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CCD 카메라를 이용한 이미지 트랙킹 시스템의 하드웨어 구현

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Hardware Implementation of an Image Tracking System Using CCD Camera

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Abstract **- This work describes a hardware implementation of a precision image tracking system which employs a CCD camera mounted on pan/tilt device. Unknown translation between two successive images of a moving object is estimated by using a generalized least-squares method. Estimated position error obtained by the tracking algorithm is used to drive DC motors built in the pan/tilt device for the camera to follow the image. An experimental result shows a sub-resolution tracking error for a image moving with a uniform velocity.**

INTRODUCTION

The processing of image sequences involving motion has become an increasingly important problem. Because of the rapid progress in electronics, we have now reached a stage when many useful processing tasks for image sequences can be done in a reasonable amount of time.

There have been many researches in processing of image sequence. A texture-based system which is able to track the human motion was proposed. Multiple target tracking and opposite motion tracking were also investigated. Recognizing and tracking parts on a moving conveyor belt in a factory enables robots to pick up the correct parts [3,4].

Some important applications such as space-based surveillance systems or missile warning satellites require precision tracking capabilities. For this, one tracking method under investigation employs a forward-looking infrared (FLIR) sensor together with a correlation algorithm to provide relative target position information to the laser pointing system [6]. The correlation algorithm first stores a complete set of intensity data from the image sensors, and then correlates those data with the new information at a later time.

One of the purposes of this research is to derive a precision tracking algorithm which has a better accuracy than the conventional correlation algorithm by using generalized least-squares estimation (GLSE). Sub-resolution tracking is a very important aspect to overcome hardware limits and cost. It also includes DC motor control to alter the angular position of camera fixed in pan/tilt device. Digital PI controller shows a desirable experimental result as a velocity and position control.

PRECISION MOTION ESTIMATION

The basic generalized least-squares estimation (GLSE) problem may be stated as follows. Given a set of N observations, an appropriate weighting matrix and a model from which corresponding observations may be computed, determine the values of M model parameters to minimize the expression

$$Q=[Q_m-Q_c(P)]^T W[Q_m-Q_c(P)] \tag{1}$$

where Q_m is measured observations vector $(N\times 1)$, Q_c is computed observations vector $(N\times 1)$, P is model parameters vector $(M\times 1)$ and W is observation weighting matrix $(N\times N)$. The weighting matrix, W, is usually determined from a priori measurement noise statistics or from experimental knowledge of measurement confidence levels. The observation model function, $Q_c(P)$, usually represents a nonlinear function of P. Consequently, the GLSE problem represents a nonlinear minimization problem.

The relation between successive image is as follows.

$$i_N(x,y)=i_O(x-\delta_x,y-\delta_y)+n(x,y) \tag{2}$$

where $i_N(x,y)$ received image, $i_O(x,y)$ stored reference image, δ_x horizontal(azimuth) shifts, δ_y vertical(elevation) shifts and n(x,y) two-dimensional zero-mean-gaussian white noise. The purpose of the tracker is to obtain the best estimates $\hat{\delta}_x$ and $\hat{\delta}_y$ of the unknown imaginary shifts δ_x and δ_y.

Define

$$P=[\delta_x \ \ \delta_y]^T \tag{3}$$

$$I_N=[i_N(x_1,y_1) \ \ i_N(x_1,y_2) \ \cdots \ i_N(x_m,y_n)]^T \tag{4}$$

$$I_O=[i_O(x_1,y_1) \ \ i_O(x_1,y_2) \ \cdots \ i_O(x_m,y_n)]^T \tag{5}$$

$$N=[n(x_1,y_1) \ \ n(x_1,y_2) \ \cdots \ n(x_m,y_n)]^T \tag{6}$$

Then, with those definitions, Eq.(2) may be expressed as a vector form

$$I_N=I_O(P)+N \tag{7}$$

Eq. (7) represent nonlinear relation of two images. As state above, let the measurement residual by

$$e = I_N - Io(\hat{P}) \tag{8}$$

and objective function to be minimized is

$$Q = e^T We \tag{9}$$

Various methods exist for minimizing an objective function of the type in Eq.(9). One convenient method is to use the Gauss' iterative algorithm [5] which is given by

$$P^{(i+1)} = P^{(i)} - \{[J^T WJ]^{-1} J^T We\}_{P=\hat{P}} \tag{10}$$

If $\hat{P}^{(0)} = 0$, then first iteration is

$$\hat{P}^{(1)} = -\{[J^T WJ]^{-1} J^T We\}_{P=0} \tag{11}$$

Here Jacobian Matrix, J , is

$$J = \frac{\partial e}{\partial P} = -\frac{\partial}{\partial P} Io(P) \tag{12}$$

and

$$J_0^T = \begin{bmatrix} -\frac{\partial}{\partial x_i} io(x_i, y_i) \\ -\frac{\partial}{\partial y_i} Io(x_i, y_i) \end{bmatrix} = \begin{bmatrix} w_x(i,j) \\ w_y(i,j) \end{bmatrix} \tag{13}$$

Assume weighting matrix, W = I

$$J_0^T J_0 = \begin{bmatrix} w_x(i,j) \\ w_y(i,j) \end{bmatrix} [w_x(i,j) w_y(i,j)]$$

$$= \begin{bmatrix} \sum_i^n \sum_j^m w_x(i,j)^2 & \sum_i^n \sum_j^m w_x(i,j) w_y(i,j) \\ \sum_i^n \sum_j^m w_x(i,j) w_y(i,j) & \sum_i^n \sum_j^m w_y(i,j)^2 \end{bmatrix}$$

$$= \begin{bmatrix} C_x & C_{xy} \\ C_{xy} & C_y \end{bmatrix} \tag{14}$$

Generally off-diagonal terms are smaller than diagonal terms so they can be ignored. Finally We obtain the estimated values by

$$\begin{aligned} \hat{\delta}_x &= -\frac{1}{C_x} \sum_{i=0}^{n} \sum_{j=0}^{m} w_x(i,j)[i_N(i,j) - io(i,j)] \\ \hat{\delta}_y &= -\frac{1}{C_y} \sum_{i=0}^{n} \sum_{j=0}^{m} w_y(i,j)[i_N(i,j) - io(i,j)] \end{aligned} \tag{15}$$

Eq. (15) is a similar result to correlation algorithm [6]. For the digital computation, $w_x(i,j)$ and $w_y(i,j)$ are given by

$$\begin{aligned} -\frac{\partial}{\partial x} io(x,y) &= -\frac{io(x+1,y) - io(x-1,y)}{2} \\ -\frac{\partial}{\partial y} io(x,y) &= -\frac{io(x,y+1) - io(x,y-1)}{2} \end{aligned} \tag{16}$$

Image Tracking System

A. Tracking System Configuration

Fig. 1. shows a block diagram of image tracking system. The CCD camera converts the image focused on the CCD sensor into a NTSC type TV signal. It takes about 1/30 sec to produce one frame image. This analog signal is converted into a digitized image data by the image grabber which has a high speed ADC. Typically it has 256(h)×256(v) resolution for non-interlaced TV signal. The tracking algorithm derived above then estimates image shift between two images. Generally we use some portion of the whole image data for saving computational time. The resultant angular difference measured by the tracker, generally referred to the tracker error signal, is used to drive a pointing mechanism to align the sensor line of sight to the target position. The digital PI speed controller is located in the inner loop and speed information is estimated by the observer from the motor voltage and current. A digital PI position controller is also used to reduce the steady state error in tracking the uniformly moving image. Overall hardware scheme is also depicted in Fig. 2.

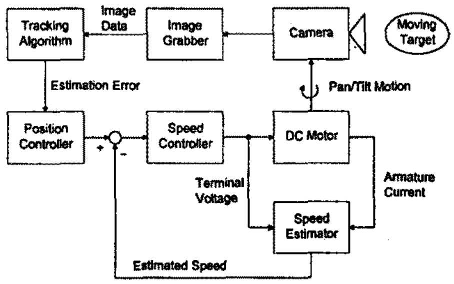

Fig. 1. The Block Diagram of Tracker System

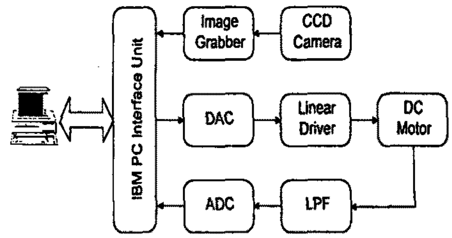

Fig. 2. The Hardware Scheme of Tracker System

B. DC Motor Servo Control

The DC motor dynamic equation is

$$e_a = R_a i_a + L_a \frac{di_a}{dt} + K_b \omega_r \tag{17-a}$$

$$K_t i_a = B\omega_r + J\frac{d\omega_r}{dt} + T_L \tag{17-b}$$

Assuming the effect of B and L_a as negligible and including the gear ratio, k,

$$L_a = B = 0,\ K_b = K_t = K_m,\ \omega_r = k\omega_c,\ T_c = kT_r \tag{18}$$

Subscript c means camera and r rotor. This simplified dynamics ignores electrical time constant which is smaller than the mechanical time constant.

$$\begin{aligned} \frac{d\omega_c}{dt} &= -\frac{(K_m')^2}{J'R_a}\omega_c + \frac{K_m'}{J'R_a}e_a - \frac{T_L'}{J'} \\ i_a &= -\frac{K_m'}{R_a}\omega_c + \frac{1}{R_a}e_a \end{aligned} \tag{19}$$

where

$$\begin{aligned} &K_m' = kK_m,\ J' = k^2 J,\ T_L' = kT_L \\ &\tau_m' = \frac{J'R_a}{(K_m')^2},\ \ \tau_e = \frac{L_a}{R_a} = 0 \end{aligned} \tag{20}$$

For the purpose of digital control it is desired to convert a continuous-time system into a discrete-time system. This may be achieved by adding a ZOH before the plant. In direct discrete design of digital controllers, the continuous-time plant is first discretized. Then, a controller is designed for the discrete-time system. Direct discrete design gives more accurate performance than those by continuous controller redesign using the BLT or the MPZ, while also allowing larger sample periods T [1]. We have discrete-time system as follows.

$$\omega_c(k+1)=A_d\omega_c(k)+B_d e_a(k)+E_d$$

$$i_a(k)=C\omega_c(k)+De_a(k) \tag{21}$$

where

$$A_d=e^{-\frac{1}{\tau'}T},\ B_d=-\frac{1}{K_m'}(e^{-\frac{1}{\tau'}T}-1),\ C=-\frac{K_m'}{R_a}$$

$$D=\frac{1}{R_a},\ E_d=\frac{\tau' T_L}{J'}(e^{-\frac{1}{\tau'}T}-1) \tag{22}$$

In the pan/tilt device we used, it was impossible to attach a speed sensor to get speed information. Therefore, the speed information for DC motor drive was obtained by a speed observer which estimates the speed by the use of terminal voltage e_a, and armature current i_a. The state estimator dynamics is given by

$$\hat{\omega}_c(k+1)=A_d\,\hat{\omega}_c(k)+B_d e_a(k)+L[i_a(k)-(C\,\hat{\omega}_c(k)+De_a(k)]$$

$$=(A_d-LC)\,\hat{\omega}_c(k)+(B_d-LD)e_a(k)+Li_a(k) \tag{23}$$

and the estimation error dynamics is

$$\tilde{\omega}_c(k+1)=(A-LC)\,\tilde{\omega}_c(k)=A_0\,\tilde{\omega}_c \tag{24}$$

The observer design problem is to select observer gain matrix, L, so that the error vanishes reasonably quickly.

Experimental Results

The moving image was generated on the PC monitor. For experimental purpose image motion was restricted to only horizontal direction with a relatively simple target shape and noiseless background. Rectangular shaped target was reciprocated on the monitor about 60 [mm/sec]. We used 1/2 inch CCD sensor and the focal length of lens is 16 [mm]. The distance between image and camera is 1.75 [m]. For the 256 pixels in the horizontal direction, the unit angle corresponds to a pixel is about 0.089 [deg/pixel] and unit distance is about 2.75 [mm/pixel].

The sampling time, T, was 0.01 [sec] and during which the motor current is observed to estimate the angular speed of the camera. Image data is transferred to tracking algorithm from image grabber buffer memory and generate error signal every 0.03 [sec]. Experimental result is illustrated by Fig.3 and Fig.4. The estimation error is shown to be within a sub-pixel. The estimated camera rotational speed is approximately 0.034 [rad/sec] which corresponds to 60 [mm/sec] image motion.

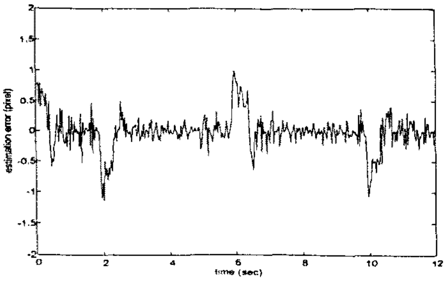

Fig. 3. The Error Signal Obtained by GLSE Tracker

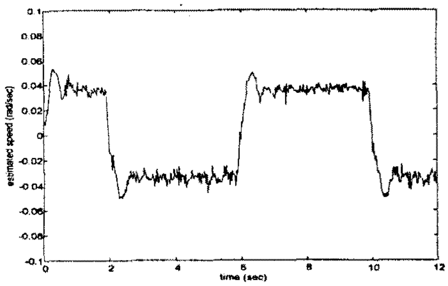

Fig. 4. The Estimated speed of a Camera

Conclusion

We have demonstrated a precision tracking performance of an image tracker through the new tracking algorithm based on the GLSE and the hardware consisting of CCD camera and pan/tilt motor systems, which forms a control system with an optical feedback. Further research should include the studies on the effect of SNR (signal-to-noise ratio), background disturbances and small target spot size relative to detector size. In many practical tracking problems the type of target being tracked may be known. This implies that certain target parameters such as shape, size, and acceleration characteristics will either be known or could be estimated. Moreover, the statistical effects of atmospheric disturbances are known and could be supplied to the tracker that would aid in separating the true target motion from the apparent motion (jitter) due to these disturbances. Currently, the research is underway to analyze and enhance the tracking performance and robustness of the filter in more realistic environment, especially in the presence of background clutter.

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