Test Stand Design & Construction for Affordable and Safe Drone Flight Tests

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A small Test-stand (TS) has been designed, constructed and tested to help optimize the autopilot design of small Vertical Takeoff & Landing (VTOL) drones. The TS can be used in the testing, verification & Validation of autopilot performance, particularly in the design of the Stability Augmentation System (SAS). The TS provides flight test engineers safe testing environment and saves time & resources. The TS demonstrated the ability of independently obtaining Euler angles from the TS encoders, then test & verify the performance of a drone Inertial Measurement Unit (IMU). This capability is very valuable to check the performance of autopilots, particularly when safety is required at high-frequency maneuvers.

Nomenclature

OSU = Ohio State University

TS = test stand

VTOL = vertical takeoff and landing

IMU = Inertial Measurement Unit

SAS = Stability Augmentation System

MoI = Moments of Inertia

Kv = SAS gain

θ = pitch angle

ϕ = roll angle

t = time

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I. Introduction

In the last few decades, the use of small drones has experienced tremendous growth in both the domestic and international markets. Their usage has been observed heavily in military applications, geographic mapping, agricultural use, logistics, and delivery. The rapid adoption is largely due to advances in enabling technologies and reduced component costs.

For a drone to be commercially viable, significant amounts of research are required. Much of the effort goes into designing and testing flight controls, particularly the core autopilot functions such as Stability Augmentation System (SAS), attitude, altitude, and airspeed holds. Testing these flight modes on a prototype drone is costly, test consuming, and risky. It requires highly skilled test pilots, safety personnel, spacious test fields far from campus, and ample supply of spare parts to fix crashed drones.

Our research team sought a stationary platform that can be used to test autopilot functions in our lab. After extensive searches on the web and after consulting experts, it was clear to us that such a system does not exist, therefore this research was born. This research addresses some of these concerns by reducing the cost and risk of early flight testing. A ground test stand is designed and constructed to support attitude control development of any small-sized drone by mounting it to a multi-axis gimballed platform. The platform allows the drone to freely pitch, roll, and yaw to a specified attitude limit.

In a typical application, the drone is commanded to perform an attitude displacement. The resulting motion is recorded by both the drone's inertial measurement unit (IMU) and high-resolution encoders integrated within the test stand. The IMU measured attitude estimates are then compared against the encoder measurements to assess control performance. Performance is assessed by comparing rise time, overshoot, settling time,… or assessing frequency domain parameters such as gain and phase margins.

Timestamps, attitude commands, and measurements from IMU and encoders are sampled at an appropriate rate and recorded using an embedded microcontroller. The sampling rates can run from 1 Hz to 100 Hz. The mechanical structure is inspired by a gyroscope-type mechanism. The platform permits rotation about an instrumented roll axis supported by a pair of encoders, with a perpendicular pitch axis similarly instrumented. The pitch axis is mounted on a fork assembly, which is supported by a vertical shaft secured to a rigid base through low-friction roller bearings, enabling smooth and decoupled rotational motion.

This test stand provides an affordable, safe, and repeatable environment for drone attitude control testing, validation, and verification prior to outdoor flight testing.

II. Need for a Test Stand

At OSU, a large group of students are working on design and construction of small size drones. For every newly designed drone, considerable effort goes into flight tests to ensure flight performance. To verify & validate the performance of the autopilot, flight tests are conducted by skilled pilots and only in designated safe places. After crashing numerous drones, went through ample spare parts, and wasted valuable time, the idea of a test stand emerged. The test stand was predicted to be significantly safer and save time & money.

III. Test Stand Construction

At OSU, when designing drone autopilot, successive loop closure methodology is adopted. On each axis, the most inner feedback loop is normally designed first to provide the needed damping. That is the Stability Augmentation System (SAS). To select the proper damping on a given axis, the gyro rotational speed of that axis is multiplied by a gain Kv and feedback to the pilot input signal. The damping gain Kv can be optimized to vary the damping. Since this function depends purely on the attitude change of the drone, the idea of placing the drone on stationary platform that can pitch, roll & yaw with drone. With the drone anchored to the platform, anyone can command attitude in a safe environment. The platform would have its own independent attitude readings and therefore we can compare the commanded pitch, IMU pitch and the platform absolute pitch.

The design of the mechanical mechanism started as follows:

1- A flat square surface holding the drone was printed, I call this the platform
2- The platform was allowed to rotate about the horizontal roll axis. See Fig 1, 2
3- Roll axis is allowed to rotate about a horizontal pitch axis. See Fig 1, 2
4- The pitch axis is attached to a vertical shaft
5- The vertical shaft is housed on a sturdy table via bearings and allowed to yaw. See fig 1

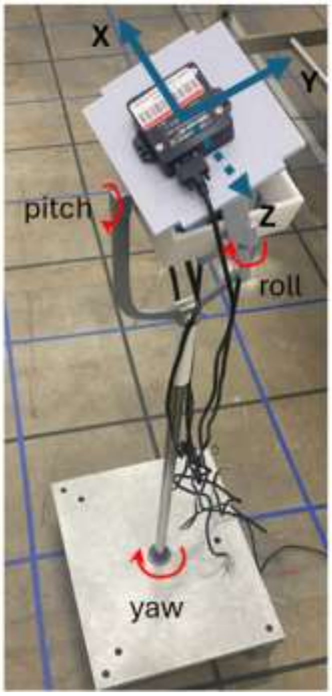


Fig. 1 Pitch, roll, yaw axes

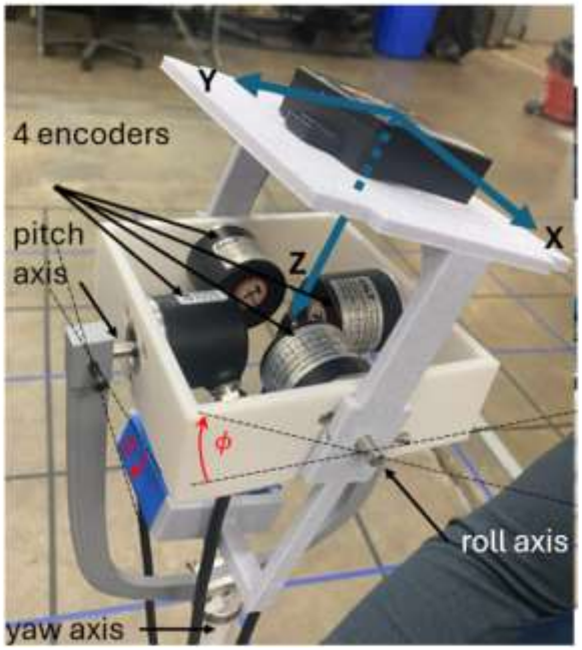


Fig. 2 Platform roll & pitch angles

On the positive side, two encoders were used on each axis to improve reading accuracy and balance platform mass distribution. In addition, two independent sources of measurements allow for redundancy and resilience of the system. On the negative side, despite using very light materials to construct the platform, the platform has small moments of inertial (MoI) about the center of rotation. If the test drome is relatively large, the drome MoI is dominant and no further action is needed. If the drone is very small and its MoI is large relative to platform, then platform MoI must be taken into account. This is a subject that deserves more attention. Our team is aware of it, and we are currently taking steps to mitigate its effect or put a lower limit on the drone size to be tested.

IV. Test Procedure & Results (Dhruv)

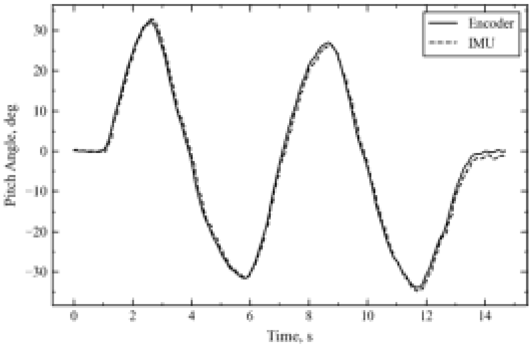
To validate the accuracy and functionality of the TS, a *LORD MicroStrain 3DM-GQ4-45* inertial measurement unit is used to compare IMU attitude against that of the ST encoders. The IMU is mounted on top of the TS platform and is read at 25 Hz, giving roll and pitch angle estimates. The TS encoder signals are read and parsed through an algorithm to give the true angle of the test stand. This is processed by an Arduino Uno R3 microcontroller reading at 20 Hz.

A Python script reads both threads simultaneously and marks the timestamps for each datapoint. Since the IMU and encoders are read at different sample rates, the encoder data is interpolated onto the IMU timestamps, producing matched data pairs at every IMU sample time. Only sample points where both streams overlap in time are retained. Before streaming begins, both IMU and encoder angles are zeroed out to ensure no offset bias is present.

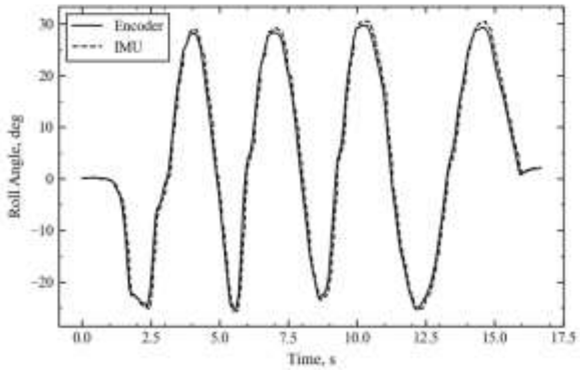
During the test stand validation process, the pitch and roll axes were tested. For each axis, the platform was manually oscillated $\pm 30°$ at different angular rates to characterize the effect of rate on error response and simulate sudden movements of a drone.

Table 1: Summary of Test Results of Pitch and Roll

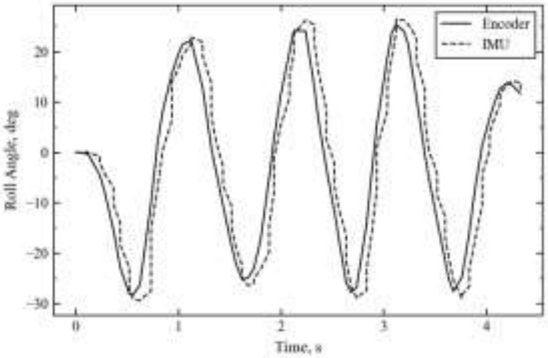
Axis	Max°	Min°	Frequency (Hz)	Max |Error|
Pitch	32.6	-33.9	0.14	3.77
Pitch	27.2	-32.9	0.48	9.49
Pitch	27.3	-24.7	0.87	11.86
Roll	29.7	-25.2	0.24	8.15
Roll	24.9	-29	0.75	16
Roll	25.4	-28.3	0.92	17.43



Plot 1: Pitch comparison (Slow Rate)



Plot 2: Roll Comparison (Slow Rate)



Plot 3: Roll Comparison (Fast Rate)

At the slow oscillation rate, the IMU pitch and roll estimates track the encoder reference closely across the full range, as shown in Plot 1 and Plot 2. However, as the oscillation rate increases, there is a larger signal lag as demonstrated in Plot 3. The high oscillation rate can mimic a drone making sudden movements, and visualizing this signal lag is critical in optimizing autopilot gains of on-board flight system.

V. Conclusion

A safe environment for testing/optimizing the performance of the control system of a drone is sought. A simple & low-cost TS has been designed, built, and tested. Using the TS encoders as independent set of sensors, Euler angles & body rates are read independently, and attitude performance is evaluated. To test the validity of such system, a high quality IMU was mounted on the TS and both IMU and TS data were acquired. Test results showed good tracking of the IMU and TS Euler angles. As expected, at low frequency IMU attitude angles are tracking TS attitude very closely. As the frequency of motion increased, IMU angles lagged TS's angles in a proportional pattern. Such a low-cost system has proved that drone Euler angles can be compared against the TS 'trues' angles in a safe environment.

Acknowledgments

We thank the OSU undergraduate UAS team for providing space in their Lab to test our TS and use their tools.