Development of an Autonomous UAV Platform for Advanced Research Applications

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ABSTRACT

In recent years popularity of unmanned aerial vehicle (UAV) systems has been increased rapidly. There have been various research projects on the robotics and control community on these systems. In this work, a general UAV platform that can be used for education as well as research has been proposed. This system has embedded computers and various sensors such as IMU, camera, LIDAR sensor to implement various control algorithms. To emphasize the usefulness of the system, an embedded visual tracking algorithm has been developed and presented. In experiments, the quadrotor UAV could be able to successfully track the marker under Proportional-Integral-Derivative (PID) control, with the help of the on-board vision computer.

CCS Concepts

- **Computing methodologies → Robotic planning**
- **Computing methodologies → Vision for robotics**
- **Computing methodologies → Tracking**
- **Computer systems organization → Robotic autonomy**
- **Computer systems organization → Robotic control**
- **Computer systems organization → Sensors and actuators**
- **Computer systems organization → Embedded systems**

Keywords

UAV; Embedded Vision; Tracking

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) can be defined as small aircrafts that do not have the ability to carry human onboard the vehicle. They are being used in military and civilian sectors. The control of these vehicles are typically performed using a ground terminal or more recently with the help of advanced on-board controllers.

There are various commercial and experimental vehicles in use or under development in many universities, companies or in workshops of many hobbyists [1-4]. The quadrotor is a special UAV platform that is widely used. In recent years there have been many studies on quadrotor modeling and control [5-15].

The goal of this study to establish an autonomous quadrotor UAV that does not depend to any ground controls what so ever. The need for a ground control computer for control purposes or for vision processing tasks, greatly limit the autonomy of UAV systems. The data and video link capabilities and delays limit the UAV application success. In order to avoid these limitations, the main goal of this study is to develop a system that has all the onboard processing capabilities to perform the required tasks effectively.

In case of emergencies, or for the performances of any special tasks, a human operator should gain control with a R/F controller. A ground system was also developed to monitor and record activity onboard the UAV.

Twin goal of this study is, to develop a system that can be used for future studies as a test platform. The embedded system and sensors can be used for any future research studies. The system has a high level, mini computer system (Odroid XU4) that is able to deal with high level computer vision tasks onboard the UAV.

The flight controller to guide the vehicle was selected as Naza – M v2. Flight experiments of the systems are performed on Flight Test Arena at ITU. This flight arena has safety nets to securely perform various experiments.

Initial experiments involved the use of remote control and vision computer concurrently. Following experiments involved the use of flight controller with the vision-computer. Initial flight tests suggest that the designed system is a promising flight platform for advanced autonomy and vision tasks.

2. VEHICLE DESIGN

The UAV platform has to carry various sensors, on board computer and batteries. Additional systems not only increase total mass, but also consumes on board power as well. The vehicle is expected to have at least 15 minutes flight time. Considering these design limits, we have decided to use DJI E1400 propulsion system including the type 3508 brushless motors and ESCs.

The core of the system is an Odroid XU4 embedded computer, manufactured by Hardkernel. For autonomy,

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processing of data, including computer vision tasks have to be performed onboard the vehicle. Unfortunately, the payload and power are limited onboard a small UAV. This high level card can deal with algorithms for autonomy, as well as vision. The card has Ubuntu 15.04 Robotic Edition, which has ROS (robot Operating System), OpenCV and PCL (Point Cloud Library) installed.

In order to run the motor system a 22.2V Lithium Polymer (Li-Po) battery is used. The motors are installed on a commercial quadrotor frame that is strong and light weight. A 14.8 V Li-Po battery was used to supply power to Odroid and Naza – MV2. The reasons for the additional battery are the limitations of Naza, as well as the need to limit effects of power consumptions of motors. The downside of this choice is the increased weight.

Figure 1: Designed quadrotor UAV system

Odroid is responsible for data processing. An USB camera and an USB LIDAR sensor provides environmental data to the quadrotor. In addition, it receives IMU data through serial interface from Arduino Mega. Since the embedded IMU onboard the Naza is not open-source, an additional IMU has to be placed on board the system to achieve vehicle information. This is the disadvantage of using a closed-source product such as Naza

The vehicle integration and communication info structure has been presented in Figure 2. The control signals obtained through the evaluation of sensor data are sent from Odroid to Arduino mega through a serial connection. Arduino mega is transferring these to flight controller Naza. In addition, it is responsible to read the R/C commands that might be transferred to take control from autonomous control to manual code and transfer these signals to the flight controller. The signals that might be coming from the R/C have a higher priority. This is required since for emergency tasks, the operator might gain control, even if the odroid is sending specific autonomy directives. The Arduino Mega also reads and transfers IMU data to Odroid, which will be used to improve navigation algorithms.

The flight controller Naza, is responsible to generate necessary signals to the Electronics speed controllers (ESCs), which are controlling the motors.

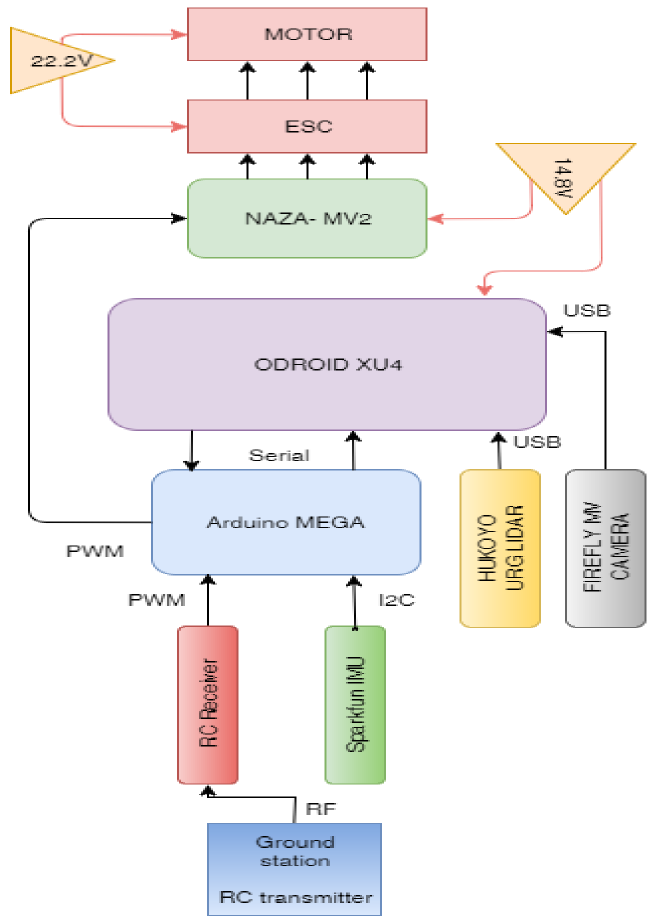

Figure 2: Components of the Designed UAV

Once the vehicle has been manufactured and all of the components are installed, flight tests were performed. It was flown initially manually with an R/C controller, then with onboard data stream.

Proportional Integral Derivative (PID) controllers are widely used in control applications for simplicity and robustness. In order to control states of the quadrotor UAV, a set of are PID controllers are used. To determine successful PID coefficients a ball-tracking application has been introduced. The ball coordinates that are determined with camera are used to calculate errors along vertical and yaw axes which are then feed to the PID controllers as presented on Figure 3.

The control signals for z (throttle) and yaw motions are then generated and transferred to Naza to control the quadrotor. The rest of the states are kept constant, meaning that the helicopter is hovering while tracking the ball, and either going up or down and either turning clock-wise or counter-clock-wise to track it.

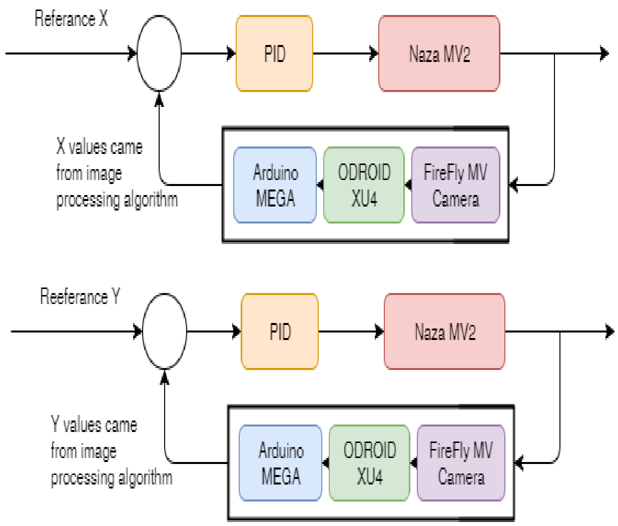

Figure 3: PID control flowchart

3. COMPUTER VISION

The UAV has a Firefly Machine vision camera from Point Grey Inc. It grabs images and these images are transferred to onboard vision-computer through USB. This computer runs Ubuntu. A code has been generated to grab images using Point Grey library and process them using OpenCV library and generate trajectories for the quadrotor to take in order to keep the ball in the center of the camera frame (Figure 4).

Feature identification and tracking is an important topic in computer vision. This task can be simplified with the aid of color information. The ball color, which is unique in the environment, is being used with segmentation to filter out other colors. The next step is to calculate the center coordinates of the ball and the error with this coordinate and the image center coordinated. This task confirms the ability of onboard processing being able to work together with the flight controller and the Arduino Mega processor, successfully.

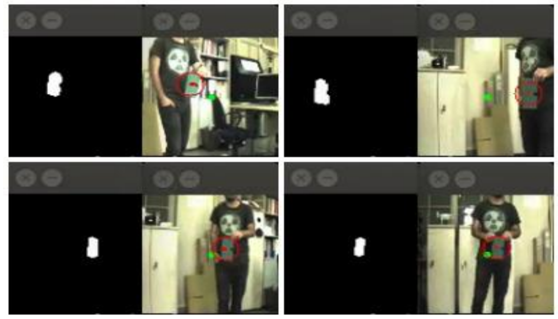

Figure 4: Ball tracking

4. EXPERIMENTS

In order to perform experiment securely, a test area was set-up. The set-up involves a tether system to enable separate test of UAV states (Figure-5).

In experiments, the quadrotor could be able to successfully track the marker under PID control, with the help of on-board vision computer. The results of the experiments are presented on Figure 6.

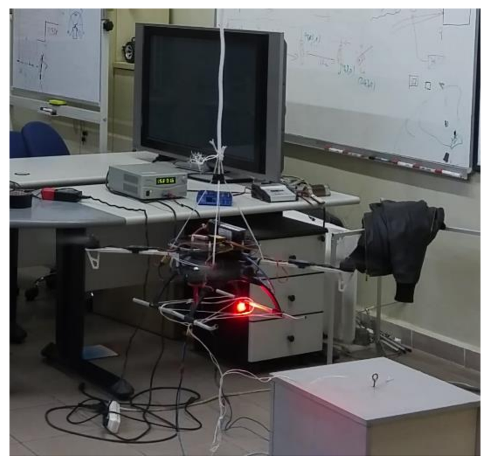

Figure 5: UAV on test area

In control algorithm midpoint of camera are chosen as references point. Our camera frame is 100x100 pixel. That mean our references points are 50 pixels for X and Y axes. Marker location is obtained from image processing algorithm and express with pixels' values as well. As seen on the PID control result, marker position tent to remain between 40 and 60 pixels, because control algorithm does not product control signal and send signal to Naza for these error space. If the error exceeds 10 pixels, algorithm starts to send control signal to Naza to reduce the position error.

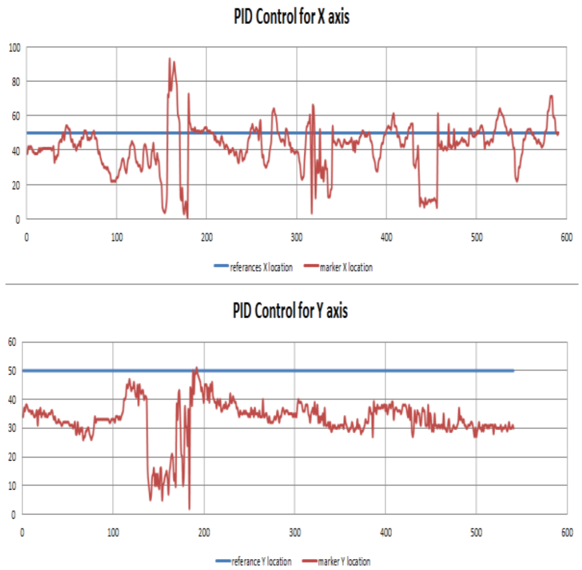

Figure 6: Experiment results

5. CONCLUSION

Unmanned air vehicles have many different uses in recent years. Some of these tasks are for civilian, and some for military purposes. Using camera to control the UAV has many advantages; it is very small and has the ability to provide valuable information for autonomous flight. Also it is ideal solution for lack of space.

In this work, we integrated commercial Naza controller (closed source flight controller) to our system. Flight controlling of UAV was very stable with the Naza integration. The limitations of Naza limited the further development of the system. The Naza system does not enable read of the vehicle states, or ability to change any control parameters. We could only obtain input and output of Naza, for this reason, we had to use an extra IMU for collecting data.

In the future, we plan to integrate localization and mapping using the onboard camera, LIDAR and IMU sensors. After that, we aim to develop a completely autonomous UAV based on image processing algorithm.

6. ACKNOWLEDGMENTS

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