

RTOS-Based Satellite Telemetry Simulator

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Abstract— The increasing demand for reliable satellite communication and space mission monitoring has created the need for efficient real-time telemetry systems. An RTOS-based Satellite Telemetry Simulator is designed to simulate the monitoring and transmission of satellite parameters using a Real-Time Operating System (RTOS). The system continuously acquires simulated sensor data such as temperature, pressure, battery voltage, and orientation values, and processes them in real time using multitasking techniques. The RTOS efficiently manages different tasks such as sensor data acquisition, telemetry packet generation, communication handling, and system monitoring with precise timing and scheduling. The simulator helps in understanding the working of satellite onboard systems and real-time data communication without requiring actual satellite hardware. The collected telemetry data can be displayed on a monitoring dashboard or serial terminal for analysis. This project demonstrates the importance of task scheduling, synchronization, inter-task communication, and reliability in embedded aerospace applications. The implemented system provides a low-cost and flexible platform for learning satellite telemetry concepts, RTOS task management, and embedded system design. The simulator can be further extended for advanced space communication research and educational purposes.

Keywords— *Real-Time Operating System (RTOS), Satellite Telemetry, Embedded Systems,*

Multitasking, Task Scheduling, Real-Time Monitoring, Telemetry Data Transmission.

INTRODUCTION

Satellite telemetry systems play an important role in modern space missions by continuously monitoring the health and status of satellites. Telemetry refers to the automatic measurement and wireless transmission of important satellite parameters from space to ground stations. These parameters include temperature, voltage, pressure, position, orientation, and communication status. Reliable telemetry systems are essential for ensuring proper satellite operation and mission success. In real-time satellite applications, multiple operations must be executed simultaneously within strict timing constraints. A Real-Time Operating System (RTOS) is widely used in such systems because it provides deterministic task scheduling, multitasking, fast response time, and efficient resource management. RTOS enables different satellite functions such as sensor monitoring, communication control, fault detection, and data transmission to run concurrently without delay.

The RTOS-Based Satellite Telemetry Simulator is developed to demonstrate the working principles of real-time satellite monitoring systems in a simulated environment. The system generates virtual telemetry data and processes it using RTOS tasks. Different tasks are assigned for sensor simulation, telemetry processing, data transmission, and display operations. This helps in understanding real-time scheduling and communication mechanisms used in aerospace

embedded systems.

The simulator provides an educational and experimental platform for students and researchers to study satellite telemetry concepts without expensive hardware. It also helps in learning RTOS concepts such as task prioritization, synchronization, semaphores, queues, and inter-task communication. The project can be implemented using embedded controllers and RTOS platforms for practical real-time system analysis

A. LITERATURE SURVEY

This literature review focuses on recent developments in IoT-based livestock monitoring systems and smart animal health management technologies. Wu et al. implemented an anomaly detection system using LSTM and One-Class SVM for irregular spacecraft telemetry data. The system used time-aware LSTM networks to process telemetry data with irregular intervals and detect abnormal behaviour efficiently. The proposed method improved anomaly detection accuracy in telemetry monitoring applications as discussed in [1]. Elmquist et al. developed a GPU-accelerated Solar Radiation Pressure modelling technique for accurate spacecraft trajectory simulation. The system used ray-tracing methods and parallel GPU processing to improve trajectory prediction accuracy and computational efficiency as discussed in [2]. Xiang and Lin proposed a GRU-RNN and Extreme Value Theory based anomaly detection method for multivariate spacecraft telemetry data. The RNN model learned normal telemetry behaviour, while EVT identified abnormal extreme values for effective anomaly detection without labelled datasets as discussed in [3]. Saha et al. implemented a sketch-based telemetry framework for fine-grained anomaly detection in high-speed systems. The framework used compact telemetry data structures to reduce storage requirements while maintaining anomaly detection efficiency as discussed in [4]. The SCOSA middleware architecture introduced a scalable and reliable distributed on-board computer system for spacecraft applications. The middleware provided fault detection, recovery mechanisms, and heterogeneous node management for reliable spacecraft operations as discussed in [5]. Kim and Yang developed reliability optimization techniques for real-time satellite embedded systems under temperature variations. The system dynamically adjusted workload allocation and operating parameters to reduce temperature-induced failures and improve reliability as discussed in [6]. Garcia-Bonilla et al. implemented a message-passing simulation framework for exo-atmospheric spacecraft

trajectory and telemetry systems. The framework used modular communication between subsystems to support scalable and flexible spacecraft simulations as discussed in [7]. Eshaq et al. proposed a modular CubeSat flight software architecture supporting autonomous operations, payload management, and software reusability. The system improved mission flexibility and efficient resource utilization in CubeSat applications as discussed in [8]. Shakya et al. developed propagation and channel models for Low-Earth Orbit communication systems operating in FR1 and FR3 frequency bands. The models analyzed signal propagation effects such as fading, delay spread, and path loss for reliable satellite communication performance as discussed in [9]. The CEAS Space Journal presented a synthetic telemetry data generation library for machine learning based anomaly detection systems. The framework generated labelled synthetic telemetry datasets for training, testing, and benchmarking anomaly detection models as discussed in [10].

B. PROPOSED METHODOLOGY

The proposed RTOS-Based Satellite Telemetry Simulator is designed to simulate real-time satellite monitoring and telemetry communication using multitasking concepts of a Real-Time Operating System (RTOS). The system continuously generates and processes simulated satellite parameters such as temperature, pressure, battery voltage, altitude, and orientation values.

The overall system is divided into multiple RTOS tasks to achieve parallel and efficient operation. Each task performs a specific function within the telemetry system. The sensor simulation task generates virtual satellite sensor data at regular intervals. The data acquisition task collects and processes the generated values for telemetry packet formation. The communication task transmits telemetry data to the monitoring interface or serial terminal. A display task continuously updates system parameters for real-time monitoring.

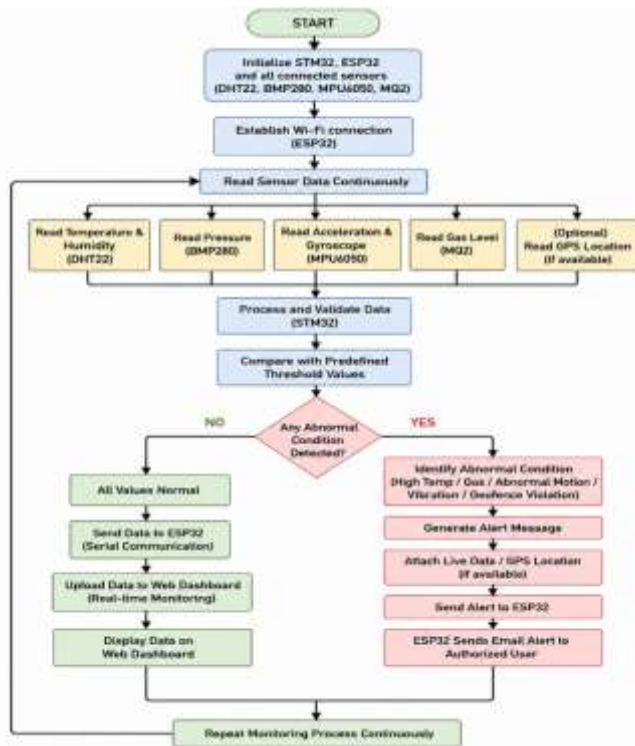


Fig 1: Flowchart of RTOS-Based Satellite Telemetry Monitoring and Alert System

The RTOS scheduler manages task execution based on priority and timing constraints to ensure reliable real-time performance. Inter-task communication mechanisms such as queues, semaphores, and mutexes are used for synchronization and safe data sharing between tasks. The simulator also includes fault monitoring functions to detect abnormal parameter values and system errors.

The proposed system provides an educational platform for understanding satellite telemetry operations, RTOS task scheduling, and embedded communication systems. The methodology improves real-time performance, efficient resource utilization, and reliable telemetry transmission. The system can be further extended for advanced aerospace applications and real satellite communication research

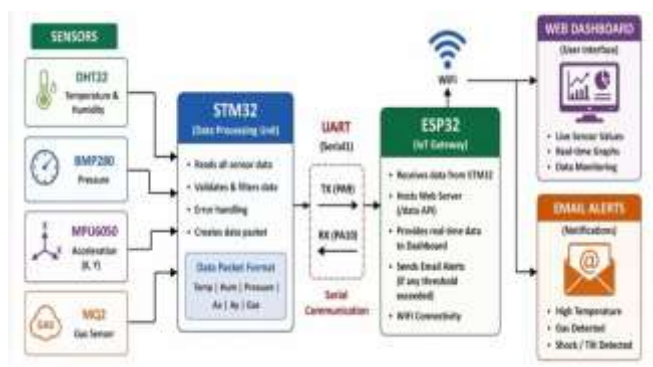


Fig 2: General block diagram of the proposed satellite telemetry simulator

I. HARDWARE COMPONENTS

ESP32 Microcontroller works as an IoT gateway for wireless communication. It sends telemetry data to the web dashboard through Wi-Fi.

STM32 Microcontroller acts as the main controller of the system. It processes sensor data and manages RTOS-based telemetry operations.

DHT22 Sensor measures temperature and humidity values from the environment. The data is used for real-time telemetry monitoring.

BMP280 Sensor measures atmospheric pressure with high accuracy. It provides pressure data for telemetry analysis.

MPU6050 Sensor detects acceleration and orientation changes. It simulates motion monitoring in satellite systems.

MQ2 Gas Sensor detects gas leakage and smoke levels in the environment. It helps in abnormal condition detection and safety monitoring.

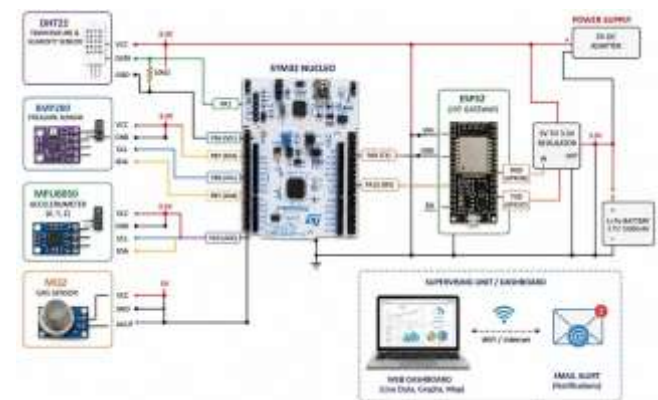


Fig 3: Circuit diagram and sensor interfacing of the proposed system

II. SOFTWARE IMPLEMENTATION

Arduino IDE is used for programming and firmware development of the ESP32 microcontroller. It supports easy sensor integration and wireless communication configuration.

FreeRTOS manages multitasking and task scheduling in the telemetry system. It enables real-time execution of multiple operations efficiently

Embedded C programming language is used to develop the system logic, sensor interfacing, data processing, and alert generation.

Blynk provides a cloud-based dashboard for real-time telemetry monitoring. It displays sensor values, graphs, and alerts remotely.

Wi-Fi communication is used to send telemetry data to cloud platforms. It enables remote monitoring and alert systems. and alert notifications.

III. SYSTEM IMPLEMENTATION AND RESULTS

The RTOS-Based Satellite Telemetry Simulator was implemented using the STM32 Microcontroller as the main processing unit and ESP32 as the IoT communication gateway. Multiple sensors including DHT22 Sensor, BMP280 Sensor, MPU6050 Sensor, and MQ2 Gas Sensor were interfaced with the STM32 controller for telemetry data acquisition.

The system was developed using STM32CubeIDE and FreeRTOS to implement multitasking operations. Separate RTOS tasks were created for sensor reading, telemetry packet generation, UART communication, Wi-Fi data transmission, and dashboard monitoring. UART protocol was used for serial communication between STM32 and ESP32 modules.

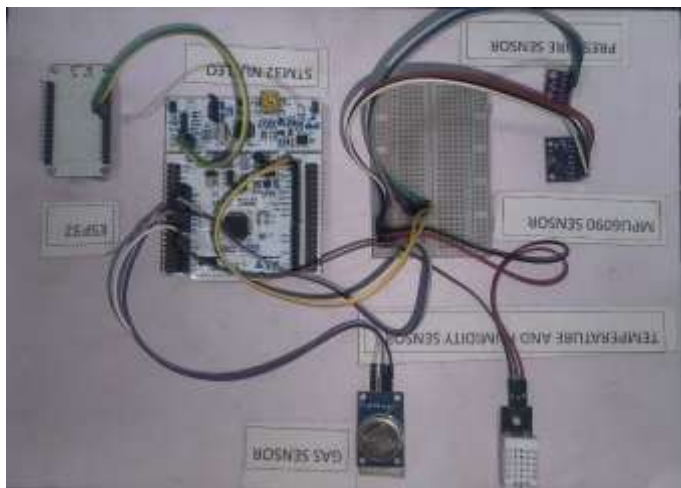


Fig 4: Hardware Implementation of RTOS-Based Satellite Telemetry Simulator

The ESP32 module transmitted real-time telemetry data to a web dashboard through Wi-Fi connectivity. The dashboard displayed live sensor values, graphical plots, acceleration vectors, and raw telemetry logs for continuous monitoring. Alert notifications were also

generated during abnormal environmental conditions such as high gas levels or temperature variations.

The implemented system successfully demonstrated real-time telemetry acquisition, task scheduling, and remote monitoring operations. The RTOS efficiently managed concurrent tasks with reliable timing and fast response. The web dashboard provided smooth real-time visualization of telemetry parameters, improving system monitoring and analysis capabilities.

The developed RTOS-Based Satellite Telemetry Simulator successfully monitored and transmitted real-time sensor data through the web dashboard.

The system continuously displayed temperature, humidity, pressure, acceleration, and gas sensor values with stable communication performance.



Fig4: Real-Time Web Dashboard for RTOS-Based Satellite Telemetry Monitoring System

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IV. ADVANTAGES

- Provides real-time monitoring of multiple sensor parameters simultaneously.
- RTOS enables efficient multitasking and accurate task scheduling.
- Supports reliable telemetry data transmission using UART and Wi-Fi communication.
- Web dashboard allows remote monitoring from any connected device.
- Reduces delay and improves system response in real-time applications.
- Supports fault detection and alert generation during abnormal conditions.

V. LIMITATIONS

- The system is designed for simulation and educational purposes only, not for actual satellite

CONCLUSION

The RTOS-Based Satellite Telemetry Simulator was successfully designed and implemented for real-time monitoring and telemetry communication applications. The system efficiently collected sensor data such as temperature, humidity, pressure, acceleration, and gas levels using multiple sensors interfaced with the STM32 microcontroller. FreeRTOS enabled efficient multitasking, task scheduling, and reliable real-time processing of telemetry operations.

The ESP32 module provided wireless communication and transmitted telemetry data to the web dashboard for remote monitoring. The dashboard displayed live sensor values, graphical plots, and telemetry logs for continuous system observation. The implemented alert mechanism also helped detect abnormal conditions and notify users effectively.

The developed system demonstrated stable real-time performance, efficient resource management, and reliable telemetry data transmission. The project

deployment.

- Limited sensor range and accuracy compared to professional aerospace-grade equipment.
- Wi-Fi communication range depends on network availability and signal strength.
- Real-time performance may decrease when additional high-speed tasks are added.
- The system uses low-cost hardware components with limited processing capability.

VI. APPLICATIONS

- Satellite telemetry monitoring and simulation systems.
- Aerospace and spacecraft communication research.
- Real-time embedded system learning and experimentation.
- Educational projects for RTOS and IoT applications.
- Remote environmental monitoring systems.
- Industrial safety and gas leakage detection systems.
- Smart monitoring and alert generation applications.
- Wireless sensor network research and development.
- Real-time data acquisition and visualization systems.
- Fault detection and condition monitoring applications.

provides a low-cost and flexible platform for understanding satellite telemetry concepts, RTOS operation, embedded communication, and IoT-based monitoring systems. The system can be further enhanced with advanced communication protocols, cloud integration, GPS tracking, and AI-based anomaly detection for future aerospace applications.

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