A 2-D Model of Optical Satellite Communication System

Team 33

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1. Introduction

1.1 Objectives and Background

With the rapid development of aerospace and communication technologies, our demand for more multifunctional, stable, and advanced satellite communication products is increasing. Low Earth Orbit (LEO) satellites have gained widespread popularity due to their advantages, such as low latency and low deployment cost. They have shown promising potential in climate and geographical studies. With the advent of Starlink, LEO satellites have made their way into everyday households, delivering internet access to even the most remote areas. However, LEO satellites face a set of challenges. Since each satellite covers a smaller area and moves much faster than the Earth's rotation, a large constellation is required to ensure global coverage. Therefore, we believe that studying how these satellites communicate with ground stations is essential. We try to understand the dynamics of these interactions and optimize communication efficiency.

1.1.1 Goals

Our goal is to design and construct a 2-D model that simulates the movement of a LEO satellite around the Earth. The model consists of two concentric disks of different sizes, a laser transmitter, and a laser receiver. The smaller inner disk represents the Earth, while the larger, outer disk represents the satellite's orbit. The laser transmitter will be mounted on the inner disk, and the receiver will be positioned on the outer disk to simulate communication between signal transmitters on the ground and satellite receivers in space.

1.1.2 Functions

- Both disks will rotate to simulate the Earth's self-rotation and the satellite's orbital motion around the Earth. The rotations will be powered by motors positioned beneath the disks. Their relative angular speeds should be controllable by a circuit board that drives the motors.
- The laser receiver can detect optical signals but only within a limited scattering angle of the laser source.
- A storage component will be included to retain the received signals for decoding. The transmitted signal will be encoded in binary, with a value of 1 when the laser is emitted at a specific frequency and 0 when it is not.
- To evaluate system performance under various conditions, a graphical user interface (GUI) will be developed to control the rotation speed of each disk and the laser transmission frequency. The GUI will also visualize the impact of these parameters on signal transmission efficiency through graphical representations.

1.1.3 Benefits

- Our design is educational, as it performs as an interactive platform that teaches the younger generation on satellite communications.

- Our design is user-friendly, as we have a GUI to operate and control our model.
- Our design could inspire further interest in research in this field and lead to innovations in space technologies.

1.1.4 Features

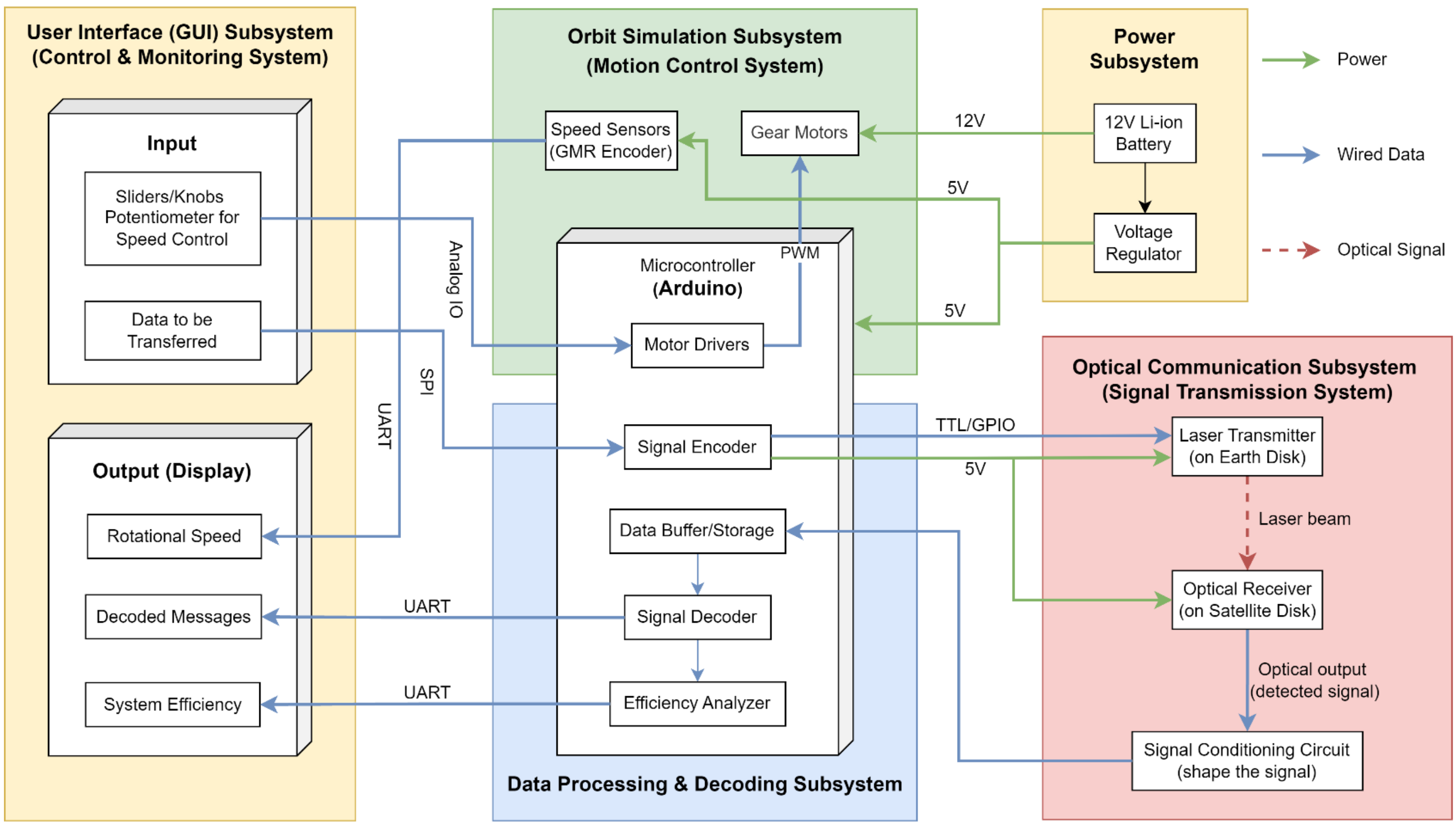
- Our system is cheap to deploy. Building and launching a real satellite is expensive and complex; even using them for communication experiments would require the purchase of some services. Our system provides easy and affordable simulation that can be used to test satellite-ground communications. Telecommunication developers can use the model to prototype and test optical signal transmission strategies before implementing them in real-world satellite systems.
- Unlike large-scale space simulation setups, our compact model can be easily deployed in classrooms, labs, or corporate research facilities.
- Users can easily adjust parameters to test our model under different scenarios, even the disks, since they are made from PP and are customizable.

1.1.5 High-Level Requirements

- The disks can rotate at 6 rpm.

2. Design

2.1 Block Diagram



2.2 Block Descriptions

We plan to develop an optical communication-based orbit simulation system that integrates motion control, data transmission, and a graphical user interface subsystem. The system allows a user to control and monitor the rotational speed of a satellite simulation disk and transmit data via an optical communication link. An Arduino-powered microcontroller should be implemented to manage motor control, signal processing, and efficiency analysis. Power is supplied via a 12V Li-ion battery, and data transmission will be through an optical communication system containing a laser transmitter and receiver.

2.2.1 Graphical User Interface (GUI) Subsystem

This subsystem provides an interface for users to control the rotational speed of the disk and modify desired data for transmission. It also displays real-time feedback about system performance. This subsystem takes input from the user and sends speed control signals and transmission data to the Microcontroller in the Data Processing & Decoding Subsystem. Meanwhile, it read the real-time rotational speed data, decoded messages, and system efficiency results from the Microcontroller for display. It enables users to monitor the system, allowing for real-time control and assessment of performance.

2.2.2 Orbit Simulation Subsystem

The Orbit Simulation Subsystem simulates the orbital movement of a satellite by controlling the rotation of a disk through gear motors and sensors. It's the core component of the system we plan to build since it simulates satellite movement, providing a dynamic target for optical communication and making the transmission system more realistic. Core components include Gear Motors and Speed Sensors. Gear Motors receive control signals from the Microcontroller, adjusting the disk's rotation, while Speed Sensors provide feedback on rotational speed to the Microcontroller for real-time adjustments.

2.2.3 Data Processing & Decoding Subsystem

This subsystem acts as the processing hub, managing motion control and data transmission, ensuring smooth system operation. It processes motor control signals, encodes data for transmission, buffers and stores data, decodes received signals, and analyzes communication efficiency. As for connection, the Motor Drivers should receive speed control commands from the Microcontroller and send power signals to the Gear Motors in the Orbit Simulation Subsystem. The Signal Encoder converts user data from the GUI Subsystem into an optical signal format for the Optical Communication Subsystem. The transmitted and received data should be held in Data Buffer of Arduino. The Signal Decoder processes optical signals received from the Optical Communication Subsystem, converting them back into digital data. Finally, the last component, Efficiency Analyzer evaluates signal integrity and system performance, sending results to the GUI Subsystem for display.

2.2.4 Optical Signal Transmission System

The signal transmission system is responsible for simulating satellite communication by transmitting data via an optical laser system, demonstrating real-world optical data transfer techniques. It handles wireless data transmission using a laser-based communication system, simulating space-based optical links. The Laser Transmitter on the smaller Disk that represents Earth receives encoded data from the Signal Encoder in the Data Processing & Decoding Subsystem, converting it into a laser beam. On the other hand, the Optical Receiver on the Satellite Disk captures the transmitted laser signal and converts it into an electrical signal.

2.2.5 Power Subsystem

The final subsystem is the power subsystem which provides stable power to the entire system, ensuring the continuous operation of all subsystems. A 12V Li-ion Battery supplies power to the Voltage Regulator, and the Voltage Regulator distributes stable voltage to the Microcontroller, Gear Motors, Laser Transmitter, and other components. The power subsystem ensures the system has a consistent power supply, allowing all components to function efficiently.

2.3 Risk Analysis

The greatest difficulty and risk lie in implementing both the Optical Communication Subsystem (Signal Transmission System) and the Orbit Simulation Subsystem (Motion Control System). Our model includes rotating mechanical disks driven by motors, which might have potential risks while rotating. To ensure safety at startup, we will implement safety guards, clearly mark rotating components, and set strict speed limits during testing. Besides we will also set emergency stop mechanisms to stop operations immediately if dangerous situations arise.

We use Laser to represent the signal transmission which needs to be concerned about. Our team will utilize low-power lasers to minimize risk. Clear hazard signals, proper protective eyewear, and specific training sessions will be mandatory for all users. Access to lasers will be restricted to qualified individuals only in order to reduce accidental exposure or misuse.

3. Ethics and Safety

3.1 Ethics

Our project mainly involves a controlled, simplified 2D simulation of an Optical Satellite Communication System, which has little risk of ethical violations. It does not involve handling personal data, addressing privacy risks, or influencing the environment. We have reviewed our responsibilities thoroughly according to IEEE [1] and ACM [2] Codes of Ethics. Besides, because our model is used purely for educational and demonstrative purposes, concerns like conflicts of interest or discrimination are negligible. Our team fully understands the IEEE and ACM Codes of Ethics and will follow them throughout the project's lifecycle.

3.2 Safety

Since our project involves electrical components, such as DC motors, power supplies, and circuits, we must take care of electrical safety. We will check all the electrical components regularly for proper insulation, secured connections, and grounding. We will understand all the properties of electrical components to ensure proper use.
To meet campus policy requirements, we will follow University laboratory safety guidelines. Proper lab wear, mandatory safety training, clear operational guidelines, and documented risk assessments will ensure our safety during project execution.
Our model is primarily educational and demonstrative in nature, which has little risk to end users. However, ensuring the safety of everyone involved is important. So, we will guide the users on how to use the model properly to make sure all interactions with the model are risk-free and informed.
Since we have carefully identified all potential safety issues and addressed them through comprehensive safety planning, additional significant safety plans are currently unnecessary. However, continuous monitoring and risk reassessment will be part of our development cycle.

4. References

[1] IEEE Code of Ethics: https://www.ieee.org/about/corporate/governance/p7-8.html
[2] ACM Code of Ethics and Professional Conduct: https://www.acm.org/code-of-ethics