Institute Technical Summer Project
Quadcopter Flight Controller based on Kalman Filter

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OBJECTIVE

To enhance the stability of a quadcopter by implementing Kalman Filter on the Inertial Measurement Unit of the flight controller, minimising (gaussian) errors of various sensors such as gyroscope, acelerometer, magnetometer and producing best possible output by combining individual output of the sensors (Sensor Fusion)

INTRODUCTION

An IMU(Inertial Measurement Unit) is a self contained system that measures angular motion of a body, using a combination of accelerometer, gyroscopes and sometimes magnetometers. An IMU attached to a quadcopter reports its real time orientation to the flight controller during flight. But these sensors are prone to errors which makes it difficult to calculate acurate real time orientation data.
Gyroscopes measure angular rate. Since the output of a gyro is integrated to find the orientation angle, constant bias errors grow linearly with time. Thus gyroscopes drift over time and thus are not good for longer flight operations.
Single- and multi-axis models of accelerometer are available to detect magnitude and direction of the proper acceleration, as a vector quantity, and can be used to sense orientation (because direction of weight changes). But vibrations(which are basically accelerations) coming from rotating propellers makes the output of accelerometers very noisy. Thus accelerometers are noisy but free from drift, which makes them more desirable for longer durations.
The output of gyroscope is less noisy(as it is integrated) but prone to drift. Accelerometers, on the other hand, are quite noisy but drift free. By performing Sensor Fusion, combining data from both the sensors using a suitable method, to get the best posible output. This is where the Kalman Filter comes into play. The Kalman Filter is found to be one the best ways to achieve Sensor Fusion.

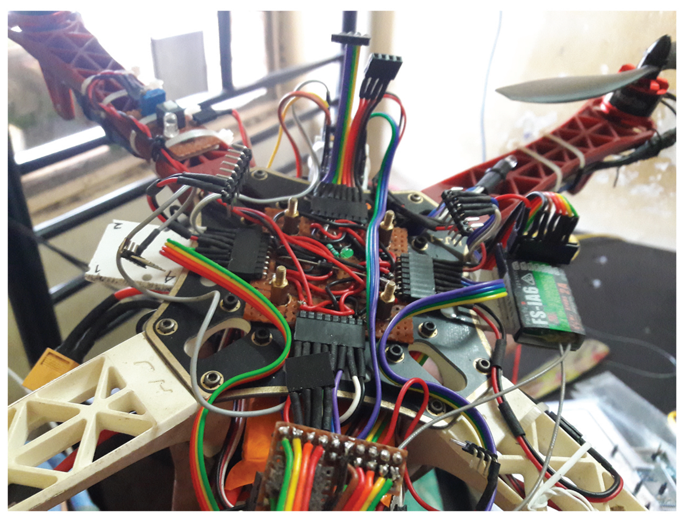
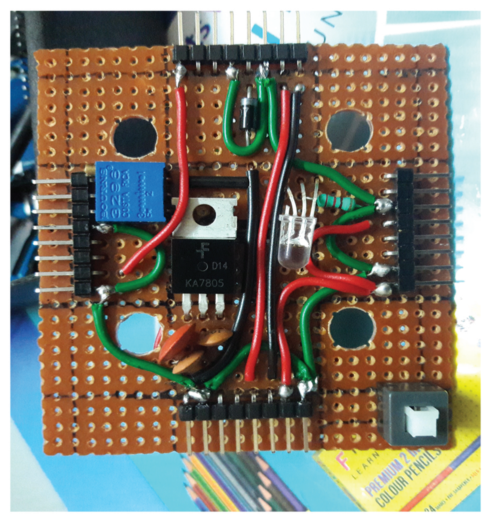
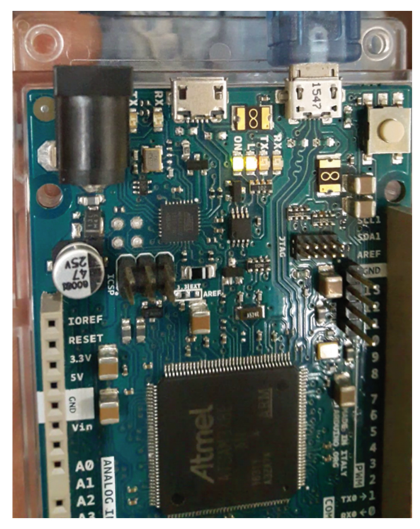
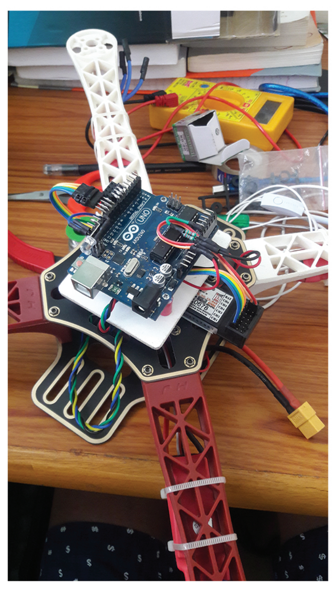
CHALLENGES

The brain of the flight controller is the Arduino Due, which is based on the 32 bit Atmel SAM3X8E ARM Cortex-M3 CPU. It runs at 84 MHz, way faster than 16 MHz AVR based Arduino Uno. This extra proceesing power is required to perform faster calculations in a limited amount of time. But learning to program ARM microcontrollers is a challenge in itself. Also this microprocessor is not so popular which makes it diffucilt to find solutions or referensces online. Most of the programming was done by referring to the datasheet directly, which is a very time taking and head cracking process.

It was quite difficult to get the I2C sensors responding properly, as the sources of errors were numerous but pin-pointing them out was quite challenging. Most of the debugging was done on trial and error basis due to which it was very time taking to get the code right. Also with this new ARM processor, I encountered with new problems and learnt numerous ways which did not work.

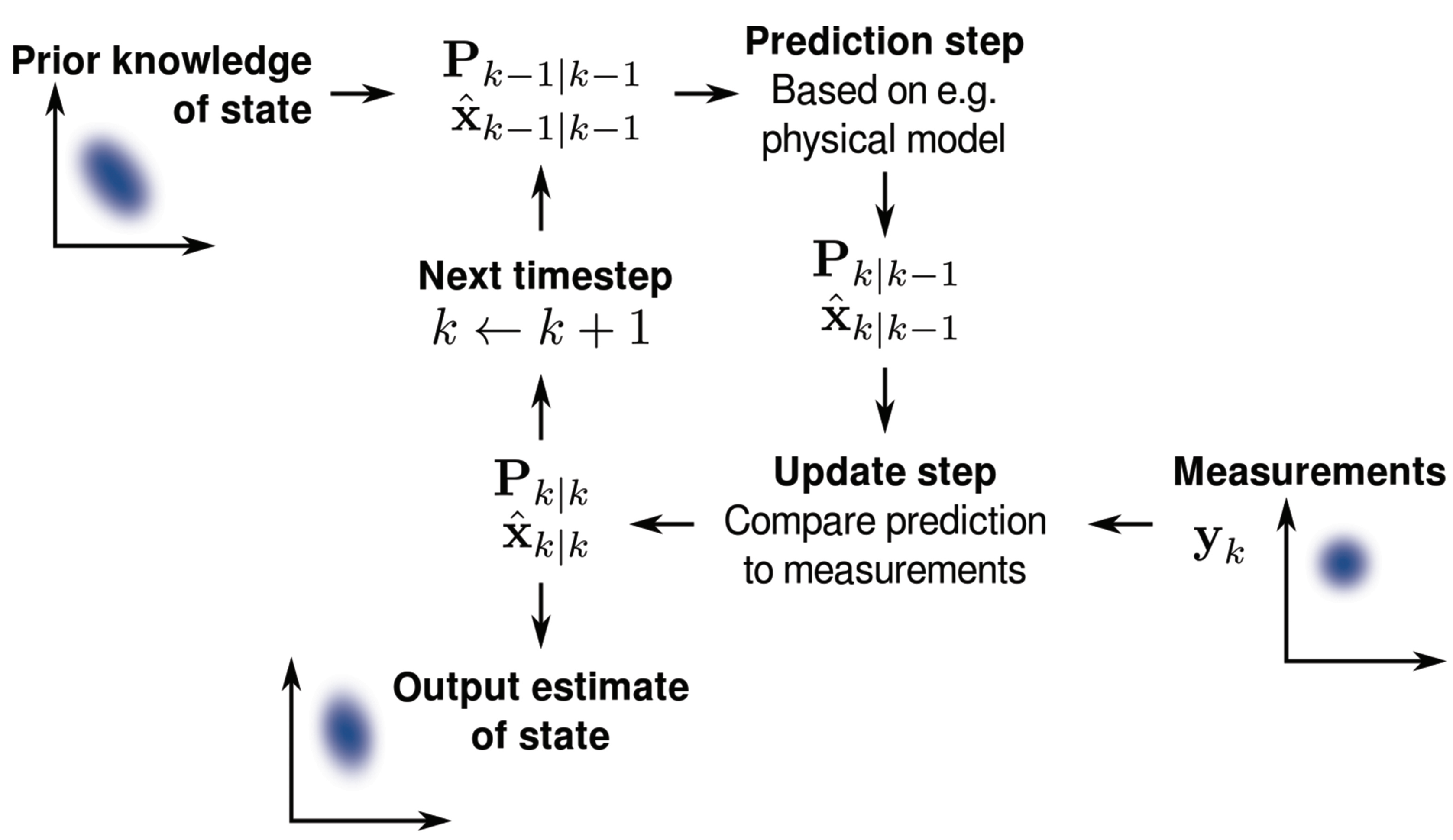
The path to programming a complete flight controller from scratch, requires one to learn & understand many difficult stuff, specifically, Euler angles, Quaternions, Kalman Filter, PID Controller etc. Also to read and find the required content out of elaborate datasheets of sensors and microprocessors is challenging.

PICTURES

WORKING MECHANISM

Kalman filtering, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone, by using Bayesian inference and estimating a joint probability distribution over the variables for each timeframe.



The Kalman filter keeps track of the estimated state of the system and the variance or uncertainty of the estimate. The estimate is updated using a state transition model and measurements. $X_{k|k-1}$ denotes the estimate of the system's state at time step k before the k-th measurement y_k has been taken into account; $P_{k|k-1}$ is the corresponding uncertainty.

FUTURE SCOPE

There is a lot of improvement that can be done on this quadcopter. The quadcopter built in this project has the auto-level feature. Many new features can be further added such as position hold(by incorporating an altimeter or flow sensor), obstacle avoidance, gps hold, real time information transfer to ground station via telemetry, ability to perform complex athletic maneuvers etc. Moreover, the drone can be made completely autonomous.