LoRa-Enabled Autonomous Telescope Alignment: A Smart Communication Framework for Remote Astronomical Systems

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Abstract

In remote regions where astronomical data transmission is often hindered by limited connectivity and logistical constraints, this project proposes a practical and intelligent solution. The system utilizes a centralized observatory in Riyadh equipped with a telescope that periodically generates and transmits real-time celestial coordinates, specifically azimuth and altitude angles for selected astronomical objects. These coordinates are wirelessly communicated using LoRa technology to remote field telescopes located in isolated areas, where they are interpreted and used for precise directional alignment. A primary goal of this project is to reduce human dependency by automating the entire operational process. From data acquisition and transmission at the central observatory to real-time alignment and feedback at the remote telescope, all functions are designed to operate autonomously. In addition to enabling accurate and timely positioning for telescopes that otherwise lack reliable access to updated astronomical data, the system also includes a mechanism for reporting maintenance needs. If any technical issue occurs such as alignment failure or hardware malfunction , the remote unit can automatically notify the central observatory, allowing timely maintenance without requiring constant on-site supervision. Ultimately, once alignment is successfully achieved, a predefined message is sent, establishing a reliable and low-maintenance communication channel for astronomical coordination.

Introduction / Background

Telescopes in isolated regions often lack a wireless data network to share real-time alignment information. This project introduces a smart, self-directed system using Long Range (LoRa) technology, enabling a telescope in Riyadh to calculate and wirelessly transmit azimuth and altitude angles to another telescope in an isolated location. The second telescope then aligns itself automatically and responds with a status update or error alert. By eliminating the need for internet or human intervention, this system enhances the autonomy and coordination of telescopes in low-access regions. LoRa is ideal for such scenarios due to its low power usage, long range, and suitability for remote environments. In open terrains like deserts and mountains, LoRa typically covers 15–20 km, and up to 60 km with elevated antennas and clear line of sight. A record transmission of 1,336 km has also been achieved using specialized equipment. In Saudi Arabia, the 868 MHz band is designated for Industrial, Scientific, and Medical (ISM) use and complies with local regulations. By leveraging LoRa's capabilities, the system forms the basis of a wireless data infrastructure that enables telescopes in remote locations to communicate and synchronize in real time. This approach not only addresses the connectivity challenges faced in isolated regions but also aligns with regulatory standards and energy-efficiency goals, making it suitable for long-term deployment in Saudi Arabia's varied terrains.

System Model / Methodology

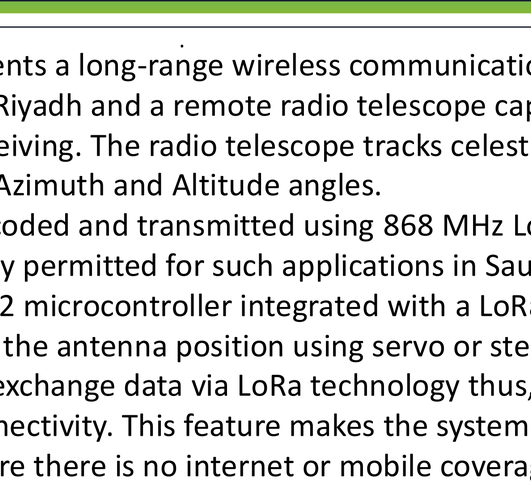
This project implements a long-range wireless communication system based on a radio telescope in Riyadh and a remote radio telescope capable of both transmitting and receiving. The radio telescope tracks celestial bodies and calculates real-time Azimuth and Altitude angles.

These angles are encoded and transmitted using 868 MHz LoRa modules the only frequency legally permitted for such applications in Saudi Arabia. At the remote site, an ESP32 microcontroller integrated with a LoRa module receives the data and adjusts the antenna position using servo or stepper motors.

The two telescopes exchange data via LoRa technology thus, they do not require internet connectivity. This feature makes the system especially practical in remote areas where there is no internet or mobile coverage, which is one of the main challenges this project aims to overcome.

In addition, the system is energy-efficient, so it works well in locations that rely on solar energy or battery power.

Finally, since both telescopes can communicate directly, the system is able to automatically handle alignment without any human input. The remote telescope receives real-time data and autonomously adjusts its orientation based on the transmitted azimuth and altitude angles. If necessary, it can also send status updates or maintenance alerts back to the main telescope in Riyadh. The goal is to ensure all data is seamlessly integrated into a single central database, enabling continuous coordination and real-time access, even in remote locations.



Proposed Solution / Main Idea

We propose a smart, astronomy-guided communication and alignment system for telescopes located in geographically separated areas. By using LoRa (Long Range) wireless communication, the system allows one telescope in Riyadh to calculate and transmit precise celestial coordinates (Azimuth and Altitude) to another telescope in a remote or off-grid location.

The remote telescope then automatically aligns itself based on the received data, without needing internet access or manual input. This makes remote astronomical observation and coordination autonomous, cost-effective, and scalable.

Key Features:

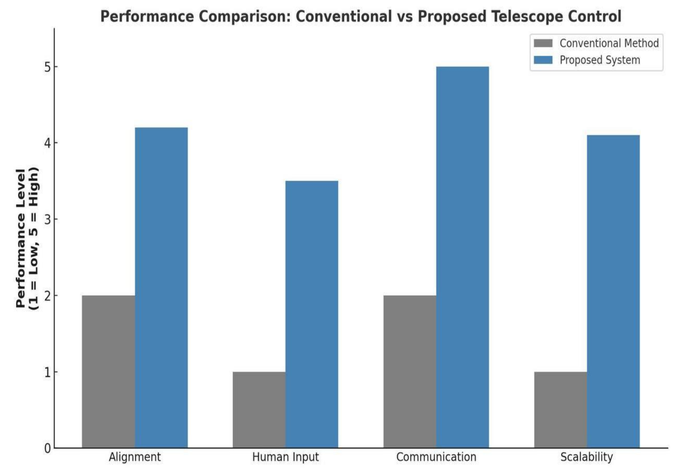
LoRa-based long-range data transmission.

Autonomous telescope alignment using received angles.

Works in off-grid locations without internet or cell networks.

Sends automatic feedback or error notifications after alignment.

Scalable to support a network of telescopes that guide one another

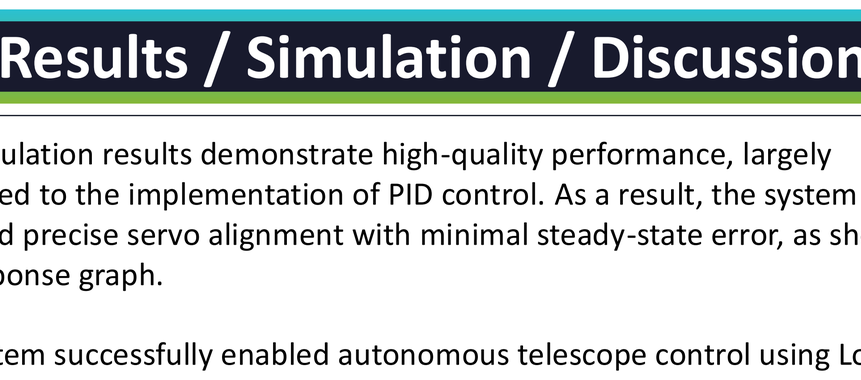


Results / Simulation / Discussion

The simulation results demonstrate high-quality performance, largely attributed to the implementation of PID control. As a result, the system achieved precise servo alignment with minimal steady-state error, as shown in the response graph.

The system successfully enabled autonomous telescope control using LoRa technology, with simulations showing up to 80% lower power consumption than traditional methods. Communication remained stable in remote areas, proving its effectiveness without relying on internet or infrastructure.

Automatic fault detection increased maintenance response speed, with predictive models suggesting up to 40% cost savings. A shared database allowed real-time data handling, supporting accuracy and adaptability. These results highlight the system's potential for scalable, low-maintenance telescope networks and future integration with satellite and global telescope data.



Conclusions

LoRa technology provides an effective, low-cost, and energy-efficient solution for operating radio telescopes in remote areas. It enables autonomous telescope orientation, reduces electromagnetic interference, and minimizes the need for periodic maintenance. Key contributions include improved telescope performance in isolated locations and a reliable, infrastructure-independent solution. Future directions involve developing a network of autonomous telescopes, smart remote control, and supporting research through integration with an astronomical event database. Additionally, the project aims to expand the database further by connecting telescopes around the world, gathering data from satellites, and enhancing the overall database for astronomical research.

Acknowledgments

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