MULTIPLE MARKER TRACKING IN A SINGLE-CAMERA SYSTEM FOR GAIT ANALYSIS

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SUMMARY

Human gait analysis for stroke rehabilitation therapy using video processing tools has become popular in recent years. This paper proposes a single-camera system for capturing gait patterns using a Kalman-Structural-Similarity-based algorithm which tracks multiple markers simultaneously. In addition, a Graphical User Interface (GUI) is developed for visualization of the experimental results. The proposed method aims to explore an alternative and portable approach to implement human gait analysis with significantly less cost compared to a state-of-the-art 3D motion capture system.

INTRODUCTION

During a stroke rehabilitation program, stroke patients are encouraged to complete a series of exercises and training modules after the patient's condition has been stabilized. For periodical evaluation, gait and motion analysis systems are widely used to record the change of knee joint kinematics, and give visual feedback for stroke patients. Typically, 3D motion analysis uses multiple infrared cameras to track the spatial positions of reflective markers fixed on the joints of a patient with high accuracy in real time, and compute the knee joint angle simultaneously. However, optical 3D tracking systems can be costly and not easily transported. This paper proposes an alternative, portable and cheaper approach that simultaneously tracks multiple markers in videos captured by a single camera.

METHODS

The objective of the proposed method is to accurately capture patient gait patterns by tracking bulls-eye black-and-white markers stuck to the skin over the joints of the patient and observed with a single-camera video. A scaled walking mat (600cm in length and 70cm in width) is used for helping the subject walk in a straight line. As shown in **Figure 1**, a digital camera (EX-FH20 EXILIM, Casio) with resolution 360x480 pixels and 210 frames per second (fps) was mounted on a tripod (0.5 metres in height) and positioned 2 metres away from the middle of the walking mat. The length of the walking mat covered in the camera scene was 2.9 metres. As shown in **Figure 2** (marked by yellow squares), 7 markers were fixed on the hip, knee, ankle, toe, and heel of a subject's effected leg, and 2 on the heel and toe of the contra-lateral leg. Data was captured simultaneously using the proposed system and a 12-camera Vicon MX Giganet (6 x T40 and 6 x T160) (Oxford Metrics, UK).

The proposed marker tracking method consists of: 1) a Kalman filter [1] which determines the centre coordinate of a marker search area for each marker in the current frame based on the centre coordinates of each marker from the previous frames; 2) Structural SIMilarity (SSIM) [2], which is an image processing algorithm from an image formation point of view. In our experiments, it was used to calculate the similarity value (between 0 and 1) between each candidate block of pixels within the searching area and the template of the marker. The candidate block with the largest similarity value is chosen and the new centre coordinate for the marker is determined. This algorithm was compared to the tracking results of the 3D system.

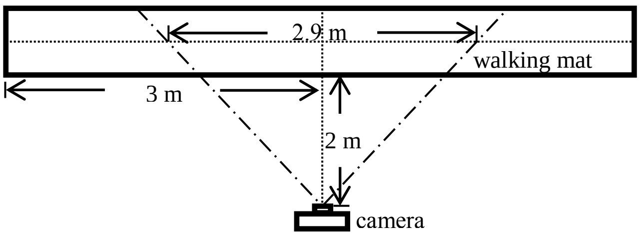

Figure 1: Overhead view of hardware setup.

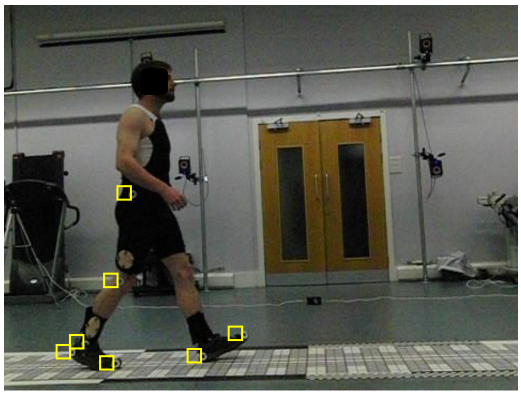

Figure 2: A sample frame in a video sequence.

During the tracking process, the hip marker would sometimes be occluded due to arm swing. Similarly, the contra-lateral heel marker and toe marker would sometimes be occluded due to leg swing. We address this problem by setting an SSIM [2] threshold, i.e., when the maximum SSIM [2] value of the candidate block within the searching area is less than the threshold, the corresponding frame is determined as the first frame of occlusion. The SSIM [2] algorithm continues to process the next frames until it detects a block with a similarity value larger than the threshold, i.e., the hip marker appears after occlusion in the corresponding frame. After this process, a non-linear interpolation process based on the distance between hip marker and knee marker is used to estimate the positions of the hip marker within the occluded frames. A similar process is used to fill the gaps for the contral lateral heel and toe markers.

The centre coordinates of the markers obtained within tracking process were used to calculate the knee joint angle and tibia-to-vertical angle. The knee joint angle obtained by the proposed method and the 3D motion system were compared as were those for, sample trajectories and the tibia-to-vertical angle.

RESULTS AND DISCUSSION

In the experiments, 6 videos of walking from the same volunteer were captured. This set of videos contained 3 left-to-right normal walking videos and 3 right-to-left slow walking videos. These videos were analysed and then decimated from 210 fps to 100 fps to make comparison with the 3D system. Note that a butterworth filter (second order low-pass filter with 0.1 rad/s cutoff frequency) was used to smooth the knee joint angle plots of the proposed method. As shown in **Figure 3**, the plots using the proposed method were in phase with those of the 3D system. The corresponding errors are shown in **Table 1**.

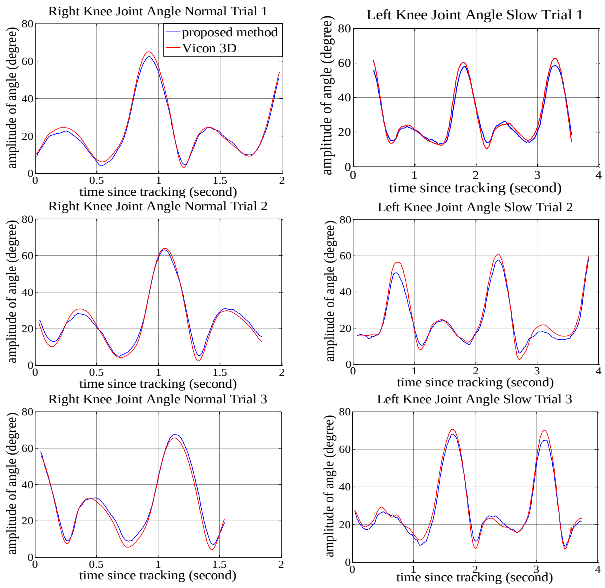

Figure 3: Comparison of knee joint angle plots between proposed method (blue) and Vicon 3D (red).

Table 1: Errors compared to Vicon 3D.

Video	Maximum error (degree)	Mean square error (degree^2)
Normal 1	-4.472	3.564
Normal 2	4.387	4.478
Normal 3	4.483	5.946
Slow 1	-6.278	5.459
Slow 2	-8.371	8.137
Slow 3	-5.891	5.344

The overall proposed method adopts the projected angle from the plane $\boldsymbol{\alpha}$ (determined by hip, knee, and ankle markers) to the camera scene. In fact, the dihedral angle $\boldsymbol{\theta}$ (determined by these two planes) is changing during walking (due to internal or external rotation, combined with abduction or adduction of the leg segments), which makes the projected angle differ from the one on $\boldsymbol{\alpha}$ most of the time. Since 3D motion analysis uses spatial positions of the hip, knee, and ankle joints, the generated knee joint angle is closer to the one on $\boldsymbol{\alpha}$ (actual value) than that using the proposed method. Consequently, as shown in **Figure 3** and **Table 1**, there are several points of intersection and corresponding errors compared to Vicon 3D. However, the two methods show good general agreement as to the shape, timing and magnitude of the knee kinematics of the subject.

In order to visualize the experimental results using the proposed method, a GUI is developed (**Figure 4**). In the GUI one can select the video file he/she would like to process and determine the number of markers to track. The template markers can be selected by mouse-clicking within the “current frame” window directly. The appearance and the centre coordinate of each selected marker are then displayed, and they can also be re-selected if they are not suitable. Once the tracking process begins, the appearances of each marker would be displayed in the “tracked markers” panel; the trajectories of the 5 affected leg markers, the knee joint angle, and the tibia-vertical angle are displayed frame by frame (the first, second, and third figure in the second row of the GUI in **Figure 4**, respectively). The butterworth filtered results are displayed in the third row of the GUI. When tracking finishes, automatic gait event detection based on the change of the centre coordinate of each marker is applied (crosses indicate the gait events on the affected leg, diamonds the contra-lateral leg; black: initial contact, green: foot flat, red: midstance, blue: heel raise, pink: terminal contact, yellow: midswing). In addition, one can use the slider below the “current frame” window to select one frame for checking each gait event. Note that the red lines in the knee joint angle plots and tibia-vertical angle plots indicate the current frame the user selects. Unsuitable detected gait events can be corrected by clicking the corresponding knee joint angle in the filtered knee joint angle figure and then clicking the desired position.

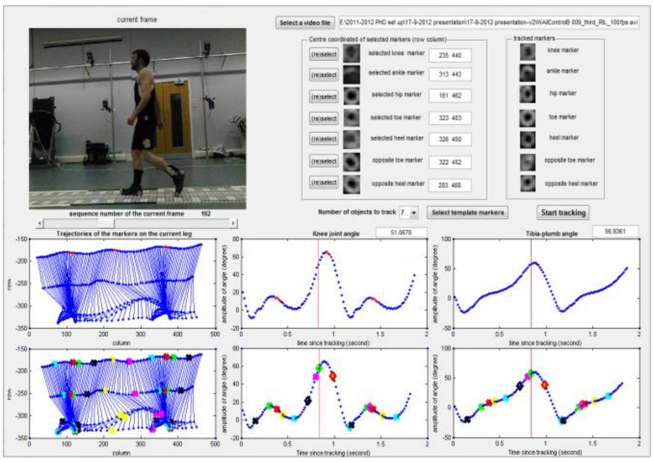

Figure 4: Developed GUI for visualizing the results.

CONCLUSIONS

As a whole, this paper proposes a portable and cheaper approach to implement gait analysis compared to the 3D tracking system. The overall system contains one single digital camera and a tracking algorithm implemented in Matlab. The current trial datasets come from healthy people only. Future work would focus on implementing the system on a smart phone. In addition, the walking pattern of both healthy people and patients will be investigated for generalized automatic gait event detection.

REFERENCES

1. G. Welch, and G. Bishop, “*An Introduction to the Kalman Filter*”, TR 95-041, July 2006.
2. Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, *“Image Quality Assessment: From Error Visibility to Structural Similarity*”, *IEEE Trans Image Processing*, vol. **13**, no. 4, pp. 600-612, April 2004.