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Implementation of autonomous visual tracking and landing for a low-cost quadrotor

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ABSTRACT

This paper presents an implementation of a hybrid system consisting of a low-cost quadrotor and a small pushcart. The quadrotor is controlled with classical Proportional–Integral–Derivative (PID) controller for autonomous visual tracking and landing on the moving carrier. The vision-based tracking and landing approach utilizes enhancement of red, green and blue (RGB) color information rather than grayscale information of the helipad on the carrier, which shows fast and robust performance in different lighting conditions. This work is characteristic with utilizing the off-the-shelf affordable quadrotor and accomplishing the complex task using only the relative pixel position in image plane without communication between the quadrotor and carrier. The quadrotor's relative position to helipad is estimated with a frequency up to 30 Hz from the video stream, which enables the quadrotor to fly autonomously while performing real-time visual tracking and landing on the carrier. Series of experiments show that our system is easy to deploy and tune, simple and robust, also low-cost.

1. Introduction

Unmanned Aerial Vehicles (UAVs) have recently aroused great interests in both industrial and military fields. UAV is a type of very complex system which integrates different hardware components, such as camera, Global Positioning System (GPS), Inertial Management Unit (IMU), controller, and different software components, such as image processing, path planning and inner loop control [1]. Due to the ability to perform dangerous and repetitive tasks in remote and hazardous environments, UAV is very promising to play more important roles in many applications and recent developments have proven the benefits in different ways [2].

Computer vision is a field that includes methods for acquiring, processing, analyzing, and understanding images and high-dimensional data from the real world in order to produce numerical or symbolic information [3]. Computer vision is an excellent solution as a low-cost and information-rich source complementing the sensor suite for control of UAVs [4]. For fully autonomous UAV, the ability of autonomous visual tracking and landing is of vital importance for a complete mission in case of GPS signal lost [5,6]. Many researches have designed various types of UAVs that are quite large and expensive. Shakernia et al. propose a novel multiple view algorithm to improve the motion and structure estimation for vision-based landing of UAV [7]. Saripalli et al. present a real-time vision-based landing algorithm for an autonomous unmanned helicopter [8], and they also implement the landing of a helicopter on a moving target [9]. Zeng et al. design a vision system for helicopter landing by using image registration [10]. Wang et al. designed another type of vision system for UAV landing in complex environments [11].

In our work, the quadrotor is controlled to track a moving carrier by holding a constant position overhead, and land on the helipad autonomously. Quadrotor is a type of rotorcraft that consists of four rotors and two pairs of counter-rotating, fixed-pitch blades located at the four corners of the body. The idea of using four rotors is realized as a full-scale helicopter as early as 1920s [12]. However, quadrotor is dynamically unstable and not widely developed in applications until the advance in computers and micro sensors.

There are several advantages to quadrotors over traditional helicopters. Quadrotors simplify the design and maintenance of the vehicle because of simple mechanical structure. Furthermore, the use of four rotors allows each individual rotor to have a smaller diameter. In this way, the damage caused by the rotors can be reduced greatly. Herisse et al. make use of optical flow algorithm for hovering flight and vertical landing control of the quadrotor developed at French Atomic Energy Commission [13]. Wenzel et al. utilize a low-cost commodity consumer hardware-Wii remote

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camera as optical sensor to accomplish hovering and landing onboard for a quadrotor from Ascending Technologies [14,15].

This paper presents a new solution for autonomous tracking and landing, which is implemented in a type of low-cost off-the-shelf quadrotor-AR.Drone. The autonomous tracking and landing scheme is realized by using the monocular camera onboard with ground control station for off-board image processing.

The rest of this paper is organized as follows. The test-bed including the quadrotor and pushcart is introduced in the next section. Then, the proposed vision algorithms are given in Section 3, which can estimate the relative position between the quadrotor and the known helipad. In Section 4, our control architecture for tracking and landing are designed. The ground control station and experimental results are given in Section 5. Our concluding remarks are contained in the final section.

2. The quadrotor and carrier test-bed

The hybrid test-bed system includes the quadrotor and ground carrier realized by a pushcart. A ground control station is developed to perform image processing and position controlling. It is also used for monitoring and parameter variation in the experiments.

2.1. The quadrotor

AR.Drone is a WiFi-controlled quadrotor with cameras attached to it (one facing forward, the other vertically downward). AR.Drone is developed by Parrot Inc. It is an affordable (usually under $300) commercial quadrotor platform offering an open Application Programming Interface (API) and freely downloadable Software Development Kit (SDK) for developers [16]. Many useful pieces of development information can be found on the developers' websites or the official forum.

AR.Drone uses an ARM9 468 MHz embedded microcontroller with 128 M of RAM running the Linux operating system. The onboard downward Complementary Metal Oxide Semiconductor (CMOS) color camera provides RGB images in size of 320 × 240. The inertial system uses a 3-axis accelerometer, 2-axis gyro and a single-axis yaw precision gyro. An ultrasonic altimeter with a range of 6 m provides vertical stabilization. With a weight of 380 g or 420 g (with "indoor hull") it can maintain flight for about 12 min with a speed of 5 m/s. Fig. 1(a) shows the top view of the quadrotor and Fig. 1(b) shows the side view of the flying quadrotor.

2.2. The carrier and helipad

The carrier in our system is a common pushcart (see Fig. 2). The pushcart is powered by man, and can move according to a specific path, which is like a moving automobile. The helipad is with a green shape "H", which is a concise copy of standard helipad for helicopter.

The color pattern is printed on a standard A4 paper and fixed on the carrier. We also designed two rectangles in red and blue for the helipad pattern. The helipad is used to determine the position error between the quadrotor and carrier. The two rectangles can help to determine the bearing of the quadrotor by calculating the relative position of the two rectangles.

3. Computer vision algorithm

3.1. RGB filtering and thresholding

In this work, a simple and fast red, green and blue (RGB) filter [17] is adopted to implement filtering of the noisy signals. The RGB filter uses three values (red, green and blue) to focus the attention toward the specific color. RGB filter can diminish all pixels that are not the selected color. This filter is different from direct RGB channel comparison. The white pixels are diminished even though they may contain the color selected. Our helipad is pure green, so the RGB filter is accomplished eliminating the red and blue channels by using the following equation

$$\begin{cases} G = (G - B) + (G - R) \\ B = 0 \\ R = 0 \end{cases} \tag{1}$$

where G is the green value, B is the blue value, and R is the red value. Based on Eq. (1), it is obvious that the value of the white pixel results in zero, and the pure green pixel ($R = 0$, $G = 255$, $B = 0$)

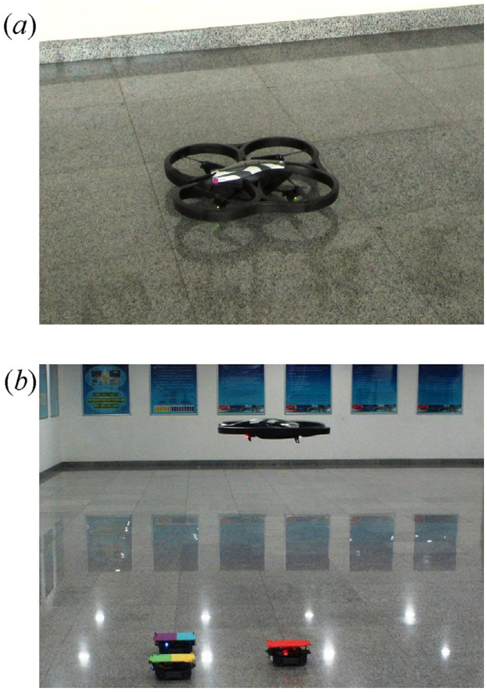

Fig. 1. Quadrotor AR.Drone picture from different views: (a) top view and (b) side view.

Fig. 2. Pushcart carrier with the green helipad and two color rectangles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)