Vision Based Surveillance System using Low-Cost UAV

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Abstract. This paper describes the development of a surveillance system in the laboratory for small unmanned aerial vehicles (UAV). This system is an important equipment of a mission-oriented UAV. For making a good performance on search, this can track images and take 3-D measurement of a target as well as acquire high quality images. Image tracking is carried out by the Kalman Filter. The position of the target in an image and the relationship among the coordinate systems of the UAV and the Camera and reference are used to solve the 3-D position of the target in real coordinates. This paper presents the hardware system as well as algorithm for the EOS, and then verifies the performance of the image tracking and real-time 3-D measurement of a target's position. Especially, to reduce the 3-D measurement error of the target, Linear Parameter Varying (LPV) is applied to the measurement system. The performances for their algorithms are presented in the figures in this paper.

1 Introduction

Recently, interest about UAV system has been increased. Basically, guidance and control were researched. After UAV system had ability to make a stable performance, some researchers are finding new algorithm to make a good result, like as neural network, fuzzy algorithm. Others make efforts to get a satisfied result using the exact measurement, UAV's attitude, position and velocity and target's position and velocity.

To get the accurate measurement about UAV and target, INS and GPS system are being studied. Also, machine vision system is being researched, recently. Vision system on UAV is necessary to acquire information of target and operate missions, such as surveillance and rescue at mountain or ocean. For civil system, to observe fire place at mountain is researched [1], and searching algorithm to track person or car at the urban is studied [2].

To measure 3D position of target using monocular vision, perspective matrix is used mostly [3]. This is easily to solve the position in image or real world with consider attitude between camera and target. However, algebra equations from perspec-

tive matrix are under determinant. To get the answer about the position, we need to know some points.

On the contrast, we can know distance between UAV and ground using GIS. If altitude of UAV and target in ground is known, perspective matrix is not necessary. We can acquire position through only relative equations about image and real world coordinate system. In this paper, nonlinear filter is employed to estimate 3-D position of target. Filter gains of this are derived by linear parametric varying system of error dynamics. This algorithm will be introduced and verified at chapter 4. Chapter 2 explains guidance/control, and hardware system on our UAV. Chapter 3 represents vision system.

2 UAV System

2.1 System Description

In this paper, the UAV system was used to study and design the algorithm that will allow image tracking and 3-D measurement of the position of the target in real space using a monocular image. Specification of UAV, used for experiment is PNUAV that we made ourselves, is represented in Table 1.

Table 1. Specification of PNUAV.

Wing Span	2,050mm
Wing Area	79.5 sq·dm
Empty Weight	3,300 g
Fuselage	1,633 mm
Class of Engine	19.96 CC

The flight control system consists of the main controller, GPS, Attitude Heading Reference System (AHRS), actuator, communication system, power supply and ground control system (GCS).

The AHRS offer the plane's attitude and position information to the sub-processor, that is, the main processor, which calculates algorithm to control the surface of plane directly via the actuator. Also, the states of plane can be observed at the ground station via the communication system, which can be used to transmit the control command to UAV from ground system when needed.

The GPS receiver that was used has comparative high performance and authoritativeness by altitude range in 18km and speed range in nearly 1850km/h that measuring is possible, produced by NovAtel Inc. Data output mode used NMEA, and used the GSA protocol which supplied position information and GGA protocol which included satellite information.

The RF data modem is used as communication device that receive and confirm all sensor data of UAV, when UAV is in flight. The antenna in the modem greatly affects the communication equipments. A directional antenna has a big gain value, but the UAV uses non-directional dipole antenna to considering the UAV has wide active area.

2.2   Guidance & Control

The UAV has various waypoints, where it can obtain images and drop the something (like a bomb), so the correct/accurate passing of the waypoint is a very important performance index of the operation of the UAV. Point navigation guidance is used in the flight test. The guidance logic is based on the difference between the line of sight angle, which is measured from the reference axis to the waypoint, and the UAV's heading angle, which is set as an error, that is made to be zero. In a straight level flight, the angle of the velocity vector and the LOS angle are used for lateral direction control. The longitudinal direction guidance uses proportional control that is based on the difference between the present altitude and the target altitude.

When only the P controller is used, the overshoot increases. On the other hand, if the PID controller is used, the steady state error will be reduced. However, I gain has less influence on flight performance and the computation load is added to the main processor. For this reason, the PD controller was used. It used the fluxion of angle, so it makes different to the weight of control. That is, the effect of fluxion is small when the flight to straight. However, if the LOS angle grows, the control value will increase, and then the UAV will show a fast response.

When the UAV passes a waypoint, without converging, the waypoint is in the minimum turning range. The UAV will fly, turning many times. Therefore, in this case, the UAV must escape the minimum range to follow the former control command. Fig. 1, it shows the geometric relations of UAV's flight range and the waypoint.
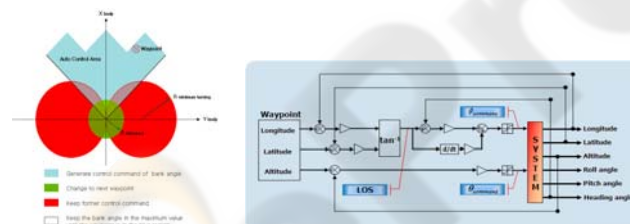

Fig. 1. control range at body axis (left), design PD controller (right).

3   Vision System

The vision system of PNUAV consists of a transmission system, gimbal controller, and image acquisition system. The gimbal controller provides the control input for pan and tilt movements. Camera zoom and focus are also controlled by the gimbal controller.

On the ground, two ground control system (GCS) operate to command and acquire information. One is the data GCS that can show the state of the UAV and command the UAV to fly on waypoint or to achieve missions. The other is the vision GCS.

The vision GCS is built using LabVIEW. This provides the image from PNUAV, and has a command window where the user can input the angle of gimbal's pan and tilt or other control inputs. Command from the user input is transmitted to gimbal

controller through data GCS. Data GCS sends control inputs to move the vision system, as well as to maneuver the UAV.

3.1   Derivation of Arithmetic Range

In this paper, the dynamic relationship among the UAV, vision system, and GCS is derived. The 3-D position of the target is calculated from a monocular image as shown in Equations (1) and (2).

$$x = f\frac{X}{Z} \tag{1}$$

$$y = f\frac{Y}{Z} \tag{2}$$

Where, f is focal length, (x, y) is the position in the image, and (X, Y, Z) is the position in the real spacer. If the position along Z-axis is known, the 3-D information can be determined.

However, the 3-D information from Equations (1) and (2) is the result with respect to the camera frame. To transfer the coordinates from the camera to the reference frame, the attitudes of the camera and UAV are necessary. The attitude of a UAV with respect to a body fixed coordinate, is known as an onboard AHRS.

To get the position along Z, we assume the following ; 1) target is on a flat plane(zero altitude), and 2) the attitudes of UAV and camera can be measured. Using directional vector from the camera axes, the attitudes of the UAV and camera are obtained. A linear equation on 3-D is made from a unit directional vector from the camera to the target at zero altitude. The distance along Z-axis can be derived from a linear equation. Equations (3) and (4) represent the unit directional vector and the distance along Z, respectively [4].

$$\vec{l} = \left(T_V^i\right)^{-1}\left(T_C^V\right)^{-1}\begin{bmatrix} 0 & 0 & 1 \end{bmatrix}^T \tag{3}$$

$$\|\vec{m}\| = \sqrt{\left(\frac{l_1 z_v^i}{l_3}\right)^2 + \left(\frac{l_2 z_v^i}{l_3}\right)^2 + \left(z_v^i\right)^2} \tag{4}$$

Where, $\vec{l}$ is the unit directional vector between the camera and the target, T_V^i is the Euler transformation matrix of the UAV attitude with respect to the reference, and T_C^V is the Euler transformation matrix of the camera attitude with respect to the UAV. z_v^i is the altitude of the UAV with respect to the reference frame.

3.2   3-D Measurement using LPV

Method using arithmetic derivation can cause an error because of sensor noise. The result of this algorithm depends on the attitudes of the UAV and camera. This type of error is made at initial installation and by drift.

To reduce the error caused by the attitude sensor, the filter, which was studied, is applied on the 3-D measurement using monocular vision. The basic and popular filter is the Kalman filter for the estimation of the 3-D position. However, the dynamics derived to measure 3-D position of the target by monocular vision has nonlinearity. Although the Kalman filter can be applied on a nonlinear system, system error can be caused by the assumption of linearization. Therefore, the extended Kalman filter or a particle filter can be more effective. However, these filters are too complex to design and run. LPV, on the other hand, can be applied easily on the 3-D measurement of a target, and is effective on nonlinear systems.

General EOS uses a laser range finder or other measurement equipment to measure the distance between the camera and the target. Such additional equipment increases the weight and complexity of the system. Thus $\|\vec{m}\|$, which is derived for deciding the distance using the attitude and position of the camera and UAV, is used in this paper.

To improve the result in a asynchronous system, a modified nonlinear filter is derived. In [5], this filter is used on an out-of-sight problem. However, in this paper, filter is modified for an asynchronous system. Equation (5) represents the modified nonlinear filter.

$$
\begin{cases}
\dfrac{d}{dt}\left(\hat{P}_c\right) = -V + V_{tg} + sk_1 T_i^c H^{-1}(\hat{P}_c)(g_{\psi\theta}(\hat{P}_c) - y_m) \\[2mm]
\dfrac{d}{dt}\left(\hat{V}_{tg}\right) = sk_2 T_i^c H^{-1}(\hat{P}_c)(g_{\psi\theta}(\hat{P}_c) - y_m) \\[2mm]
\hat{P}_c = T_c^i(\hat{P}_c)
\end{cases}
\tag{5}
$$

Where, V_{tg} and y_m are the position and measurement of the target, respectively. y_m is the same as $(g_{\varphi\theta}(P_c)$. $H(\hat{P}_c)$ is the Jacobian matrix of $g_{\varphi\theta}(\hat{P}_c)$. In Equation (5), data asynchronous means that non receiving UAV information and out-of-sight of target in image. Fig. 2 shows the results obtained with the modified nonlinear filter. Fig. 2, which are obtained from the modified filter system show good performance. The average distance error of the arithmetic method is about 94m, whereas the LPV is about 10m.
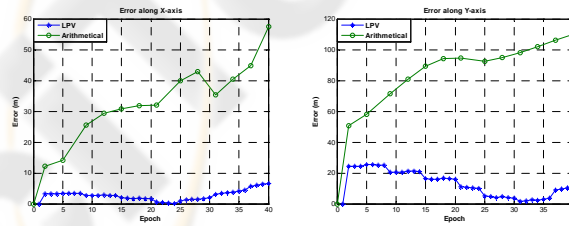

Fig. 2. Error along X-axis (left), Error along Y-axis (right).

4 Conclusions

This paper describes the development of a laboratory level vision system for small UAVs to measure the 3-D position of a target from a monocular image, acquired from the vision system on a UAV.

The Kalman filter is used to track the target in the image in real time. Through the algorithm for 3-D measurement, the 3-D position of the target can be estimated in the real space based on the target's position in the image, position and attitude of the UAV, and the attitude of the camera.

To make a simple vision system, the range between UAV and target is determined by arithmetic method. This range is used for a nonlinear filter system, derived from LPV and LMI. Since a nonlinear filter do not considered synchronism in receiving data, performance is similar with arithmetic method.

A modified nonlinear filter was suggested to prevent this problem. We can verify that the modified nonlinear filter is effective.

Acknowledgements

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