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Co-funded by the Erasmus+ Programme of the European Union

European Defence Challenge

III EDITION
2022-2023

SECURITY threats identification and defence strategies

PROPOSAL:

ERSI-1

The European Reconnaissance Space-based Infrastructure

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The European Reconnaissance Space-based Infrastructure: ERSI-1

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INTRODUCTION

Satellite systems play a pivotal role in national security and defense. With a multitude of payloads, satellites can be used in reconnaissance, GPS, and early detection of hostile missiles. The problem of conventional satellites is that the launch and development costs are very high, thus being limited to the wealthier countries in the European Union.

In the last decade, the developments in nanotechnology have changed the space industry, by miniaturizing and optimizing satellite components. Although most of the launched nanosatellites have been launched for educational purposes, they have a big potential in defense. Nanosatellites can be launched in swarms called constellations in a single launch and can be positioned in an orbit network, allowing the analysis of vital information.

Our proposed infrastructure, called ERSI-1 is a concept project for a European early threat detection project which proposes the usage of innovative nanosatellite technology.

Framed within the context of previous projects and the necessity of the improvement of defense satellite technology, we will argue that possession of a modern fleet of resilient satellites will allow the EU to efficiently address threats and generally improve its security capabilities.

We will structure this argument within several key areas of analysis, discussing early missile detection, protection of satellites against hostile attacks, socio-economic benefits and general distribution of data in Europe. Thus, our proposal addresses the following questions:

1. How can nanosatellite constellations be used for early missile detection and threat identification?
2. Why might nanosatellites be a better choice for future European Programs?
3. How can intelligence be distributed equally to all European countries?
4. How can we protect our nanosatellites against hostile countermeasures?

To approach this topic, it is also important to consider possible challenges in cooperation, international laws, and socio-environmental aspects.

TECHNOLOGY CONSIDERATIONS

An early missile and threat detection system could improve the European defense capability on all decision-making levels. From tactical decisions on the battlefield to strategy and policy making, the satellite data provided by an early threat analysis system could be critical. To be able to early detect threats to national security, such as missile launches, we propose to equip our nanosatellites with hyperspectral imagers. For better spatial resolution, a Cassegrain telescopic configuration is recommended, due to its high focal length. Since the most important characteristics of such a system are resilience and agility, the data needs to be quickly transferred to a processing facility. For this reason, our proposed satellites would be equipped with laser communication terminals.

For a safer and more reliable satellite constellation, the satellite constellation should be distributed in two separate layers. The so-called “Spotter” satellites will be placed in an Low Earth Orbit (LEO) layer, allowing for the coverage of large areas and early detection of activity that can be categorized as a threat. A second nanosatellite geostationary constellation will be employed to provide real-time tracking and detailed threat analysis over a stationary area. Additionally, to the imaging satellites, relay satellites will be used to support the communication and transmission of data. Relay satellites will be equipped with terminals with more optical ports than the surveillance satellites and will facilitate full coverage in the low earth orbit constellation layer. These will form a network always connected with the ground stations and can be placed both in a GEO and LEO orbit.

The orbit types can be seen in the image below:

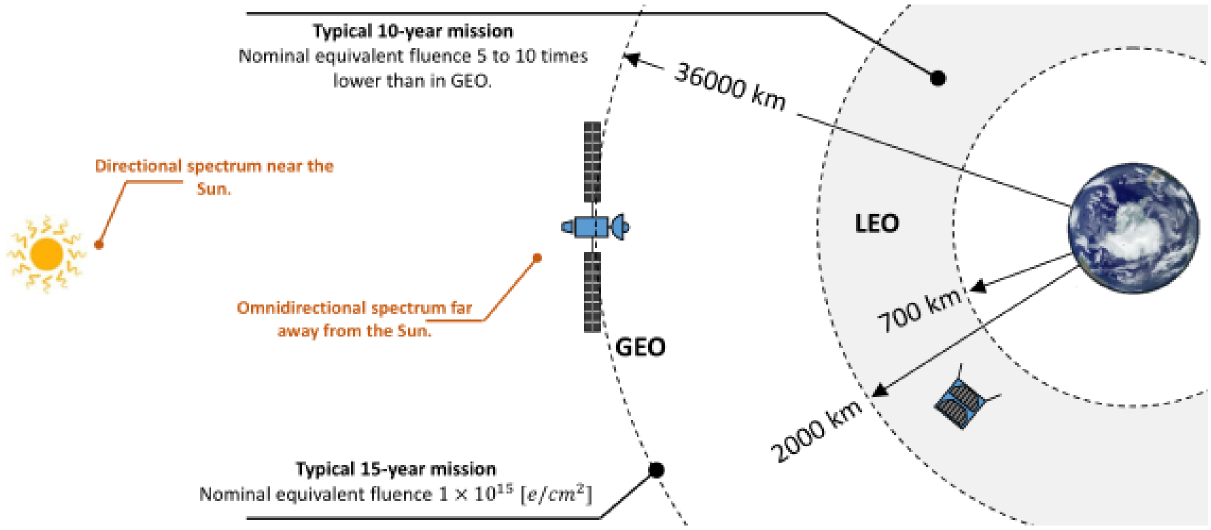

Figure 1: Illustration of the low earth orbit (LEO) and geostationary earth orbit (GEO) Source: [23]

The schematic of the dataflow can be seen in the image below:

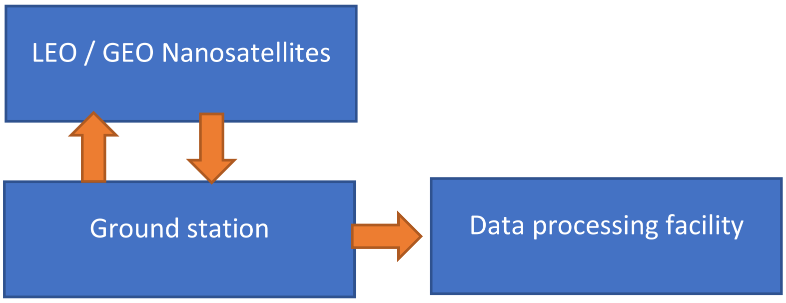

Figure 1: Satellite dataflow

The advantage of nanosatellites over conventional satellites lies in the quick development. The design of the system requires the production of large quantities of satellites. This allows keeping the average cost per satellite low. The more satellites produced; the cheaper production gets. For the development of the mission, the ECSS will need to be followed to allow a smooth collaboration between the project commissioner and contractors. At the same time, ECSS standards offer clear guidelines in quality management, and product assurance.

In case of a first strike attack on European soil, the missile launches should be detected by the hyperspectral nanosatellites in low earth orbit and immediately tracked by the geostationary satellites and other airspace surveillance systems. Using the data received from the satellites, interceptors and air defense systems can be then used to shoot down the hostile missiles.

THREAT ASSESSMENT FOR NANOSATELLITES

When considering any defense project, it is essential to consider possible vulnerabilities and risks of the systems security.
Satellites are increasingly vulnerable to multi-domain threats. There are multiple counterspace capabilities, such as: kinetic physical, non-kinetic physical, electronic, and cyber [1]. If the adversary knows of the existence of the early detection system, it will try to determine the orbit of the satellites through optical and radar detection and disable them. The usage of counterspace weapons on NATO space defense assets can be interpreted as a first sign of an imminent attack on allied soil.

Kinetic counterspace threats are highly unlikely for nanosatellites due to their low dimension and radar cross section. Even in case of a successful hit, the created debris could affect everyone, including the state actor who launched the attack. That might result in serious international diplomatic consequences. Due to low development and launch costs a high number of nanosatellites can be placed in orbit, making the constellation proliferated, meaning that even if a small number of satellites become destroyed, the system remains operational [1]. Also, to increase the mission reliability, both constellations will be disaggregated, ensuring maximum architectural defense. Changing the orbits of satellites in LEO can also provide extra security by making it harder to plan attacks on individual satellites.

The CSIS Think-tank states that conventional satellites are jammed by “emitting noise of the same radio frequency (RF) within the field of view of the satellite’s antennas” [2] This works equally with ground-station antennas. The jamming of satellites is part of hybrid warfare and has occurred recently in the Russia - Ukraine war [3]. Using laser communication, we can avoid being jammed by electronic counterspace weapons. There would, however, be an increased vulnerability to non-kinetic weapons, such as high power lasers. Although unlikely, adversaries could try to blind the laser terminals and sensors, and disrupt the up-link and down-link communication. This poses a high risk, since permanent damage may occur. This vulnerability could be solved by using a safety filter and shutter. The usage of filters and shutters may disrupt the nominal operation of the satellites, but it could prevent irreversible damage.

We assess that the highest threat originates from cyber-attacks that can be initiated not only by state actors, but also criminal organizations. Both the satellites and ground stations are vulnerable to cyber-attacks and require strict preventive measures. Cyberattacks on satellites can be used to monitor data traffic patterns, intercept data, or insert false or corrupted data in a system [4]. A solution to reduce the cyber vulnerability of the infrastructure would be to use Encryption and Air-Gapped systems [1].

Space debris is another important threat to consider because collisions with satellites can lead to critical system failure if multiple satellites are affected. To avoid satellites colliding with debris, orbit control systems need to be included in the satellite design. Moreover, space situational awareness is needed to extensive monitor space debris that could cross the path of a satellite. Sending commands to avoid a collision of any form is an important requirement.

CRITICAL SATELLITE COMPONENTS

1) Hyperspectral camera

For early missile and threat detection, hyperspectral cameras are crucial. Hyperspectral cameras can detect light signals invisible to the human eye and hyperspectral observations can be used to see through clouds and identify patterns that might be considered hostile. The hyperspectral data is captured using spatial scanning. A critical difference to regular camera images is that hyperspectral data is 3-dimensional (x, y, lambda) instead of 2-dimensional (x, y). Thus, it becomes more difficult to analyze and process the data. Also, due to the complexity of the imager and limited dimensions in nanosatellites, the onboard hyperspectral cameras will have a limited spatial resolution.

To track missiles, it is important that the system is able to detect the exhaust plumes. Overall, spectroscopic information can provide critical information for analyzing threats important to national security.

Luckily, the technology for hyperspectral cameras has evolved over the last years, making it possible to mount such complex sensors onboard the payload of nanosatellites. One example of a nanosatellite hyperspectral camera can be seen in the image below:

Figure 2 Nanosatellite hyperspectral camera HyperScout® M (https://satsearch.co)

2) Laser communication

The data-transmission rate achievable with laser communication exceeds radio-wave communication by far. Nasa presents modern satellite radios with a data transmission rate of up to 0,125 gigabytes per second [6]. However, new laser communication terminals, like the ones used in Airbus' Space Data Highway, allow transmission rates of up to 1,8 gigabytes per second [7].

Relay Satellites will need terminals with the capability to transmit multiple laser signals simultaneously. This parameter will play a significant role when designing the constellation, since it partly determines how many relay satellites will be needed.

The architecture of a laser communication port can be seen in the image below:

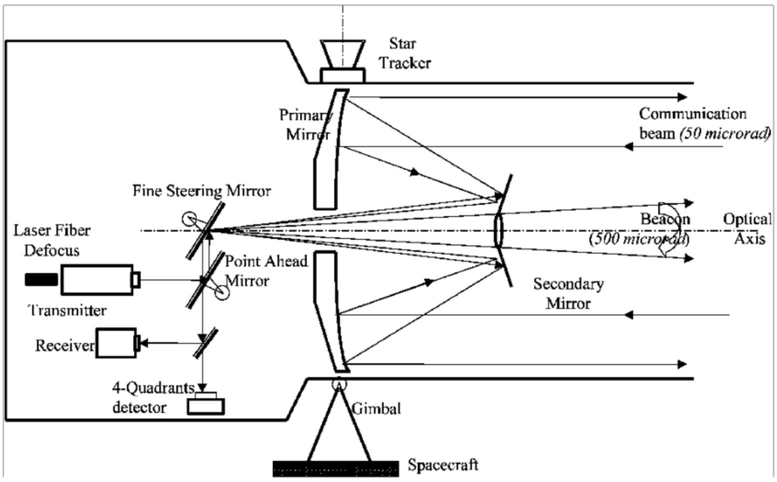

Figure 3: Laser Terminal Structure, Source: [8]

Laser communication makes it increasingly difficult to intercept data that is sent from the satellites to earth. A laser beam has a significantly smaller width than a radio wave does. Mynaric states that a laser beam wave traveling 4000 km has a size of 111 m, while a Ka-Band radio wave has a size of 145000 m [9]. To intercept a laser beam would mean being in its path, which requires a lot of technical effort considering the satellites are in constant movement.

Consequently, laser communication offers the opportunity of protecting data sent more than data sent on radio waves. To make laser communication even faster, it could be considered to not encrypt data sent. This way, computing capabilities on the satellites as well as time could be saved.

3) **Telescopic Cassegrain Configuration**

For the nanosatellites, Cassegrain telescopes can be utilized to improve close-up image quality. Generally, a Cassegrain telescope has a very long focal length compared to its relatively compact size. A longer focal length results in higher magnification of an object. The hyperspectral camera would be mounted to the eyepiece (see image). Using such an optical instrument therefore enhances the ability of the system to get high-close-up images of a small area. The ability to focus the optical instrument in order to get sharp images has to be implemented in the design of the satellite.

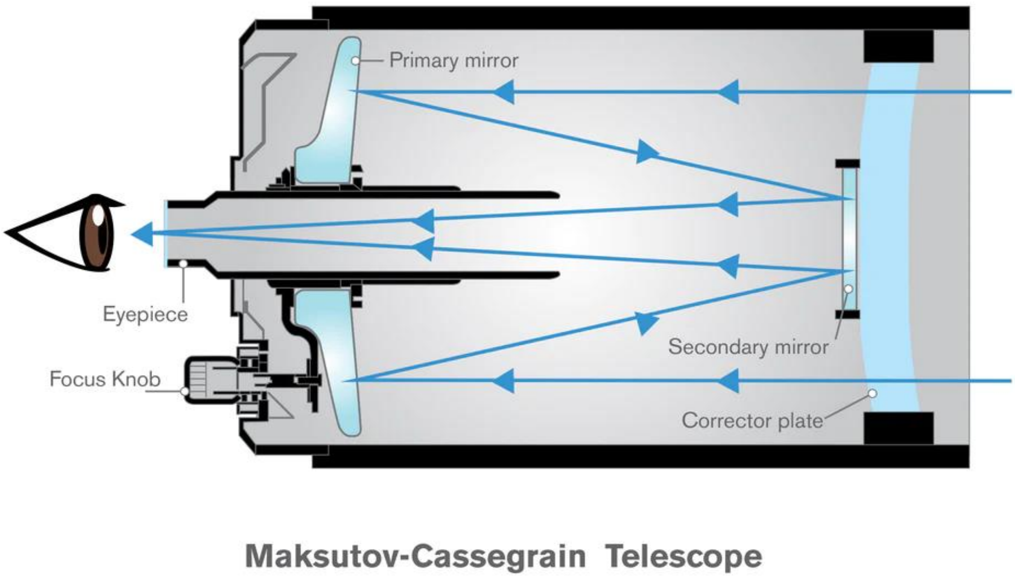

Figure 4: Cross-section of a Cassagrain Telescope Source: [10]

GROUND STATIONS AND DATA PROCESSING FACILITIES

Ground stations are the essential communication link between space and ground. They are facilities that communicate with the satellites through laser technology, their central element being a powerful laser terminal. Placing the ground stations strategically is crucial. If they are compromised by an attack, the system collapses.

Data processing facilities are the brain of the early detection system, analyzing all data and finding the potential threats. Vast computational capabilities will be their central element. Without them, early detection itself would not be feasible. LEO satellites will deliver an enormous flow of data, due to the structure of hyperspectral data and due to their large coverage of earth’s surface. Therefore, the computing power must be sufficient to meet the requirement of analyzing all data.

It can be argued that these ground stations and data processing facilities are more vulnerable to outside attacks than the satellites. Sabotaging the laser communication or the power supply can potentially lead to complete system failure. Protecting the ground facilities is therefore a substantial aspect of the whole system's integrity and security. Countermeasures for any form of sabotage on ground must be considered in the overall planning. The tactical distribution of these centers must be considered as well. Placing them in different areas across Europe, equipping them with their own power supply and spending extra resources on security are some basic proactive measures.

Processing and analyzing such large quantities of data cannot be done without powerful algorithms and ML trained to detect anomalies which trigger further defense mechanisms. The advantage of ML is the superior accuracy it can achieve compared to a human-programmed algorithm.

ORGANIZATION ON A EUROPEAN LEVEL

The successful organization and execution of the project requires an institution on a European level. The institution we propose to lead is the European Satellite Centre, SatCen. This institute is already established in the field of satellite data and provides data for EU countries and organizations. It states that its tasks are “including European Union crisis management missions and operations, by providing products and services resulting from the exploitation of relevant space assets and collateral data, including satellite imagery and aerial imagery, and related services.” [20]. Furthermore, the agency has a democratic structure, since it is working under “supervision of the Political and Security Committee and the operational direction of the High Representative of the Union for Foreign Affairs and Security Policy.” [20].

All requests to use the satellites for a specific purpose should be received and administered by SatCen. One task can be to approve the use of GEO satellites on a specific target, cross-checking a list with forbidden areas.

CHALLENGES ON A EUROPEAN LEVEL

Identifying possible challenges when implementing a joint satellite program is of utter importance. This becomes visible when looking at the European projects TWISTER and HYDEF. Twister is funded by the Council of the European Union and is part of the Permanent Structured Cooperation (PESCO) program while HYDEF is partly funded by the European Defence Fund. TWISTER is focused on the PESCO commitments of the member states. These commitments essentially aim at embedding EU interests in national defense planning of each member state [21]. HYDEF focuses on developing Spain's defense industry by including six spanish companies in the program [22]. They both, however, have an overlapping goal: establishing space capabilities for intercepting hypersonic weapons. Even though they share a common goal, they work independently. This means that vast resources are spent on two projects where it would be reasonable to argue that a single project might be sufficient. The IISS Think tank reports that this could lead to “undermining the EU’s broader defence and security aims” [22]. Channeling resources and efforts instead of focussing on individual industries should be a priority. The same is valid for developing projects with clear and not-overlapping goals.

INTERNATIONAL LAWS RELEVANT FOR SATELLITE MISSIONS

When it comes to launching a satellite or a satellite constellation, it is of critical importance to stay in line with all rules and regularities established.

The Outer Space Treaty provides the “basic framework on international space law” [11]. Its fundamental principle of using space freely sets the stage for space missions like the proposed project.

The registration convention further elaborates on registering space vehicles, such as satellites [12]. This is necessary to identify spacecraft in orbit, especially useful in case of accidents. Registration is also important when it comes to liability. The Liability Convention defines that the launching state is fully liable for its spacecraft [13]. This means the state also compensates for any damage done by the state. In the case of our project, the EU will be liable for the mission as it has been in previous missions, for example Copernicus [14].

SOCIO-ECONOMIC BENEFITS

Looking at the benefits of our proposed project, it becomes clear that it also offers socio-economic advantages.

Firstly, the European space industry could be greatly strengthened. This is important when it comes to competing with other global players in the space industry, especially the US and China. Developing such a large-scale structure will require a lot of investments into diverse companies. Current studies show that there is in fact a lack of investment in Europe's space industry. The European Space Policy Institute expected a "slowdown of investments" for the end of 2022 and more visible slowdown from 2023 onwards [15]. Especially start-ups form the foundation of a modern and capable space industry. To ensure the survival of structurally critical start-ups, public funding is needed [15]. Investments can greatly boost innovations. The European parliament concluded that "Copernicus, Galileo and EGNOS have had positive socio-economic impacts, […], encouraging Europe's SMEs and start-ups to develop and provide innovative services." [16].

Secondly, talented workers with their know-how would have more reasons to stay in the EU and to work here. As mentioned previously, the US space industry offers more and often better paid jobs than the European space industry does. Hence, brain-drain can occur where well educated engineers leave the EU and are (temporarily) lost for the local space industry. However, a large project with sufficient funding is not only a totally new challenge which might interest people, it also offers many opportunities for work. Creating well-paid jobs should be a priority to hold the workforce in Europe.

Figure 5: Space Manufacturing Jobs, Source: [16]

ENVIRONMENTAL IMPACT

Two factors are important when it comes to space as an environment in a broader sense.

Space sustainability is very important to ensure the safety of the future european satellites. Space debris resulting from satellites reaching their end of life and colliding in space is a serious issue. The high number of nanosatellites could produce additional space junk, so it is important to have aerodynamic brake modules to steer the satellites to burn in the earth's atmosphere.

A major problem in space is the number of small particles orbiting earth. ESA estimates there to be 29,000 objects for sizes larger than 10 cm, 670,000 objects for sizes larger than 1 cm, and more than 170 million objects for sizes larger than 1 mm [17]. Since every new launch of satellites can potentially increase the amount of space debris, it is important to minimize the risk of producing any. To do so, satellites in LEO will be steered into the atmosphere after the end of their life. This can be achieved by for instance utilizing aerodynamic brake modules. Due to their smaller size, they will fully burn leaving no space debris behind [18]. Satellites in GEO will be stationed on a so-called graveyard orbit. According to ESA, raising their orbit by 300 km is sufficient to minimize collision risks with other satellites. Even though it requires satellites to leave their orbit 3 months prior to their planned end of life, it is the most efficient precaution to take [17].

The second factor is light pollution by satellites, because it can greatly affect other fields of science, especially astronomy. To preserve the night sky, it shall be kept to a minimum. According to astronomers, larger satellite structures have contributed to unprecedented disturbances in image-observation. The most known examples are the starlink satellites. Ever since its launch and constant expansion of the fleet, now ranging about 3000 satellites, they have been “photo bombing” pictures taken by professional astronomers across the world [19]. Light pollution of satellites is not a thing to be neglected since it severely hinders the important work of astronomers. In its own way, reducing light pollution should be considered sustainable highlighting again that even space should be managed sustainably. In the proposed fleet, the small volume and consequently the smaller reflecting surface-area keep light pollution of the night sky to a minimum. Today, there is unfortunately no technology allowing zero light reflection on the solar panels, but considering the size of the fleet the effect on night-sky pollution will be marginal.

CONCLUSION

Nanosatellites are a resilient solution to an orbital early missile and threat detection system. The technical know-how could help Europe further develop space-based capabilities and help the European space industry. The technology needed to develop the proposed infrastructure has a high technological readiness level (TRL) and could make such a project feasible. For such a project to succeed, appropriate funding and a good collaboration between the industry and the European institutions is essential.

Part of a threat assement, we identified in this proposal multiple potential risks and vulnerabilities of satellite systems and how nanosatellites could be a better alternative to conventional satellites. At the same time, we discussed the socio-economic benefits and the international legal requirements of such a defense infrastructure project.

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Co-funded by the Erasmus+ Programme of the European Union

European Defence Challenge

III EDITION
2022-2023

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