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Simulation of a POCKETQUBE Nanosatellites Swarm Control System via Linear Quadratic Regulator

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INTRODUCTION & AIM

Developing an advanced simulation to control a swarm of 20 PocketQube nanosatellites using a Linear Quadratic Regulator (LQR) involves several crucial steps that go beyond the initial scheme.

The concept of deploying these nanosatellites in swarms further amplifies their capabilities, enabling distributed sensing, enhanced coverage, and improved mission resilience through redundancy. However, managing the complex dynamics and maintaining precise relative positioning within such a swarm necessitates sophisticated control systems .

A comprehensive approach requires a deep understanding of orbital mechanics and in particular the challenges presented by the nanosatellite platform. The inherent limitations of nanosatellite power, propulsion, and communications systems require careful orbital selection and maneuver planning to achieve mission objectives efficiently and reliably.

Our article focuses on simulating the attitude control of PocketQube nanosatellites in a swarm using the Matlab/Simulink environment.

The simulation aspect of this study is crucial for validating the proposed control strategy in a virtual environment before costly and time-consuming hardware implementation.

METHOD

When performing the work, the following tasks were set:

- Development a mathematical model for the relative coordinates of a nanosatellite swarm;
- Development of a mathematical model of the Linear Quadratic Regulator implementation in the relative navigation;
- Simulation of the attitude control of 20 PocketQube nanosatellites using the Matlab/Simulink environment;
- Illustration of the swarm scenario and attitude control system data.

The initial phase of our work which involves the development of a mathematical model for the relative coordinates of a nanosatellite swarm is crucial for understanding and predicting the dynamic behavior of individual nanosats within the swarm relative to each other and to a central reference point.

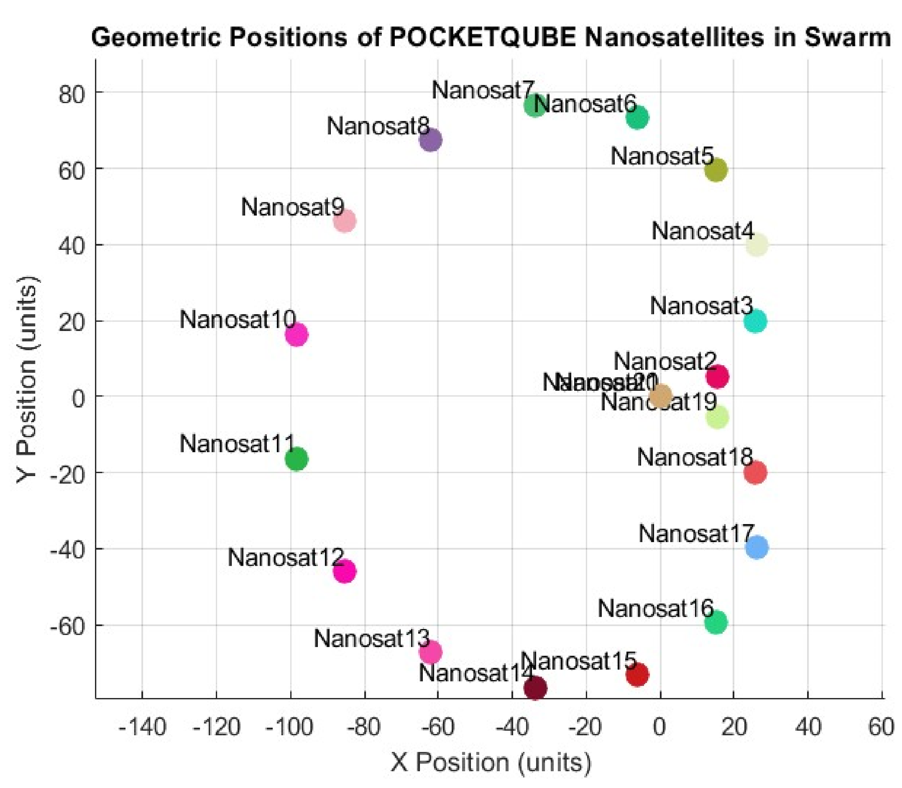
Following the relative coordinate model, the next step is the development of a mathematical model of the Linear Quadratic Regulator implementation in the relative navigation. The LQR is an optimal control method that minimizes a quadratic cost function, which typically includes terms related to the state deviations and control effort.

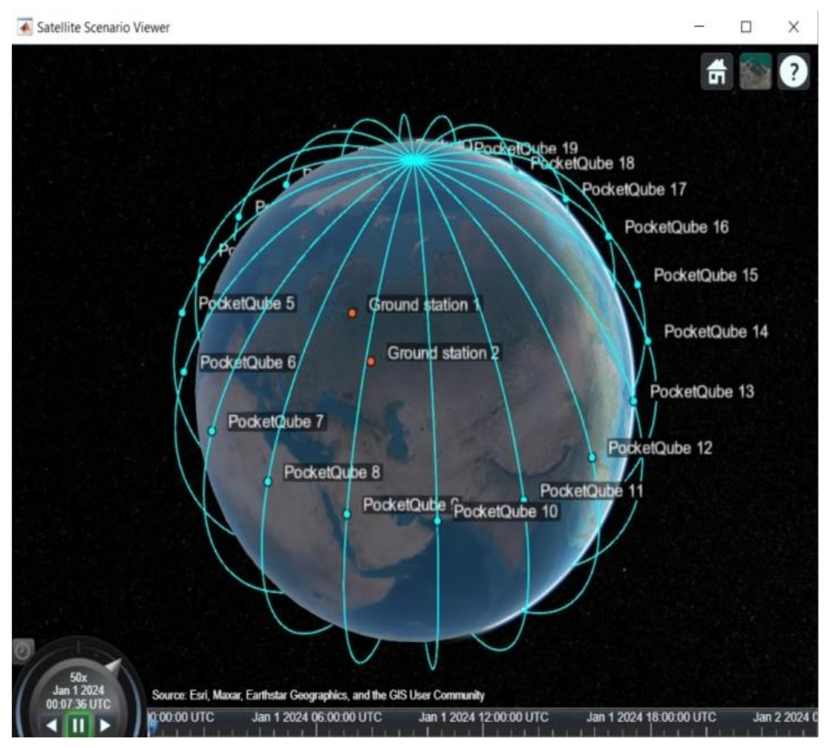
The core of our work involves the simulation of the attitude control of 20 PocketQube nanosatellites using the Matlab/Simulink environment. Matlab/Simulink provides a powerful platform for modeling complex dynamic systems, including spacecraft attitude dynamics and control systems . Each PocketQube nanosatellite, with its specific inertia properties and actuator capabilities.

The final task is the illustration analysis of swarm scenario and attitude control system data. This involves processing and visualizing the simulation results to evaluate the performance of the LQR-based attitude control system for the PocketQube swarm.

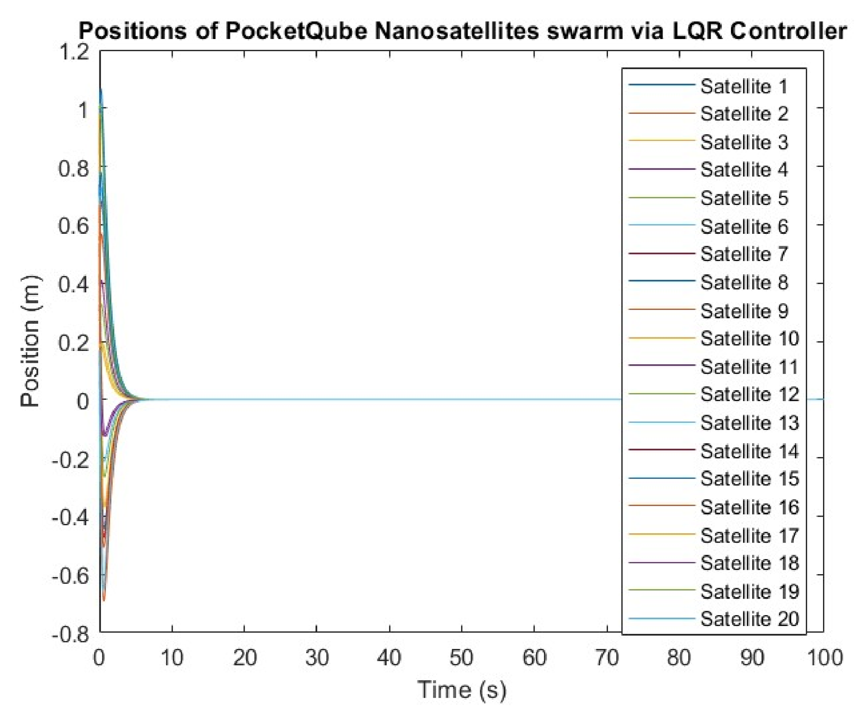
RESULTS & DISCUSSION

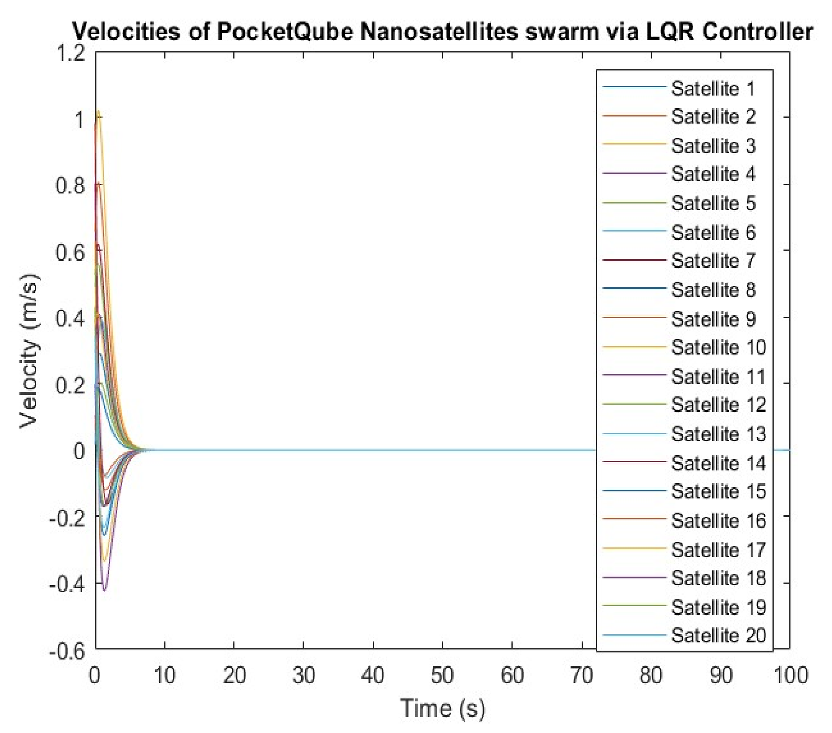
Simulating a swarm of PocketQube nanosatellites necessitates meticulous consideration of inter-nanosatellite spacing to present collisions. A minimum safe distance is paramount for operational success and realistic simulation. In our model, we used 20 nanosatellites. We've established a minimum separation distance of 20 meters between any two nanosatellites. By using two different areas, we could see that there were no collisions between nanosatellites.





Our model must capture the spacecraft's inertial properties as mass, moments of inertia and center of mass because these parameters significantly influence its rotational response to control torques.





CONCLUSION

Our research concludes the development and simulation of a coordinated nanosatellite swarm control system. We developed a mathematical mode describing the relative positions and velocities of the nanosatellites within the swarm which is a crucial step for predicting and managing their interactions.

The attitude control system of the PocketQube nanosatellites swarm has been subjecting to extensive testing using Matlab/Simulink simulations. These simulations, by using Aerospace Blockset for dynamic visualization, provided crucial data demonstrating the stability of the system under various operational conditions.

Visualizations within the simulation environment clearly demonstrated the independent orbital paths of each nanosatellite, critically adhering to minimum safe separation distances. The minimum distance constraint seen as a crucial safety and operational parameter was paramount in the development of a robust relative navigation algorithm. This algorithm enables to others within the constellation. It's essential for autonomous operation and coordinates maneuvers.

Furthermore, simulating the stability of a PocketQube nanosatellites swarm presented a significant challenge. The simulations considered not only the individual nanosatellite's attitude control system, but also the complex interactions between multiple nanosatellites. The simulation video clearly showed the nanosatellites' attitude trajectory, accurately reflecting its predicted movement within the Earth-centered inertial coordinate system.

FUTURE WORK / REFERENCES

Except the challenge about the integration of sophisticated communication protocols, our next work will rely on the simulation of an optical design integrated into a swarm of nanosatellite for space debris detection.