MATEC Web of Conferences **401**, 08004 (2024) https://doi.org/10.1051/matecconf/202440108004
ICMR2024

Remote sensing mission sentinel pro: analysis of satellite tracking, control, and health monitoring system with solar tracking capability

Muhammad W. Baig[1*] and *Mahmoud* Shafik[1]

[1]University of Derby, College of Science and Engineering, Markeaton Street, Derby, DE22 3AW, UK

Abstract. Nowadays, satellite systems are experiencing noticeable disruptive issues due to the single functionality, high cost of operations, and limited adaptability. This paper presents a satellite mission control system with RF duplex communication, which gives multiple functionalities and health monitoring systems with solar tracking capability. This aims to present a flexible and affordable solution called the Remote Sensing Mission Sentinel Pro Platform. The quantitative approach is used and implemented to trans-receive data from space and pass it to the ground station. Arduino-based prototype uses the nRF24L01 module with an antenna at the ground station to trans-receive satellite data has been developed. Testing and verifications of the developed platform prototype indicated that satellites could monitor key health parameters, including temperature, humidity, and battery charge capacity.

Keywords: Remote sensing, satellite communication, satellite operations, satellite health monitoring, telemetries, satellite orbital movement, satellite tracking, satellite control activities

1 Introduction

Nowadays digital computing power has greatly increased with the development of Moore's Law, and measurement and operation control technology that can realize multi-satellite all-day in-orbit control, as well as automatic process control of equipment, satellite commands, and software operation. As per WHO(2022), air pollution is considered as hazardous aspect for global health and as space technology innovation has been emerging, there is a need for a robust and cost-effective solution that uses the satellite data which is obtained by measurement and control technology[1,2]. This is to analyse possible problems, speculate on its attitude when it loses control, look for the best rescue opportunity, send instructions to the satellite according to the presumed position, and finally found the satellite and restored it [3]. Remote Sensing Mission Sentinel Pro is an innovative initiative that combines advanced

* Corresponding author: m.baig3@unimail.derby.ac.uk

robotics, wireless connectivity, and environmental sensing. This uses the Robocar chassis which describes the abilities of the satellite systems by incorporating multiple functionalities that are cost-effective and capable of performing several user controller tasks. Apart from the traditional satellite systems, this aims to perform several functions within the user-controlled satellite systems as per the new developments in space technology. The application of the remote sensing satellite missions within monitoring has been studied in recent times rapidly which ensuring the observation with spectral resolution and high spatial over huge area [4].

2 State of the art of technology

Remote sensing is the process of detecting and monitoring the physical characteristics of the environment, measuring its reflected and emitted radiations involving satellites, spacecraft, space shuttles, aircraft, near space vehicles, and other planetary platforms [3]. Artificial satellites orbit planets and space bodies and capture Earth's images using their sensors, which are referred to as remote sensing satellites. Satellites can monitor the space effectively through the intended measures that will be provided. Satellites can efficiently monitor the whole globe or a particular area of it within a consigned period [5]. It has been seen that in Earth's orbit, about 4,550 satellites are orbiting us. These satellites have made great contributions to mankind in various aspects of communications, meteorology, and earth resource exploration [6,4]. Satellite telemetry, tracking, and command systems are used to monitor and control satellites from the take-off stage to the end of the satellite's space life. The system can send downlink signals and receive uplink signals to tell the satellite measurement and control station on the ground exactly how the equipment on the satellite is working, and then receive and execute the command signals from the ground measurement and control station [7]. After the satellite is launched into space by a rocket, the telemetry, tracking, and command system will track the satellite, capture it in orbit, perform orbit calculations based on the relevant data of the satellite in orbit, determine its position, predict its future trajectory, and monitor the satellite. Hence it conducts a series of "health" checks to prepare the satellite for official service. After collecting information from each satellite subsystem, the Sentinel system can send the data to the ground measurement and control centre through information encoding. The command system receives and executes commands to the satellite from the ground satellite control centre to adjust the satellite's operating speed, angle, position, etc. Satellite missions have long been a primary data source for land monitoring and conservation. These missions are known for their extensive imaging coverage and the ability to integrate with different types of compatible imaging sensors.

3 Proposed sensing mission control pro platform

The process of analysing the remote sensing-based satellite missions is being gathered through a quantitative approach. Earth observation remote sensing, utilising technologies such as drones, satellites, and the Internet of Things (IoT), is transforming land management and conservation practices [6]. These technologies provide highly detailed information about the environment on a large scale, which was previously challenging to obtain. For remote sensing 4WD robocar has been used to serve as the space segment, simulating a satellite in circular orbital movement around the ground station. Upon user input, orbital manoeuvres can be performed by varying the radius of satellite movement. A DHT11 sensor has been used within the space segment to provide humidity and temperature readings. Furthermore, a solar panel has been installed at the top along with a 3.7V Li-ion battery to configure space segments along with a servo motor and LDR sensors, to track solar radiation and optimise solar panel orientation for maximum sunlight exposure. Arduino microcontroller has been used for data processing, battery monitoring, and orbital calculation.

Radio waves and microwaves are forms of electromagnetic energy and both serve as means of communication. Radio waves are employed for the transmission of television and radio programs, whereas microwaves are utilised for mobile phones and Wi-Fi. Out of the many choices, satellite communication utilises radio waves. The nRF24L01 module has been used with an antenna at ground and space segments to send and receive satellite data transmissions for the duplex communication process. The satellite features a solar tracking system to optimise energy harvesting from solar panels, that can be utilised to enhance overall energy efficiency. An ultrasonic sensor has been used along with a servo motor to develop the sweeping motion from 15 to 165 degrees and to track the satellite within the ground segment scope. A solar tracking system has been integrated within the space segment to help optimise solar panels' energy and hence improve energy consumption efficiency. Figure 1 shows the circuit system of the Remote Sensing Satellite and how it works for gathering data and developing communication between space and ground station.

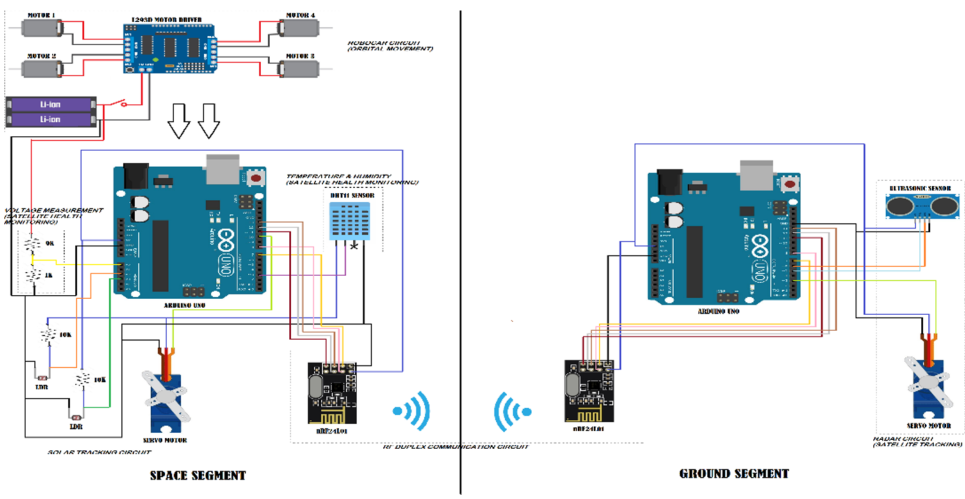

Fig. 1. Space segment (left) and ground segment (right)

4 Testing, Verification, Results and Discussions

Testing has been performed to verify and validate the performance and to make sure that the satellite will communicate effectively with the ground station while providing accurate readings of the sensor and performing commands based on orbital movement and adjustment. The testing has shown a precise satellite orbital movement through a 4-wheel drive robocar, which is programmed to move in a circular direction using a loop function as shown in figure 2.

Satellite orbit control enables the precise management of satellite movement inside a predetermined orbit. Throughout extended satellite operations, the satellite's orbit will experience "orbital perturbation" as a result of the Earth's gravity, atmospheric drag, and the gravitational forces exerted by the sun and the moon [6]. Throughout the operational lifespan of the satellite, it is imperative to consistently monitor and assess the trajectory and execute any adjustments and upkeep to the orbit.

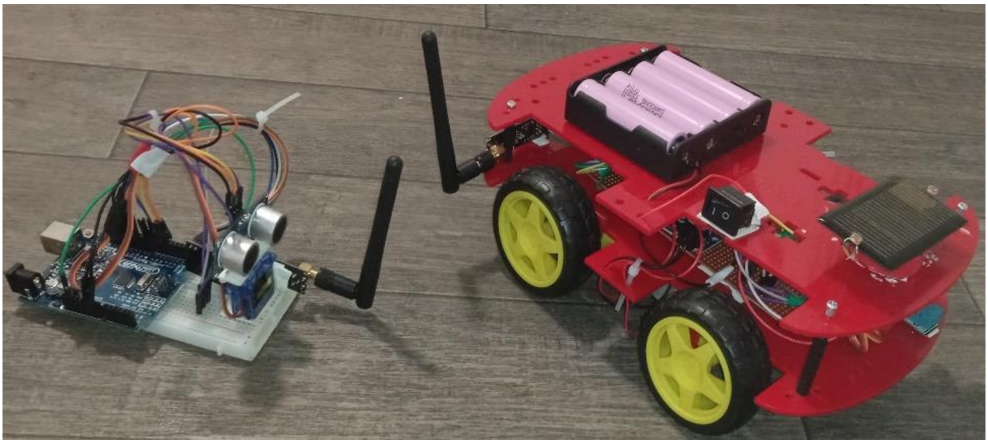

Fig. 2. Satellite orbital movement through a 4-wheel drive robocar

In satellite orbit control systems, the task of maintaining the desired orbit is typically achieved by deploying a thrust mechanism. One additional responsibility of the attitude and orbit control system is to guarantee the orientation of the satellite. For instance, a communication satellite necessitates continuous alignment of its antenna towards the Earth's surface, but an Earth observation satellite necessitates continuous alignment of the observation instrument's window towards the Earth's surface [3].

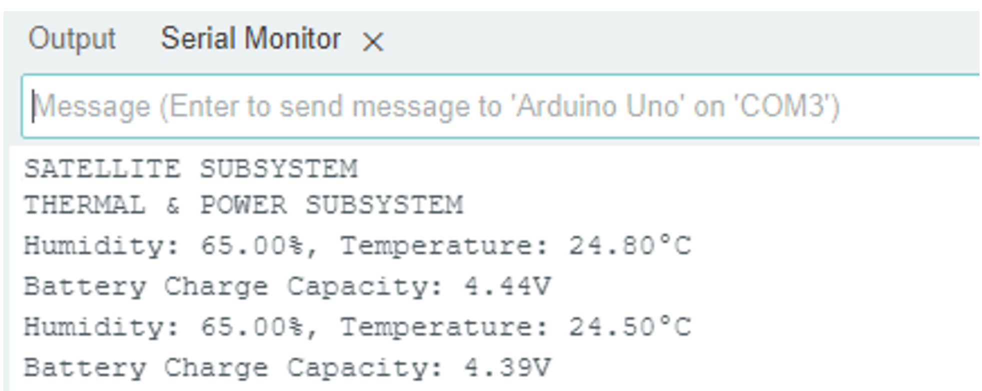

Fig. 3. Telemetry received from satellite subsystems.

After the satellite is launched into space, the telemetry, tracking, and command system will track the satellite, capture it in orbit, perform orbit calculations based on the relevant data of the satellite in orbit, and check the temperature and humidity [3]. Hence, a series of health checks will be conducted to prepare the satellite for official service. Figure 3 shows the data that is received from the telemetries. After collecting information from each satellite subsystem, the telemetry system can send the data to the ground measurement and control centre through information encoding. The traditional satellite systems usually work on the command system that receives and executes commands to the satellite from the ground satellite control centre to adjust the satellite's operating speed, angle, position, etc. For developing communication between space and grounds, an nRF24L01 transmitter was used to send and receive data from both ends, providing accurate readings. The satellite antennas have been used for developing the connection effectively and it ranges up to approximately 100 meters. It has been analysed that the satellite's antenna system must possess an onboard switching function and ample bandwidth to guarantee efficient communication with high data capacity. Additionally, it is essential to implement derotation measures to maintain a consistent wave speed of the satellite's antenna despite the star's rotation. Lastly, ensuring proper isolation is crucial. The capacity to segregate distinct beams to safeguard satellites from external influence.

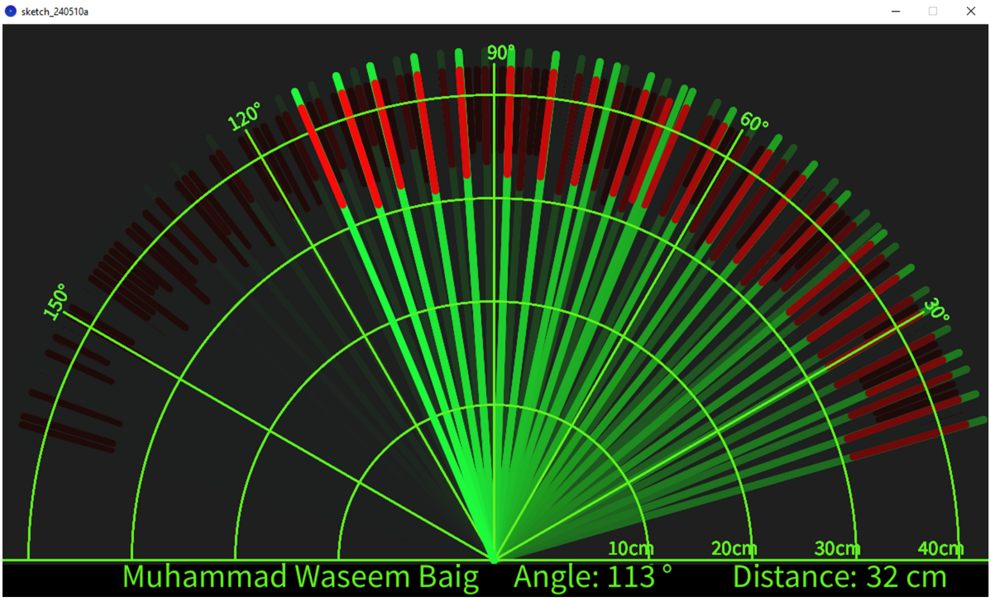

Fig. 4. Satellite Tracking Visual Output

The satellite tracking function plays a pivotal role in ensuring continuous surveillance and monitoring of the satellite's position and trajectory from the ground station, Figure 4 above shows the satellite visual outputs. By deploying ultrasonic sensors and servo motors, the system enables precise tracking and localisation of the satellite within the ground station's field of view. During testing, the satellite tracking system has undergone a rigorous evaluation to validate its accuracy, reliability, and responsiveness in detecting and tracking the satellite's movement in real-time. Moreover, the ultrasonic sensors, strategically positioned within the ground station, emitted sound waves and measured the time taken for the waves to reflect off the satellite and return to the sensor. This data was then processed and analysed to calculate the satellite's distance and position relative to the ground station.

Satellite antenna systems comprise omnidirectional antennas, antennas with worldwide coverage, antennas with regional coverage, and antennas capable of generating spot beams. Various types of antennas can be arranged to accomplish distinct functions. Due to the absence of gravity in orbit, the flight attitude of a satellite can be influenced by high-speed moving dust, micrometeoroids, and other satellites in motion. The attitude control system must incorporate both spin stabilisation and three-axis stabilisation. During the working life of the satellite, there is a need to continuously track and measure the orbit and perform orbit correction and maintenance when necessary. In satellite orbit control systems, this task is usually accomplished by launching thrusters. Another task of the attitude and orbit control system is to ensure the attitude of the satellite. For example, a communication satellite requires its antenna always to be pointed at the ground, while an Earth observation satellite requires the window of its observation instrument always to be pointed at the ground. Satellite data are mainly incapable of interpreting the main cause observed with the change in temperature and humidity health status. However, this system can analyse the proper aspects of planned health assessment that are being managed through a user-controlled mechanism [8].

5 Conclusions

This paper presented a satellite mission control system with RF duplex communication, which gives multiple functionalities and health monitoring systems with solar tracking capability. The quantitative approach to trans-receive data from space and passes it to the ground station is used and implemented. Arduino-based prototype uses the nRF24L01 module with an antenna at the ground station to trans-receive satellite data has been developed. Testing and verifications of the developed platform prototype indicated that satellites could monitor key health parameters, including temperature, humidity, and battery charge capacity. The analyses of the results also showed effective communication of satellites with the ground station while providing accurate readings of sensors and performing commands based on orbital movement and adjustment. It also provided initial information that lies in its potential to reshape the landscape of satellite applications, making space exploration and research more accessible.

References

1. N. Alaa, A. El-Zeiny, M. Sowilem, W. Moselhi, M. Elshaier, Acta Geophysica **72**, 3737–3750 (2024).
2. T. Manisha, D. Mukhopadhyay, K. Dabhadker, Int. J. Environ. Clim. Change **14** (4), 174-193 (2024).
3. W. Fu, J. Ma, P. Chen, F. Chen, *Remote Sensing Satellites for Digital Earth.* In: Guo, H., Goodchild, M.F., Annoni, A. (eds) Man. Dig. Earth. (Springer, Singapore, 2020).
4. R. Dorijan, J. Obhođaš, M. Jurišić, M. Gašparović, Land **9** (11), 402 (2020).
5. M. A. Aguilar, M. M. Saldaña, F. J. Aguilar, Int. J. Remote Sens **34** (7), 2583-2606 (2013).
6. H. Guo, G. Liu, Y. Ding, Int. J. Digit. Earth **11** (6), 546-557 (2018).
7. H. Guo, Y. Ding, G. Liu *et al.*, Sci China Earth Sci **57** (8), 1771–1779 (2014).
8. M. Danilo, H. Alvarez, R. Zalakeviciute, D. Macancela, C. Sanchez, S. Bonilla, Remote Sens. Appl. Soc. Environ **31** 100990 (2023).