DYNAMIC ANALYSIS OF HUMAN MOTION USING HYBRID VIDEO THEODOLITE

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ABSTRACT

Video image sequences often give important information about dynamics of human motion in the field of rehabilitation or sports training. In order to understand dynamic analysis of the natural human motion from video image sequences, the authors have been developing a Motorized Video Theodolite System and Digital Video Camera. Furthermore, in order to acquire digital image sequences and camera rotation parameters simultaneously, these systems were combined and applications for human gait analysis were investigated. However, there were some issues for practical applications of this combined system. These problems include, necessity of increased speed for tracking, 3D data acquisition, and synchronization of video image sequences and camera rotation parameters while tracking.
With this objective, and for multiple applications such as 3D objects modeling or so on, Hybrid Video Theodolite (HVT) System was developed by the authors. The applications of the HVT system for dynamic analysis of human motion are investigated in this paper.

1 INTRODUCTION

Human motion analysis using video image sequence is one of the effective methods in the field of sports training or rehabilitation. Generally, dynamic analysis of human motion using video image sequences has been performed under the condition that camera position and rotation are fixed. Therefore, it is possible to calibrate the camera parameter in advance. However, in order to analyze the most natural human motion, limitation for the camera should be removed.
With this motive, the authors have been concentrating on developing a video theodolite system consisting of a CCD camera, a theodolite and a video recorder. It have been concluded that the video theodolite system have ability to determine camera parameters while recording a moving objects, and the effectiveness of the video theodolite system for dynamic analysis of human motion have been demonstrated [Chikatsu and Murai, 1995, Chikatsu and et. al, 1996, Anai and et al, 1998].
On the other hand, from the viewpoint of digital imaging, the digital video camera system for human motion analysis have been developed by the authors, and the remarkable features of the digital video camera system have been also demonstrated [Anai, Chikatsu and Murai, 1998]. Furthermore, in order to acquire digital sequential images and camera rotation parameters simultaneously, digital video camera was mounted on the motorized video theodolite, and human gait analyses have been performed [Anai and Chikatsu, 1999].
However, there are some issues, which need to be resolved before this combined system may become operational in the field of sports training or rehabilitation. These problems include synchronization with the video theodolite and digital video camera, increasing tracking speed and 3D data acquisition.
For this goal, and for multiple application such as 3D modeling, auto-tracking for moving object and real-time positioning or so on, the Hybrid Video Theodolite (HVT) System was developed by the authors [Chikatsu and Anai, 2000]. After brief describing the HVT, the effectiveness of the HVT System for human gait analysis are investigated in this paper.

2 HYBRID VIDEO THEODOLITE (HVT) SYSTEM

The HVT system consists of 6 parts: sensor, pan head and tilt body, imaging, recording, control and monitors. Figure 1 shows the configuration of the HVT System, and the remarkable points are as follows:

・ Sensor part
+ Stereo image sequences are taken by the CCD 1 and 2 camera (Sony XC-711, 768H×493V)
+ Tracking is performed by the CCD3 camera (Sony XC-75, 768H×493V).
・ Head and body Part
+ Pan and tilt rotation angles are controlled with 10 seconds.
+ Maximum rotation speed of pan and tilt are 45° per second.
+ Rotation of the cameras is synchronous to the rotation for the pan head and tilt body.
・ Imaging part
+ Synchronization for stereo image is performed.
+ Time for each image is generated at interval of 1/100 seconds.
・ Recording part
+ Synchronized stereo image sequences and times are continuously superimposed on image frames and thus recorded on video recorder.
・Control part
+ Pan and tilt rotation angles are controlled.
+ Time, pan and tilt rotation angles are connected, and thus recorded on PC.
+ Tracking is controlled.
・ Monitor part
+ Stereo image with times are displayed on VTR monitor.
+ Time data, pan and tilt rotation angles and tracking image are displayed on PC monitor

Then, the synchronized stereo image sequences, times, pan and tilt rotation angles can be obtained in real-time.

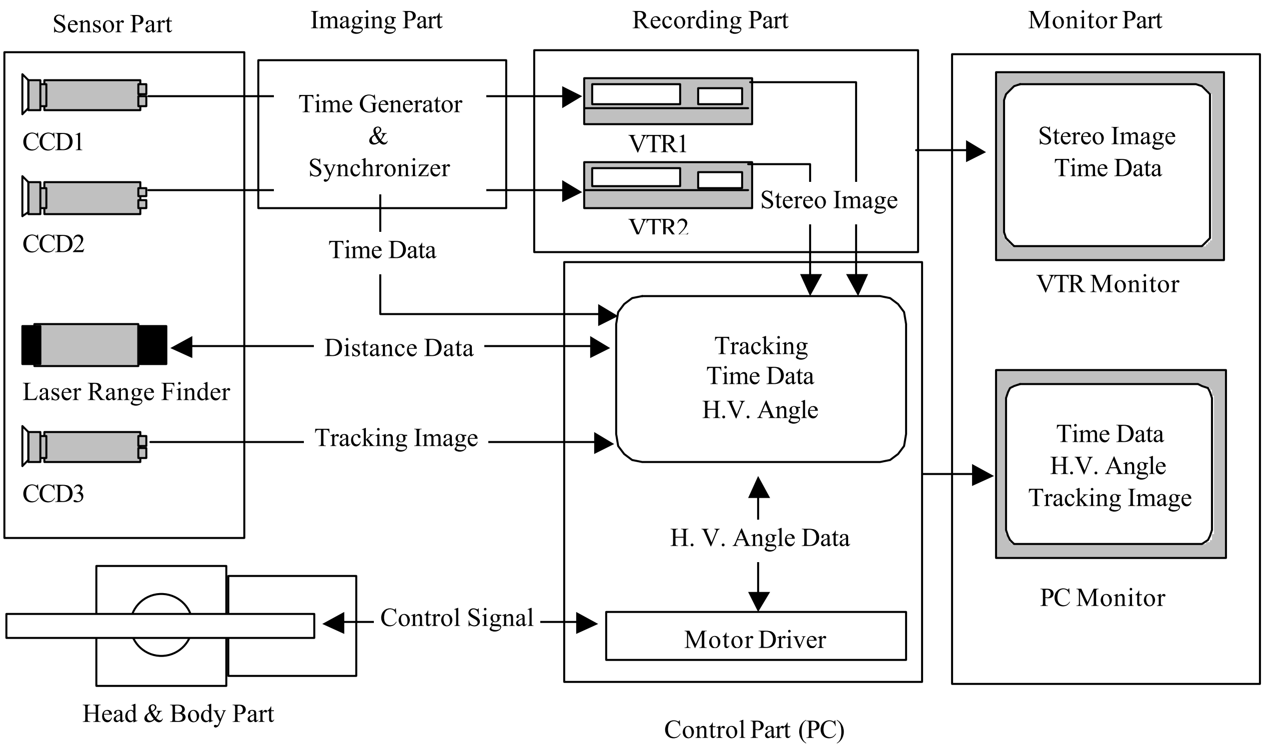


Figure 1. System Configuration

3 HUMAN GAIT EXPERIMENT

In order to evaluate the effectiveness of the HVT System for dynamic analysis of human motion, human gait experiments using the HVT system were performed after camera calibration.
Camera calibration for the CCD1 and CCD2 can be performed by the same procedure in basically for the video theodolite with one target.

Figure 2 shows the HVT system and test field of gait experiment, and experiments procedure are as follows:

+ The subject walked along the 10m course under the condition that the right knee and right ankle was fixed by brace on the assumption of suffer.
+ In order to acquire the 3D coordinate of subject's feature points such as the head, shoulder, knee or so on, markers were fitted on the subject's body.
+ The subject was illuminated by the two video lights mounted on the pan head, and aperture of the cameras were turned down for effective marker extraction.

CCD 3 camera mounted on center of the pan head is connected to PC directly, then image processing for tracking are performed in real-time, and the rotation of the HVT system can be controlled using the results of image processing. The authors developed an auto tracking function for moving object using template matching based on SSDA method in this paper. Figure 3 shows the basic flow of the auto tracking procedure for the HVT system, and detail procedures are as follows:

1. Camera parameters (focal length, scale factor) of the CCD 3 are inputted
2. The HVT is rotated to the start position and image for the subject on the start position is taken. Also, template area and search area are determined.
3. Subject start gait motion.
4. Tracking image is taken.
5. Template matching is performed, and image coordinate for the center of template is obtained.
6. Changing values for horizontal and vertical angle are calculated from image coordinate and camera parameters.
7. Repeating the tracking processing.

In order to increasing the tracking speed, the resolution of tracking image was compressed as150 Pixel (H.) × 120 Pixel (V.) (8 bit monochrome) in this paper. Figure 4 shows the tracking image of this experiment, and the maximum speed of tracking was 12 frames per second.

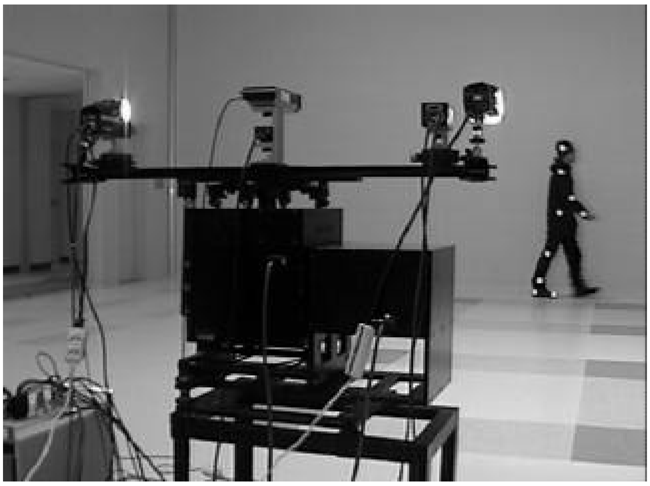


Figure 2. HVT System and Test

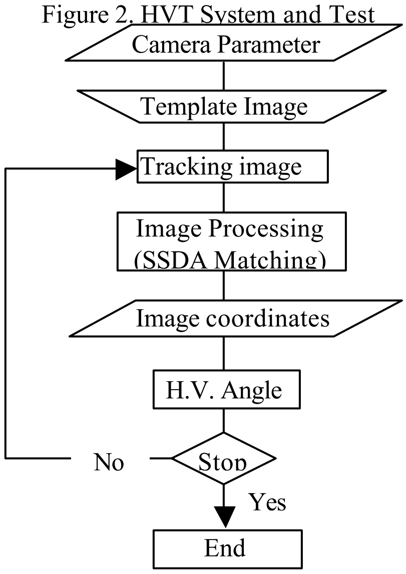


Figure 3. Basic Flow of Tracking

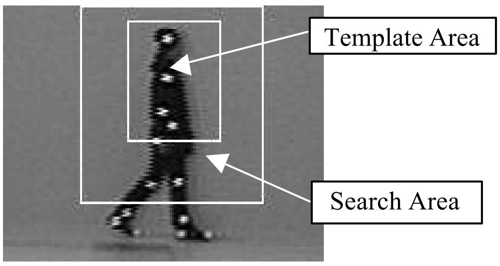


Figure 4. Tracking Image

4 GAIT ANALYSIS

The analysis of walking cycle is effective method for estimation of human gait motion. Generally, Human walking cycle is divided into two phases, i.e., stance phase and swing phase, and each phase consist of following walking elements.

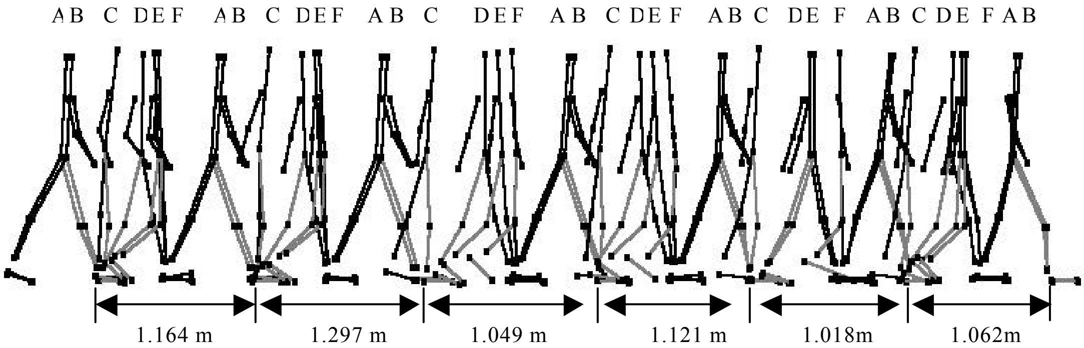
Stance phase
+ Heel strike
+ Foot flat
+ Mid stance
+ Heel off
+ Toe off

Swing phase
+Acceleration
+Mid swing
+Deceleration

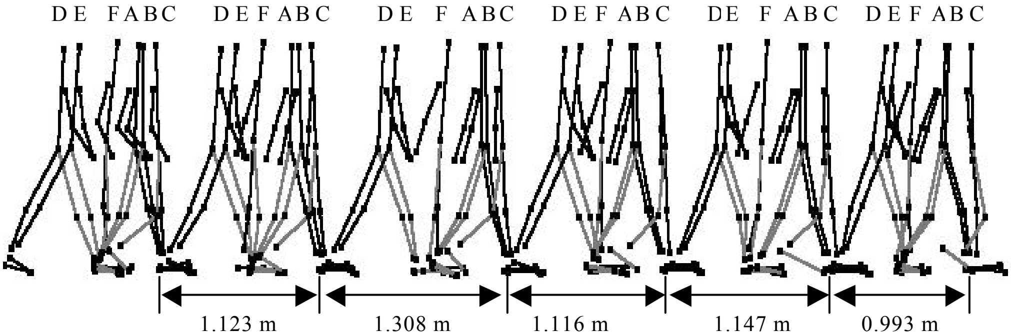
It is reasonable to take into account the movement of some walking elements for gait analysis. Therefore, let assume that gait analysis is performed using walking elements, in this paper.

For this goal, firstly the authors developed a function for automated detection of walking elements from 3D coordinates of human feature points, and the length of stride and walking cycle are obtained from this function.

Secondly, in order to easy understand of human walking cycle, skeleton images for critical elements such as heel strike, foot flat, mid stance, heel off, toe off and mid swing are displayed on PC monitor. Figure 5 shows the skeleton image for critical elements and stride length of subject. Here, let express the walking elements by sign, such as heel strike (A), foot flat (B), mid stance (C), heel off (D), toe off (E), and mid swing (F). Period A and E show acceleration, and E and A show deceleration.



(a) Left Leg



(b) Right Leg

Figure 5. Skeleton Model and Stride Length

It may be seen from Figure 5 that,

1. The average value of stride length for the left leg was 1.118m.
2. The average value of stride length for the right leg was 1.137m.
3. The maximum horizontal displacement of the head was found between mid swing (F) and heel strike (A) in Figure 5(a). However, the maximum horizontal displacement of the head was found between mid stance (C) and heel off (D) in Figure 5(b).

Consequently, it is concluded from the result that the main horizontal locomotion was performed during the swing phase of the left leg.

Figure 6 shows the walking cycle and Figure 7 shows the acceleration of the head in Z direction

It may be seen from these figure that,

1. The average value of one walking cycle was 1.26 seconds for both legs.
2. Stance and swing phase for the left leg are analyzed as 0.80 and 0.46 seconds respectively.
3. Stance and swing phase for the right leg are analyzed as 0.69 and 0.56 seconds respectively.
4. Large acceleration can be found in the left leg, and the peak positions coincide with toe off.

It is evaluated from these results that the deference of walking cycle and acceleration between the left and right leg were occurred by the influence of the braces.

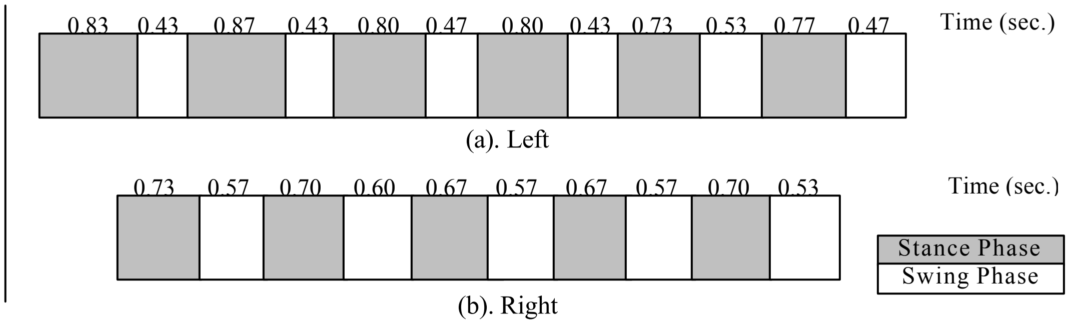


Figure 6. Walking Analysis

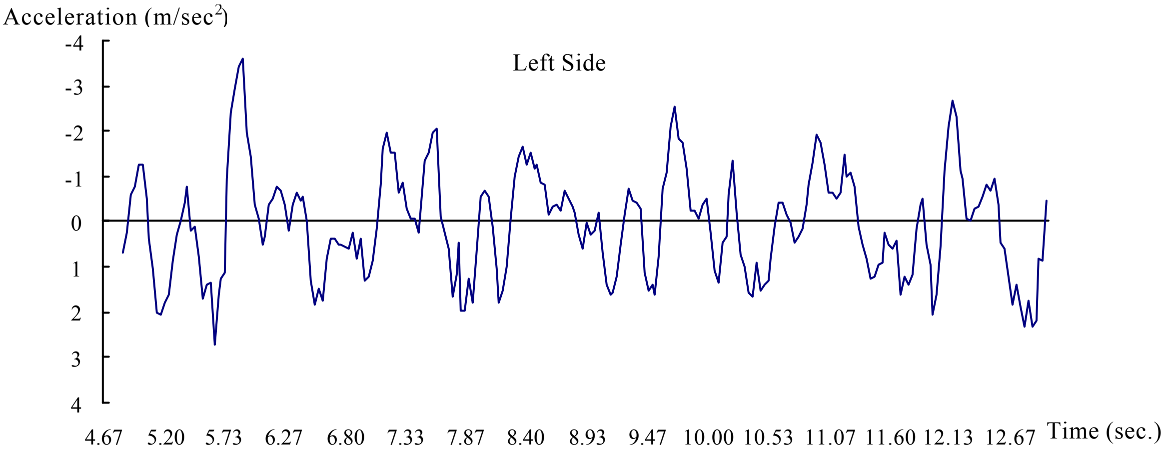


Figure 7. Acceleration of Head in Z direction

5 CONCLUSION

The effectiveness of the HVT System for dynamic analysis of human motion, in particular for human gait analysis were investigated through the gait experiments, and it was confirmed that automated tracking were performed sufficiently and synchronized stereo image sequences were obtained and rotation parameters for each stereo image was acquired in real-time. Furthermore, gait analysis using walking elements obtained by 3D coordinates of human feature points were performed efficiently.

Consequently, it is concluded that the HVT system developed by authors become useful instrument for human gait analysis. However, there are some issues, which need to be resolved before the HVT system becomes operational in the field of sports training or rehabilitation. These problems include, real-time digital imaging, down sizing of the HVT system or so on.

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