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Autonomous Landing for a Quadrotor UAV Using a Visual Input

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Abstract

This paper presents the design and implementation of a real-time vision system for a quadrotor UAV in order to estimate its state relative to a known landing target. The quadrotor UAV is required to identify a landing target, and track on it. We use contours algorithm for landing target recognition and an Extended Kalman filter for position estimation. We use linear segments with parabolic blends for trajectory planning of quadrotor UAV. The quadrotor UAV can track and land on a target by using PID controller. Flight test results show that our vision-based state estimator along with the effectiveness of PID controller are accurate within 30 cm by measuring from the center of quadrotor UAV to the center of landing target.

Keywords*:* Autonomous landing, Visual input, Vision, PID controller, UAV.

1. Introduction

One of the primary reasons for the current interest in small unmanned aircraft is that they offer an inexpensive platform to carry electro-optical (EO) and infrared (IR) cameras. Almost all miniature air vehicles that are currently deployed carry either an EO or IR camera. While the camera is a primary use to relay information to a user, it makes sense to attempt to use the camera for the purpose of navigation, guidance, and control. Further motivation comes from the fact that birds and flying insects use vision as their primary guidance sensor [1].

Recently, several groups are working on the topic of vision-guided autonomous UAV landing [2-6]. In the topic of Vision-Based Autonomous landing of an Unmanned Aerial Vehicle [2] is presents a real-time algorithm that identifies an “H”-shaped landing target using invariant moment. Another black and white pattern consisting of 6 squares of different size is used by [3] to land a helicopter. The system is described to be accurate within 5 cm translation. Two different approaches for safe landing site identification without explicit markers or landing pads are described in [4] and [5]. More patterns are used by [6] to control a quadrotor UAV. This approach is technically appealing but does not seem to be robust enough to be feasible for outdoor use.

Most approaches for autonomous landing that use known patterns have one disadvantage that we tried to overcome in our work. The patterns have to be completely visible in order to be identified successfully.

2. Systems overview and autonomous landing strategy

These small four-rotor UAVs, can carry up to 1 kg of payload for about 20 to 25 minutes. A quadrotor is propelled by four brushless DC motors and equipped with a variety of sensors. Associated with the usual accelerometer, gyros and magnetic field sensor, a pressure sensor and a GPS module, inputs for a sophisticated sensor fusion algorithm is provided. This algorithm control loop runs at 1 kHz. Besides the sensors, we include a GoPro camera with 3-axis gimbal control, a sonar, an Atmega328 microcontroller, a 900 MHz Xbee-Pro radio module and a 5.8 GHz video downlink. A completely equipped quadrotor has a weight of 2.5 kg including LiPo batteries.

The concept of autonomous landing for a quadrotor using visual input is shown in Figure 1, an images are transmitted by video downlink at 5.8 GHz to ground PC, while ground PC estimates the position of a quadrotor by image processing. In addition ground PC are transmitted a control signal to a quadrotor by Xbee-Pro at 900 MHz.

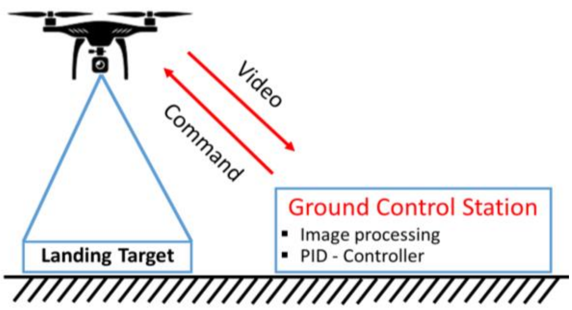

Fig. 1 shows concept for autonomous landing for a quadrotor using visual input.

The autonomous landing process of a quadrotor is divided into two stages.

Stage 1: To get back to the place near the landing point through the GPS navigation system and hover above the landing location at height of 10-15 meters, searching for a landing target.

Stage 2: To identify the target and then land gradually according to the guide on the pose information from the vision system, and its controlling estimation flow is shown in Figure 2.

Fig. 2 Quadrotor autonomous landing Strategy.

3. Landing target design and landing target detection algorithm

3.1 Landing target design

Landing Target plays an important role in Autonomous Landing System. Vision system will estimate the position of the aircraft and apply the estimation to control the aircraft landing.

The concept for target design is quite simple and practical. It has to be used without concerning about the height of the aircraft or the situation when the camera cannot clearly detect the target; for instance, when the aircraft slips out to the side of the target. To efficiently design the target pad, the landing algorithm needs to be awarded. The algorithm begins when the aircraft position is over the target with the beginning height. The camera is able to detect all circle in the pad. The lower the aircraft is, the fewer circle can be captured. These steps are capable of bringing the aircraft down to the ground.

The target pad consists of three color circle. The radius of the circle is 100 cm. 75 cm. and 45 cm. respectively which are shown in Figure 3.

Regarding the number and the size of the circle, they are adjustable. For example, if the aircraft is operated at a higher level, the target can be equipped with more circles and larger in size. New proportions will be implemented in the programming for further height calculation.

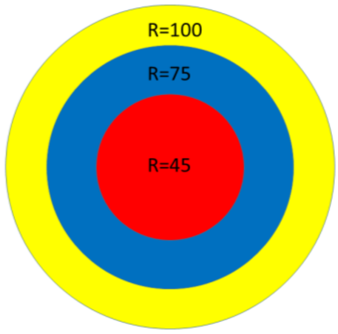

Fig. 3 Landing target.

3.2 Landing target detection algorithm

Our landing target detection algorithm (Fig. 4) is programmed in C/C++ and based on OpenCV [7] in favor of detection. The picture resolution is 640×480 pixel. After the aircraft completely recognizes the target, conversion from gray-scale image to binary image is the first step of image processing using threshold technique. The second step is to achieve the accuracy, the unwanted parts of the image will be eliminated. The third step is the process of circle recognition which is shown in Figure 5. The fourth step is the process of estimation the position of a quadrotor compared with landing target. The fifth step is the process of the position data filter is completed by Extended Kalman filter.

The final step is to do the experiment and troubleshoot problem if any error exists.

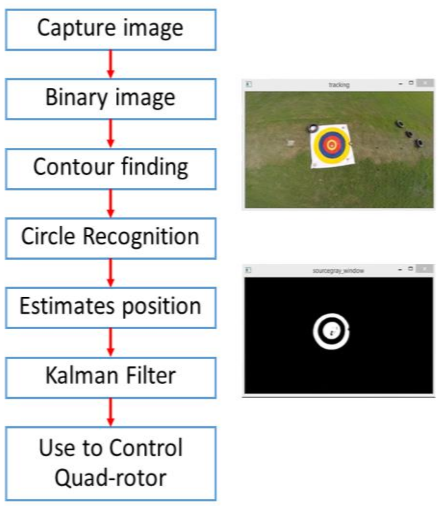

Fig. 4 Landing target detection algorithm.

3.3 Landing target recognition algorithm

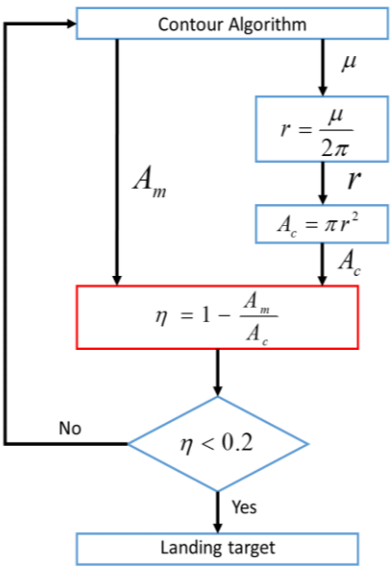

Fig. 5 Landing target recognition algorithm.

The process of the landing target recognition is shown in Figure 5, the contour length from contour algorithm is used to calculate the radius of the circle by equation 1.

$$r = \frac{\mu}{2\pi} \qquad (1)$$

where r is the radius of the circle, and μ is contour length. We use the radius to calculate the area of the circle by equation 2.

$$A_c = \pi r^2 \qquad (2)$$

where A_c is the area of the circle by calculation. We calculate an error by comparing between the area from calculation and the area from measurement by equation 3.

$$\eta = 1 - \frac{A_m}{A_c} \qquad (3)$$

where η is the error by comparing the area between area from calculation and the area from contour algorithm. And η is used for the landing target recognition. A_m is contour area from contour algorithm.

4. Autonomous landing for a quadrotor

For an autonomous landing for a quadrotor using a vision system, we use linear segments with parabolic blends for trajectory planning of quadrotor [8]. In addition, we use PID controller to control the position and velocity of a quad-rotor.

4.1 Position control

The basic concept of the Flight control is to offer easy programmability and to provide safety while testing our control algorithms. To recover from critical flight situations during test flights, the pilot can always switch back to the well-proven control algorithms on the low-level processor as a safety backup. The concept of the position control of quadrotor using a visual input is shown in Figure 6. The high-level processor is used to switch between modes and send command control to a low-level processor. The low-level processor handles sensor data processing, data fusion and our fast and stable attitude control algorithm with an update rate of 1 kHz. It also processes the position control algorithm by using the onboard magnetometer and GPS module as additional sensor inputs.

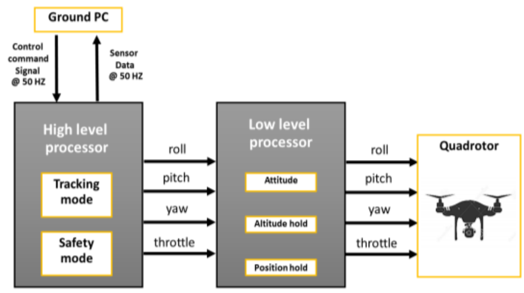

Fig. 6 The concept of the position control of quadrotor using a visual input.

The block diagram of a position control for a quadrotor using visual input is shown in Figure 7. In the controller are have two loops control. The first is an inner loop control. The second is an outer loop control. The outer loop control is used for control of the position of a quadrotor run at 50 Hz by the high-level processor. The inner loop control is used for attitude control of a quadrotor run at 1 kHz by the low-level processor. When the user switches to track mode a quadrotor will fly over landing target and try to track on the center of landing target all the time.

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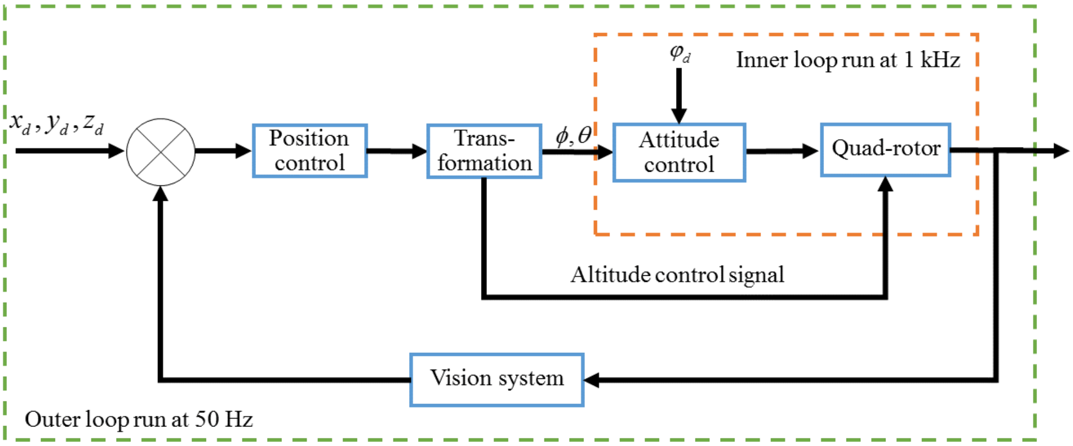

Fig. 7 shows the block diagram of a position control for a quadrotor using visual input.

5. Experiments and Result

In this section, we tested the position control with the landing target detection and controlled loop. In this experiment, flight test of a quadrotor with wind speed 5 knot is shown in Figure 8, in flight test a quadrotor will be hover at the altitude 15 m and landing to the ground automatically after 80 seconds.

Fig. 8 The flight test of a quadrotor with wind speed 5 knot.

The altitude of a quadrotor is shown in Figure 9, which are show a performance of an altitude control for takeoff, hovering and landing. The PID-controller is able to follow the set point very closely and stabilizes quadrotor at the commanded set point with 3 cm accuracy.

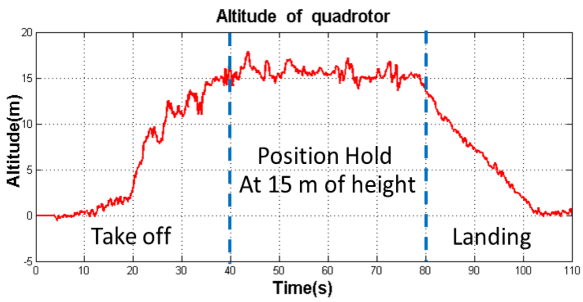

Fig. 9 Altitude plot showing an altitude hold and landing maneuver.

The performance of the position controller combined with the landing target detection control loop is shown in Figure 10. The plot shows the 2D position of the quadrotor during 40 seconds of flight. The quadrotor tried to stabilize its position directly over the landing target center located at the origin of the plot.

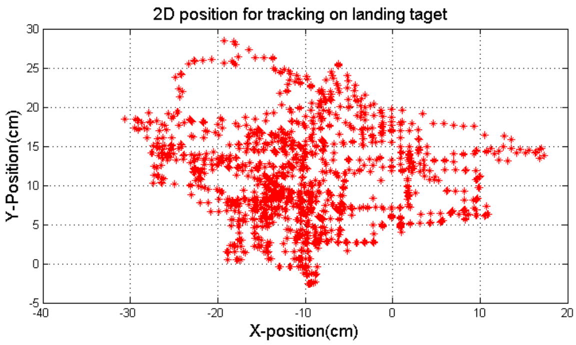

Fig. 10 shows performance of the position controller combined with the landing target detection.

The flight test of an autonomous landing for a quadrotor using visual input is shown in Figure 11. The quadrotor tried to track on the center of landing target. After the pilot commanded to land, a quadrotor will be landed on the target, which is accurate within 30 cm by measured from center of quadrotor to center of landing target.

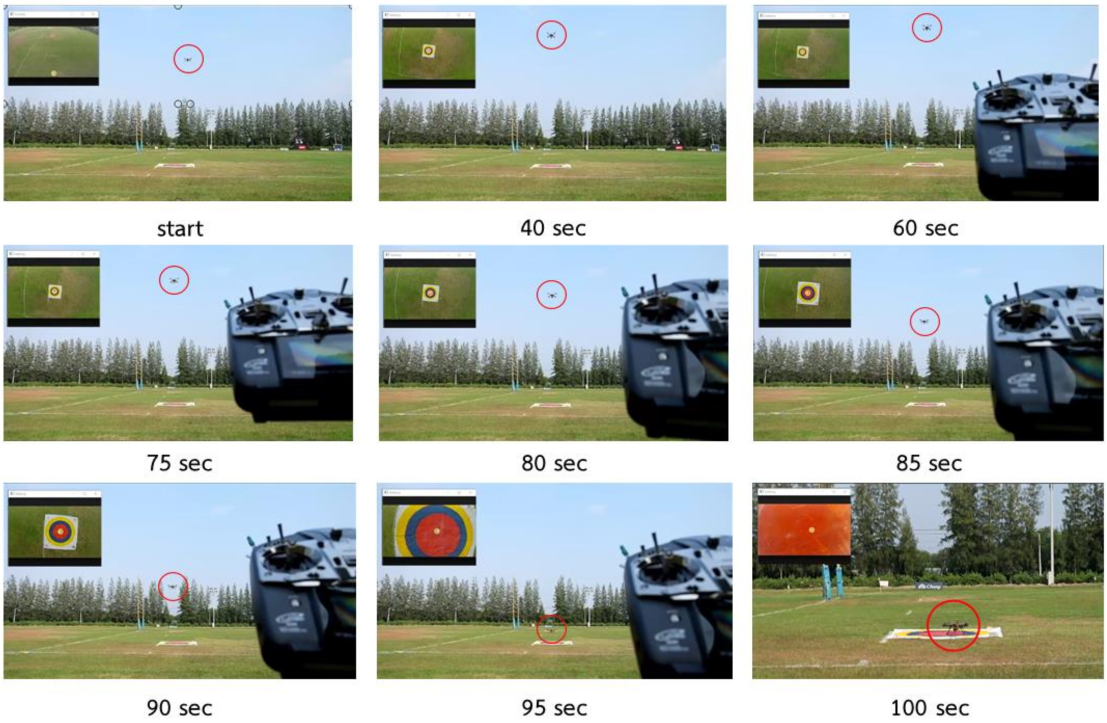

Fig. 11 The flight test of an autonomous landing for a quadrotor using visual input.

6. Conclusion

We have presented the design and implementation of the real-time vision-based system for detecting a landing target and a controller to autonomously land a quadrotor on the target. The algorithm estimates 2D-position of the quadrotor relative to the landing target using the known real word dimensions of the maker and the intrinsic camera parameter. Our experiments proved both the high efficiency and accuracy of the detection and position estimation algorithm and that the landing target can be identified from different height in real- time. Based on our vision system we are currently parameterizing the controller structure for autonomous landing test with our quadrotor.

7. References

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