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Hybrid Terrestrial and Aerial Quadrotor (HYTAQ) with Obstacle Detection and Surveillance System

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Abstract — Hybrid Terrestrial and Aerial Quadrotor (HYTAQ) robot with Obstacle detection and Surveillance is a unique addition to the field of locomotion robots that has dual capabilities, i.e. it can both drive and fly. Its original design was put forward by Illinois Institute of Technology (IIT). Starting with the original concept of the robot, we have not only reconstructed the robot, but we have also added new features like Obstacle detection to it. HYTAQ is engineered with a quadcopter enclosed within a protective, cylindrical cage. The cage is what provides this robot the ability to translate on ground. Only four actuators are employed in the robot, which provide both land and aerial capabilities to this machine; using a minimal number of motors ensures longer battery life and smaller overall load of the robot. The obstacle detection mechanism of the robot is based on IR sensor circuit while the surveillance system is comprised of an FPV camera. The wireless video transmission and control of the robot are both provided by RC telemetry. Although HYTAQ provides an improved locomotion mechanism over the traditional mobile robots that provided only terrestrial or aerial locomotion, there is still room for its enhancement. In its future upgrades, measures can be taken to reduce the cost of its construction, switch from obstacle-detection to obstacle-avoidance mechanism, and employ real-time image processing techniques to the video obtained from FPV camera.

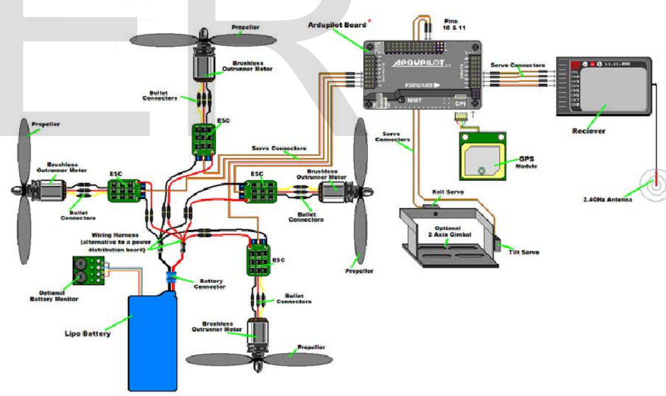
Keywords : Collision avoidance, Obstacle detection, Infrared sensor, Terrestrial and Aerial robot.

1 Introduction

Hybrid Terrestrial and Aerial Quadrotor HYTAQ is a robot that combines both ground and aerial capabilities into a single device. This means, HYTAQ can not only fly and run on all kinds of surfaces, but it can also jump over any obstacle in its track of motion. Structurally, a HYTAQ is a quadcopter with a rolling cage attached to allow ground locomotion. The quadrotor is mounted onto a fixed shaft. At the shaft's ends, the planar bearings connect the cage to the robot. The advantage of having a rolling cage is manifold. Not only does the cage provide ground locomotion, but it also acts as shock absorber when the robot is on land. During flight, it acts as a crash resistance for the robot, hence protecting the propellers and other delicate components of the quadcopter. The cylindrical symmetry of the cage minimizes the rolling resistance encountered by the robot during translational motion. Also, the planar bearings attaching the cage the remaining structure allows the cage to roll like a wheel, without the need of any extra actuators. This means, the four motors used during robot flight are sufficient to permits ground locomotion as well.

Having a single set of actuators and controller for both land and air locomotion make HYTAQ robots highly power efficient too. According to a rough estimate, battery of a hybrid land and aerial robot will last six times longer than a simple (fly-only) quadrotor, and the robot will cover four times longer distance as compared to its aerial counterpart.

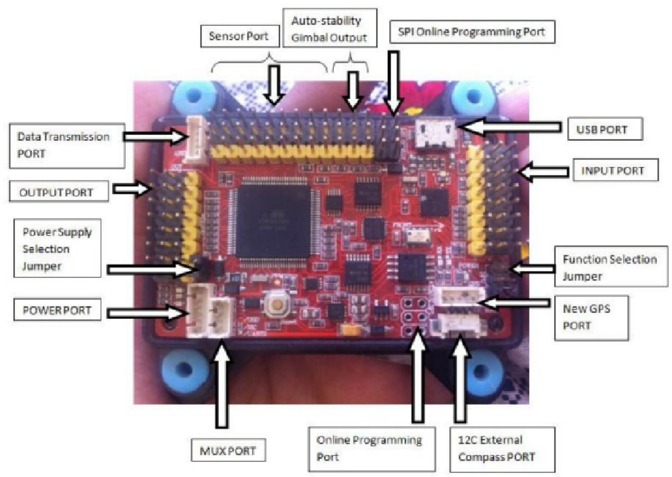
2 Methology



1. Typical Layout of a Quadcopter

2.1 Ardu pilot Board (Controller)

The Ardu pilot Mega is an unmanned aerial vehicle platform which is arduino compatible controller used to operate fixed planes, quad-copters , hexa-copters, multicopters and ground rovers. APM has a feature either to programmed it by a software MISSION PLANNER or can also be programmed by APM PLANNER .This Ardu pilot systems use 6 Degree of Freedom. APM has built-in 3-axis accelerometer, high speed altimeter, high performance barometer MS5611-01BA03, 3-axis gyroscope, magnetometer and on-board compass.



2. APM Controller

2.2 Global Positioning System (GPS) Module

The purpose of using the GPS module along with the HYTAQ is to enable robot to identify its position and to fly pre-programmed missions. This means, we can graphically indicate the locations to the robot on a GPS map using the Ground Control Station, and the robot will autonomously follow this indicated path using the GPS module.

The added benefits attainable using GPS include Auto trim Return-To-Launch (RTL), and Circle. Auto trim is a feature that enables the robot to return to its original position in case it is pushed away by the wind. This ensures that the robot remains at precisely fixed coordinates unless specified by the user operating the robot. RTL is the feature of mobile robots to return back at the end of the flight to exact location where they began their journey. Circle is a flight mode available APM based robots that allow a robot in programmed mode to fly in a complete circle, with its pointing to the center of the circle; this allows FPV camera to capture images of a location from all possible directions. All these impressive features are incorporated into the robot using the GPS module.

2.3 Radio Control Transmitter and Receiver

The command to controller will go by means of RC Transmitter and Receiver. The RC transmitter used in our project is FS Fly sky FS-i6 and its compatible receiver used is FS-iA6. This is a 6-channel, 2.40-2.48 GHz transmission system which provides a bandwidth of 500 kHz for the communication link. The transmitter operates on 4.2V while the receiver can work on 4.2-6.5V. All six channels in this RC control system provide a proportional control of signals, i.e. a change in position of the switches (joysticks) in the transmitter provides a proportional change in robot's movement. Moreover, the transmitter is also provided with four additional 2-way/3-way switches which offer users extra features like: mode selection, altitude hold, etc.

The communication link between transmitter and receiver is based on AFHDS (Automatic Frequency Hopping Digital System). This means, the signals broadcasted are not only immune to noise, but are also protected against any interference due to other RC signals roaming in the region.

2.4 Electronic Speed Controller (ESC)

An ESC is a trapezoidal wave generator. It produces three separate waves, one for each wire on the motor (i.e. it converts DC power to 3-phase AC power). ESC supplies power from battery to the brushless DC motors. This power is not constant, but it varies according to input signal. Brushless ESCs are used to control brushless motors that are used on most locomotion robots. During operation, the ESCs get power directly from the Lipo battery. The control input terminal of each ESC is connected to the output pins of the APM v2.8 flight controller. Based on the control signal from RC transmitter, the APM generates the corresponding output signals. These signals are carried at the ESCs' control input terminals. In response, the ESCs control the speed/RPM of each LDC, hence producing correct locomotion in the robot.

2.5 Anti-Vibration Board

Although not a mandatory component for the robot, anti-vibration boards are still used for the better performance of the robot. Our project also uses an anti-vibration board (or shock absorbing plate). The APM is mounted onto this plate using double sided foam tape.

As the name suggests, anti-vibration board prevents vibrations from reaching the flight controller. It physically isolates the controller from the remaining mechanical structure of the robot. Ideally, it must damp the high frequency vibrations from motors before they reach the APM. However, at the same time, the board must not be too stiff that it blocks small changes in the robots position from reaching the controller. So, in theory, this board absorbs the high frequency oscillations but allows the lower frequency vibrations to reach the controller.

2.6 Chargeable Lithium Polymer (LiPo) battery

Batteries are combination of cells and cells can be connected in Series (S) and Parallel (P). This S and P is written on the battery pack in order to identify it's inside connection of cells. LiPo batteries are also the combination of cells so the power of a battery depends on number of cells connected in series. It comes in following series:
1S, 2S, 3S, 4S, 5S, 6S,
The output voltage is determined by the number of cells connected in series. Each cells provide 3.7V so for the above cells the output rating will be
1S: 3.7V x 1cells = 3.7V
2S: 3.7V x 2cells = 7.4 V
3S: 3.7V x 3cells = 11.1V
4S: 3.7V x 4cells = 14.8V
5S: 3.7V x 5cells = 18.5V
6S: 3.7V x 6cells = 22.2V

2.7 Professional Battery Charger

The battery charger which is used in HYTAQ for charging the battery is IMAX B6AC PROFESSIONAL BATTERY CHARGER. It provides fast charging because of high speed processors and a fast OS which is capable to monitor the all cells of battery. Many types of Lithium Batteries can be charged with this battery charger. Its sophisticated software is able to ceases the charging of battery when the battery voltage is greater than the threshold voltage. The battery is capable to charge a 1s-6s batteries or 15 cells. For LiPo batteries it can charge each cell up to 3.7V and the maximum voltage can be charge up to 4.1V for each cell.

2.8 Mini-Quadcopter Frame

The main considerations while choosing a material for the quadcopter are:

- The frame must be light-weight.
- It must be inexpensive and locally available.
- The material used must be electrically insulated.
- It must withstand high temperature, and must not change shape due to heating.
- The material must be strong enough to lift the robot's weight, but not too rigid that it may break during landing.

The spinning of motors produce vibration; hence the copter frame should have ability to damp these unwanted oscillations.

The common materials chosen for quadcopter frames are plastics, aluminum, carbon fiber, and glass fiber. All materials possess certain pros which make them ideal for a copter's frame, but each has their drawbacks too.

2.9 Software (Mission Planner)

Ground Control Software (GCS) is any application that runs by our PC (computer, laptop, tablet, or smartphone), and allows configuration, control, and navigation of a mobile robot. The flight controller used in HYTAQ robot is APMv2.8, which is enabled to be operated by several GCSs.

However, the one we are using is Mission Planner. Mission Planner is the oldest, and hence the most developed /evolved GCS used with APM based robots. It is a Microsoft Windows based application which allows not only the configuration, control and navigation of the robot, but it also supports troubleshooting of robot parts (like motors) and simulation of robots. We have mostly used Mission Planner for loading firmware, setting up basic robot parameters, and troubleshooting of flight related issues of HYTAQ.

2.10 Brushless Direct Current Motors (BLDC)

For optimum performance of the motors in any mobile robot, the key issue is to determine the maximum weight a single motor can handle, without degrading the performance of the robot. This issue is more concern in aerial robots, as compared to the terrestrial robots. Since HYTAQ is both aerial and terrestrial robot, determining the weight limit of our robot was an essential task.

A general rule regarding the motor selection is that the motor must be able to provide twice as much thrust than the weight of the robot. If the thrust provided by the motors is too little or the weight of the robot is too large, the robot will be unable to take-off from the land. On the other hand, if the thrust is provided by motors is too much, the robot might become too agile and hard to control. Hence, the general accepted rule developed for required thrust per motor in the robot became :

$$\textit{Thrust per motor} = \frac{(\textit{Total weight of the robot}) \times 2}{\textit{Total number of motors used}}$$

3 Choose Propeller Wisely

Propellers are the mechanical structures that convert power from motors into thrust that lifts a robot, while rpm from the motors is converted into velocity. Various materials and structures of propellers are available; however, using the right propellers can greatly enhance the flying capacity of a robot. Important factors to consider for selecting the correct propellers are: propeller diameter, pitch and blade angle. The size of the propellers is chosen in accordance with the motor-to-motor length of the quadcopter frame; the diameter of propellers used in this project is 5 inches. Choosing propellers with correct pitch is also essential, since the output power of propellers is directly related to propeller's diameter and pitch :

$$\textit{Output power} = 5.3 \times 10^{-15} (\textit{rpm})^3 (\textit{propeller diameter})^4 (\textit{propeller pitch})$$

The angular velocity (ω) of the propellers is constant at a given rpm; hence, the velocity (v) of the propeller blades vary throughout the blade's length. Therefore, to ensure this velocity (v) becomes constant, the blade is twisted. This twisting is maximum at the inner part of the blade and gradually reduces at the outer edge. This twisting is called the blade angle. With propellers having the correct blade angle, the air will strike the propellers at same speed throughout, and the robot will move forward at constant speed, without toppling.

For HYTAQ, we used plastic propellers. Although the plastic propellers are noisier than the other types of propellers available, they produce more thrust and are relatively cheap. Two clockwise and two counter-clockwise propellers are fixed diagonally on the quadcopter frame. Their simultaneous operation provides HYTAQ the ability to navigate in the desired directions.

4 First Person View (FPV) Camera

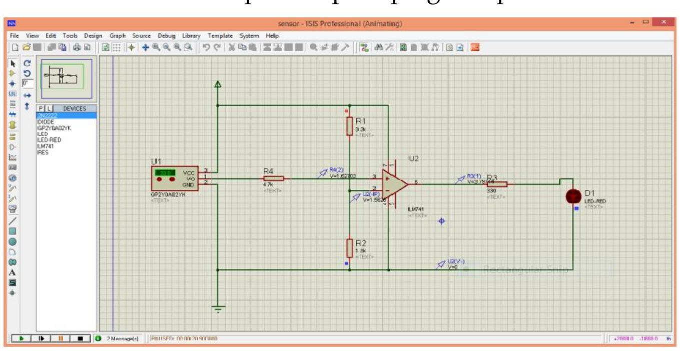
FPV camera is used to monitor many parameters like path of the copter, upon hurdle in the path of copter to change its path and direction and to take live videos taken by camera fitted in the copter as live shows and functions. FPV camera setup consist of a little mini camera, RF transmitter and receiver and a monitor screen to view video. Quality of camera picture and videos depends mostly on resolution of camera and focal length of lens.

5 IR Sensor GP2Y0A02YK :

The proximity sensor used by HYTAQ for the obstacle detection purpose is Infra-Red (IR) sensor. This device comprises of two essential components: the IR rays generator and its detector. The generator part of the sensor is made up of IR-LED (Light Emitting Diode). The LED generates electromagnetic radiations with wavelength in the range of 700nm to 1mm, i.e. the frequency range of emitted radiation is 430THertz to 3000GHertz. This range corresponds to infra-red radiations in the electromagnetic spectrum. Likewise, the IR detector portion of the sensor operates for the same range of wavelengths and frequencies. The detector is simply an IR photodiode. When IR rays of the correct wavelength strike this photodiode, there is a corresponding change in the resistance of this device. The change in resistance produces a change in output voltage across the photodiode. This change in output voltage indicates the presence of an obstacle.

5.1 Software Simulation

The working principle of all IR sensors is same - the only difference is the voltage at which they operate and the maximum range at which they can detect a barrier. Hence, for the simulation of the obstacle detection system, we have simply chosen the IR sensor GP2Y0A02YK available in Proteus simulator. The voltage level for the power rails is chosen to be 5 Volts. The threshold distance, i.e. the distance at which the sensor must be able to detect the obstacle, is selected as 33 centimeters. The reference voltage is selected as 1.5 Volts. According to the rated specifications of the IR sensor used in the simulation, the voltage across the sensor measures just above 1.5 Volts at the threshold distance. This means, whenever the obstacle is anywhere closer than 33 centimeters, the red LED at the output of op-amp lights up.



3 Simulation for Obstacle Detection

For the physical circuit, the threshold distance can be chosen to be any value by simply adjusting the reference voltage.

6 Why use Obstacle Detection?

Hybrid Terrestrial and Aerial Quadrotor (HYTAQ) with obstacle detection and surveillance system, provides the real-time video footages of where the robot is heading, we are still uses an obstacle detection mechanism. Although the use of this system might appear an over-do since we can already see any upcoming obstacle in the video; however, its importance can be reviewed as follows:
Not all obstacles will be visible in the video we obtain from the camera. For instance, a transparent glass window / wall will not be observable in the video. However, IR sensor based obstacle detection system can still sense this barrier and warn the human operating the robot.
When HYTAQ is operated outside in daylight, chances are that reflecting beams of sunlight may cause the video obtained from camera to be blank frames of bright light. Any obstacle in the path of the robot during this brief instant may go unnoticed and may end-up with the robot crashing if not for the presence of the obstacle detection system.

7 Uses Of This Paper

7.1 Military

Military use the surveillance system of robot to guard a particular area and to get safe from enemies during any mission and from the danger of leaking the confidential information.

7.2 Under mines

Robots can also be used under mines where a person is not able to reach under a guaranteed depth to get alerts about the minerals achievements.

7.3 Media purposes

Our media is getting advanced day by day uses the robotic feature to enhance their performance. Media uses robots in each function, live shows, events where it is dangerous for workers to go there and make videos themselves, robot ease their work and record programs by just getting input commands from so far distant places.

7.4 Human Identification

Camera in robots also use to identify any person which is the search for others. Robot save the identity of that person in its memory and it's the key task of that robot to identify the person, its location and to track its path.

7.5 Obstacle Detection

Feature of camera helps in detection of obstacle and to save itself from that obstacle. When an obstacle comes in the way of robot it fly above or jump above it mostly it changes its path to save itself.

8 Future Prospects

HYTAQ is a robot engineered for surveillance. What makes HYTAQ ideal for this application is the ability of this robot to travel on any kind of land and air. Generally, the locomotive robots either have aerial or terrestrial capabilities, but HYTAQ integrates both into a single package. It can be used by Pakistan defense authorities to monitor the conditions in any area. It can be used to get aerial view of regions affected by a natural disaster to evaluate the magnitude of destruction. It can also be used to closely investigate locations like sites containing radioactive debris, where human presence is unadvisable.

For similar reasons, HYTAQ also finds prospects of widening its reach to some other organizations / fields. These include: the geographical research groups, mining locations, security monitoring, etc.

9 Conclusion

HYTAQ is the latest introduction to the class of mobile robots. Its unique ability to perform both aerial and terrestrial locomotion is the key feature stimulating the interest of engineering community. The fact that it uses the same set of actuators for the drive and flight, hence reducing battery consumption, is yet another article of interest driving everyone towards this robot. As a part of our Final Year Project, we have not only conquered the objective of robot locomotion, but we have also integrated into this robot the additional mechanisms of Obstacle Detection and Surveillance. This will enable our robot to move in all kinds of indoor and outdoor conditions, and send live video streaming to human operator situated at a remote locations. In a nutshell, Hybrid Terrestrial and Aerial Quadrotor (HYTAQ) with Obstacle Detection and Surveillance System can provide ideal solution to security, under mines, and high risk applications.

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