UAV LiDAR Mapping

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Abstract
This paper will dissect the architecture of the Pixhawk flight controller in order to gain an understanding of how flight controllers are used to take a helicopter from one state to a new desired state. It will start with a brief discussion of the history of helicopters to understand the importance of flight controllers and then each component of the flight controller will be analyzed.

Introduction
Small-scale helicopters have quite recently become popular due to their numerous applications which include photography, agriculture and weather telemetry.[5] The first quadcopter, shown in Figure One, was actually invented in the 1920s. This quadcopter was only able to fly up to five meters and could not move laterally. The lack of movement was because the quadcopter relied on manual operation to fly and just keeping it level turned out to be a difficult task.[5] It was not until the 1990s that the next quadcopter, a small scale remote controlled device, was developed by a company in Japan. At this point computers were able to assist in handling the computation that flying quadcopters required. However, this was a small system that could only achieve three minutes of flight. Thanks to flight controllers, computers whose sole purpose are to figure out how to fly vehicles like quadcopters, the computation required to fly larger systems for longer periods of time with even more rotors than quadcopters has become available. However, quadcopters large enough to carry people are not that common today as it is still quite difficult to control these systems.[6]

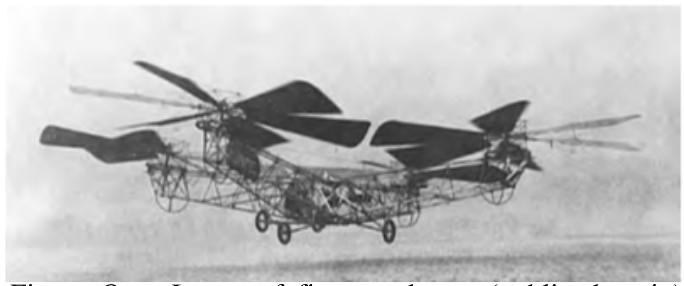

Figure One: Image of first quadcopter(public domain) [9]

The rest of this paper will break down the Pixhawk Flight Controller. Specifically, we will look at the flight stack(Figure Two) which is the part of the Pixhawk responsible for flying the copter. We will break it down into three components: how a copter moves, how the flight controller gets the copter to where it wants to go and how the controller knows the state of the copter.

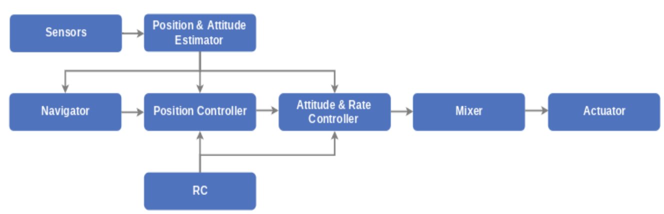

Figure Two: The Pixhawk flight stack(CC BY 4.0.) [1]

How a Copter Moves
Defining Vertical Thrust and Attitude
Looking at Figure Three, the rotors of the copter are facing upwards. When these are rotated fast enough they create a force perpendicular to the frame of the copter, known as its vertical thrust, in order to lift it off the ground. There is no direct way to apply a force in a direction that is not perpendicular to the frame. If the copter wants to move left, right, forward or backward in the air it has to change its orientation, also known as its attitude, so it can apply force in that direction. The attitude of the

copter can be broken up into three angles: pitch, roll and yaw depicted in Figure Four. While this does depict a plane the angles are the same for copters. Moving left or right requires adjusting the copter's roll angle and forward or backwards requires adjusting the copter's pitch angle. To actually adjust the attitude the speed of the rotors relative to each other are adjusted.

Figure Three: Copter in Flight (Pixabay License) [8]

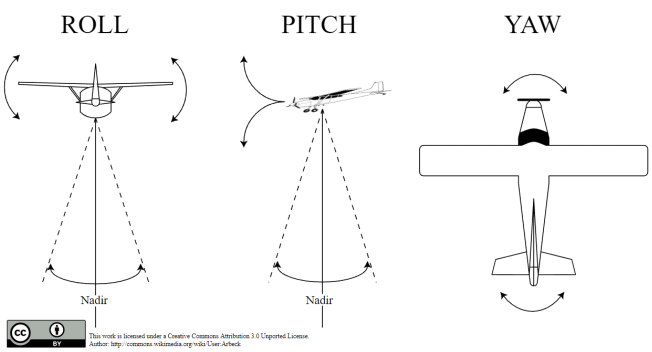

Figure Four: Roll, pitch and yaw angles (CC BY 3.0.) [3]

Where this fits into the flight stack

The rotors are referred to as the actuators in the flight stack. Actuators are devices that "influence the controlled variable of the process".[2] The attitude and vertical thrust are the controlled variables as that is what is changed to move the copter. Connected to the actuators are mixers which determine how fast each rotor should rotate based on the desired attitude and vertical thrust.[1]

How the Controller gets the Copter to where it wants to go

The role of a Controller

The desired attitude and vertical thrust have to be determined before actually moving the rotors. The copter has to take input of either what direction or specific location the pilot wants it to go. Once it has this information, it uses what's called a controller to determine how it should move. The goal of the controller is to take information on a desired value for a variable, such as where the copter wants to go, and a current value such as where the copter currently is in order to determine how to get to the desired value.[1] There are two controllers for the Pixhawk: a position controller and an attitude and rate controller. The rate refers to the rate of change of the three angles that determine the attitude.

How a Controller Works

Figure Five depicts the Pixhawk's implementation of the position and attitude/rate controllers for a multirotor copter. The difference in current position and desired position is found to estimate the needed velocity. From there, the same is done to velocity in order to estimate the desired attitude that would achieve the desired velocity. The mixers can then use the desired attitude and vertical thrust to determine how to move the motors.[1]

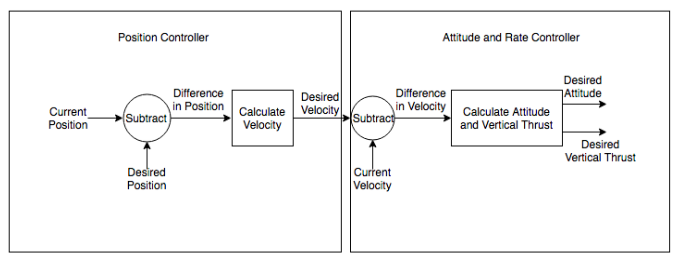

Figure Five: Pixhawk's Controller Implementation

How the Controller Knows the State of the Copter

What is an Estimator

One issue with the implementation of the controllers in Figure Five is that there is no way to know the exact position and attitude of the copter. This issue is what an estimator combined with sensor feedback solves. An estimator guesses information such as velocity and position of the copter based on sensor readings.[1] The Pixhawk has estimators for position, velocity, attitude and wind speed. The estimator uses Kalman filtering to deal with the fact that sensor readings are not completely accurate. Kalman filtering is a method of combining sensor measurements and input data in order to estimate state variables (i.e. position and attitude).[7]

Kalman Filtering

Kalman filtering works by starting with a desired state variable, say the desired z velocity of the copter, and then predicting what the actual state variable is, so actually how fast the copter moves in the z direction. From there it tries to predict what the error in the sensor is to estimate what the sensor should currently be reading. If there was a sensor that was estimating the z velocity of the copter then the Kalman filter would try and calculate what its estimate would be. The Kalman filter updates its estimate of the actual state variable based on the difference between its estimated sensor reading and the actual sensor reading and then repeats the process. This process is depicted in Figure Six.

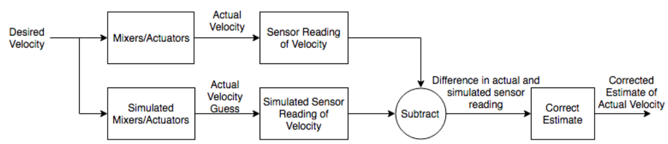

Figure Six: An estimator using Kalman Filtering

Conclusion

The flight controllers for helicopters operate by first estimating its current attitude and position with estimators, then determining its desired vertical thrust and attitude with controllers, translating that into individual motor commands using mixers and finally sending those commands to its actuators.

My team's Senior capstone project uses a hex copter combined with multiple sensors to try and create topological maps of the area the copter flies over. We use the Pixhawk flight controller to fly the copter and store the data we need to create the maps. While we do not need to directly program the Pixhawk, understanding how it works is important for adjusting the flight controller's parameters to change how we filter the data, getting log files, debugging and flying the copter.

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