BEST PRACTICE COLLISION AVOIDANCE FOR NANOSATELLITE OPERATORS WITHOUT MANOEUVRING CAPABILITIES

Edvard Foss
Department of Electronic Systems
Norwegian University of Science and Technology
Trondheim, Norway
edvardfo@stud.ntnu.no

Roger Birkeland
Department of Electronic Systems
Norwegian University of Science and Technology
Trondheim, Norway
roger.birkeland@ntnu.no

December 22, 2021

ABSTRACT

An increasing number of satellites are orbiting Earth at over 7 km/s, repeatedly crossing each other's orbital tracks. Performing collision avoidance tasks has become a daily activity for large satellite operators, and the workload is rapidly increasing. Subsequently, nanosatellite operators, typically smaller or less professional operators as universities, are increasingly becoming occupied with collision avoidance tasks. However, most nanosatellite operators do not have the capability to move their satellites. They are often unaware of procedures and required actions to do collision avoidance, and to a great extent, not sure what to do. In this paper, we aim to provide an overview of a suggested best practice for collision avoidance.

Moreover, we aim to show that operators with satellites without manoeuvring capabilities are not just to stand by and do nothing in the event of a conjunction. The suggested best practice for collision avoidance has three main elements: monitoring, assessment, and coordination. We conclude that nanosatellite operators should utilize GNSS data for precise orbit determination, ensure a high level of data-sharing and implement automated processes to monitor, assess and coordinate conjunctions. At last, we propose the use of the *spaceguard.ai NANO* system, which will automatically monitor, assess and coordinate conjunctions. This system will be available for testing in late 2021.

Keywords Nanosatellite · Collision Avoidance · Best Practice

1 Introduction

This section will briefly overview the current and future space environment, and the challenge of being an operator of a nanosatellite in LEO without manoeuvring capabilities will be presented.

1.1 The New Space Environment in LEO

The manageability and safety in Low Earth Orbit (LEO) are about to change due to the current increase of satellite constellations being launched. There is a new space race with commercial actors at the forefront.

Constellations of thousands of satellites are changing the space environment, rapidly increasing the number of spacecraft in orbit. Currently, there are more than 20,000 satellites proposed to be launched in the coming years [7]. For perspective, fewer than 8,100 payloads have been placed in Earth orbit in the entire history of the space age. Only 4,800 satellites remain in orbit today [7], and approximately 3,000 of those are still active [7]. The new constellations will bring great benefits to people on Earth, including global internet access and precise location services. However, this development does not come without cost. The constellations are bringing with them challenges, particularly in keeping a safe and sustainable space environment. The task of creating a safe and sustainable space environment is of global importance. In the following years, it will be necessary to establish Global coordination in space. Additionally, more and more nations are developing space sustainability requirements and rating systems to ensure safety in space, regulation of in-space operations is coming [4]. Until then, the individual operators should do everything in their power to ensure the safety of space by conducting best practice collision avoidance.

Conjunction events, meaning situations that can lead to collisions, will happen multiple times daily in LEO, compared to monthly as today. High-risk conjunction events have been increasing quadratically in the last year [5], and the increase is expected to be even greater in the coming years. More than 50% of conjunction events are between active satellites; the rest involves debris [3].

1.2 A challenge: Nanosatellites Without Maneuvering Capabilities

Due to constraints related to cost, physical size, complexity, or the need associated with a propulsion system, many nanosatellites do not have a propulsion system. Accordingly, these nanosatellites cannot move when a conjunction is estimated to occur. The non-manoeuvrability will be the case for years to come [6]. This lack of propulsion significantly limits the nanosatellite operator's options for taking action before a conjunction event. Until now, nanosatellite operators have mostly been bystanders [1] as the larger satellite operators zigzag their satellites between the nanosatellites. However, as extensively discussed in the literature [4], increased situational awareness, data sharing and communication between operators are three elements that significantly benefit the in-space safety related to satellite operations.

2 Best Practice Collision Avoidance

The operators of the non-manoeuvrable nanosatellites should facilitate situational awareness for operators with manoeuvrable satellites. This paper presents an effective solution for how this best practice can be defined and executed. The best practice collision avoidance for nanosatellite operators without manoeuvring capabilities is here divided into three main elements: *monitoring, assessment, and coordination*. Each element will be discussed individually below.

2.1 Monitoring

In this section, monitoring the space environment and detecting potential conjunctions will be discussed.

2.1.1 Where is the nanosatellite?

There are multiple methods for monitoring the position of the satellite in space. One method is to use measurements from networks, named Space Surveillance Network (SSN). From that data, we can determine the orbital elements and present them as the well-established Two Line Elements (TLE) format. Another method is to use on-board measurements from sensors and/or a Global Navigation Satellite System (GNSS) receiver to determine the orbital parameters. That is a more accurate method than estimating the orbit based only on SSN measurements [4].

2.1.2 Where are the other satellites?

The next step is to figure out where the other satellites are. This can be achieved by using sensor networks or sharing orbital data based on on-board satellite measurements. The latter is preferred due to its higher accuracy [4].

2.1.3 Is the nanosatellite going to collide with someone?

When the orbits of all satellites are known, it is possible to estimate conjunctions based on finding crossing satellite orbits. Many entities continuously perform such task, here called Space Situational Awareness (SSA) supplier(s). These suppliers include the US Air Force (provide the service for free) and commercial companies like LeoLabs (subscription-based service). Nanosatellite operators can continuously check if the SSA suppliers have detected a conjunction involving their satellite(s) and retrieve detailed information about the event. All the information regarding a conjunction event may be put into a so-called Conjunction Data Message (CDM) and shared by the SSA suppliers with the operators involved. CDMs are usually created and shared three times a day before the conjunction.

Summary Since on-board GNSS data has higher accuracy than TLE estimates sourcing from SSNs, all future nanosats should have a GNNS-receiver on-board, and this data should routinely be shared with other operators.

2.2 Assessment

The next element is assessing the potential collision. Based on the retrieved CDMs from the SSA supplier and on-board measurements, the nanosatellite operator should continuously assess collision risk. A system consisting of filters (with specified collision risk thresholds) and forecasting models can be put in place to minimize the manual workload. The workload is minimized by avoiding assessing low to no risk conjunction events. This is a system similar to the Automated Retrieval and Filtering System in [4]. The high-risk event should be closely assessed and followed up.

Summary The operators should specify a collision risk threshold. In [4] a 10^{-4} threshold is established for nanosatellites. The operator should then develop filters and forecasting models to minimize unnecessary workload and continuously assess high-risk conjunctions, using CDMs and the on-board measurements.

2.3 Coordination

Last but not least is the element of coordination. The most important a satellite operator, with no manoeuvring capability, can do, is to communicate detailed information about its nanosatellite to the operators with satellites that can move. This information includes, but is not limited to, satellite geometry, orbit information (preferably based on on-board GNSS), a suggested collision avoidance plan (for a nanosatellite without manoeuvring capability, this would mean that it will stay put), and contact information. GNSS data should be shared continuously amongst operators. The information will ensure that the manoeuvrable operators can conduct collision avoidance manoeuvres with greater confidence and a higher degree of security.

Summary The operators should establish a communication channel with the other satellite operator involved in the conjunction and share information (satellite geometry, lack of manoeuvring capability, 24/7 contact information). Moreover, the operator of the satellite with no manoeuvering capability should continuously share GNSS data and orbit information with the other operator.

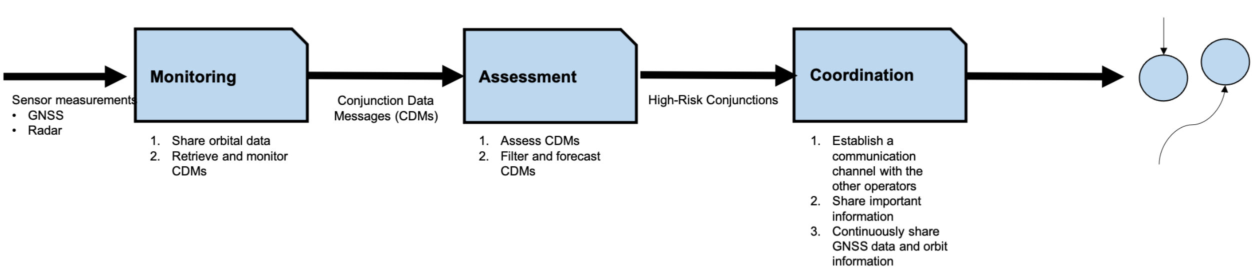

Figure 1: Best Practice Collision Avoidance for Nanosatellite Operators Without Manoeuvering Capabilities Flowchart.

3 Challenges

The best practice elements may seem obvious, but they require three essential parts: a GNSS receiver, operators to handle collision avoidance, recognize the importance of data sharing and acting upon CDMs, and the development of various tools and procedures. GNSS receivers are costly [8], relative to, for example, sun sensors [2]. Sun sensors can be used for "good enough" orbit determination for most nanosatellite missions but are not good enough for precise orbit determination to be used for collision avoidance. Secondly, access to and resources for collision avoidance operators are limited. Lastly, the development of collision avoidance tools and procedures are resource-intensive.

- **GNSS Receivers are Expensive**: Many nanosatellite missions are flying or being developed with the absence of GNSS receivers due to their cost. Less accurate orbit determination systems such as sun sensors are commonly used.
- **Access to and resources for extra operators are limited**: Nanosatellite missions are typically associated with universities and research institutions. Typically, these operators do not have resources for more than the bare minimum setup to conduct satellite operations. Hence, adding a significant increase in workload (15 hours for each high-risk event [4]) to conduct an, often unnecessary, collision avoidance practice is a challenge.
- **Tool and Procedure Development is Resource Intensive**: Developing systems to retrieve/filter/forecast CDMs to monitor and assess a conjunction and communication systems to coordinate are complex and beyond what nanosatellite operators can undertake. The development calls for coordinated efforts and jointly developed systems and/or new actors providing such a system.

4 spaceguard.ai NANO: An Automated and Coordinated Collision Avoidance System for Operators of Nanosatellites in LEO

A potential solution is the proposed spaceguard.ai system [4]. The system will ensure that potential conjunctions are continuously monitored, assessed, and fully coordinated automatically. Sharing of data may be done through machine-to-machine interfaces and Application Programming Interface (API), without the need for human intervention. Summary reports will be provided to the nanosatellite operators through a web-based user interface.

This system will reduce the need for additional operational resources and develop tools and procedures in-house. Moreover, the system also offers an optional module for nanosatellites, including a GNSS receiver and processing power reserved for collision avoidance related tasks. The optional module will be offered at a comparable price as other orbit determination setups, more commonly used by nanosatellites. The early version of the spaceguard.ai NANO system will be available to nanosatellite operators with GNSS receivers on-board in late 2021.

5 Conclusion

In this paper, we propose a three-element best practice for operators of nanosatellites in LEO without manoeuvering capabilities. There are three main challenges with the proposed best practice; the cost of GNSS receivers, access to extra operators to do collision avoidance is limited, and the development of tools and procedures is resource-intensive. A potential solution to these challenges is the spaceguard.ai NANO system, ensuring affordable and efficient collision avoidance for small, non-commercial satellite operators.

References

[1] University of stuttgart webex-meeting march 4, 2021, 2021.

[2] CubeSatShop. Nss cubesat sun sensor, 2021.

[3] ESA. Space debris - the movie (8th european conference on space debris), 2021.

[4] E Foss. Master thesis: An automated and coordinated collision avoidance system for operators of small satellites in low earth orbit. 2021.

[5] E Foss. Ohb systems interview, 2021.

[6] D Krejci. Space propulsion technology for small spacecraft. *IEEE*, 2018.

[7] NASA. Nasa orbital debris quarterly, 2018.

[8] PumkinSpace. Gnss reciever module, 2021.