitatively and objectively assessing 180 degree turns using low cost video sensors. A three-dimensional voxel reconstruction, which is built using silhouettes captured from two calibrated web camera views, is used to represent the human body. Experiments were conducted in which participants performed the standard Timed Up and Go tests where 180 degree turns are evaluated. Our two calibrated cameras captured the images during the test. Two key parameters including turn time and turn steps are extracted using the voxel data. Good agreement for the turn time was found for our system compared to the expert rating. The extracted numbers of turn steps are one step less than the expert rating in many test runs. The difference comes mainly from the nature of the pivot turns, and the turn time difference between the expert rating and the algorithm, namely the determination of the time duration from the beginning to the end of the turn. The development of this technology provides potential for assessing 180 degree turns in the home setting as part of a balance, stability and fall risk assessment tool.

I. INTRODUCTION

Turning around is a frequently performed task for older adults during activities of daily living. It is a motor skill required for independent living without substantial risks of injury. It has been shown that impaired turning increases the risk of falls and fall injuries. In addition, difficulty in turning can be associated with cerebellar disease, hemiparesis, visual field cut, or reduced proprioception. Short shuffling steps with en bloc turning suggest Parkinson's Disease [1]. A normal turn requires a pivot. One foot is kept on the ground and rotation occurs on the ball of that foot. The patient with Parkinson's Disease turns "en bloc," in one piece, using two or more steps. Sometimes the patient turns in a large circle, as if making a U-turn. Turning frequently causes loss of balance, in all gait disorders [2].

The 180 degree turn performed at the 3-m mark of the Timed up and Go (TUG) test is a natural candidate for evaluating turns. Turns of this magnitude are performed during activities of daily living, with 13% of turns within the home being between 166 and 210 degrees. Also, a turn of this magnitude is considered to contain a complex enough gait pattern change to bring out any balance or mobility

difficulties present. Therefore, this turn is well known and frequently used within the field of rehabilitation [4]. A 180 degree turn test has been reported by Dite and Temple for its reliability and validity of a 3-item turn test in a sample of adults aged over 65 years. This turn test was evaluated by using a videotaped performance during the 180 degree turn of the TUG test. The 3 items were as follows: (1) number of steps in the turn (turn steps), (2) turn time (in seconds), and (3) appears steady, moving fluently and without hesitation (rated as yes or no). Turn time and number of steps were scored as continuous level measurements.[3] The time taken to turn, and the number of steps in the turn achieved strong correlation with existing balance measures and high sensitivity for identifying multiple fallers. [4].

Recent technology development has made it possible for a more detailed and quantitative assessment of the turn movement, allowing for more objective and sensitive determination of fall risk. Greene et al [5] used inertial sensors consisting of a triaxial accelerometer and triaxial gyroscope for quantitative fall risk assessment using the TUG test, with the 180 degree turn as part of the assessment. Salarian et al [6] used inertial sensors to analyze the 180 degree turn for early signs of progression of Parkinson's Disease. Skrba et al. [7] used automatically extracted video-based parameters to quantify turning in elderly adults while performing the TUG. However, 2 uncalibrated video cameras were used without 3D information. This approach is affected by view angles and only suitable for lab settings.

The TUG and Dite turn 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.

The study reported here aims to show how low cost video sensors, such as web cameras can be used to extract turn parameters derived from the TUG test. A two-camera system developed in our lab is used to objectively assess the 180 degree turns. Our approach of using 3D voxel data has eliminated the limitation of a controlled walking path, and is thus suitable for daily assessment in the home environment.

Section II describes the turn-around analysis methodology. Section III presents experiments, results and discussion. Section IV summarizes.

II. METHODOLOGY

A. 3-D Voxel Reconstruction from Silhouettes

As an initial stage in the analysis, a silhouette extraction is performed to segment the human body from the background.

Manuscript received April 15, 2011. This work was supported in part by the U.S. National Science Foundation under Grant IIS-0703692.

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This step not only defines the region of interest, but also helps protect the privacy when monitoring an elderly person in the normal daily living environment. Our research shows that elderly residents do not consider the use of silhouette imagery to be a privacy invasion [8]. Fused texture, color features, and dynamic background update techniques are used for background subtraction [9, 10]

Our three-dimensional human model, called voxel person, described and used in [11,12], is constructed in voxel (volume element) space by back projecting silhouettes from multiple camera views. The intrinsic and extrinsic calibration parameters of the cameras are estimated *a priori*. Here, the voxel resolution is 1 inch (2.54 cm). Figure 1 illustrates the silhouette extraction and 3-D reconstructed voxel person during a turn.

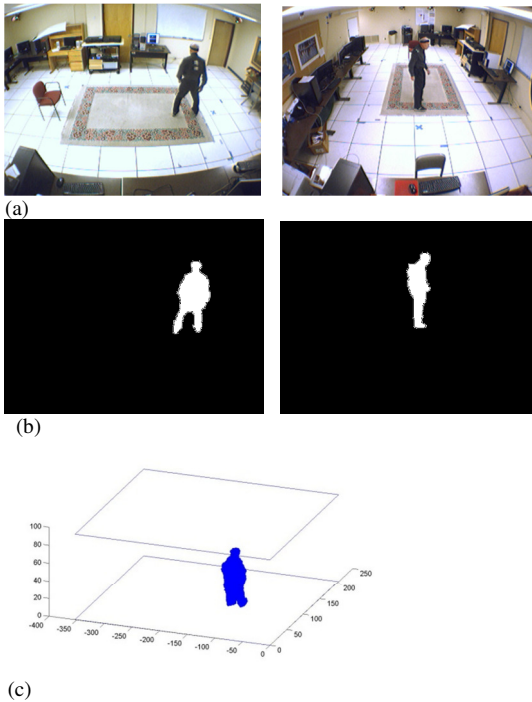


Fig.1 (a) Two raw camera images monitoring the same scene. (b) Human silhouettes (c) The reconstructed three-dimensional voxel person.

B. Turning Time

The body centroid for voxel person is estimated as the mean of all voxel locations detected as part of voxel person for that frame. In Fig. 2(a), a person's body centroid extracted from the reconstructed 3D voxel person is projected onto a 2D plane during a TUG test. The circled region is where the 180 degree turn occurs. The velocity vector V is computed using the centroid locations from the two consecutive frames as illustrated in Fig. 2(b). The angle is then calculated between two consecutive velocity vectors as:

$$\theta = \cos^{-1} \left(\frac{V_1 \cdot V_2}{|V_1| |V_2|} \right) \quad (1)$$

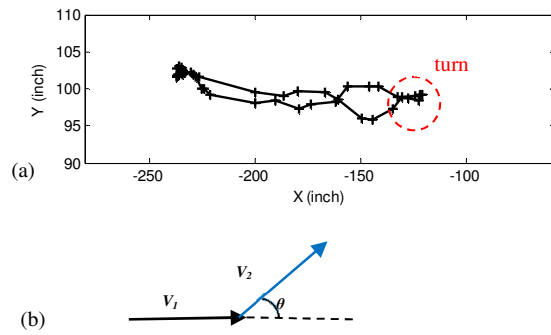


Fig.2 (a) A person's walk and turn trajectory during the TUG test. (b) Velocity vector illustration

The turn starts when the voxel person trajectory begins to deviate from the straight walk, and ends when it returns back to the straight walk. The calculated angles between velocity vectors are shown in Fig. 3. It clearly shows a large angle change where the 180 degree turn takes place.

The extracted angle data is then fitted with a Gaussian model described in Eq. (2).

$$y = y_0 + A * \exp \left(-\frac{(x-x_c)^2}{2w^2} \right) \quad (2)$$

where y_0 represents the offset angle values, A is the peak angle amplitude; x_c is the center of the peak; and w represents the standard deviation. The turn time is defined using the 3-sigma rule, which is $6*w$.

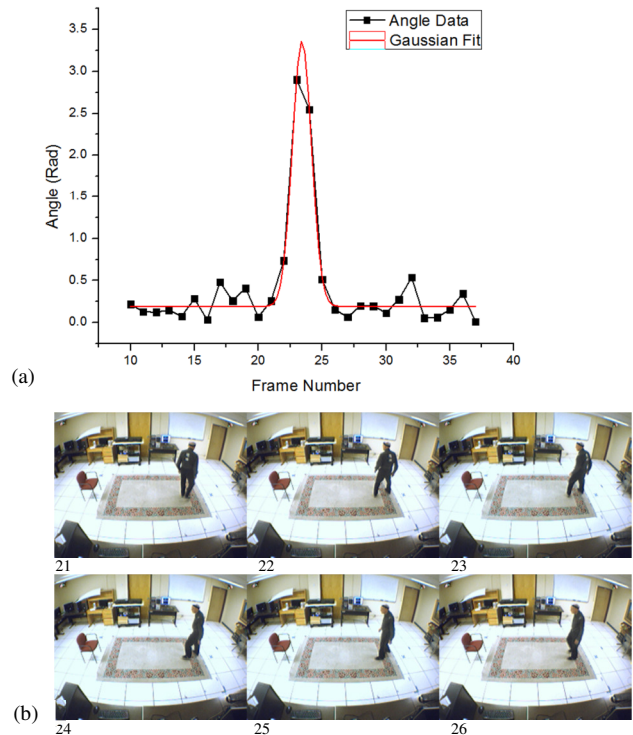
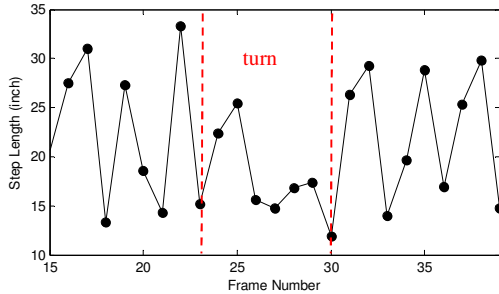


Fig.3 (a) Angles extracted from velocity vectors. (b) Image 21-26 from one camera view detected as a turn using the model.

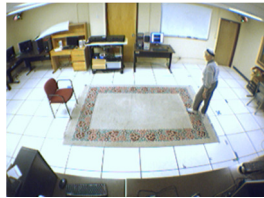
C. Number of Turn Steps

To count the number of steps taken in the turn, we use a method we previously developed to detect steps during

walking [12]. In this method, the voxels with a height below 4 inches from the ground plane are used to capture foot motion. They are projected onto the 2D space, and the length from the front of one foot to the end of the other foot projected along the walking direction alternatively expands (shown as peaks) and contracts (shown as valleys) over time as the person's feet spread and close during the gait cycle (Fig. 4). The number of steps is obtained directly from the number of peaks representing the number of gait cycles. In Fig. 4, a turn is detected from frame #23 to #30, where frame #26 and #29 have peak step length; the corresponding images are shown in Fig. 4(b).



(b) Frame 25



(c) Frame 29

Fig.4 (a) Step length variation during the walk and turn. (b) Images 25 & 29 from one camera view which are detected as peak step lengths during a turn.

III. VALIDATION EXPERIMENTS

A. Experimental Setup

Two stationary cameras were placed in approximately orthogonal locations to record images while the subjects performed the TUG tests. Unibrain Fire-i Digital Cameras were used for the experiments. The images were recorded at a frame rate of 5 and later upgraded to 7.5 frames per second (the upper limit for the webcam used), with an image resolution of 640x480 pixels.

Seven people participating in the test were volunteers with an age range of 25 to 88. All were in good health condition with no fall history. The participants were given instructions identical to those used in the TUG test and were not informed that the turn was being evaluated. A total of 24 test runs were recorded. The recorded videos were later evaluated by a physical therapy expert; turn time and turn steps are rated by the expert for comparison.

B. Results

Turn time extracted from the model is compared with the turn time rated by the expert. Expert scoring started when the participant's first noticeable change in step direction occurs (at foot contact on the floor). Scoring stopped when

the participant's foot contacted the floor on the first step back toward the chair, after both feet were facing the intended direction of travel (back to the chair). Expert scoring was chosen over other means, e.g., a pedometer, because of the challenges in determining the start and the end of the turn.

Fig. 5 and Table I show the turn time comparison results. The turn time extracted from the model has a reasonably good match to the expert's rating. The mean difference is 0.11s, with a maximum of -0.6s and a standard deviation of 0.27s. We have observed that the difference is mainly caused by the fact that the expert scoring focuses on the foot movement, while the algorithm detects the body centroid change. Many times, the participants' foot started to turn, but the body centroid had not deviated enough from the straight walk to be detected as the start of the turn. Similarly, there are cases that the feet appear to exit the turn, but the body is still in the transition stage.

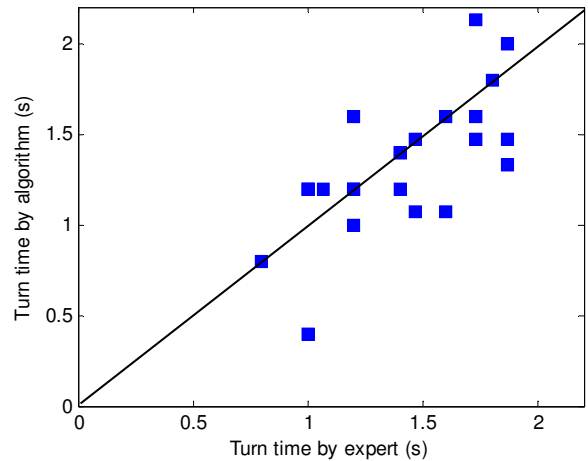


Fig.5 Turn time comparison

Table I. Turn Time Comparison

	Avg diff (s)	Max diff (s)	Stdev (s)
Model vs. Expert	0.11	-0.6	0.27

The accurate counting of the turn steps is a challenging problem, due to the various types of turns as well as the low walking speed and irregular steps people take to complete the turn, such as the smaller or shuffling steps used by those with difficulties in turning. Similar challenges in step counting exist for other type of sensor systems in a low speed situation. For example, as reported in [13], the activPAL Professional single-axis accelerometer sensor system underestimated step counts during walking, especially at slow walking speeds below 0.47m/s.

In our experiment, the turns can be categorized into three types: (1) pivot turn, (2) pivot step turn, and (3) step turn. Four participants took pivot/pivot step turns, with the majority of them being pivot step turns. The carpet surface floor may be a contributing factor in that subjects could not take complete pivot turns easily. The other three participants took step turns. As mentioned, the floor type can affect how a person turns. Our webcam fall risk assessment system should not be affected by the floor type. However, certain

types of flooring are more reflective and may cause shadows which can be challenging for accurate silhouette extraction.

The comparison of turn steps rated by the expert and those detected by the algorithm is shown in Fig. 6, and Table II. The number of turn steps ranges from 1 to 4. Normally, more than four steps indicates increased fall risk [14]. Among the total 24 test runs, the detected number of steps in 8 runs matched the expert's count, and 16 runs have one step less than the expert's count. In the 16 mismatched cases, 10 of them are pivot/pivot step turns, and 6 are step turns.

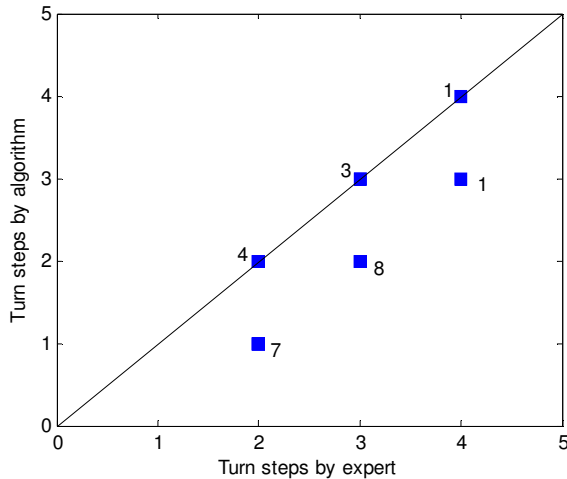


Fig.6 Turn step comparison. Number of test runs associated with each data point is listed beside the data point.

Table II. Turn Steps Comparison

Num. of steps rated by the expert	Num. of steps detected	Number of test runs	Number of pivot/pivot step turn	Number of turn steps
2	2	4	0	4
2	1	7	0	7
3	3	3	2	1
3	2	8	5	3
4	4	1	1	0
4	3	1	1	0

The mismatch in the pivot/pivot step turns case is believed to be due to the nature of the pivot step turns. In one type of the pivot step turn, the person pivots with two feet apart. In this case, the distance between the two feet remains almost unchanged during the turn such that the algorithm only detects it as one step. But the expert considers it as two steps because it involves movements of both feet. In another type of pivot step turn, one foot strides first, and the other foot moves next to this foot, then pivots. The expert scores it as two steps, but the algorithm only detects one step when the first foot strides.

One of the mismatched step turn runs is due to shuffling where the step is too small to be detected under current voxel resolution. The remaining mismatched comes from the turning time differences between the expert and the algorithm.

IV. SUMMARY

We present a methodology for quantitative, objective, analysis of 180 degree turns using low cost webcams. The

two key parameters, turn time and number of turn steps, are analyzed and compared with an expert rating. Turn times have a good match with the expert rating, while turn steps are consistently short by one step during the pivot step turn. Our future work will address these issues as well as assessing 180 degree turns in a more realistic daily living setting with a larger elderly population.

ACKNOWLEDGMENT

The authors would like to acknowledge the members in the Eldertech research team at the University of Missouri for their participation in the tests.

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