AUTO-TRACKING AND POSITIONING FOR MOVING OBJECT USING VIDEO THEODOLITE

Tsutomu KAKIUCHI, Hirofumi CHIKATSU
Department of Civil Engineering
Tokyo Denki University
Hatoyama, Saitama, 350-0394
E-mail: kaki@g.dendai.ac.jp
JAPAN

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ABSTRACT

The authors have been concentrating on developing an auto-tracking and real-time positioning system using a motorized video theodolite. The most remarkable points of the video theodolite system are its ability to obtain the camera rotation parameters and to calculate an object position in real-time while tracking a moving object. For the further application of the video theodolite system to a monitoring system or navigation system for robot, construction machine, traffic flow and human behavior, a test was performed using a radio-controlled car moved irregularly on the ground. This paper describes auto-tracking and real-time positioning techniques using the motorized video theodolite system.

1. INTRODUCTION

Auto-tracking and real-time positioning for a moving object is particularly expected in a monitoring system or navigation system for robot, construction machine and ship. Bayer, et al. (1984) developed real-time positioning system using an electronic camera mounted on a motorized theodolite. However, a CCD camera or CMOS camera recorded in real-time has been expected to become a useful tool in various digital photogrammetric fields. The concept of a video theodolite using a CCD camera was first published in Huang and Harley (1989) for automated camera calibration. Test measurements were performed by Heck (1993) using the video theodolite LEICA TM3000V to get a position of a moving object. The authors have been concentrating on developing a video theodolite system consisting of a CCD camera, a theodolite and a video recorder where the camera rotation parameters can be determined in real-time while recording a moving object. The current values of the rotation parameters are continuously superimposed on image frames and thus recorded as a part of the image data (Chikatsu and et al., 1994). The effectiveness of the video theodolite system for dynamic analysis of human motion has been demonstrated (Chikatsu and Murai, 1995, Chikatsu and et al., 1996) and the application of the video theodolite system to the ski jump also has been demonstrated (Chikatsu and et al., 1997). For the further application of the video theodolite system to a monitoring system or navigation system for robot, construction machine, traffic flow and human behavior, a test was performed using a radio-controlled car in this paper.

2. VIDEO THEODOLITE SYSTEM

Figure 1 shows the motorized video theodolite (SOKKI, MET2NV) used in this investigation. CCD 1, the upper one in the figure 1, is used for precise pointing to the target through the monitor, and CCD 2, the lower one, is used as a finder. In order to take wide scene, CCD 2 camera was mainly used in this paper.

Figure 1 Motorized video theodolite
The video theodolite system developed in this investigation, consisting of a CCD camera, a theodolite and a video recorder where the camera rotation parameters can be determined in real-time while recording a moving object.

The current values of the X and Y coordinates and velocity of a moving object are continuously superimposed on image frames and thus recorded as a part of the image data.

The detail of the CCD camera and the components of the video theodolite system are shown in table 1. Figure 2 shows the configuration of this system.

### Table 1 Components of the video theodolite system

<table>
<thead>
<tr>
<th>Theodolite</th>
<th>MET2NV (Sokkia, accuracy ±2&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD Camera</td>
<td>MET2NV (Sokkia, accuracy ±2&quot;)</td>
</tr>
<tr>
<td>Lens</td>
<td>f=300 mm</td>
</tr>
<tr>
<td>A/D Converter</td>
<td>MTAT-CL (microtecnica, 15.734 kHz)</td>
</tr>
<tr>
<td>Video Recorder</td>
<td>PVM-1464Q (Sony)</td>
</tr>
<tr>
<td>Monitor</td>
<td>HR-SC1000 (Victor)</td>
</tr>
<tr>
<td>PC</td>
<td>Optiplex GXTM 5166 (DELL)</td>
</tr>
</tbody>
</table>

![Figure 2 System configuration](image)

### 3. CAMERA CALIBRATION

Bundle adjustment is applied for camera calibration using 9 control points which were produced in the following procedures:

When the telescope is pointing to P0 point under the condition that the distance is D from the center of the video theodolite to P0, horizontal angle H0 and vertical angle V0, the image point to P0 is taken as p0 on the image. Next, when the video theodolite is rotated H1 angle, the image point to P0 is taken as p1, and the object position to image point p becomes P1. Similarly, when the video theodolite is rotated V1 angle, the image point to P0 is taken as p2, the object to p becomes P2. Repeating this operation, control points are taken on the image and are produced in the space respectively.

Ground coordinates for these control points are calculated with the following equation:

\[
X_i = -D \cos V_0 \sin (H_1 - H_0) \\
Y_i = D \left( \cos V_0 \sin V_0 - \sin V_0 \cos V_0 \cos (H_1 - H_0) \right) \\
Z_i = D \left( \sin V_0 \sin V_0 + \cos V_0 \cos V_0 \cos (H_1 - H_0) \right)
\]

The unknown parameters for the orientation image are as follows: exterior orientation parameters \{ ω, φ, κ \} (rotation parameters), \( X_0, Y_0, Z_0 \) (camera positions) and interior orientation parameters \{ f, x_0, y_0 \} (principal points), \( a_1, a_2 \) (scale factor), \( p_1 \) (lens distortion).

### 4. EXPERIMENT

Figure 3 shows the test site and the rectangular target in this figure corresponds to the above \( P_0 \) point. Similarly, Figure 4 shows a moving object (Radio-controlled car) used in this test.

![Figure 3 Test site and rectangular target](image)

![Figure 4 Radio-controlled car](image)
The relatively slow 4 images acquired per second is perhaps due to the ability of image processing board or MET2NV. Test for auto tracking and real-time positioning was performed while moving the radio-controlled car so that a locus may become "S". The detail procedures for the test are as follows:

- Window is previously cut out and color information for the car is extracted.
- Area gravity for the car are extracted using binarization and labeling procedure.
- Two dimensional ground coordinates for the area gravity can be calculated using the calibration parameters. Since the unknown rotation parameters, $\omega$ and $\phi$ for sequential images can be obtained as the sum of changing vertical and horizontal values resulting in $\omega_i$ and $\phi_i$ for the orientation image respectively and parameters other than $\omega$ and $\phi$ are considered as the same values as the calibration results for the orientation image.
- Due to the discord between the center of the theodolite and the lens of the CCD camera, exposure position for each sequential image has to be corrected to respond to the rotation of the video theodolite.

Velocity for the car can be calculated using the differences in the moved distance and time interval of a front image and a moved image.
- The current ground coordinates $(X, Y)$ and velocity for the car are continuously superimposed on the image frames.
- Rotation angles (vertical and horizontal) of the video theodolite are calculate using the ground coordinate of a front image and a moved image.
- Rotation speed of the video theodolite are then controlled so that the area gravity becomes the center of the monitor using the moved distance.

These procedures are shown in Figure 5.

Figure 6 shows a monitor image while tracking the car. The left-hand number superimposed in the upper left corner shows the ground coordinates for the area gravity of the car ($X = -4.226m$). The number just to the right is the $Y$ coordinates ($Y = -1.545m$) and the velocity (0.651 m/s).

![Figure 6 Monitor Image](image)

![Figure 7 Locus of the radio controlled car](image)
In order to evaluate the accuracy, the sheet reflector was fitted on the car, and the X,Y coordinates at 9 points illustrated in Figure 7 were measured using total station.

Figure 8 shows the X,Y errors for the area gravity. 2-3cm errors can be found due to the height difference between the area gravity and the sheet reflector fitted on the car for the measurement using total station.

Considering the above, it is concluded that the application of the video theodolite system for a moving object is a useful method.

References


