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Autonomous Control System of Compact Model-helicopter

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Abstract

We introduce an autonomous flying system using a model-helicopter. A feature of the helicopter is that autonomous flight is realized on the low-cost compact model-helicopter. Our helicopter system is divided into two parts. One is on the helicopter, and the other is on the land. The helicopter is loaded with a vision sensor and an electronic compass including a tilt sensor. The control system on the land monitors the helicopter movement and controls. We firstly introduce the configuration of our helicopter system with a vision sensor and an electronic compass. To determine the 3-D position and posture of helicopter, a technique of image recognition using a monocular image is described based on the idea of the sensor fusion of vision and electronic compass. Finally, we show an experiment result, which we obtained in the hovering. The result shows the effectiveness of our system in the compact model-helicopter.

1. Introduction

In order to realize a low-cost remote sensing system, a model-helicopter and model-airplane are often used. However, one problem is that the operation of the helicopter and airplane require skillful manual operation. Furthermore, the operation is limited only in the range where the operator can recognize the movement of the helicopter and airplane. Therefore, many advanced technologies are employed to realize autonomous flight without any human assistance [1], [2], [3]. For the military purpose, many autonomous flying machines are developed already, neglecting the cost. When we think about the commercial application of the autonomous flying machine, the cost is considered an important factor. Using the updated computer, electronics device and micro-actuator developed in the field of radio-controlled model-helicopter and model-airplane, it is becoming possible to build autonomous flying systems with low expenses in a compact body [4].

In this paper, we introduce a low-cost helicopter system controlled by a vision system and an electronic compass system including a title sensor. A feature of our helicopter system is that the system is light and compact, in addition to its low-cost. The other feature of the helicopter system is that the hovering, take-off and landing are automatically realized without any skillful manual operation.

The vision system is composed of a CCD camera mounted on the bottom of the helicopter, and a specialized landmark on the land, which can be readily recognized from the air. By detecting the landmark, the vision system can obtain the three-dimensional (3-D) information about the position and the posture of the helicopter [5], [6], [7]. Based on this 3-D information, the helicopter is controlled by the control system on the land.

Firstly, we describe the configuration of the helicopter and the control system of the land. The system on the helicopter is composed of a vision sensor and an electronic compass. To transmit images and data of the electronic compass to the control system of the land, the helicopter is loaded with a video signal transmitter and a wireless modem. The control system on the land is composed of a video signal receiver, an image processor, a wireless modem and a radio signal controller. Secondly, we introduce a measurement method of the 3-D position and posture of helicopter by our image recognition technique using a monocular image. An attitude, a roll and a pitch angle of the helicopter are determined based on the idea of the sensor fusion of vision sensor and electronic compass. Finally, we show an experimental result of hovering test with the fusion sensor system. We employed the PID control method in the hovering test on the landmark. The result shows the effectiveness of the fusion sensor system.

The goal of this study is to build an autonomous flying system using the model-helicopter that flies following the desired trajectory. The trajectory tracking experiment using a global positioning system (GPS) on the model-airplane is already succeeded without any manual operation [8]. The aim of this paper is to realize the take-off, landing and hovering of the helicopters autonomously.

2. Configuration of Model-helicopter System

In Fig. 1, a helicopter system is shown. The system is divided into the helicopter and the land.

The helicopter is mounted with the vision sensor and the electronic compass that sense the posture and position of helicopter. The video signal transmitter (RF Corp., Japan) mounted on the helicopter is used to transmit the images to the land. The helicopter is also mounted with wireless modem (Futaba Corp., Japan) that transmits the data of electronic compass to the land with radio. The vision sensor mounted the helicopter detects the image of the landmark. The images of vision sensor are transmitted from the helicopter to the control system of the land with the frequency band of 1.2GHz. By analyzing the geometry of the landmark on the images, the position and posture of helicopter are obtained. Based on the data of the position and posture of helicopter, the control signal of the helicopter is determined so that the desired position and posture can be realized. The electronic compass (Precision Navigation, INC., Canada) including the 2-axis tilt sensor supplies compass heading, pitch and roll without any interface. The data of electronic compass is transmitted to the control system of the land by the wireless modem. The wireless modem uses the frequency band from 2.472 to 2.495GHz. The sensor system on the helicopter can be constructed in a light and compact body.

Control data calculated by the computer on the land, is coded into radio control signal by a logic circuit using FPGA (Xilinx Corp., U.S.A.), and is transmitted to the helicopter.

3. Determination of 3-D Position and Posture by Vision

The position and posture of the model-helicopter can be obtained by the image of the landmark. Suppose the shape of the landmark is designed like the letter **H**. Geometrical relation of the landmark and the image is shown in Fig. 2, where $x_c y_c z_c$ of the coordinate system is settled at the

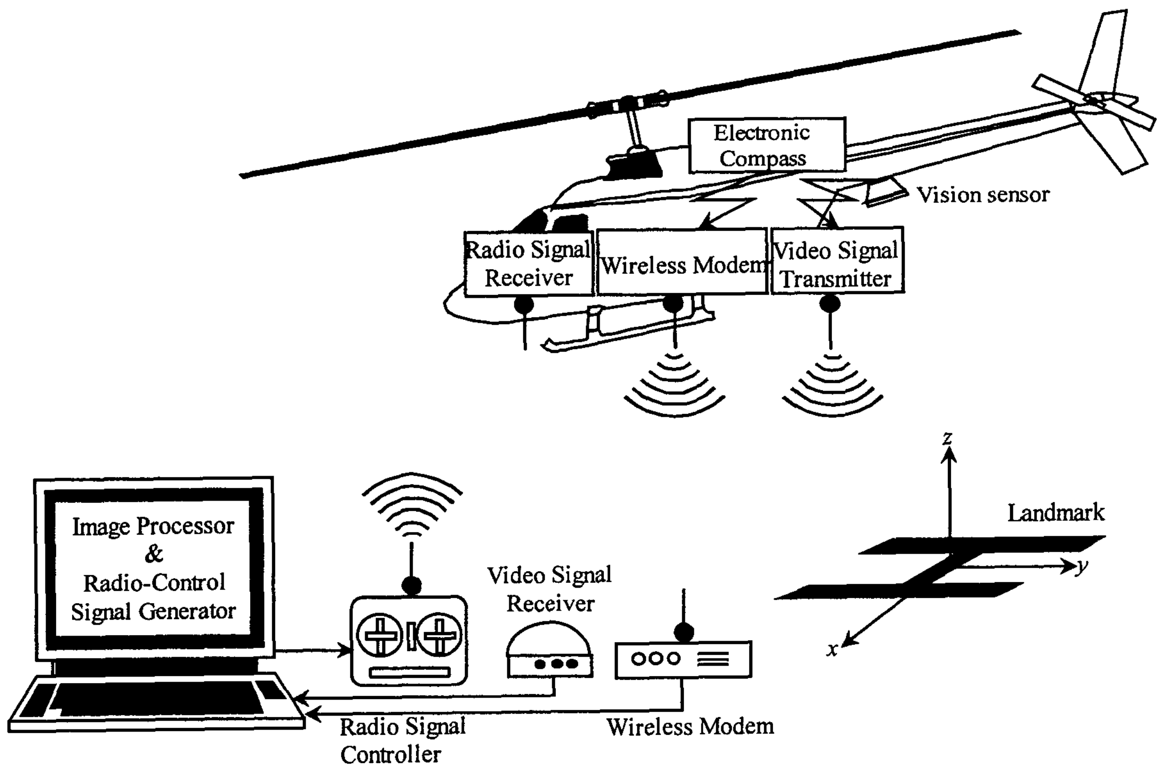


Fig. 1 Configuration of Model-helicopter System

camera. The image plane is defined by the equation,

$$z = f \tag{1}$$

Where f is the focal length of the CCD camera.

In Fig. 2 four ends of the landmark denoted as Q_1, Q_2, Q_3, Q_4 are projected onto the image plane as P_1, P_2, P_3, P_4.

Using the vector notation, we obtain

$$\mathbf{q}_i = k_i \mathbf{p}_i \ (i = 1, 2, 3, 4) \tag{2}$$

Where $\mathbf{q}_i$ and $\mathbf{p}_i$ are position vector of Q_i and P_i respectively.
From the geometry of the landmark,

$$k_1\mathbf{p}_1 - k_2\mathbf{p}_2 = k_1\mathbf{p}_1 - k_2\mathbf{p}_2 \tag{3}$$

By multiplying the $\mathbf{p}_3 \times \mathbf{p}_4$,

$$k_1\mathbf{p}_1 \bullet (\mathbf{p}_3 \times \mathbf{p}_4) = k_2\mathbf{p}_2 \bullet (\mathbf{p}_3 \times \mathbf{p}_4) \tag{5}$$

Therefore,

$$k_2 / k_1 = \mathbf{p}_1 \bullet (\mathbf{p}_3 \times \mathbf{p}_4) / \mathbf{p}_2 \bullet (\mathbf{p}_3 \times \mathbf{p}_4) \tag{6}$$

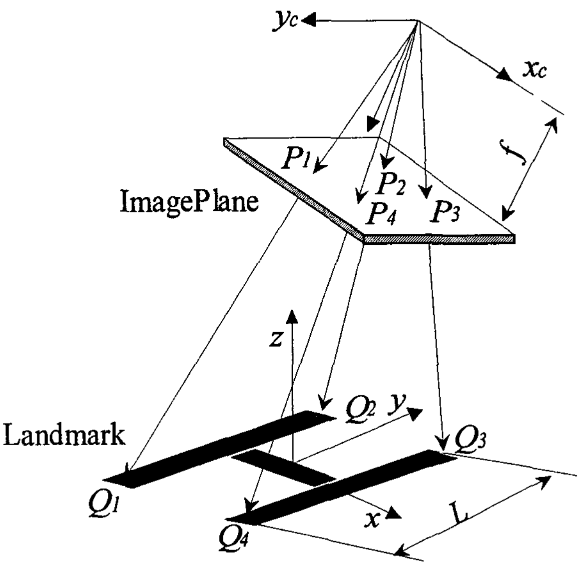


Fig. 2 Relation between landmark and its image

Similarly we can obtain

$$\begin{aligned} k_3 / k_1 &= \mathbf{p}_1 \bullet (\mathbf{p}_2 \times \mathbf{p}_4) / \mathbf{p}_3 \bullet (\mathbf{p}_2 \times \mathbf{p}_4) \\ k_4 / k_1 &= \mathbf{p}_1 \bullet (\mathbf{p}_2 \times \mathbf{p}_3) / \mathbf{p}_4 \bullet (\mathbf{p}_2 \times \mathbf{p}_3) \end{aligned} \tag{7}$$

It is important that ratio between k_1, k_2, k_3, k_4 can be determined by the above equations. Absolute values of k_1, k_2, k_3, k_4 can be determined by the length of every edge between Q_1 and Q_2, and also Q_3 and Q_4. Suppose the length between Q_1 and Q_2 is L. Then, parameters k_1 and k_2 can be determined by the following equation.

$$|k_1\mathbf{p}_1 - k_2\mathbf{p}_2| = L \tag{9}$$

Once all parameters k_i are determined, the position and the posture of the landmark in the camera coordinate system can be obtained.

The geometrical relation between the camera coordinate system ($x_c y_c z_c$) and the world coordinate system (xyz) which is settled on the landmark can be obtained by the following homogeneous transformation matrix.

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = [\mathbf{w}_1 \quad \mathbf{w}_2 \quad \mathbf{w}_1 \times \mathbf{w}_2 \quad \mathbf{v}] \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{10}$$

Where $\mathbf{w}_1$, $\mathbf{w}_2$ and $\mathbf{v}$ are

$$\begin{aligned} \mathbf{w}_1 &= \frac{(\mathbf{p}_4 \times \mathbf{p}_1)}{|\mathbf{p}_4 - \mathbf{p}_1|} \\ \mathbf{w}_2 &= \frac{(\mathbf{p}_2 \times \mathbf{p}_1)}{|\mathbf{p}_2 - \mathbf{p}_1|} \\ \mathbf{v} &= \frac{(\mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_3 + \mathbf{p}_4)}{4} \end{aligned} \tag{11}$$

From the above equation, the position and the posture of the helicopter can be determined.

One problem of the above method is the accuracy of the measurement strongly depends on the distance between the landmark and the camera. Another problem is that if some noise disturbs the image, the helicopter becomes uncontrollable readily. Therefore, the direction, roll and pitch angles of helicopter are determined considering the above characteristics based on the idea of sensor fusion of vision sensor and electronic compass.

4. Hovering Experiment of Model-helicopter

In Fig. 3, our helicopter system is shown. A commercialized compact and light helicopter (Hirobo Corp., Japan) is used. The position of the posture data of the helicopter can be obtained 30 times per a second by the image processing. The data of electronic compass revises the position and posture data of the helicopter obtained by the vision system. The position and posture data of helicopter are used as feedback signals of PID control of the helicopter. The control signal is calculated 30 times per a second. The control signal calculated, is converted to PPM signal by logic circuit and transmitted to helicopter as a wireless signal by a radio signal controller.

The size of the landmark was 30cm in height and 30cm in width. At the beginning, the helicopter was settled on the landmark, and the output data of the sensor fusion system is tested. The output data is shown in Fig. 4. In the hovering experiment, the command was to move the helicopter from the land to the hovering position, the height of this position was 2m. We succeeded to levitate the helicopter and keep it at the desired position. The roll and pitch angle of the helicopter during the hovering condition is shown in Fig. 5.

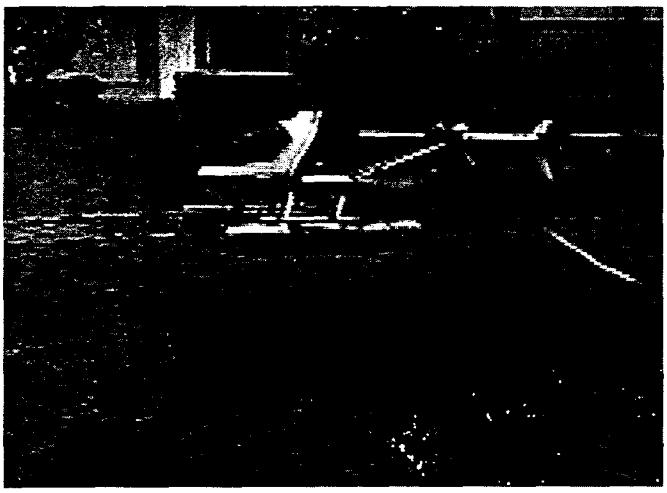


Fig. 3 Hovering Test of Model-helicopter

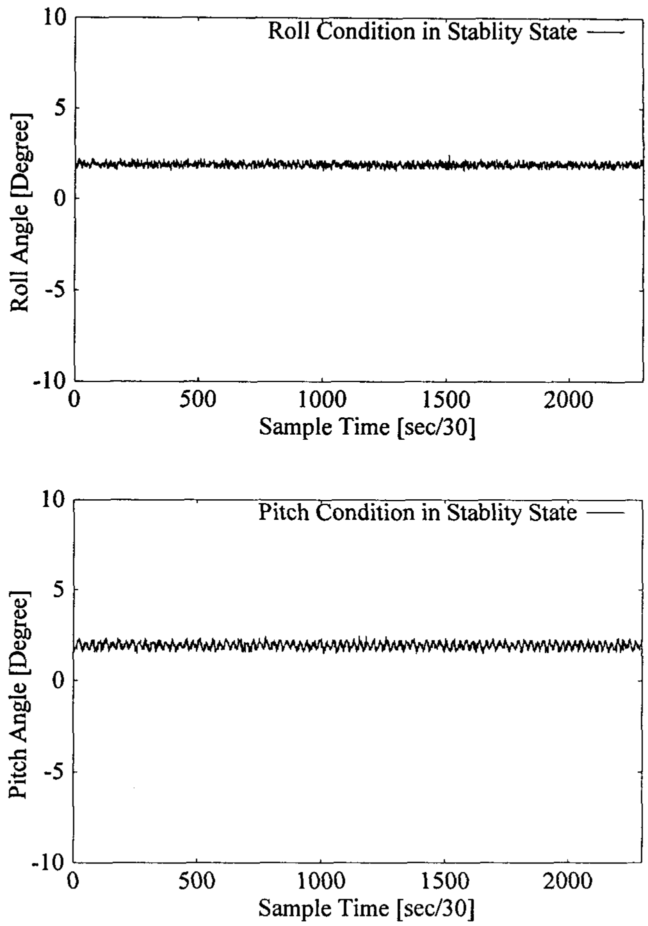


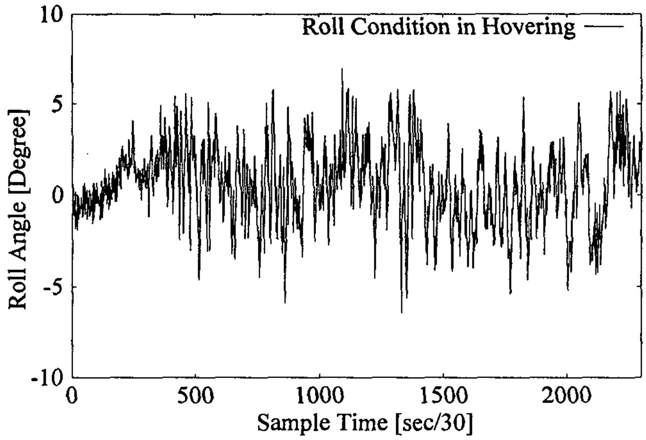
Fig. 4 Accuracy of Helicopter Posture employin Sensor Fusion System

5. Conclusion

A Compact and low-cost helicopter system is introduced whose main body is composed of commercialized low-cost model-helicopter. By detecting the position and the posture of the helicopter using the camera on the helicopter, we succeeded to realize auto hovering of the helicopter without any human assist. The proposed system employed the video signal communication system. Due to this system, main control system is settled on the land. Therefore, we need not worry about the weight of the computer system of the helicopter system. We are now preparing to install all sensors and computer system on the helicopter, since we already succeeded to fly the model-airplane by installing the computer and sensors on the airplane. Using the advanced RISC and FPGA, it will be possible to realize autonomous hovering of the model helicopter soon.

6. Reference

1. T. Yamaguchi et al. (1992), Intelligent control of flying vehicle of using fuzzy associative memory system. Proceeding IEEE International Conference on Fuzzy Systems, pp. 1139-1149
2. A. Yue, I. Postlethwaite and G Padfield (1989), H^{∞} designed and the improvement of helicopter handling qualities. Vertica, 13(2):119-132
3. B. K. Townsend (1987), The application of quadratic optimal cooperative control synthesis to a CH-47



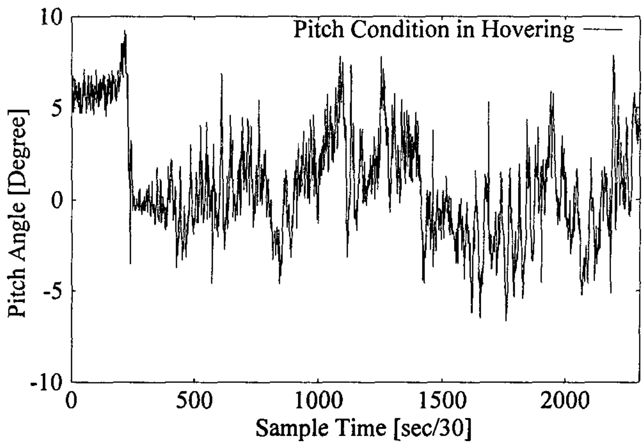


Fig. 5 Helicopter Posture in Hovering Test (Using PID Control Method)

helicopter. Journal of the American Helicopter Society, pp. 33-44

4. S. Mizoguchi et al. (1994), Modeling and robust control of a saucer-type Helicopter. Proceeding of the Asian Control Conference, Tokyo, Japan, 1994, pp. 313-316
5. H. Wang, C. Kang, T. Ishimatsu and T. Ochiai (1997), Auto-navigation of a wheelchair. Artif Life Robotics, 1:141-146
6. T. J. Broida, S. Chandrashekhar and R. Chellappa (1990), Recursive 3-D Motion Estimation from a monocular image sequence. IEEE Transactions on Aerospace and Electronic Systems 26(4):639-655
7. Joao Costeira and Takeo Kanade (1995) A multi-body factorization method for motion analysis. CMU Technical Report CMU-CS-TR-94-220, September 1994
8. C. Kang, and T. Ishimatsu(1994) Control system for model airplane on autonomous flight, Proceeding of the 2nd International Workshop on Advanced Mechatronics, Nagasaki, Japan, Dec., 1997, pp. 187-189