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CONSTELLATION OF CUBESATS TO MONITOR THE ENVIRONMENT FOR THE BENEFIT OF EUROPE

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Abstract: *In our project we are going to present a concept for the creation, launching, usage and exploiting of an innovative system of semi-autonomous, grouped in "swarm" satellites from one type with 24/7 link to Earth-based facilities and stations for control, transfer and analysis of space-gathered data. The innovation in our mission is the usage of a group of apparatuses that can work both like a structured group with one directed goal or like a loosely-chained system of autonomous machines, each with a different task or mission given by the control center on Earth.*

Keywords: space, national security, satellites, disasters

1. Introduction

Large constellations of cameras are surveying every movement of our planet. This from itself is leading to great leap in the EO sector. Surveying the Earth from space are the richest source of intel about the planet with the power to inform decisions and activities across as agriculture, mining, community safety and healthcare, weather forecasting, disaster mitigation and management, climate and water cycle modelling, land use and land cover monitoring, forestry, carbon accounting, cartographing quality of water bodies, coastal habitats, seagrass and coral reefs, mineral mapping, hydrology, cartography and cadastral, Mapping, sea surface temperature, and biodiversity monitoring. Losses through the planet claimed by disasters are expected to increase from US$260 billion in 2015 to US$414 billion by 2030. [1,2]

In the period of 2005 up to 2009, more than half of the human population affected by natural disasters lived in fragile and conflict-affected contexts. Projections indicate that this will continue to increase, with climate-related disaster vulnerability predicted to be felt most acutely in fragile and conflict-affected contexts. Natural disasters are explained by organizations such as the United Nations as: "the consequences of events triggered by natural hazards that overwhelm local response capacity and seriously affect the social and economic development of a region"; they include slow-onset disasters such as drought as well as sudden shock events. [2,3]

Floods are one of the most devastating and costly natural disasters, each year on average affecting over ninety million people around the world and causing over $13 billion in damage, according to the United Nations Office for Disaster Risk Reduction.

Climate change adaptation and disaster risk reduction have been recognized as a priority worldwide, exemplified by global frameworks such as the Paris Agreement [2,4] and the Sendai Framework for Disaster Risk Reduction [5], and European actions like the EU Climate Change Adaptation Strategy and the Floods

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Directive. It has been highlighted that reliable risk assessments are essential to take effective disaster risk reduction and adaptation actions. [5,6,7]
The execution and carrying of our mission will bring the following pros to Europe and its regions. Building disaster resilience is crucial to establishing the goal of exterminating large scale poverty. As one of the main components of disaster risk, given the way it makes and aggravates economic and social vulnerability, poverty has greatly accumulated to the growth in conditions increasing various risks which further limit the progress of sustainable development. Evidence suggests that the impacts of disasters undermine hard-earned development gains in both developing and developed countries, potentially dragging the poor and most vulnerable even deeper into poverty. [2,6,7]
Humanity's welfare is often affected as a result of disasters and other catastrophes. A great danger to public health ais raised by diseases, injuries, psychosocial effects and disabilities linked to hard weather and climate-related dangerous events. Moreover, damages to healthcare compounds not only cost lives, but also disrupt health systems, facilities and services, leaving many without access to health care in times of emergency and longer-term implications through lost preventative care (such as vaccinations and prenatal). [8]
In our project we are going to present a concept for the creation, launching, usage and exploiting of an innovative system of semi-autonomous, grouped in "swarm" satellites from one type with 24/7 link to Earth-based facilities and stations for control, transfer and analysis of space-gathered data. The innovation in our mission is the usage of a group of apparatuses that can work both like a structured group with one directed goal or like a loosely-chained system of autonomous machines, each with a different task or mission given by the control center on Earth. Our goal is to create a space net of satellites that will monitor, gather data and help humankind in fields such as ecological and climate changes, disaster warning and management and analyzing any event in the spheres of habitation (biosphere, hydrosphere, lithosphere etc.) A cluster of 18 satellites will be the ideal solution to solving the above-mentioned problems.
First of all, for the creation of such "cluster" of orbit – based mechanical objects, we need a cheap, simple, yet effective, easy to maintain and sturdy equipment that can both survive the harshness of Space and provide the facilities on land with a steady income of accurate data. [9] Such effective machines can be found in today's modern cube satellites. Their small size (classified as picosatellites by scientist and the scientific community), little cost and type of frame make them ideal for tasks such as data gathering and monitoring of events. [10]
As we know, cube satellites are used by both large space agencies, large companies and small enterprises alike, due to the above mentioned and other positive characteristics, such as their ability to be easily launched and activated in the Cosmos, thus reducing the costs and the possible negative events in launching missions. Also, cube satellites are, in recent times, becoming more and more a replacement to larger satellites used for monitoring of nature events, disasters, changes in the climate, the ecological balance of the planet and etc. Furthermore, this type of satellites offer a frame that gives us the possibility to carry a large set of equipment and instrument needed for collecting information and transferring it back to Earth. [11]
If we want the mission to be a success, finding a launching vehicle, capable of mass-transporting satellites to orbit is a must. The modern era shows us that one of the most important pillars of space launching and space missions at all is

finding or inventing a launch system that is reliable, effective and one that doesn't require much funds for the realization of each spaceflight. The next ESA Mission for example.

If we look deeper into the conundrum we must take a note of problems such as structure of the launch system, the energy source it uses (rocket fuel, energy cell, energy – driven engine etc.), the control and communications instruments and the re – entry systems. For the problem of finding such a spacecraft we give a solution the next ESA mission that will make the costs of launching the "swarm" in space cheaper, while also taking a note of implementing an AI that will help choose the best possible course for space voyage. Being able to avoid near dangerous objects roaming in orbit and in addition choosing the shortest possible route, so we can save time, resources, and above all – limiting the risk of collision with a large space object and the subsequent destruction of the craft carrying the payload.

In the modern day aerospace companies and government agencies are not pursuing a multi-spacecraft network for in-situ measurements in the lower thermosphere because the cost of a network of 50 satellites built to industrial standards would be extremely high and not justifiable in view of the limited orbital lifetime. [12] No atmospheric network mission for in-situ measurements has been carried out in the past or is planned for the future. [12]

A network of satellites for in-situ measurements in the lower thermosphere can only be realised by using very low-cost satellites, and CubeSats are the only realistic option up to the moment.[12] CubeSats are miniature satellites that are commonly used in low Earth orbit for applications such as remote sensing data gathering or communications. Furthermore, data gathered from such space project like our CubeSat constellation will be used for scientific research in educational institutions objective:

The objective of our mission is to launch a constellation of U-2 CubeSats in low Earth orbit (LEO) for the sake of providing constant monitoring of important events and disasters, like floods and earthquakes and changes in ecological balance of the spheres of Earth's habitation. The technology that covers our requirements and suits our mission goals are the CubeSats working in a constellation.In order to complete our mission goal, we put ahead of us the following tasks:

- To establish a land – based control and data collecting and processing facility.
- To design and launch a working and effective group of satellites working in a constellation in low Earth orbit.
- To establish a connection and streaming of intel from the space component of the mission to the land component of the mission and vice – versa.
- To design and execute a launch plan in order to deploy the CubeSats and their scientific payload in low Earth orbit.
- To provide accurate and up-to date high quality information to all users and institutions.

2. Mission

Our project will show the world the possibility of launching a web of U-2 CubeSats in Europe as a primary payload on a low-cost launch apparatus to perform reconnaissance, data gathering for usage in the field of national security and disaster prevention in Europe.

In order to provide an efficient monitoring, our mission needs to meet certain criteria. The cluster of satellites must be deployed in an attitude best suited for the above mentioned activities. Satellites will be deployed in low Earth orbit (between 160 and 2000 kilometers). [13] Most of the satellites are deployed in height of above 300-400 kilometers due to features of the LEO like the atmospheric drag. [13] The main reason for our group to choose this type of Earth orbit is that the majority of satellites used for observation and data gathering from the surface of the planet are currently deployed in the low Earth orbit. Our CubeSats will be at an altitude of 415 km. with an inclination of 51.6 deg. Camera actions in such height provide the best method of monitoring of objects and events. [13] There will be operating in a very cold environment with temperatures falling in ranges of around -150 to +150, so we must use smart systems, new generation state-of-the-art materials and AI for the navigation and the correction and choosing of the most suitable orbit of action. [13]

We choose CubeSats due to the fact that they are superior in both performance and cost for operating.

1. CubeSats are better for usage in formations to gather data from multiple points because they outperform other larger satellites.
2. Very well suited for University-related research.
3. CubeSats have lower production cost in comparison to larger satellites.
4. Launch options are now available for $12,000 to $18,000 for less than-1 kg picosatellite payloads that are approximately the size of a can. [9]
5. They are lightweight, yet sturdy and efficient in terms of materials used.
6. CubeSats are smaller and lighter so they require cheaper launch vehicles and can sometimes be launched in higher numbers.

Table 1 shows standard 1U CubeSast dimensions which can give a raw estimate of the technical parameters of the dimension of which the satellite covers.[9]

Footprint	100 × 100 ± 0.1 mm
Height	227 ± 0.1 mm
Feet	8.5 × 8.5 ± 0.1 mm
Rails	External edges shall be rounded R×1mm or chamfered 45◦×1mm

In Table 2 we show the dimensions of one unit of 2U CubeSat which will be used in a constellation comprising of 18 CubeSat units of the same type. [9]

Footprint	100 × 100 ± 0.1 mm
Height	454 ± 0.1 mm
Feet	8.5 × 8.5 ± 0.1 mm
Rails	External edges shall be rounded R×1mm or chamfered 45◦×1mm

In figure 1 we can clearly see the size in comparison to other CubeSats.

Where the 2U CubeSat figure is circled in red. The advantages of using this platform are that there is enough space for playload without increasing the overall size too much keeping weight down while also reducing cost. Some design changes like smaller electronics leaving more room for additional payloads. The disadvantage of this technology in the long run is that the durability is limited thus showing us that satellites form this type last less than other big size satellites.[14]

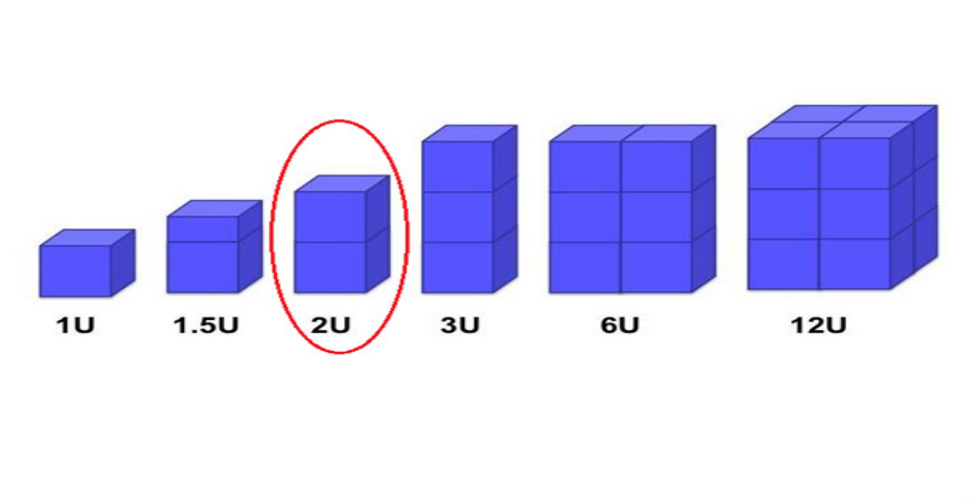

Figure 1: 2U CubeSat in comparison to other satellite versions

3. Delivery

The delivery will be accomplished by the use of delivery method best suited for our needs. The rocket must provide both reliable, safe, cheap and cost-effective transport of satellites into lower Earth orbit. We plan to launch our constellation with an ESA mission in the near future. The 2U CubeSat satellite comprises of various components with the given specification of the QB50 CubeSat which shares many characteristics and traits with the CubeSat we are planning to use.[4] [12]The components of the satellite with their mass, volume/area and power consumed details are shown in the Table 3.

Table 1: Payload mass, volume and power consumption.

S.no.	Card/subsystem	Mass(g)	Volume/area (mm3)	Power consumed (watt)
1	Structure (incl. MLI)	400	100*1	-
2	Solar panel	400	98*98	-
3	UHF/VHF antenna	100	-	-
4	PC4(lono/tomo)	80	80*80	.5
5	Payload(Main)	500	50*10	.5
6	PC2(ADCS)	100	90*90	.25
7	PC1(EPS+Batt)	200	90*90	.2
8	3*Torquer(AWG31,.12	120	80*80	.75
	PC3(SDR)	100	80*80	.4

4. Cluster formation

In order for our mission to function properly, we must arrange our CubeSats not only in a constellation or a cluster, but in an efficient formation too. A very important aspect of land monitoring is to observe every place of the inspected regions on land. Every satellite will have the same scientific instruments to use, making the project more cost – efficient.

5. Space segment

5.1. Payload

By definition we can say that the payload is the main positive cargo that is being carried in space by the CubeSats constellation or by a CubeSat unit alone.

Certain functions of the payload are required to be controlled from the ground in order to be optimize and maintain the service. Likewise certain indicators of performance are required to be monitored on a continual basis from the ground in order to optimize and maintain the service (telemetry). [15]

Fundamental telemetry parameters include:

- Unit off/on status;
- Unit temperatures;
- Transponder channel gain setting status;
- Power amplifier health status parameters
-

5.2. Primary computer

All of our CubeSats will be equipped with a primary computer which will interface with other payloads. Also a small computer will be included in order to prevent overloading the main computer system with data handling, or to ensure payload's operation continues without being interrupted by the spacecraft's other computing needs such as communication. The CubeSats's primary computer will be used for image processing, data analysis, and data compression. Tasks that the main computer typically handles are the delegation of tasks to the other computers, calculations for movement and maneuvers in outer space, scheduling, and activation of active thermal control components. [9] CubeSat computers are highly susceptible to hazardous cosmic rays will take special steps for normal operation in the highly irradiated space, such as the use of the special type of ECC RA. [16]

5.3. CubeSat Camera

Our idea is to use a micro camera because it is perfect for taking images from such high altitude such as the one in low Earth orbit and due to its small size starting from CubeSats. It will be used for monitoring and taking high definition pictures of the Earth. The camera we choose can achieve 600 meters per pixel ground resolution from low Earth orbit, using the basic version of optics (44x34 degree field of view) and sensor (640x480 pixels). [17] The camera if needed can also be equipped with complex multi lens optics for even greater detail and higher quality of the images taken. The camera will be energy effective consuming of about 65 mW with peaks of 240 mW during imaging.[17].

5.4. Avionics and flight control

The next crucial piece of hardware is the one responsible for flight control avionics and attitude control. Hardware installed inside the frame of the spacecraft should include scientific instruments for example flight modules with installed special control software. This type of hardware must be applicable to CubeSat systems of different kind. It must have the following characteristics like a 5V supply unit a 16bit ultra long microcontroller with 50 to 60 kb of flash memory.[18]

A stackable 104 pins connectors, onboard regulator for increased reliability. A system preventing override is also a must and an instrument for monitoring power consumption is critical to the survival of the spacecraft in space. [18]

5.5. Solar panels

For our CubeSat we plan to use a high performance CubeSat compatible solar panels. The panels come in 1-6U size with sun and temperature sensors and other customisations available. [19] Thanks to the very thin and customisable design they will be the best choice for utilization in the field of spacecraft constellations and clusters. The above mentioned panels will have the option to deploy themselves in fixed positions and collect sunlight throughout the day-night cycle.

5.6. CubeSat Power Systems

The main elements of the power system are the energy source and conversion, power regulation and control, energy storage and distribution. [20] The primary energy source for our CubeSat constellation will be the Sun. Solar arrays will be used to convert the solar energy into electrical energy. Furthermore, high efficiency converters will be used for regulation and control. As a secondary energy source rechargeable batteries will be used for energy storage. [20]

5.7. Propulsion

Propulsion for our CubeSat constellation will be achieved by the means of installing a propulsion system in each unit based on warm gas propulsion.

With the corona-based heating system we will increase propellant temperature and corresponding lsp to70s. [21] The power consumption of the warm gas system can be tuned above or below a preset design of around 15 Watts, with total impulse reaching around 600 N-s and fitted to work for a 2U CubeSat by increasing some technological parameters. [21] As a failsafe we will install an additional backup propulsion system based on electric propulsion modules. This will give our CubeSats the ability to sustain normal flight even in the event of a malfunction in the main propulsion system.

5.8. Price and Funding

The cost of our project will depend on the prices of the various components of our mission. The funds we will gather will be from different government funding programs and from funds offered from different European or worldwide space programs. Thus we will acquire all money and resources needed for executing our space project, involving launching a cluster of satellites around our planet.

CubeSat Constellation Formation and Working Regime Schedule

In Figure 2 we show graphically the CubeSat formation layout and a basic scheme of the principle of working of the constellation. The cluster of 18 satellites is divided into three main groups, with two sub-groups each consisting of three same – type units. While one of the main groups is gathering information, the other two are recharging its power supply and restoring their capabilities to operate in the LEO and collect data. Another main component of the satellite formation is that every sub – group of three satellites will be able to do the tasks given to it even if one of the satellites suffer a malfunction and goes out of order or is destroyed by an object or an event as presented in figure 2:

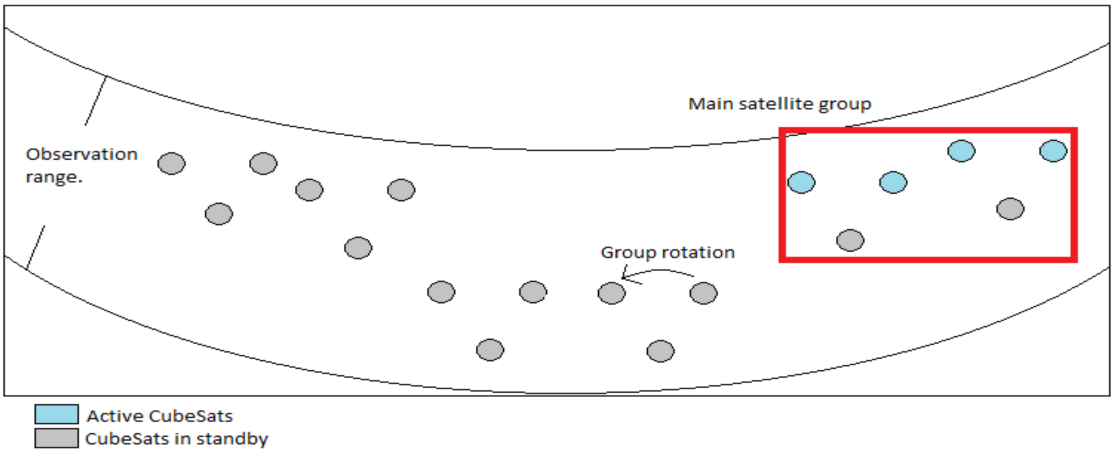

Figure 2: Cluster formation in LEO

6. Ground segment of the mission

Important aspect of the space program is the Earth – based element – the data and communication centers. As well as the challenging task of building and launching a satellite, the success of an Earth observation mission relies on being able to operate the satellite from the ground and ensure that the data gathered are of good quality and made readily available to users. [22]

There will be one main center that will use radio waves on different frequencies to enable communication between land and all the CubeSats. For our project we consider using (FSS)Fixed Satellite Services where signals transmit to and from a limited number of fixed locations on the ground while still expanding to include some BSS applications. [23] Because of the fact that there will be a lot of interference from neighboring satellite communication quality may degrade. In order to avoid such problems we must properly coordinate RF frequencies and power levels for operation in our chosen orbit. We choose to use recommended frequencies approved by the International Telecommunications Unit (ITU).For data transfer we will use multiple channels that will carry many signals each with a reduced bandwidth. Due to bandwidth limitations we will employ frequency reuse schemes to maximize the system capacity.

- Users of this type of structures can include:
- Government agencies
- Non-government organisations
- Providers of services
- Enterprises (corporations, firms, etc.)

The user organization generally needs a big land-based compound to serve as its central staging and coordination point and to give wide access to different network types, such as the Internet, corporate WAN, or the Public Switched Telephone Network (PSTN). [24]

This is a make-vs-buy decision, because the user has the option to use a public facility called a teleport, which is operated by a service provider.

A teleport is a telecommunications business that provides services to local users. [25]

Today, the most important features of the ground segment, like the usage and exploitation of control centers are:

- real-time data acquisition - when the satellite is visible from a ground station; [26]
- acquisition of LBR data from the on-board tape recorder; [26]
- data processing and generation of fast delivery products. [26]

The center of our mission will be situated in the Vasil Levski National Military University, Faculty “Combined Arms” in the city of Veliko Tarnovo. Main components of the site will include a facility to incorporate a relay antenna that will both transmit and receive data and information from Space to land and vice – versa, a site where all the hardware with the installed specialized software will be kept and connected to the main control elements. This ground station will serve as the main hub from which data will be transferred to other institutions and structures, like different ministries, agencies, other universities or educational centers, international monitoring facilities etc. A focus on our project is the creation of a system that will allow also interoperability and receiving data from other land-based hubs and centres, so that monitoring of events and objects will be more efficient. Data received from such Earth-based facilities will include statistics, other satellites or satellite constellations images, data, telemetry and charts that will show any kind of change.

7. Conclusion

The presented project is an academic achievement, as it gives a working model for the manning of CubeSats on behalf of science, security, industry and the human society as a whole.
The idea's originality is unveiled in a mission, consisting of the creation of a 18-unit CubeSat cluster working in sophisticated order and managing different scientific tasks.
Presentation of the idea is in the form of a scientific report, including scientific specifications and explanations of every part and aspect of the space mission.
This type of report gives a stable model for development and synchronization between different elements of projects of such kind.
The goals itself shows that prevention has a huge role in containing extreme situations and that funds spent for prevention are much less than the funds spent for recuperating from any kind of disaster of negative event.

References

[1] https://www.unisdr.org/we/inform/publications/46052
[2] Vousdoukas, M. I., Mentaschi, L., Voukouvalas, E., Verlaan, M. and Feyen, L., *Extreme sea levels on the rise along Europe's coasts. Earth's Future*. Vol. 5, Issue 3, pp. 304–323, 2017
[3] http://reliefweb.int/sites/reliefweb.int/files/resources/ClimateChange_DisastersFragilityConflict_EN_2015.pdf
[4] http://unfccc.int/2860.php.
[5] https://www.unisdr.org/
[6] Mechler, R., L. M. Bouwer, J. Linnerooth-Bayer, S. Hochrainer-Stigler, J. C. J. H. Aerts, S. Surminski, and K. Williges, *Managing unnatural disaster risk from climate extremes*, Nat. Clim. Change, No. 4, pp. 235–237, 2014
[7] Gall, K. H. Nguyen, and S. L. Cutter, *Integrated research on disaster risk: Is it really integrated?* International Journal of Disaster Risk Reduction 12, pp. 255-267, 2015
[8] http://www.unisdr.org/files/46052_disasterriskreductioninthe2030agend.pdf
[9] https://www.nasa.gov/content/what-are-smallsats-and-cubesats
[10] Piotr Wolański, *"Space-related activities at the Warsaw University of Technology and Institute of Aviation",* Warsaw University of Technology, Retrieved 2008
[11] http://www.pe0sat.vgnet.nl/2016/esa-cubesat-competition-winners/
[12] https://www.qb50.eu/index.php/project-description-obj
[13] www.spaceacademy.net.au
[14] https://www.nasa.gov/content/what-are-smallsats-and-cubesats

[15] https://www.slideshare.net/DedeSomantri2/geostationary-satellite-communications-systems
[16] https://www.nasa.gov/directorates/heo/home/CubeSats_initiative/
[17] http://www.aticourses.com/blog/index.php/2015/07/08/cubesats-explained-and-why-you-should-build-one/
[18] https://www.diva-portal.org/smash/get/diva2:829190/FULLTEXT01.pdf
[19] https://www.cubesatshop.com/product/single-cubesat-solar-panels/
[20] http://www.cubesatkit.com/docs/press/20120420_Pumpkin_CSDWSLO_2012-2.pdf
[21] http://www.busek.com/cubesatprop__main.htm
[22] http://www.eutelsat.com/en/support/earth-stations/eess.html
[23] http://search.itu.int
[24] http://www.huffingtonpost.com/bruce-kushnick/public-switched-telephone-networks_b_2377773.html
[25] http://www.jsati.com/why-satellite-how-GroundSegment5.asp
[26] https://earth.esa.int/ers/eeo/eeo3.324.html