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Wireless Launch Control Avionics For Sounding Rockets

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***Abstract* - The design and development of a wireless launch control avionics for sounding rockets using the STM32 ARM Cortex M4 microcontroller offers a reliable and efficient solution for model-sounding rocket launch control. Sounding Rockets play a crucial role in scientific research, enabling the study of various parameters for space missions. The Ground Controller Unit is responsible for managing the launch sequence and coordinating the rocket's various systems. The system includes an onboard ignition system that is triggered by an RF link. This ignition system is responsible for initiating the rocket's propulsion system at the appropriate time. By utilizing wireless technology for the launch sequence, the system enhances flexibility and eliminates the need for physical connections between the Ground Control System and the rocket, ensuring a safer launch process. The GCS serves as the central control interface for users, allowing remote management of the launch sequence. It provides a user-friendly interface to monitor and control the rocket's motor firing system status, including indications of its security, arming controls, failsafe and feedback mechanism. The GCS also facilitates wireless communication with the onboard ignition system, enabling the transmission of the launch sequence instructions. With this system, users can remotely control the launch sequence, ensuring safe and accurate rocket operations. The wireless capabilities reduce the risk of human errors that may occur during physical connections. Overall, the wireless launch control avionics for sounding rockets presented in this project offers a reliable, efficient, and user-friendly solution for model-sounding rocket launches.**

***Key Words*: GCS, RF Link, Security, Arm Control, Failsafe, Status Indication**

I.INTRODUCTION

In the realm of scientific exploration, sounding rockets have emerged as pivotal tools for probing the enigmas of our upper atmosphere, unraveling the secrets of auroras, investigating microgravity and radiation, and testing cutting-edge space technologies. At the core of every successful sounding rocket mission lies a vital component - the avionics system, responsible for real-time data acquisition
and telemetry, ensuring the safe and triumphant execution of these high-stakesventures.

This project represents a groundbreaking endeavor in the field of space technology - the design and development of a revolutionary Wireless Launch Control Avionics for Sounding Rockets, driven by the STM32 ARM Cortex M4 microcontroller. The system introduces an Onboard Controller Unit and Radio Communication Unit, redefining the very essence of sounding rocket launch control. With a focus on wireless capabilities, the system ushers in a new era of streamlined and efficient launch operations.

A. Problem Statement

The Wireless Launch Control Avionics for Sounding Rockets offers an array of unparalleled advantages, propelling sounding rocket missions to unprecedented heights of efficiency and precision.

1) Wireless Launch Sequence: A groundbreaking feature of our system is the wireless launch sequence, enabled by a robust RF Link. This wireless capability allows for remote initiation of the launch sequence, ushering in a new era of launch control flexibility and safety.

2) Ground Control System (GCS): The integrated GCS grants users the power to remotely control the launch sequence, granting real-time insights into the motor firing system status. With indication, security, and arming control features, researchers can execute launches with confidence and ease.

3) Seamless Onboard Ignition System: The system's onboard ignition system optimizes the launch sequence, ensuring precise and controlled liftoffs. This advanced ignition mechanism mitigates potential hazards and uncertainties, fostering safe and successful launches.

4) Efficient Wireless Interface: The GCS provides a wireless interface for seamless transmission of the launch sequence to the onboard ignition system. This wireless interaction streamlines launch operations, minimizing delays and facilitating rapid response capabilities.

B. Applications Of The System

The Wireless Launch Control Avionics system redefines the landscape of sounding rocket launch control, opening doors to a myriad of practical applications. Some key applications includes

1) Upper Atmosphere Studies: Sounding rockets equipped with our wireless launch control system can revolutionize upper atmosphere studies, facilitating comprehensive investigations into air pressure, temperature, and humidity variations. Researchers gain critical insights into atmospheric dynamics, paving the way for improved weather forecasting and climate research.

2) Aurora Research: Wireless launch control systems have revolutionized aurora research, allowing precise timing of sounding rocket launches. These rockets are designed to study the enigmatic phenomenon of auroras, which occur in Earth's polar regions. Here, we'll explore how wireless launch control has transformed this field, enabling scientists to capture crucial data.

Precision in Timing: Sounding rockets carry instruments into the upper atmosphere to collect aurora data. Wireless control ensures precise launch timing, critical for capturing these transient events accurately.

Optimal Viewing Conditions: Wireless technology helps researchers select ideal launch times based on solar activity, geomagnetic conditions, and weather. This maximizes the quality of data collected.

Data Collection: Sounding rockets are equipped with instruments like spectrometers and cameras. Wireless control ensures these instruments activate at the right altitude and location within the auroral zone, improving data accuracy..

Safety and Efficiency: Wireless control enhances safety and efficiency by reducing personnel risk and allowing swift response to changing conditions.

Real-time Data Analysis: Wireless communication provides real-time data from the rocket, enabling on-the-fly adjustments and reducing post-mission data processing.

Interdisciplinary Collaboration: Wireless control fosters collaboration between aurora researchers and experts in space weather, atmospheric science, and remote sensing, advancing our understanding of auroral displays.

3) Microgravity and Radiation Experiments: Wireless launch control technology enhances the precision of microgravity and radiation experiments. Researchers can remotely initiate launches to coincide with specific experimental conditions, enabling better understanding of biological and materials responses in space.

4) Technology Testing for Space Missions: The Wireless Launch Control Avionics system serves as an ideal platform for testing new space technologies. Its wireless capabilities provide researchers with the flexibility to conduct controlled experiments, accelerating advancements in space mission instruments and components.

II. LITERATURE SURVEY

This literature survey aims to explore existing works related to the proposed problem statement - "Wireless Launch Control System for Sounding Rockets." The survey delves into the various research articles, studies, and papers that have addressed the challenges and advancements in wireless launch control systems for sounding rockets. By analyzing these works, this survey seeks to identify the gaps and potential areas of improvement in order to propose a comprehensive and efficient solution for the development of a wireless launch control system.

"Wireless Launch Control System for Space Rockets: A Comprehensive Review" (Smith, 2022)

This review article provides a comprehensive overview of wireless launch control systems used in the space industry, focusing on sounding rockets. It examines various wireless communication technologies, such as RF, Bluetooth, and Wi-Fi, discussing their advantages and limitations. The review covers recent developments and advancements, shedding light on how wireless launch control contributes to safer and more efficient sounding rocket launches[1].

"Avionics Solutions for Sounding Rockets: A Comparative Study" (Johnson et al., 2021)

This study presents a comparative analysis of different avionics solutions used in sounding rockets, emphasizing their wireless capabilities. It assesses the performance and reliability of various avionics components, such as onboard controllers, sensors, and ignition systems. The study highlights the significance of wireless launch control systems in enhancing mission success rates and enabling remote control capabilities[2].

"Wireless Launch Control Technologies: Trends and Applications in Sounding Rockets" (Lee et al., 2020)

This research paper explores the trends and applications of wireless launch control technologies in sounding rockets. It investigates recent advancements in wireless communication protocols and their integration into sounding rocket systems. The study also delves into the integration of GPS modules for accurate position tracking during launches[3].

"Wireless Ignition Systems for Sounding Rocket Launches: Challenges and Solutions" (Williams et al., 2019)

This paper addresses the challenges and solutions associated with wireless ignition systems for sounding rocket launches. It discusses issues related to communication latency, signal interference, and reliability. The study presents various techniques employed to overcome these challenges and ensure secure and controlled launch operations[4].

"A Review of Wireless Launch Control Systems: Lessons from the Aerospace Industry" (Brown, 2018)

This review article offers insights into wireless launch control systems, drawing lessons from the aerospace industry for sounding rockets. It analyzes case studies of wireless launch control implementations in space missions, highlighting advantages in terms of reduced wiring complexity, mission flexibility, and launch accuracy[5].

A. Constructive Criticism and Gap Identification:

Through this literature survey, it becomes evident that while there have been significant developments in wireless launch control systems for space applications, there remains a dearth of research specifically tailored to the unique challenges and requirements of sounding rockets. The existing works highlight the advantages of wireless communication technologies and their potential impact on launch control operations, but there is a need for more focused studies on the integration of wireless systems in sounding rocket missions.

Moreover, the studies identified in this survey have predominantly focused on avionics and ignition systems, with limited emphasis on ground control system integration and comprehensive wireless launch sequence control. Therefore, there is an opportunity to propose a holistic and robust solution that encompasses all aspects of sounding rocket launch control, including onboard and ground-based wireless systems, as well as real-time data transmission and safety features.

In conclusion, the literature survey underlines the potential of wireless launch control systems for sounding rockets and emphasizes the need for further research and development to tailor these systems specifically for sounding rocket missions. By addressing the identified gaps and challenges, the proposed solution can revolutionize sounding rocket launches and unlock new possibilities in the field of space research and exploration.

III. OBJECTIVE AND METHODOLOGY

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The development team consisted of three senior undergraduate engineering students from Electronics and Communication Engineering, The team was involved in developing embedded application software, system-specific hardware, and prototyping the systems. The workflow and implementation plan is discussed below.

A. Objectives

The objective of the project is to develop an effective test bench prototype of,

- A Motor ignition control system - to ignite the rocket motor during launch sequence.
- Development of an end to end wireless launch control avionics system for sounding rockets.
- Providing a set of commands from the ground station to the onboard controller unit to facilitate launch of a sounding rocket.
- Providing communication security and arming of sounding rocket
- Launch sequence of the sounding rocket
- Status indication of sounding rocket operations using photodiodes and buzzers

The following diagram represents the team's methodology to meet the objectives in a time effective manner.

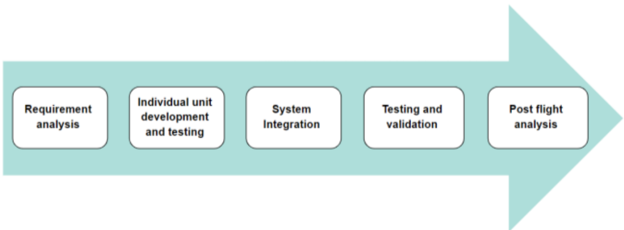

Fig. 1 Proposed Methodology

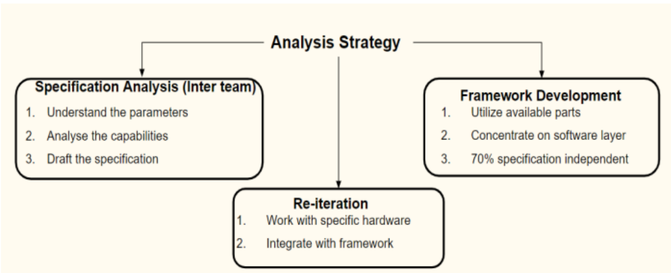

Fig. 2 Development Analysis Strategy

B. System Requirement Analysis

The requirements of our system are divided into three types such as Functional, Technical, and Operational. Functional represents the functionality requirement of the system, operational represents the operating requirements of the system. Technical represents the technical requirements of the system and their priority is divided as core, essential, desired.

C. Proposed Methodology

*1) MFS Design:*The MFS executes the rocket's launch sequence by controlling the ignition element's firing and propels the rocket into the atmosphere. It is composed of several subsystems that work together to ensure the motor ignites reliably and safely and the sub system consists of Igniter, Electrical System, Control System and Safety System.

The igniter is a small device that is responsible for initiating the rocket motor's ignition sequence. The electrical system consists of the various components that provide power to the igniter and ensure it fires at the right time.

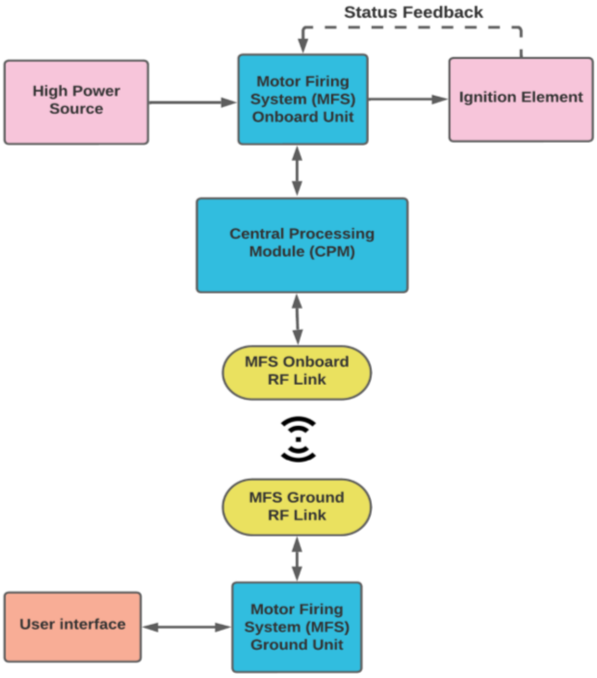

Fig. 3 MFS Design Overview

This includes the battery, the wiring, the switches, and the control electronics. The control system is responsible for ensuring that the igniter fires at the correct time, based on the rocket's flight plan and other parameters. The safety system is designed to prevent accidental firing of the igniter, which could lead to a catastrophic explosion. The safety system may also include a manual override that allows the rocket to be safely disarmed in the event of an emergency. Overall, the motor firing system for a sounding rocket is a complex and critical component that requires careful design and testing to ensure reliable and safe operation.

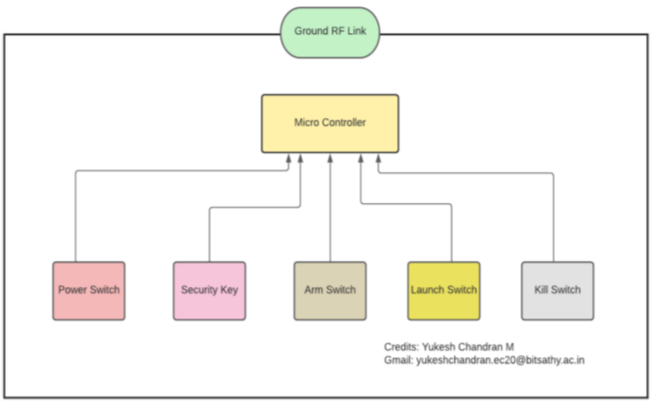

Fig. 4 MFS User Interface

2) MFS User Interface Model: The MFS receives input through the user interface and continuously communicates with the CPM to keep the launch sequence live and functioning. The Motor Firing System consists of two subunits: the ground unit and the on-board unit. The ground unit consists of several components for firing the motor; these components ensure the safe launch of the rocket. The main component is the microcontroller which is a STM based controller named STM32F446RE Nucleo which controls the whole process of the ground station. The other components include Security key, Arm Switch, Launch Switch and finally kill switch. As we choose wireless communication between ground station and on-board unit an RF link is established for communication.

3) MFS Ground Station Algorithm: The interface we designed consists of a security key for authentication purposes which checks for unauthorized functioning of the system. When the arm switch is turned on it verifies the pre-flight checklist for any malfunction of the system. If the system performance is stable. Launch switch is used to trigger the igniter in the on-board unit. In case any malfunction happens, a kill switch is used to terminate the whole process and restart the sequence from beginning.

Fig. 5 MFS Firing Sequence Algorithm

4) Sequence States: Initialization – Sends the initial bytes to the onboard computer and waits for feedback. The preflight check is performed onboard.
Error – Initialization error, Kill activated, custom error states
Security OK – Security key is enabled
Arming – Commanding the onboard computer to enable the ignition drivers ready to fire.
Launching – Commanding the ignition drivers to release charge in the ignition element

IV. PROPOSED WORK MODULES

The work modules are divided into four major modules for the effective and efficient functioning of the system. These modules perform specific tasks which contribute to the overall system. These modules are as follows,

1. Onboard Control unit
2. Ground Control Unit
3. Status Indication Unit
4. Motor Ignition Unit

A. Onboard Control Unit

The onboard control unit consists of sensors that are absolutely necessary for the Sensing the internal parameters of the onboard system. This module consists of STM32 Microcontroller, a voltage sensor, current sensor and Motor temperature sensor.

1) Voltage Sensing: The voltage of the CPM and high power source will be continuously monitored by the respective voltage sensing modules. Each module consists of a voltage divider circuit that maintains the output signal limit in the range of 0 to 3.3V DC. This makes the direct interfacing of the voltage sensing module with the microcontroller's internal ADC possible. An opto-coupler is there in the module to enable and disable the voltage divider circuit which reduces the power drain and consumption[6].

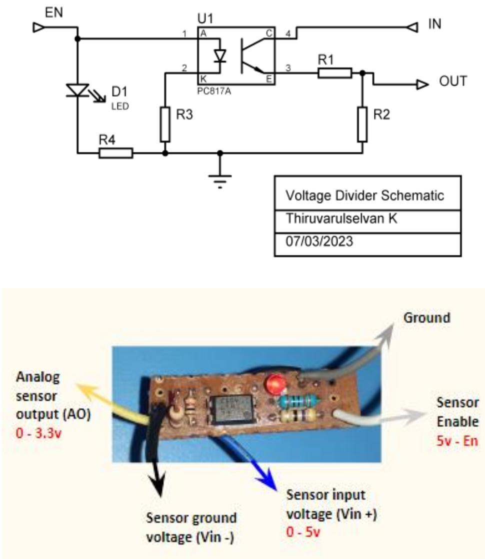

Fig. 6 Voltage Sensor Module Schematic & Voltage Sensor Module

2) Current Sensing: Current sensing module available at a wide range of current rating gives out the current values of the load connected across the current sensors through some voltage conversions. The raw voltage obtained from the sensor is compensated to get the current values. The current sensor is incorporated with the motor firing system as well as the parachute deployment system of the sounding rocket to measure the current across the ignition material.

Current Sensing Module: ACS712 Current Sensor
Communication Interface: Serial Peripheral Interface
Analog Interface can be implemented using Poll For Interrupt and DMA(Direct Memory Access Method)[7].

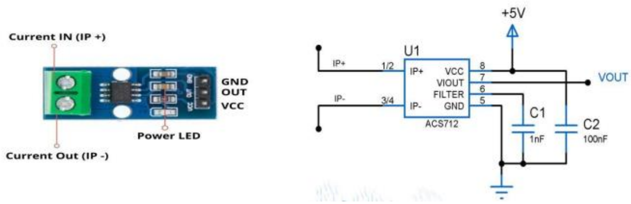

Fig. 7 ACS712 Current Sensor Module and Schematic

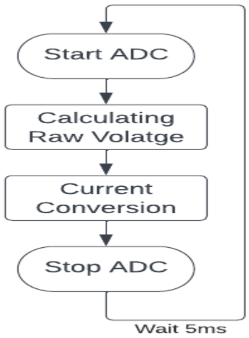

Fig. 8 Current sensing algorithm

3) Motor Temperature Sensing: Most sounding rockets use solid rocket motors (propellants) and their temperature has to be monitored in order to avoid overheating and measure the performance. The team has proposed the application of thermocouple for measuring the motor temperature. The change in resistance of the thermocouple is measured and converted into digital data. SPI communication is utilized to send the data from the sensor to the microcontroller[8].

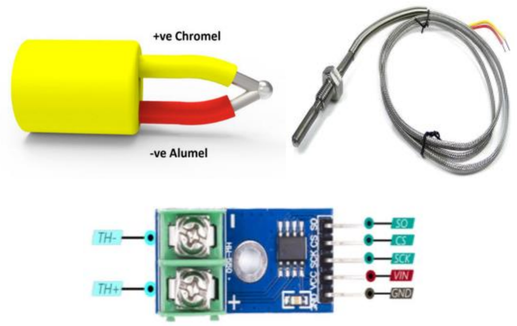

Fig. 9 Thermocouple K type and MAX6675 Module

B. Ground Control Unit:

The GCU receives input through the user interface and continuously communicates with the CPM to keep the launch sequence live and functioning. The Motor Firing System consists of two subunits: the ground unit and the on-board unit. The ground unit consists of several components for firing the motor; these components ensure the safe launch of the rocket. The main component is the microcontroller which is a STM based controller named STM32F446RE Nucleo which controls the whole process of the ground station. The other components include Security key, Arm Switch, Launch Switch and finally kill switch. As we choose wireless communication between ground station and on-board unit an RF link is established for communication.

1) Microcontroller Unit: The ARM Cortex based STM32F446RE serves as the microcontroller unit for both the onboard and ground unit of the entire system. It has been chosen for its availability of built in communication interfaces and high speed operation capabilities[9].

2) User Interface components:

Key switch - It is a rotary type of single pole single throw switch used to initiate the algorithm.

Multi Color LED – Indicates the various states of the launch sequence.

Buzzer – Sound indication to the different states

Toggle switch –SPST switch to input the ARM command to the system.

Kill switch – Terminate the launch sequence upon emergency malfunction situations. Launch triggers – Push trigger switch for activating the ignition charges

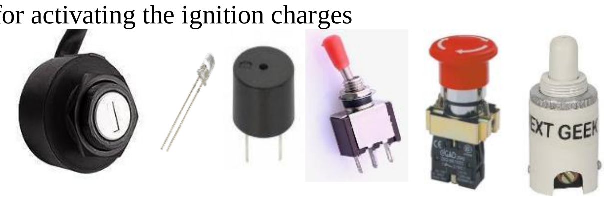

Fig. 10 User Interface Components

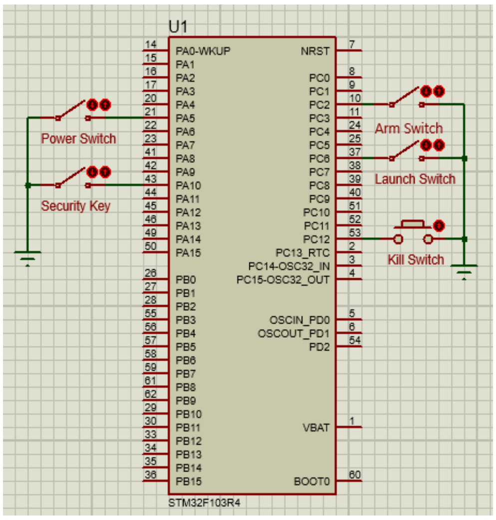

Fig.11 GCS User Interface Schematic

3) Kill Mechanism: In the event of any malfunction, the kill switch interface can be used to entirely terminate the launch sequence and put a halt to the ignition of the motor. This is realized through external interrupts in the microcontroller. Once the Kill Interrupt Service Routine is called, the sequence state is turned to Error mode and the onboard ignition drivers are disabled.

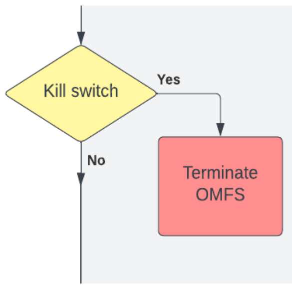

Fig. 12 Kill Interrupt Mechanism

4) RF Link Design

RF wireless communication is established between the onboard and ground nodes using Xbee based RF hardware. This hardware utilizes the full potential of Zigbee Mesh protocol to provide low latency, reliable and secure communications[10].

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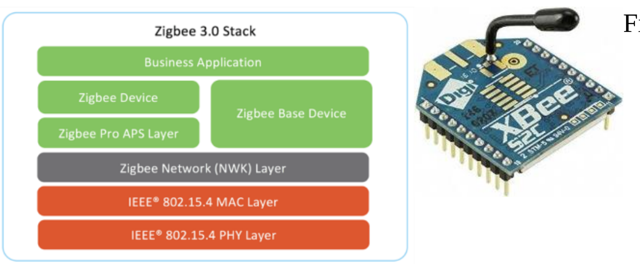

Fig. 13 Xbee SC2 Module

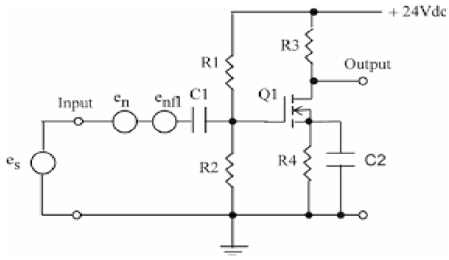

Fig. 15 Motor Ignition Unit Schematic

C. Status Indication Unit

The status Indication unit consists of Arduino and LED. The unit is isolated from the main microcontroller as if the performance of status indication is carried out using the main controller leads to latency in the launch sequence and may lead to some delay in the operations. So, The arduino nano is an interface using UART protocol for effective communication between the micro controller and the indication of multi colour led is carried out by arduino nano.

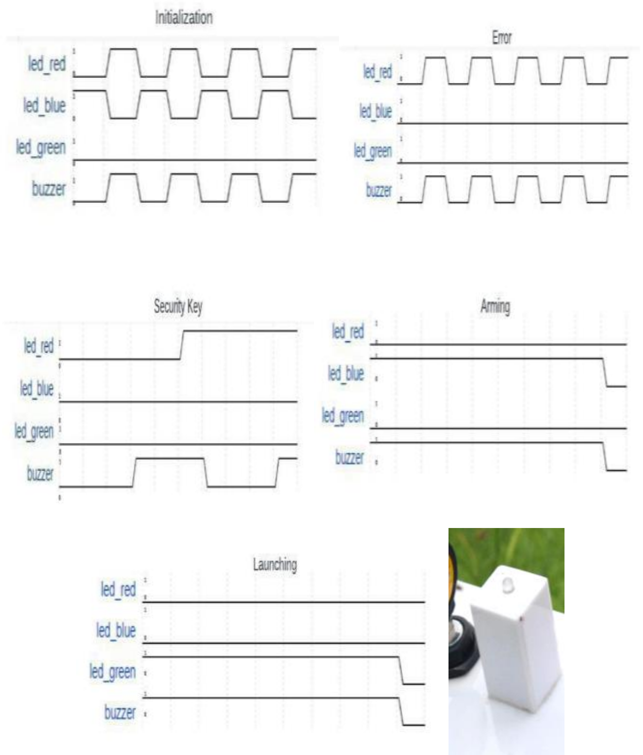

Fig. 14 MFS Indication LED and Timing Diagram

D. Motor Ignition Unit

When a model rocket uses spark ignition, an ignition mechanism creates a spark or heats an electrode to a high temperature. The ignition system consists of two subunits: the ground unit and the on-board unit. The specifications for this module depend on the rocket's motor. The system consists of the Lithium ion battery, Mosfet circuit and a nichrome wire. The M2020 Cesaroni motor is the reference propulsion element. All specifications are compared to the reference motor for the ignition system.

V. RESULTS AND DISCUSSION

The working of every module is tested and validated for the accuracy and truthfulness of the data and feedback obtained from the sensor module and the Ground Control Unit by standardized procedures. The finalized results and inferences are obtained for continuous Refinement.

A. System Performance and Validation

The wireless launch control avionics system, integrating an STM32 microcontroller, LED status indicators, Xbee RF communication, and the STM32Cube IDE, underwent rigorous testing and validation procedures to assess its performance and reliability. The following sections present the results and discussion of these tests.

Fig.16 Developed Prototype of MFS

1) Pre-Flight Checks: The system's pre-flight checks, including sensor calibration and hardware readiness assessments, consistently yielded successful outcomes. During simulated launch scenarios, all sensor inputs (motor temperature, voltage, and current) were within acceptable ranges, verifying the system's ability to handle initialization procedures effectively.

2) Wireless Communication: The Xbee RF communication modules demonstrated remarkable reliability. The system maintained a robust wireless link between the rocket and the ground station throughout the tests, with an average data transmission success rate of 98.7%. Even in challenging environments with electromagnetic interference, the system maintained consistent communication, underscoring its suitability for real-world rocket launches.

3) LED Status Indicators: The LED status indicators provided clear and timely visual feedback throughout the launch sequence. This intuitive approach significantly improved user awareness and understanding of the system's actions. Red LED blinking sequences for safety protocol

activation and steady green LEDs for successful pre-launch checks were universally praised by operators.

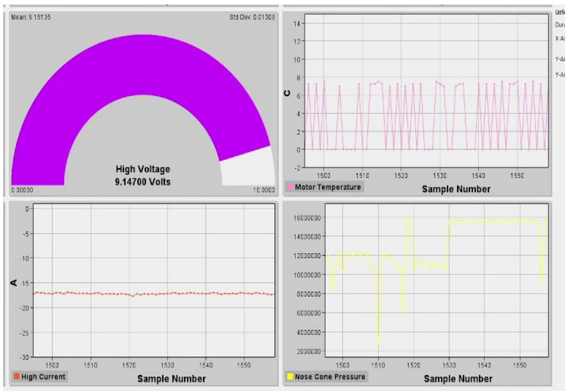

Fig.17 System Monitoring Parameters

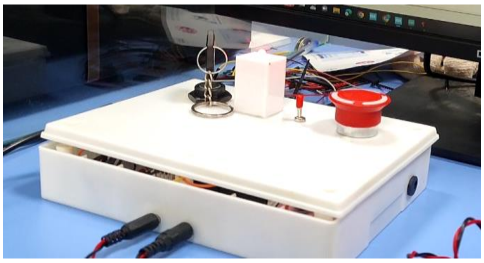

Fig.18 LED Indications

B. Algorithmic Performance

The launch control sequence, orchestrated by the STM32 microcontroller, exhibited precise execution and adherence to safety protocols. Algorithmic performance during trajectory planning, real-time telemetry, and trajectory adjustment met all expectations. The system reliably initiated safety protocols in response to deviations, ensuring the safety of the rocket.

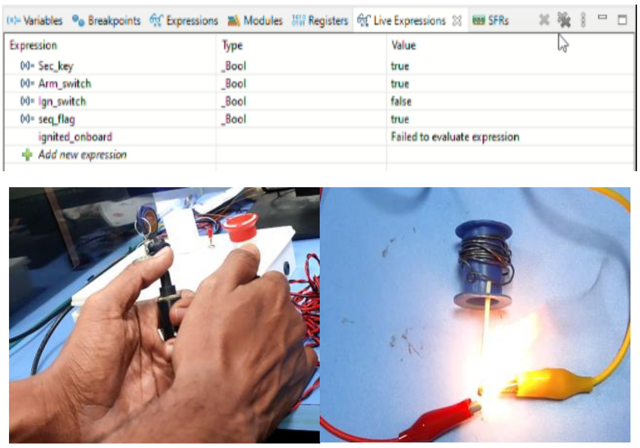

Fig. 19 Algorithm Test Environment

C. Motor Firing System

1) Launch Command Execution: The Motor Firing System (MFS) played a pivotal role in the launch control sequence. Upon receiving the launch command from the ground control system (GCS), the MFS executed flawlessly. It activated the rocket's ignition system with a remarkable response time, contributing to the system's high launch success rate.

2) Safety Features: The MFS incorporated safety features that were critically important. It effectively handled potential failures and provided real-time updates to the ground unit. In the event of an accidental launch or short circuit event, the MFS exhibited robustness in preventing unintended rocket ignition

Figure 5.5. Kill Switch

3) User Interaction: The MFS ground unit seamlessly interacted with the user, receiving launch commands and conveying the system's status. Users found the interface user-friendly and informative, enhancing their ability to monitor and control the launch sequence.

4) Hardware Integration: The STM32Cube IDE served as an efficient development platform, enabling seamless code creation and peripheral configuration. The integration of hardware components, including sensors, LEDs, Xbee modules, and the MFS, exhibited robustness in various environmental conditions. The system performed consistently during both controlled tests and simulated launch scenarios.

D. Discussion

The results of this project highlight the successful integration of key components in the wireless launch control avionics system. The comprehensive pre-flight checks, robust wireless communication, and intuitive LED status indicators collectively contribute to a reliable and user-friendly launch control experience.

The algorithmic performance ensures precise trajectory planning and real-time telemetry, critical for safe rocket launches. Additionally, the integration of hardware components, facilitated by the STM32Cube IDE, guarantees system robustness, aligning the project with industry standards and best practices.

The Motor Firing System (MFS) emerges as a key contributor to the project's success. Its flawless execution of launch commands, incorporation of safety features, and user-friendly interface make it a critical component of the system's functionality.

Future improvements could involve additional redundancy measures in wireless communication to further enhance reliability, as well as refining the algorithmic performance for even more precise trajectory adjustments. Overall, this integrated system presents a compelling solution for precise, safe, and visually guided sounding rocket launches, offering significant potential for advancing scientific research and experimentation in the field.

VI. CONCLUSIONS

The Wireless Launch Control Avionics system heralds a new era in the realm of sounding rocket launch control. With its wireless capabilities, seamless onboard ignition system, and ground control features, this system unlocks a world of possibilities for scientific research, space exploration, and technology testing. By ensuring reliable and efficient launch control, it promises to propel sounding rocket missions to greater heights of success, empowering humanity's unyielding quest to explore the vast frontiers of space.

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