Autonomous Quadrotor for the 2014 International Aerial Robotics Competition

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ABSTRACT

This paper describe the technical details of an autonomous quadrotor developed by Temasek Polytechnic robotics and automation team(TPRAC) to take part in 2014 International Aerial Robotics Competition(IARC). The unmanned aerial vehicle(UAV) is capable of autonomous navigation in an indoor environment without the help of GPS or large external physical point of reference. It can also demonstrate target identification of static and moving objects at airborne. Using sensors, controllers and mechanical system from current technology, we put together an UAV with the aim of fulfilling the tasks required of competition.

1. INTRODUCTION

2014 International Aerial Robotics Competition is the first year for mission 7. It will challenge teams to demonstrate three new behaviors that have never been attempted in any of the past six IARC missions. First, "interaction between aerial robots and moving objects (specifically, autonomous ground robots). Second, navigation in a sterile environment with no external navigation aids such as GPS or large stationary points of reference such as walls. Third, interaction between competing autonomous air vehicles. [1]

1.1 Problem Statement

The objective of IARC 7th mission is to develop an aerial vehicle that can track and interact with random moving ground robots. UAV must able to plan and herd ground robots toward a common direction of the competition arena. Navigation of the UAV will have to be done without use of GPS, obvious physical cues and any other external navigation aids. Second phase of the mission will require the task to be carried out together with multiple aerial robots. UAV needs to be able to avoid other moving aerial robots while executing its mission.

1.2 Conceptual Approach

TPRAC team has developed an UAV capable of tracking moving ground targets while avoiding moving obstacle without the use of GPS. UAV is built on a custom platform capable of carrying 800 grams payload excluding batteries with a flight time of 10 minutes. We have a fusion of sensors to provide various information of the UAV. These data will be fed to both the flight controller and the ground control station during mission. The UAV consist of an off the shelf flight controller that can achieve reasonable stabilization of the UAV during flight using the data from the sensors. Flight controller took care of the low level flight control of maintaining stability, position and altitude of the UAV. The higher level function includes moving the UAV to position relative to its last hovering position. Cameras are mounted and constantly streaming images back to ground control station(GCS) for processing. GCS will identify the targets and send relative position to flight controller for tracking and interaction. A custom made circuit with a 8 bit microcontroller will take care of the obstacle avoidance function. It interfaces with the laser range finder and transmit critical flight path to the flight controller to cancel out existing flight plan. The same board is also used to activate the electro-magnet used to herd the ground robots.

For the strategy to carry out the mission, UAV will first identify the two color lines. The plan is to maintain a close distance to the red line. It will then identify the target with the highest threat of exiting the arena and herd it back.

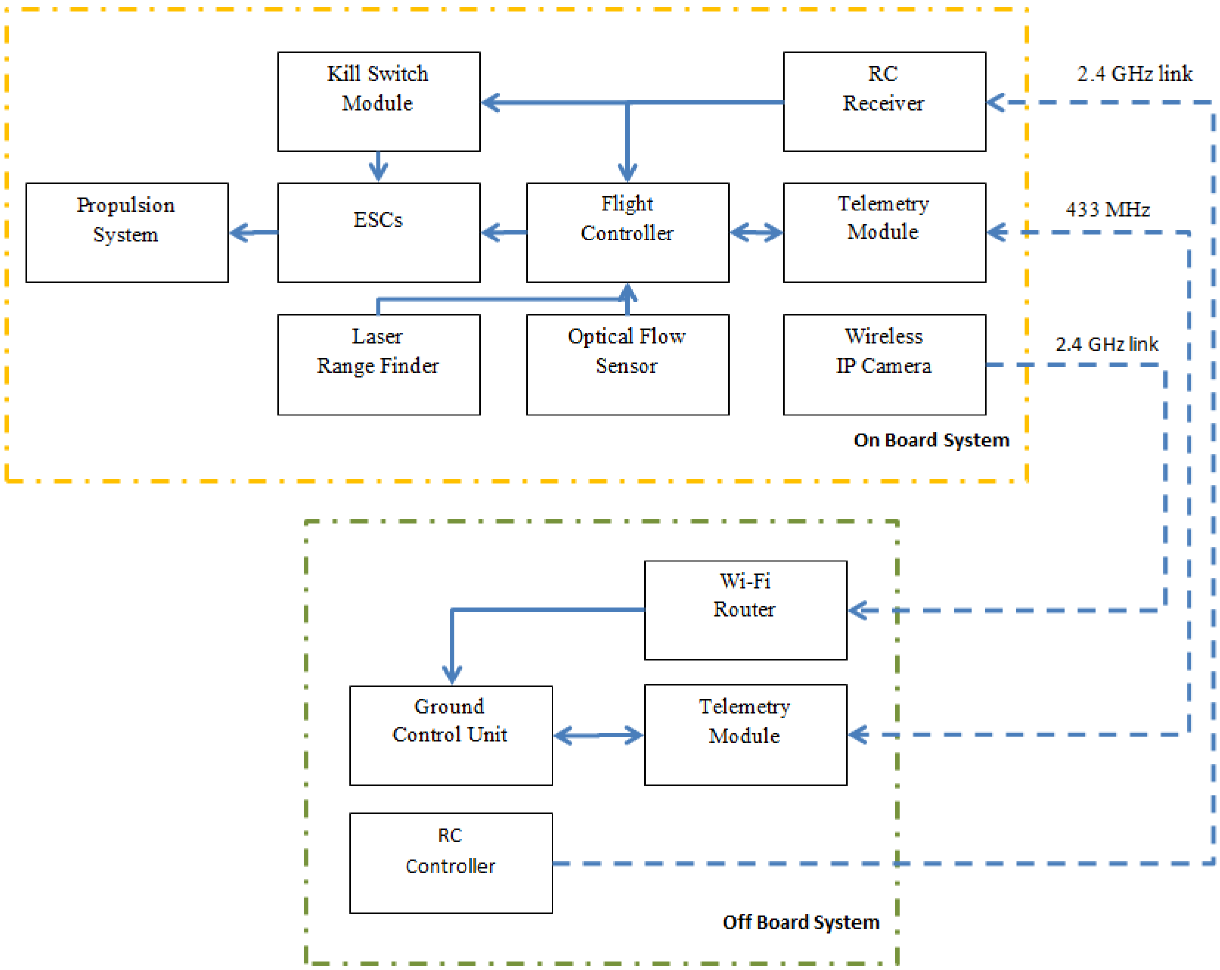

Figure 1. Overall system architecture

2. AIR VEHICLE

UAV constructed using mixture of carbon fiber and aluminum frame. Protection frame are added to the end of the propeller blades for safety. A custom made embedded system, a safety control board and a flight controller are the main embedded system on the UAV. Sensors suites includes cameras, optical flow sensor, Hokuyo laser range finder, IR sensors and on board IMU.

2.1 Propulsion and Lift

The UAV is lifted by four, 10 inch, two-blade propellers mounted on T-Motor MN3110-17 (700KV) navigator series brushless DC motors, which distribute symmetrically at the end of four arms (see figure 2a). The overall weight of the UAV is about 2.6 kg with the flight time of about 10 min. The two bladed propellers instead of three bladed propellers were chosen since the overall diameter of the UAV is not a main concern so that the efficiency can be relatively high to ensure that the battery power is sufficient enough to achieve a full flight.

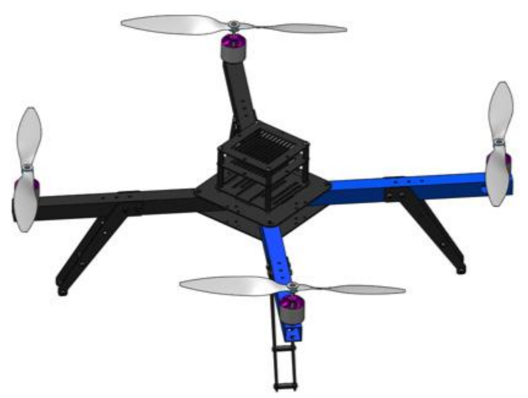

Figure 2a. Quadrotor platform

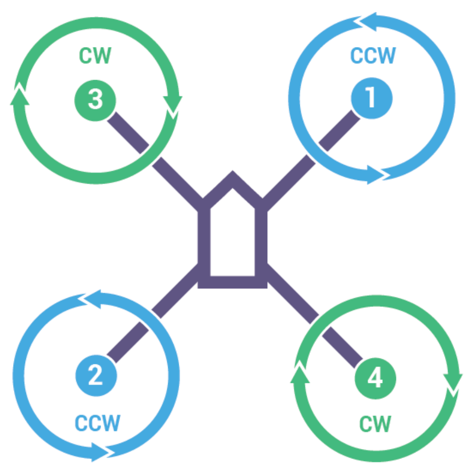

Figure 2b. Quadrotor propulsion system

As shown in figure 2b, each opposite pair of motors is spinning in opposite directions. This allows the copter to turn (Yaw) right or left by speeding up one pair and slowing the other pair of motors. Horizontal motion is accomplished by speeding up motors (increasing thrust) on one side and reducing it on the other. This causes the copter to tilt (Roll or Pitch) in the desired direction of motion and thrust is re-equalized. The angle of the copter is generally representative of its speed in that direction. To hover the copter, it needs to compensate for disturbances (gusts of wind) by tilting automatically against the direction of the disturbance. In order to accomplish this, the copter has electronic "gyros" which sense level in 3 dimensions. In addition, they also have electronic "accelerometers" which sense displacement in 3 dimensions. Altitude control or change is accomplished by speeding up or slowing down all motors at the same time. In short, we can control the attitude of the UAV by adjusting the rotational speed of the four motors

2.2 Navigation and Control

2.2.1 Stability Augmentation System

In order to jump start the development, we decided to purchase off the shelf flight controller which uses the popular open source ardupilot/APM flight control software. Figure 3 taken from ardupilot development website [2] describe the PID loops that helps to maintain the UAV in stabilize mode. The PID parameters were tuned when all the payload and structure were mounted to ensure optimum stability control.

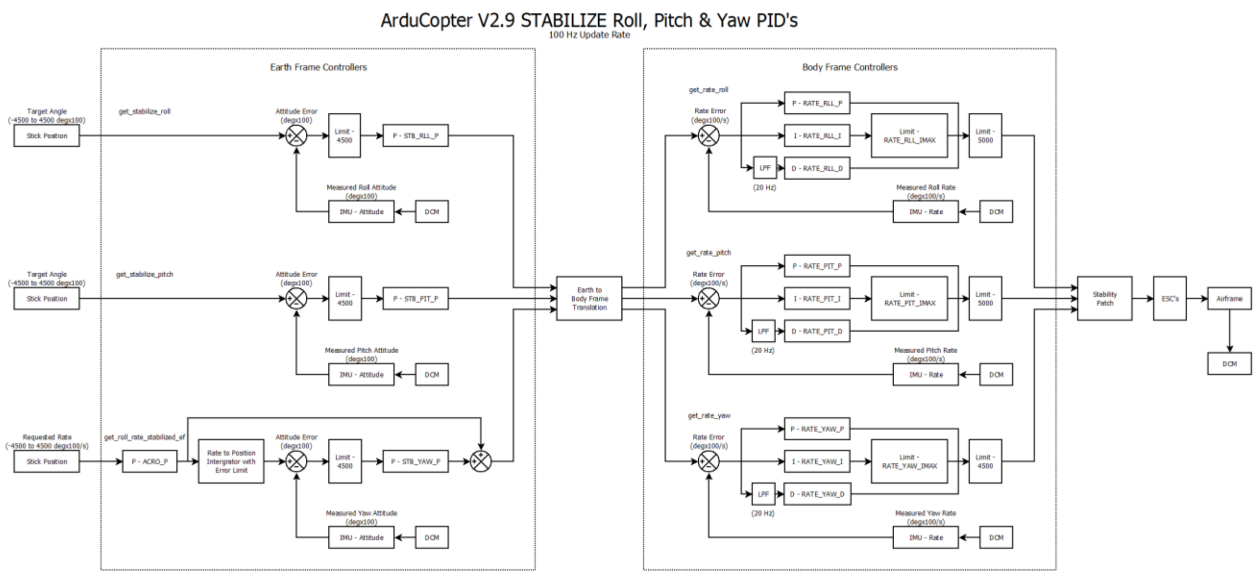

Figure 3. Ardupilot stability system

2.2.2 Navigation

With the constraints of indoor environment and without large physically feature points, the team has to rely heavily on vision system to navigate. Optical flow sensor, px4flow from the pixHawk project is used as an odometry equivalent sensor for the UAV. Cameras mounted on the UAV will be used not only to track the target, but also to feedback position of the UAV relative to the boundary. The periodical reading of the camera data will be use to correct the drift in the odometry data provided by the optical flow. Using the relative distance moved data and the position feedback from the cameras, UAV can localize and navigate around the competition arena.

The global path planning of the UAV is by the ground control station. GCS process the video stream feed and identify all targets within the vision range. Based on the odometry information shared by the flight controller and the drift correction using the vision, the GCS then analysis the threat of all targets; assignment of a threat score to all targets. A global path toward the highest score target is then periodical send to the flight controller. This will enter the target tracking phase. GCS will send the target relative vector position to the flight controller via the mavlink communication link based on the path planned.

Flight controller upon receiving the target position, will calculate the profile movement towards the set point. This will ensure a smooth movement at the optimum speed for the UAV. Sensor feedbacks for obstacle avoidance will trigger the path change and abortion of target position.

2.3 Flight Termination System

There are two ways of manual pilot to take over autopilot in case of the air vehicle become unstable and become a threat to people's safety. First, operator can override the flight control by simply flipping a toggle switch on the RC controller. One dedicated RC channel is used to connect the flight controller to select the input control source to the flight control. Second, there will be another dedicated RC channel connected to kill switch module that recommended by the IARC committee. If the kill switch module can't detect the valid pulse from the RC receiver, the power to the propulsion system will be cut as a last resort to stop the run away air vehicle.

3. PAYLOAD

3.1 Sensor Suite

3.1.1 Navigation and Control Sensors

The UAV uses build in aerometer in the flight controller and an external compass for the primary stabilization control. It uses the px4flow optical flow sensor and Hokuyo laser range finder for odometry and altitude information. The laser range finder and Sharp IR sensors are use also as sensors for obstacle avoidance.

Figure 4a. External compass

Figure 4b. Px4Flow

Figure 4c. Hokuyo Laser range finder

Figure 4d. Sharp IR sensor

3.1.2 Mission Sensors

The UAV uses four D-Link DCS-2130 HD Wireless Network cameras for iRobots and arena boundaries detection. The four cameras are arranged outwards and downwards to provide all round coverage around the UAV. The raw videos from the cameras are streamed via Wi-Fi to an off-board computer for processing. The detections are achieved using the open-source computer vision library OpenCV and sent to the mission computer to aid in the path planning and decision making.

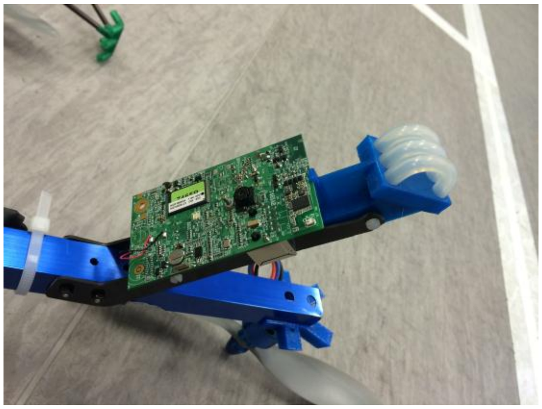

Figure 5. D-Link Network camera

3.2 Communications

The off board processing computer receives the raw videos from the on-board cameras using 802.11 b/g/n Wi-Fi links and the UAV telemetry information using MAV-Link messages. The detection information is sent directly to the mission computer

3.3 Power Management System

The air vehicle is powered by a four-cell 8000 mAh Li-ion battery with nominal voltage of 14.8 Volts. The battery is than go through a main power switch, than it split into two path. The first path goes to the flight controller, sensory module and the RC receiver module. The second path goes through the kill switch module than go to the 4 channel power distribution board that connect to the BLDC ESCs and BLDC motors. The flight controller will monitor the battery voltage and switch to auto landing mode if the battery voltage fall below certain threshold.

4. OPERATIONS

4.1 Flight Preparation

The UAV flight preparation checklist is as follows:

1. Check battery voltage level.
2. Connect the power circuit.
3. Turn on the transmitter and termination system.
4. Power up the UAV
5. Connect to the ground control station
6. Activate the pre-arm check.
7. Set UAV to autonomous mode.

4.2 Man/Machine Interface

There are three man/machine interface methods implemented for the UAV. The highest priority is the termination system which is required to maintain a handshake throughout the entire flight of the UAV. Turning it off will shut off the power to the propulsion system. The second interface is transmitter which can switch the UAV from autonomous mode and manual flight mode. During manual flight mode, transmitter will take over the flight control of the UAV. The third interface is the GCS. GCS can change flight mode and issue flight commands to the UAC. It also display flight information on the screen.

5. Risk Reduction

5.1 Vehicle Status

The air vehicle will broadcast its operating status via the telemetry module to the ground control unit using the mavlink protocol. The ground control unit will display the essential flight info such as attitude, altitude, heading, velocity and video stream from the on board camera.

5.2 Safety

To prevent people from injured by the fast spinning razor sharp propeller, four propeller guard is installed around the side of the propellers. Throughout the testing, the air vehicle is confined in a safety cell surround by safety net and no one is allowed to go in the safety cell while the air vehicle is armed

Figure 6. Propeller guard

5.3 Testing

The on board flight controller has a build in self-test system and the flight controller will not take off unless all the self-test is passed. The self-test will test on the functionality of:

1. IMU
2. Compass
3. RC channel
4. Optical flow
5. Laser Range finder
6. High level auto-pilot system

6. CONCLUSION

This paper has presented that TPRAC has developed an UAV which is capable of autonomous navigating in an indoor environment without large physical feature. Using the optical flow sensor and vision recognition data, it is able to maneuver within the competition arena. With the streaming video from the camera mounted, GCS is able to identify the target and send tracking path information to the UAV. UAV is able to track the random moving ground vehicles and interacting with it using electro magnet. The flight controller module on board calculates the attitude for the UAV to achieve optimum speed to reach the set point.

With the capability of the UAV, we developed a possible solution to IARC mission 7. TPRAC team will like to thank Temasek Polytechnic for the support in manpower and funding for the project.

6. REFERENCES

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[2] Leonard, T, ArduCopter 2.9 PID Loops for STABILIZE, ACRO and ALT_HOLD,
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