Development of A Flying Visual Sensor

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A small battery-powered helicopter whose total weight is about 200g and rotor diameter is about 30cm was developed. A CMOS camera is mounted on the helicopter and images can be transmitted to a monitor. Four photodetectors and an ultra sonic range finder, which are mounted on the helicopter, enable two maneuvers. In the first maneuver, the helicopter can follow a moving light. The position of the helicopter can thus be controlled simply by moving a light, and can follow a robot or a person carrying a light directed to the helicopter. When images taken by the CMOS camera on the helicopter are transmitted to robot or person, this helicopter can expand the visual field of the robot or person. In the second maneuver, the helicopter flying over a first light can move toward a second light, when the first light is turned off and the second light is turned on. The position of the helicopter can thus be controlled by successively switching (on and off) lights set in a row. When images taken by the CMOS camera on the helicopter are transmitted to ground base, we can monitor a view from the helicopter.

I. Introduction

Recently, a small airplane[1] and a small ducted fan[2] have been developed. Such small, lightweight aircraft will become tools to assist in everyday life. An aircraft with rotary wings[3] is particularly suitable as a small, lightweight aircraft flying around people, because it is capable of low-speed flight, including hovering flight. We have developed a small battery-powered co-axial helicopter whose total weight is about 200g and rotor diameter is 35cm. This helicopter has sensors and a microcomputer and is thus capable of autonomous flight. Details of this co-axial helicopter are described here.

II. Developed co-axial helicopter

Figure 1 shows our battery-powered co-axial helicopter. Details of this helicopter are as follows.

A. Rotors

Each of the upper and lower rotors has two blades (X.R.B. by Hirobo Corp.) and is rotated by a motor (CN12-R-XC by GWS). The lower rotor is connected to two servo motors (PICO BB by GWS) for respectively controlling the longitudinal and lateral cyclic pitches. The cyclic pitches of the upper rotor are varied by a stabilizer bar and it has no cyclic pitch control with a servo motor. The rotational speed of the rotors is adjusted to control the yawing motion and the magnitude of thrust.

B. Receiver

A receiver (R4PII by GWS) is mounted on the helicopter. The receiver gets signals transmitted from an operator for varying longitudinal and lateral cyclic pitches and lower and upper rotor rotational speed. These signals from an operator can be superposed on those from sensors stated later.

C. Microcomputer

A microcomputer (H8/3664 by Hitachi) is mounted on the helicopter. The computer transmits control signals to the servo motors, which in turn adjust the cyclic pitches of the lower rotor, and to the motor controllers, which in turn adjust the rotational speed of the rotors. The control signals are determined based on parameters measured by sensors stated in Section II and III.

D. Rate gyro and declinometer

The yawing angle and velocity are measured using a declinometer (PDCM-802 by Geosensory) and a rate gyro (PG-03 by GWS), respectively.

E. Battery

A Li-Po battery (7.4V, 340mAh by KokamRC) is mounted on the helicopter to power the motors, servo motors, microcomputer, camera, and sensors.

F. Camera

A small camera (CMOSS-RR by International Electric) is mounted on the helicopter. Moving images taken with this camera are transmitted to a computer monitor on the ground.

G. Duct

A duct that surrounds either the lower rotor or both rotors was added for safety and stabilization. When the helicopter inadvertently hits someone, the duct reduces possible injury.

This duct also stabilizes hovering flight as follows.

1) When the helicopter has pitching (or rolling) motion ($-\Delta\theta$), the moment acting on the duct (Δm) suppresses the pitching(or rolling) motion.

2) When the helicopter has translational motion (Δu), the force acting on the duct ($-\Delta F_X$) suppresses the translational motion. In addition, a pitching moment (Δm) is induced by the force acting on the duct ($-\Delta F_X$) because the duct is above the center of the gravity of the helicopter. The rotor-tip path planes, that is the aerodynamic forces induced by the rotors, are inclined in the reverse direction by Δm, thus suppressing the translational motion.

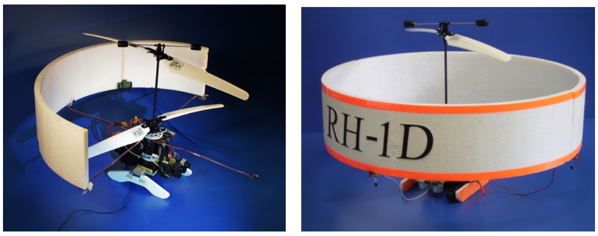

Fig.1 Co-axial helicopter with the duct

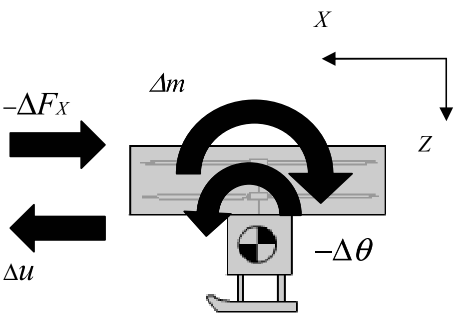

Fig.2 Stabilization effect of a duct on hovering flight

III. Flight Tests

A. Autonomous hovering flight near walls

Three IR range finders (GP2D12 by Sharp) are mounted on the helicopter. One measures the height of the helicopter from the ground, and two measure the distance from two walls. The microcomputer has a pre-programmed flight plan, namely, the required time variations in height and distances from the two walls. Based on the differences between the pre-programmed and measured distances, the computer transmits control signals to the two servo motors to adjust the cyclic pitches. The magnitudes of the control signals are determined by the PD control.

Figure 3 shows a block diagram of the control process for hovering flight near walls. When the receiver gets no signals from an operator, the flight is autonomous.

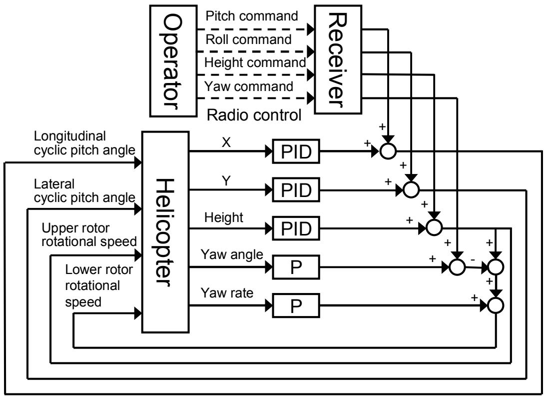

Fig 3. Block diagram for hovering flight near walls.

Autonomous flight of this helicopter is considered here as 'Take off, hover for 1 minute, and land". Figures 4(a) and (b) show the position of the center of gravity (pink circles) viewed from the top and from the side, respectively, during this autonomous flight. Variation from the target hovering position during the flight was less than 30cm.

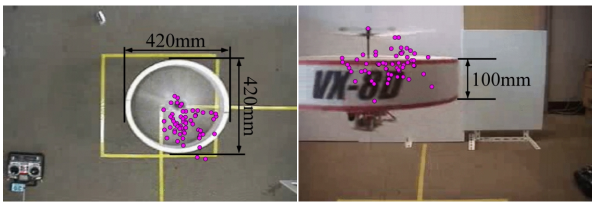

Fig.4 Position of the center of gravity (pink circles) of the helicopter during autonomous hovering flight near two walls. (a)Top view, (b) Side view. Circles indicate the position measured every 2s.

B. IR-guided flight

An ultrasonic range finder (US2 by Besttechnologies) is mounted on the helicopter to measure the height And four IR photodetectors (Toshiba TPS614) are mounted on the lower surface of the duct as shown in Fig. 5. Photodetectors A and B determine the direction the helicopter moves parallel to line AB, andphotodetectors C and D determine that to line CD. The control process used by the photodetectors to determine the direction that the helicopter will move can be explained as follows, using Photodetectors A and B as an example.

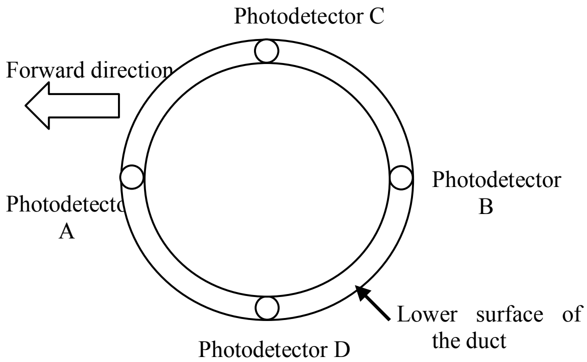

Fig.5 Position of photodetectors on the lower surface of the duct

(i) When both A and B detect an IR, the microcomputer transmits no signal to the servo motors for changing the cyclic pitches. (ii) When only A detects IR, the micro computer transmits a signal to the servo motor for the longitudinal cyclic pitch to move the helicopter in the forward direction. (iii) When only B detects IR, the computer transmits a signal to the servo motor for the longitudinal cyclic pitch to move the helicopter in the reverse direction. (iv) When neither A nor B detects IR after steps (ii) or (iii), the computer transmits a signal to the servo motor to increase the longitudinal cyclic pitch. The functionality of this helicopter and its control system were determined based on two tests.

[1] Navigation with a moving light

In the first test, IR on a small car was directed toward the helicopter (Figs. 6 and 7). The car moved straightforward and turned to the left. The moving velocity of the car was less than 0.3m/s. The helicopter succeeded in following the car. And the height of the helicopter, which was measured by the ultra range finder, was set 1m.

The success in this test means that this helicopter can follow a robot or person that has an IR light (Fig. 8). Moving images from a camera on the helicopter can be transmitted to the robot or person, thus expanding the visual range of the robot or person. And the height measured by the ultra range finder is varied dramatically when the helicopter flies over an obstacle. When this dramatic variation of the measured height is transmitted to the robot, the robot can recognize the obstacle in advance. Note that the position of the helicopter relative to the robot can be controlled by varying the direction of IR light.

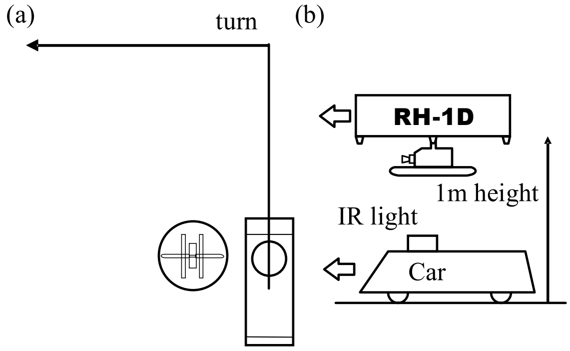

Fig.6 The helicopter and the ground vehicle followed by the helicopter.
(a) Top view, (b) Side view.

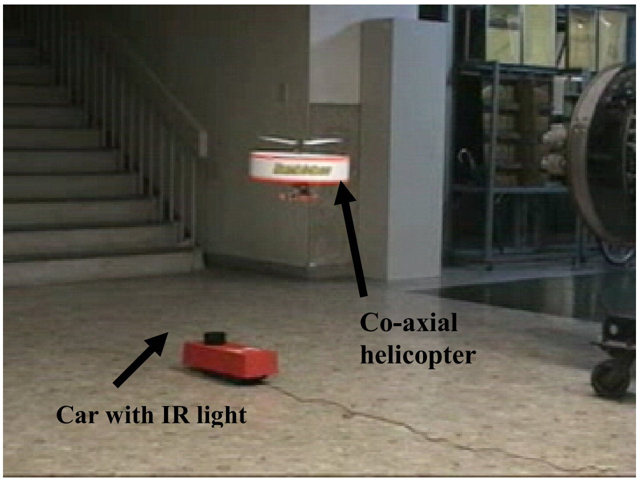

Fig.7 Flight test of the co-axial helicopter guided by a car with an IR light on its top.

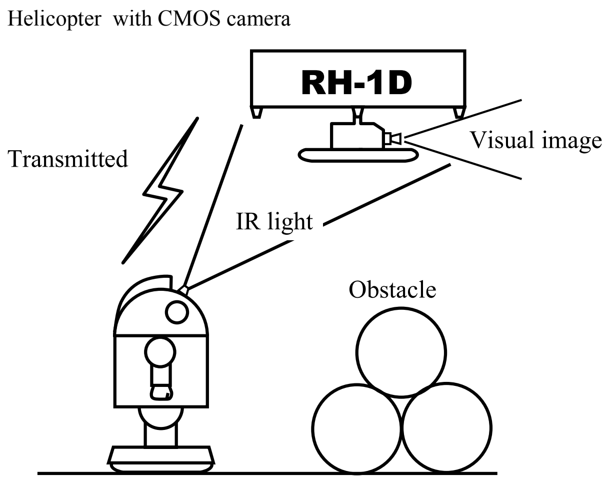

Fig.8 The helicopter autonomously following a robot with IR light

[2] Navigation with an array of lights

In the second test, IR lights were arranged about 20cm apart on the floor. The first light was turned on and the others were turned off. The helicopter was placed over this first light. When the first light was turned off and the second light was turned on, the helicopter moved toward this second light. By switching successive lights on and off, the helicopter moved over the series of lights (Fig. 9).

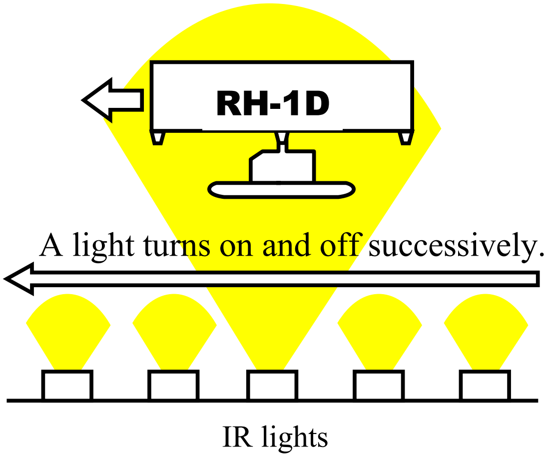

Fig. 9 Navigation by a row of lights

The success in this test means this helicopter can be easily navigated with a row of lights. When the images taken with the camera can be transmitted to ground, we can monitor a view from the helicopter.

IV. Conclusion

A small battery-powered co-axial helicopter that has a total weight of 200g and a rotor diameter of 35cm was developed. A CMOS camera is mounted and visual image from the helicopter is transmitted to ground base. This helicopter can function as an extra visual sensor of a robot and a person.

When four photodetectors and an ultrasonic range finder are mounted on the helicopter, the position of the helicopter can be controlled simply by moving a light or by successively switching (on and off) lights set in a row. Then, the helicopter can follow a robot or a person that has a light aimed at the helicopter. When a camera on the helicopter transmits moving images to the robot or person, the visual range of the robot or person is expanded. And the helicopter can be easily navigated by a row of lights. When a camera on the helicopter transmits moving images to ground base, we can monitor a view from the helicopter.

Future study will include (a) increasing the stability of flight in wind so that the helicopter can be used outdoors, (b) increasing the flight duration (currently, 3 minutes), and (c) mounting lighter sensors and more powerful batteries. These improvements will expand the applications of this helicopter.

References

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