Active Control and Guidance-Aided Propulsive Landing Research for Small-Scale Vehicles

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Introduction

- In recent decades, rocket launches have been primarily single-use with an average cost of over 1 billion dollars.
- With the breakthrough from SpaceX, reusable systems started to be widely adopted.

Aims

This project aims to apply reusable technology on a smaller scale by propulsively land model-scale rockets using active thrust vectoring and GNSS guidance.

Methods

- **Flight Computer**
  The 7th Generation flight computer is equipped with a single iMXRT1060 chip. The flight computer has spare PWM ports, 12C ports, and more for further application. The additional XBee installation enables telemetry data communication under 2.4GHz and remote ignition. The onboard IMU and barometer will be accurately reading the position of the rocket.

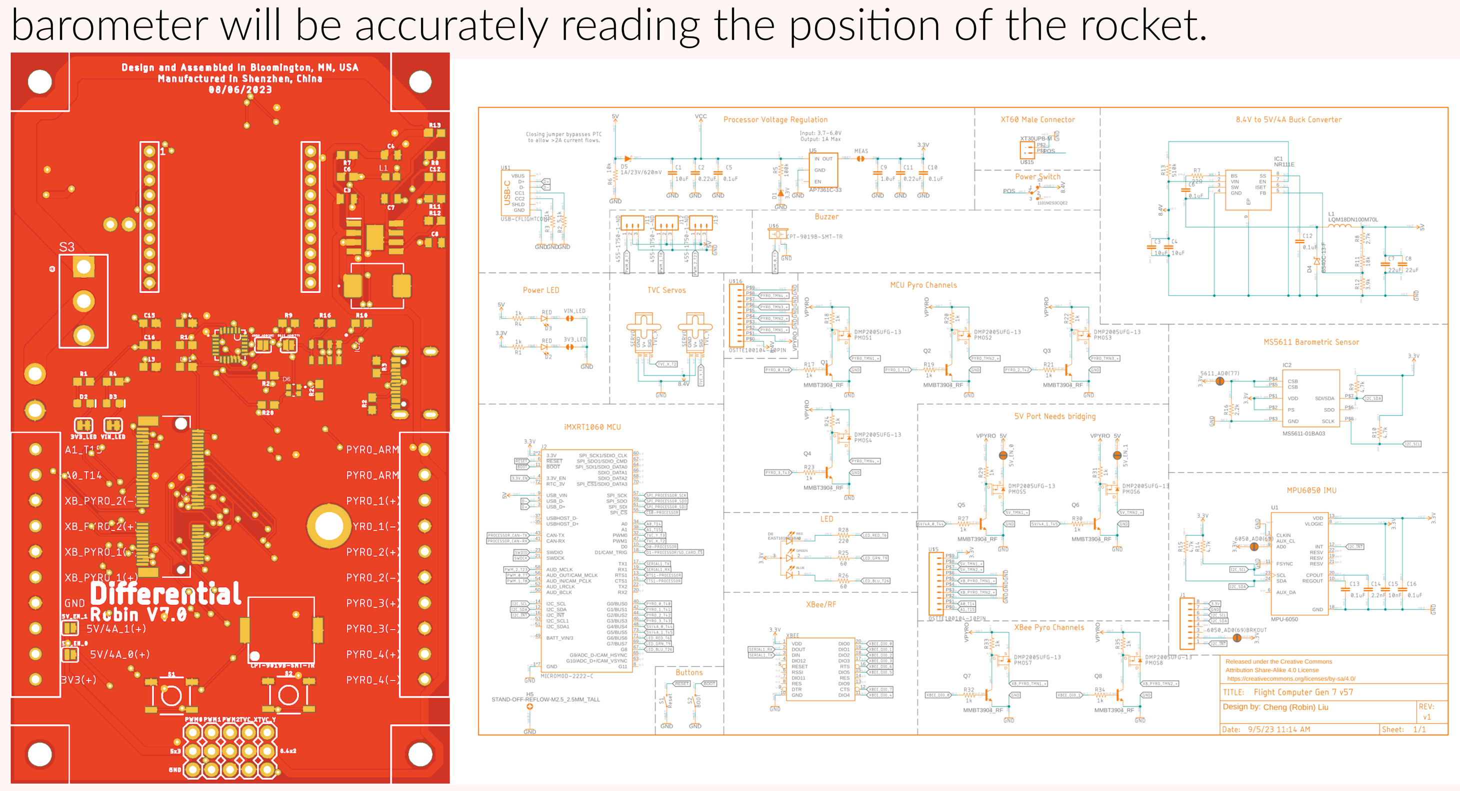

Figure 1. Flight Computer PCB and Schematics

- **Thrust Vectoring Module (TVM)**
  TVM actively controls the vehicle's orientation using two KST-X08 servos through PWM communication with the flight computer. It is equipped with an ascending F15-0 and descending E16 motor, both connected to the flight computer for ignition control. Upon reaching apogee, TVM ejects the empty ascending motor and loads the descending motor.

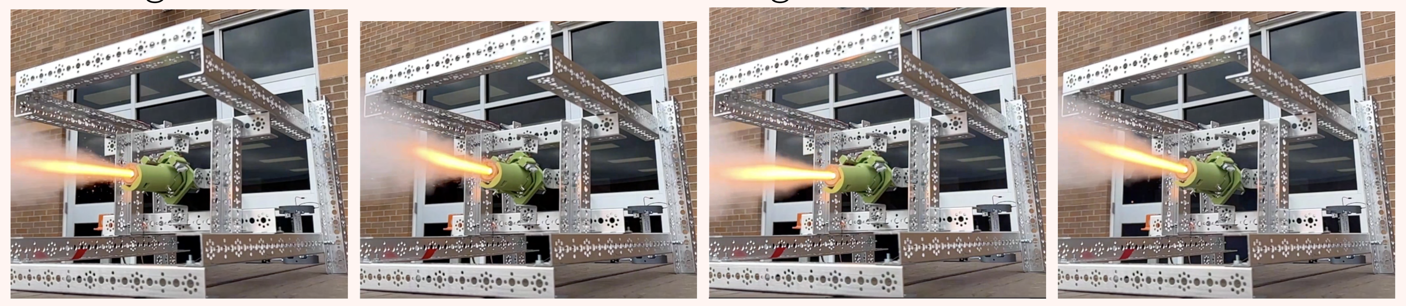

Figure 2. TMV Pivots ±7 degrees on X and Y axis during static fire

- **Flight Software**
  Running under an RTOS (Real Time Operating System) framework, the flight software runs the sensor inputs through filters such as PID and Kalman filter to reduce noise and improve accuracy. For example, the flight software integrates IMU acceleration and fuse data with the onboard barometer and GPS output to generate an accurate prediction. After determining the vehicle's orientation across the stages of flight, the flight software can decide the critical execution of the vehicle.

Four-Bar Linkage Problem Inside TVM

Issue Noticed During Actuation of TVM

One of the concerns identified during the test flight was the inability of the TVM (Thrust Vectoring Mechanism) to achieve the precise angular adjustment as commanded by the flight computer. Upon a thorough analysis of this matter, it was determined that the root cause of this discrepancy was a structural design deficiency, resulting in a phenomenon commonly recognized as the "four-bar linkage problem."

Solution

$$\omega_{AB} = \frac{det \begin{bmatrix} CB_i \; OA_i \cdot \omega_{AO} \\ CB_j \; OA_j \cdot \omega_{AO} \end{bmatrix}}{det \begin{bmatrix} BA_i \; CB_i \\ BA_j \; CB_j \end{bmatrix}} \tag{1}$$

$$\omega_{BC} = \frac{det \begin{bmatrix} BA_i \; OA_i \cdot \omega_{AO} \\ BA_j \; OA_j \cdot \omega_{AO} \end{bmatrix}}{det \begin{bmatrix} BA_i \; CB_i \\ BA_j \; CB_j \end{bmatrix}} \tag{2}$$

The equation calculate the angular speed of the TVM and relative to the angular speed of the servo. In this case, AB is the linkage arm between servo and TVM, while BC is the TVM and AO is the servo arm.

Thrust Vectoring

By applying PID filter and Kalman Filters, the vehicle is able to actively control the heading of the rocket by adjusting the direction of thrust through TVM.

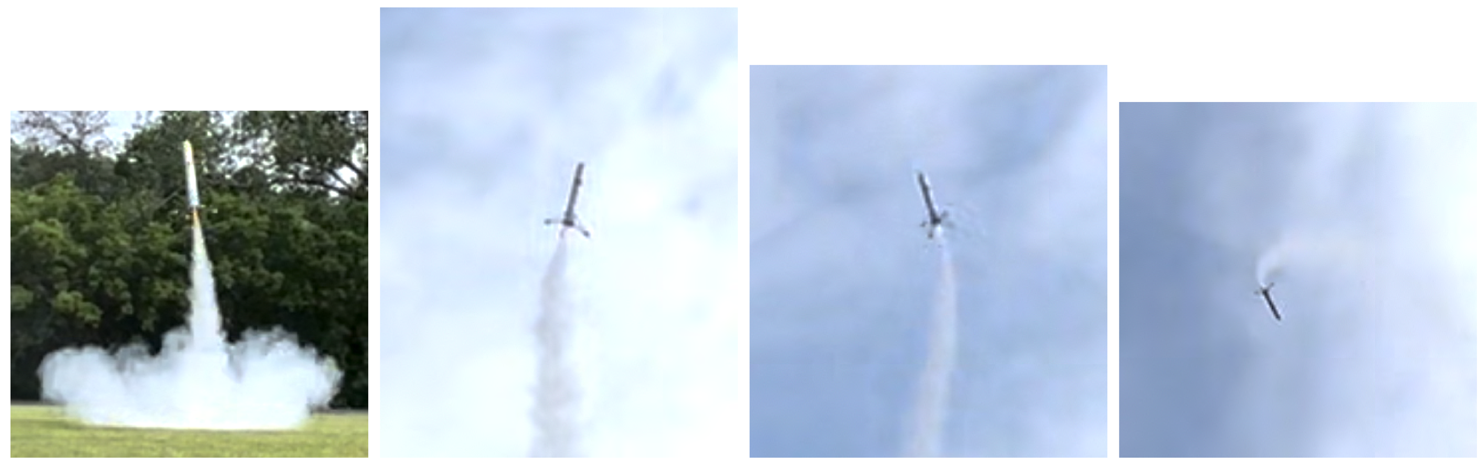

Figure 3. TMV reacting to the deviation detected by the IMU sensor onboard, last picture shows an over-correction of TVM

Sensor Data Filtering

Following the implementation of the Kalman filter for data filtering, a notable reduction in the noise within the output signals from both the Inertial Measurement Unit (IMU) and barometer has been achieved.Without extensive filtering, the unfiltered input signals exhibit spikes, thereby inducing abrupt and undesirable perturbations in the flight dynamics.

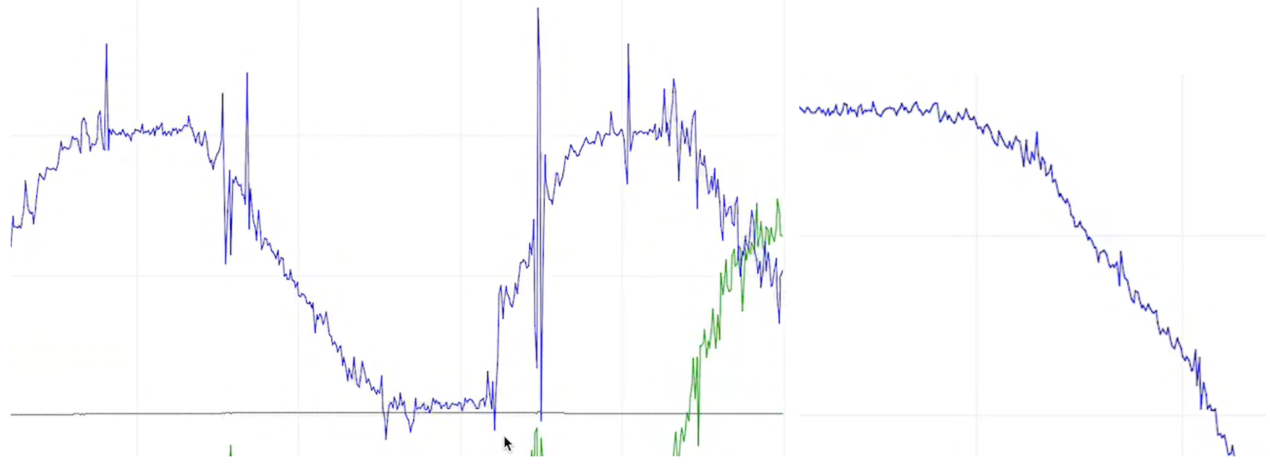

Figure 4. IMU output before and after filtering

Telemetry

- The latest iteration of our flight computer boasts advanced features, including the incorporation of an XBee telemetry module. This telemetry module facilitates communication via the Zigbee protocol, a short-range wireless communication standard operating within the 2.4GHz frequency band and adhering to the IEEE 802 specifications.
- A noteworthy change in the design of the new flight computer is the omission of SD card slots. Instead, the system will exclusively log data based on telemetry information received, streamlining the data acquisition process.

Discussion

- While the flight computer effectively detected and positional deviations in the rocket's trajectory through the application of PID filtering, observations indicate that the TVM system may be exhibiting excessive responsiveness, potentially leading to over-correction of the rocket's heading. To address this concern adjustments will be made to the proportional (P) and derivative (D) coefficients within the control software. Fine-tuning these coefficients can serve to reduce the sensitivity of the TVM system, promoting more stable and controlled flight dynamics.
- The project is aiming to introduce a physical throttling mechanism in addition to the existing throttling algorithm. This strategic enhancement will contribute to a more comprehensive and adaptable control system, further enhancing the precision and reliability of our rocket's performance.

Acknowledgment & Disclosure

- This work was supported by the ISM Parents Connection and Teen Entrepreneurship Foundation. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the funders.
- Special thanks to Manny Peterson and Steve Song for mentoring the project, Max Peng and Dylan Becchetti for participating.

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