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Thrust Vector Control (TVC) Using Gimbal Mechanism

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ABSTRACT: This project focuses on the design and fabrication of a thrust vector control system utilizing a gimbal mechanism for model rockets. Thrust vectoring, an essential technique in aerospace engineering, allows for the manipulation of thrust direction to control vehicle attitude and angular velocity. By integrating a gimbal mechanism into the model rocket, we aim to enhance stability and maneuverability compared to traditional fin-stabilized systems. Drawing inspiration from successful implementations in space launch vehicles like the Space Shuttle... Our thrust vector control system offers a promising avenue for improving rocket performance. This system facilitates easier control stability, potentially reducing the payload burden on rockets. Future iterations could further enhance performance by integrating additional thrust vector control systems such as thrust vector control via propellant injection. Further development avenues include incorporating storage devices like cards to store programming, minimizing the need for repeated microcontroller uploads. Additionally, considering variations in mass during prolonged flight durations is essential for optimizing system performance.

KEYWORDS: Thrust Vector Controlling, Gimbal Mechanism

I. INTRODUCTION

To design, fabrication and testing the performance of thrust vector control system (Gimbal mechanism). Thrust vector control technology is advancing rapidly and being updating day by day. There are some types of TVC that being used in the rockets for controlling Thrust vectoring, also thrust vector control or TVC, is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor in order to control the attitude or angular velocity of the vehicle.

Paper is organized as follows. Section II describes literature survey. The methodology is given in Section III. Section IV presents experimental results showing results. Finally, Section V presents conclusion.

1.1 THRUST VECTOR CONTROL

Thrust vector control (TVC) is a mechanism used in rockets and missiles to control their orientation and trajectory during flight. It involves adjusting the direction of the engine's thrust to steer the vehicle. TVC systems typically consist of movable nozzles, vanes, or gimballed engines that can deflect the exhaust plume, thereby changing the direction of the thrust force. TVC provides several advantages, including, maneuverability, stability etc.

2.1 GIMBAL MECHANISM

To maneuver the rocket in flight, several different systems can be used. Early rockets, and some air-to-air missiles, use movable aerodynamic surfaces like the elevators on an airplane. Of course, this system only works on rockets that remain in the atmosphere. rockets designed to exit the atmosphere used small vanes in the nozzle exhaust to vector the thrust. Most modern rockets, like the Space Shuttle and the Saturn V moon rockets, use a system called gimballed thrust in a gimballed thrust system, the engine or just the exhaust nozzle of the rocket can be swelled on two axes (pitch and yaw) from side to side. As the nozzle is moved, the direction of the thrust is changed relative to the center of gravity of

the rocket. The diagram illustrates three cases the rocket center line at an angle called the gimbal angle. Since the thrust no longer passes through the center of gravity, a torque is generated about the center of gravity and the nose of the rocket turns to the left. If the nozzle is gimballed back along the center line, the rocket will move to the left. The rocket engine gimbal is a pivot at the top of the combustion chamber that the engine thrust acts through. The engine is gimballed or tilted using hydraulic (or 12 electromagnetic) pistons often called thrust vector control (TVC) actuators, as shown here on a Merlin engine. The Quadra pod structure takes the thrust from the gimbal pad on the combustion chamber. There are two TVC actuators on most engines for X and Y control. Interestingly, on the Merlin, from that image, it looks like the 'Turbo Pump Assembly' on LHS does not gimbal with the engine since it has fixed length struts. In inertial navigation, as applied to ships and submarines, a minimum of three gimbals are needed to allow an inertial navigation system (stable table) to remain fixed in inertial space, compensating for changes in the ship's yaw, pitch, and roll. To accomplish this, the gyro error signals are passed through "resolvers" mounted on the three gimbals, roll, pitch and yaw. These resolvers perform an automatic matrix transformation according to each gimbal angle, so that the required torques are delivered to the appropriate gimbal axis. The yaw torques must be resolved by roll and pitch transformations. The gimbal angle is never measured. Similar sensing platforms are used on aircraft. In inertial navigation systems, gimbal lock may occur when vehicle rotation causes two of the three gimbal rings to align with their pivot axes in a single plane.

II. RELATED WORK

"A new thrust vector-controlled rocket based on JOA using MCDA" by Noorulden Basil, Hamzah M. Marhoon, Ahmed R. Ibrahim. This paper discusses a study on a thrust vector-controlled rocket model called TVCASB, which aims to correct the trajectory during its fall. A thrust vector-controlled rocket model consists of army science board model responsible for computing the angles of the gravity center with a directivity of trajectory positions (x, z). A thrust vector-controlled rocket model is known to be #TVCASB for fall trajectory correction solving, but the falling issue of the trajectory correction is a hard when restricted to ASB model. In this work, we study TVCASB model, a mathematical model of TVCASB calculating which involves ASB variables in addition to position variables, and refer to this question: Why falling issue of the trajectory and correction of TVC is a hard on ASB model? Depend on MCDM results from JOA cases, we show that four MCDM methods can choose the better case for a two pieces of fractional order proportional integral derivative controller when set tuning process for TVC model on ASB with a suitable falling of trajectory correction whether be limited or specified for a high or low distance for the rocket motion. The abstract discusses a study on a thrust vector-controlled rocket model called TVCASB, which aims to correct the trajectory during its fall. The second paper is "Physical modeling and simulation of electro-mechanical actuator-based TVC systems for reusable launch vehicles" by Stefano Farì, David Seelbinder, Stephan Theil, Pedro Simplicio, Samir Bennani, The concept of this paper discuss about a detailed model of a Thrust Vector Control (TVC) system using Electro-Mechanical Actuators (EMAs) for Reusable Launch Vehicles (RLVs). Unlike simpler models, this high-fidelity model allows for a more accurate assessment of system performance and robustness of on-board software against various challenges. By thoroughly simulating the dynamics of EMAs and TVC components, including power drive electronics and mechanical properties, this study demonstrates improved understanding and potential enhancements in TVC system design and reliability. This paper presents the high-fidelity physical modeling of a Thrust Vector Control (TVC) system operated by Electro-Mechanical Actuators (EMAs) for Reusable Launch Vehicles (RLVs). In contrast to simplified, often linear, models, high-fidelity physical models enable a better assessment of the actual system performance and a deeper verification of the onboard software robustness against disturbances, unmolded dynamics or degradation. This aspect is essential to enable the reusability concept as driven by long-term reliability requirements. Moreover, critical systems like Fault Detection, Isolation and Recovery (FDIR) logic, whose robustness and efficacy are often difficult to prove, can be thoroughly tested without requiring hardware experiments with eventual invasive modifications for fault injections. This work captures the whole dynamics of the EMA and TVC components, including the power drive electronics, the electrical motor, and the mechanical transmission for the EMA, as well as the mechanical properties of the engine nozzle acting as a load. The resulting differential algebraic equation system is modeled in the Modelica a causal objectoriented modeling language. An ad-hoc framework is implemented to guarantee flexibility and modularity, which allows models with different fidelity levels to be easily exchanged to achieve the simulation objectives and needed accuracy level. The impact of the different models on the closed-loop TVC dynamics is analyzed in both the frequency and time domain, and then benchmarked with a realistic RLV mission. The results show that the high-fidelity physical models provide a better understanding of the more complex effects governing the TVC dynamics and can, in turn, effectively improve its requirement definition process. "Thrusting maneuver control of a small spacecraft via only gimballed thruster scheme" by

Mansour Kabganian, Hamed Kouhi, Morteza Shahravi, Farhad Fani Saberi, is third paper related to our paper. This paper explores using thrust vector control (TVC) with a solid rocket motor (SRM) for attitude control in small spacecraft. They focus on gimbale TVC, where the spacecraft's structure consists of a body and a gimbaled-SRM without traditional attitude control systems like RCS. They develop a linear control law to stabilize the spacecraft's attitude against disturbances and demonstrate its effectiveness through 3D maneuver simulations. The thrust vector control (TVC) scheme is a powerful method in spacecraft attitude control. Since the control of a small spacecraft is being studied here, a solid rocket motor (SRM) should be used instead of a liquid propellant motor. Among the TVC methods, gimbaled TVC as an efficient method is employed in this paper. The spacecraft structure is composed of a body and a gimbaled-SRM where common attitude control systems such as reaction $\dot{1}2$ control system (RCS) and spin-stabilization are not presented. A nonlinear two-body model is considered for the characterization of the gimbaled-thruster spacecraft where, the only control input is provided by a gimbal actuator. The attitude of the spacecraft is affected by a large exogenous disturbance torque which is generated by a thrust vector misalignment from the center of mass (C.M). A linear control law is designed to stabilize the spacecraft attitude while rejecting the mentioned disturbance torque. A semi-analytical formulation of the region of attraction (RoA) is developed to ensure the local stability and fast convergence of the nonlinear closed-loop system. Simulation results of the 3D maneuvers are included to show the applicability of this method for use in a small spacecraft.

III. METHODOLOGY

Fins are used on rockets to provide stability and control direction. It works in the same way as placing feathers at the tail of an arrow. These can be mounted at the tail portion of the rocket, which makes the design too heavy and also increases the weight of the rocket. In this, we are going to use an Arduino NANO board to upload programming by using Arduino software to control the motion of servo motors. We have used MPU 6050 (Gyroscopic sensor) to make the change in angle of the gimbal by moving it on 6 axes by using servos. Also we use barometric sensor BMP 180 to sense the pressure and temperature. We have installed four servos to move the gimbal mechanism. By making changes in the angle of the gyro sensor, the gimbal mechanism will move according to the moment. At first we designed a conceptual model of a rocket in software called solidworks then, select the major components such as Four servo motors, Barometric sensor, Gyroscopic sensor, Arduino Nano (ATmega 328)

Dimensions: The design process begins with conceptualizing the basic structure and components of the rocket, including the body, fins, nose cone, and propulsion system. Our conceptual design prototype is given in figure 3.1.

Designing of prototype: The design of a simple rocket model using SolidWorks involves creating a digital representation of a basic rocket structure that can be used for visualization, analysis, and simulation purposes. SolidWorks is powerful computer-aided design (CAD) software that enables engineers and designers to create detailed 3D models of various mechanical components, including rockets. The design process begins with conceptualizing the basic structure and components of the rocket. Using SolidWorks, sketches are created to outline the overall dimensions and shape of the rocket components. The figures are shown below.

Assembling The Components: If we are building a gimbal mechanism, how the role of the frame and screws, the same role will be there for the servo motors, that we are going to use. Make sure that we have correctly printed the motor mounts for the assembling of two servo motors. We have fixed the motors to the motor mount safely to make the movements accurate of the mechanism by using the connecting rods to the frame. In our project, the Arduino will be acted as a Flight controller, it interprets input from the source of our laptop, where we are going to upload the programming to the Arduino UNO Board, in that so many electronics will be there to control the movement of the gimbal mechanism for the axis that we want. A gyroscope is an instrument, consisting of a wheel mounted into two or three gimbals providing pivoted supports, for allowing the wheel to rotate about a single axis. A set of three gimbals, one mounted on the other with orthogonal pivot axes, may be used to allow a wheel mounted on the innermost gimbal to have an orientation remaining independent of the orientation, in space, of its support. In the case of a gyroscope with two gimbals, the outer gimbal, which is the gyroscope frame, is mounted so as to pivot about an axis in its own plane determined by the support.

Testing and Validation: Once the gimbal mechanism is installed, it undergoes rigorous testing to ensure proper functionality and performance. This includes functional tests to verify that the gimbal can move within its intended range of motion and calibration tests to ensure accurate control of the engine thrust. After assembling, testing can be done by giving all the connections of the electronic parts like servo motors, Arduino UNO, Gyroscopic sensor, Barometric sensor, Bread board by using jumper wires. The programming can be compiled and uploaded to UNO board by using cable from Laptop.

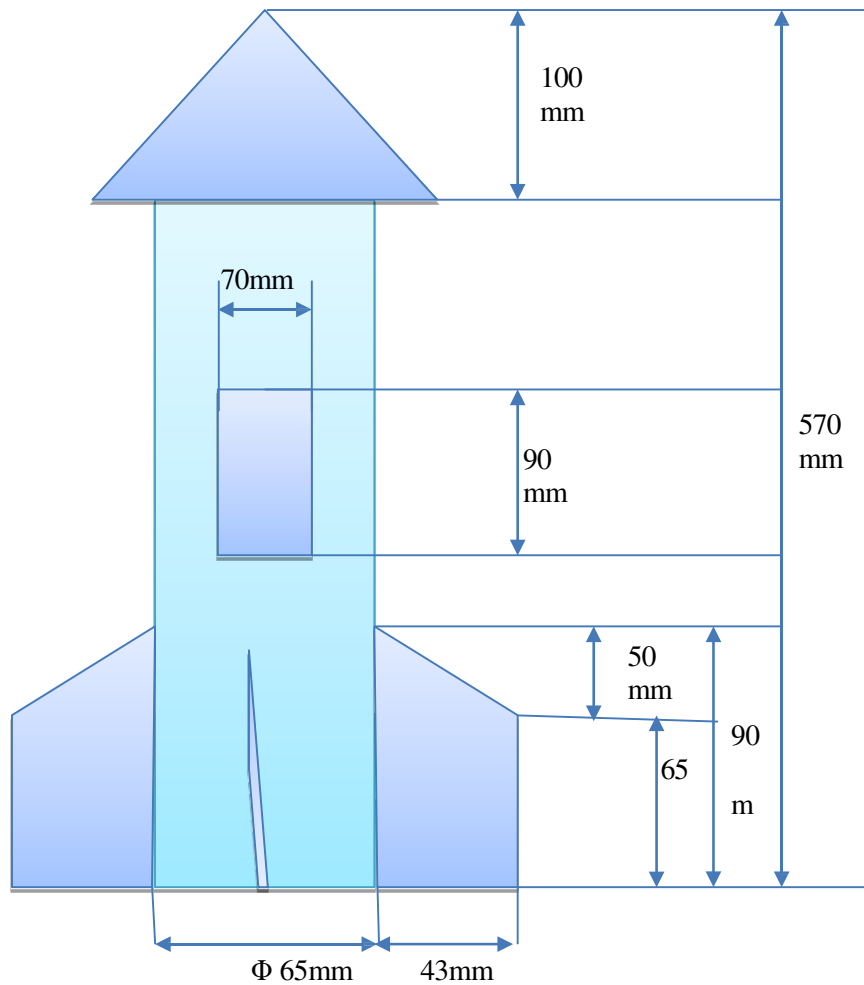


Figure 1 dimensions



Figure 2: Front View of Prototype

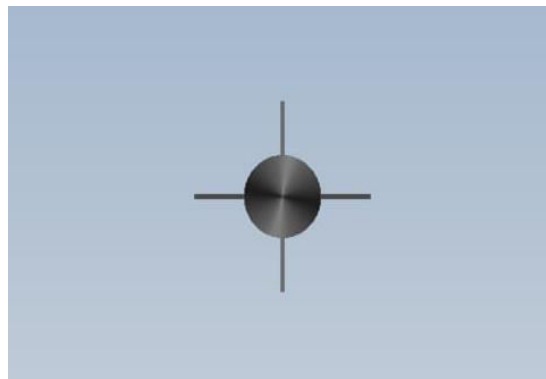


Figure 3: Top View of Prototype

IV. EXPERIMENTAL RESULTS

After making all the connections, the rocket nozzle can be controlled by changing the direction of the gyroscopic sensor tilting it in one direction, make changes in deflection of nozzle also the same thing applies to the other condition, if we move the gyroscopic sensor in another direction, it will move in opposite direction. This can be seen by changes of fins the deflection of fins like pitch up, pitch down, left, right and roll moments. The program is saved in the Arduino NANO and shows the deflection. By working four servos connected with four fins we can see the deflection. We have successfully completed the work by making the prototype. Thus we successfully designed a rocket prototype for improving the stability and maneuverability. Also there is a chance to have future application on this project by adding camera module.

1. ARDUINO NANO: The Arduino Nano serves as the central control unit for the entire circuit. It provides power and communication interfaces for all connected components.
2. BMP 180: The BMP 180 sensor measures barometric pressure and temperature. It is connected to the Arduino Nano via the I2C interface (SDA and SCL pins) for data communication and powered from the Arduino's 5V and GND pins.
3. MPU6050 Gyroscope: The MPU6050 module contains both an accelerometer and a gyroscope for measuring acceleration and orientation. It is also connected to the Arduino Nano via the I2C interface and powered from the Arduino's 5V and GND pins.
4. Servo Motors (4 in total): The servo motors are used for controlling mechanical movements. Each servo motor is connected to a separate digital pin on the Arduino Nano for control signals (e.g., D2, D3, D4, D5). All servo motors share a common power supply, connected to the Arduino's 5V pin, and ground, connected to the Arduino's GND pin. This circuit allows the Arduino Nano to read data from the BMP180 and MPU6050 sensors via the I2C bus and control the position of four servo motors simultaneously. The Arduino can process sensor data and execute servo motor commands based on programmed logic, enabling various applications such as robotics, automation, or sensor-based control systems.

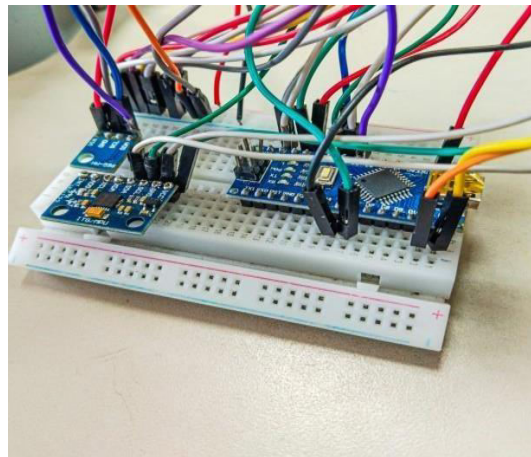


Figure 4: Assembling of sensors with Arduino NANO

V. CONCLUSION

The aim of the presented work was the design and fabrication of a thrust vector control system (gimbal mechanism) model thrust vectoring, also known as thrust vector control (TVC), is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor(s) to control the attitude or angular velocity of the vehicle. In recent years the Gimbal Mechanism in Thrust Vector Control is the most useful mechanism that has been implementing by many successful companies in space launch vehicles, including the Space Shuttle, the Saturn V lunar rockets, and the Falcon 9. Our developed thrust vector control system (Gimbal Mechanism) for a model rocket instead of using a fin stabilized system. Guided model rocket can be made using thrust vector control system. Thrust vectoring concept is implemented in model rocket using gimbal mechanism. In this further development can be done by increasing the performance of mechanism using additional other TVC system like Thrust Vector Control by injecting propellant at the Rocket nozzle.



Figure 5: Final output with fin

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