Space Tech SEI

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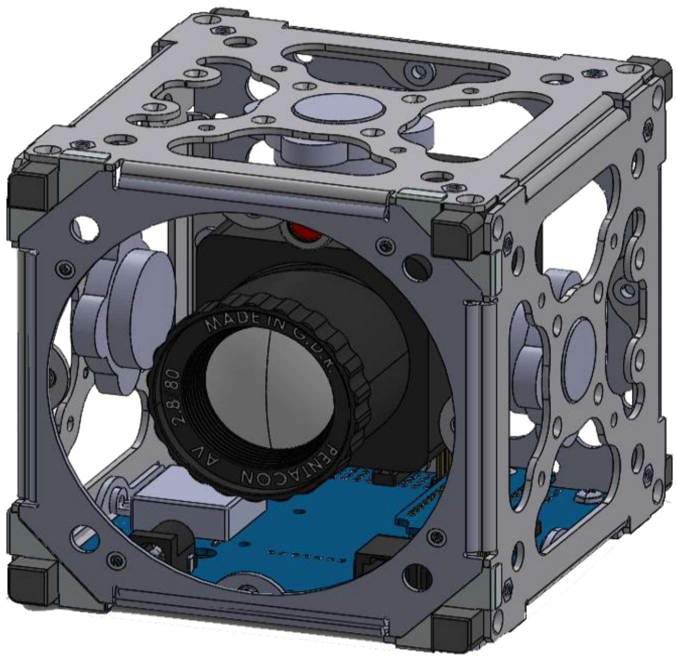
Executive summary

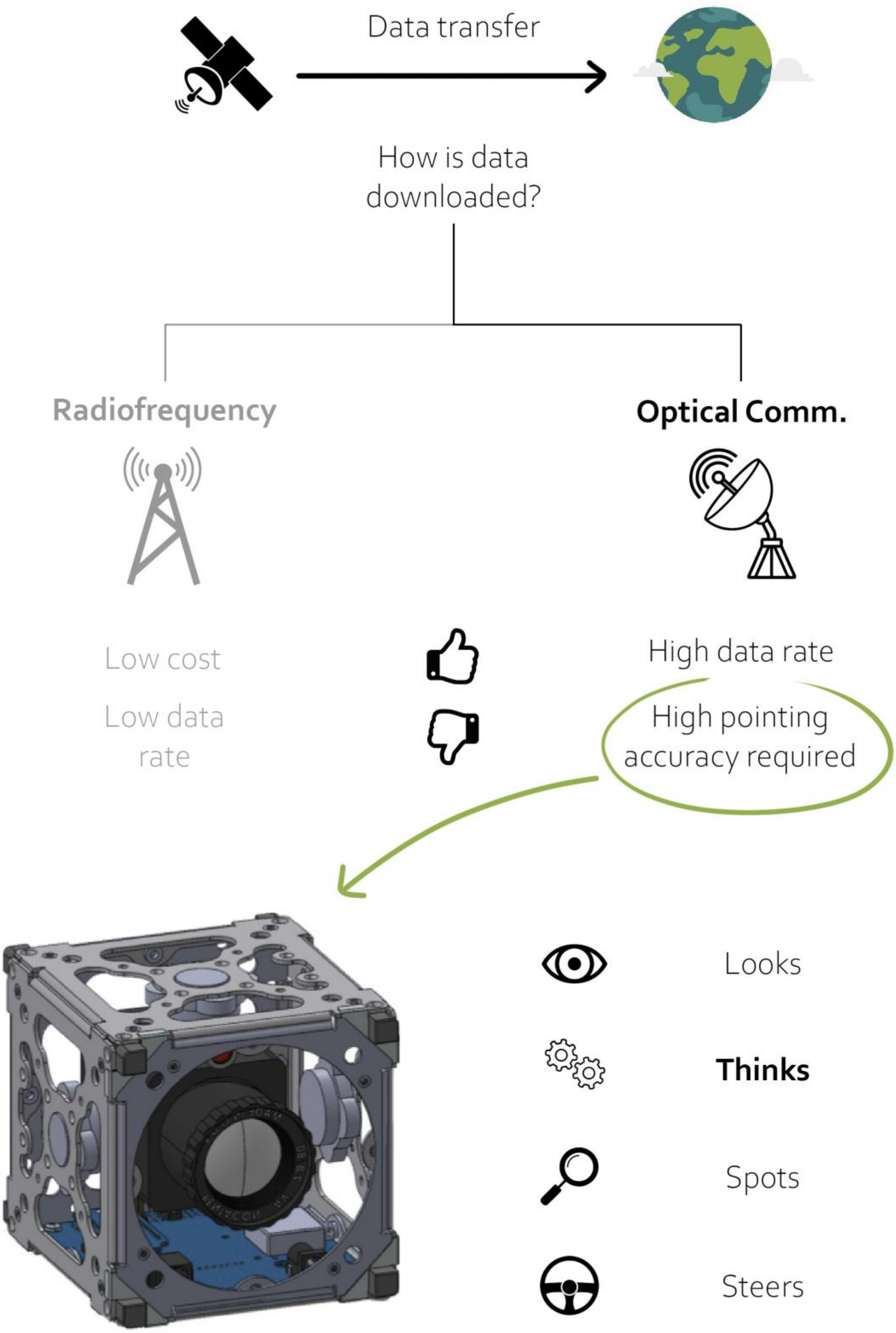
Since humanity has been able to make satellites orbit around the planet Earth, everyone's life changed: not only due to GPS and wireless communication development; a deeper knowledge of our planet has been reached as well, and this helps in many ways, such as climate change monitoring. As a proof of the importance of the information we gather from Space, the amount of data that is collected by satellites around the Earth has been impressively increasing during the past few years; however, a Space to Earth communication system capable of quickly and efficiently transmitting this data is still missing. Our team identified in Optical Communication the technology candidate to do it. One major challenge when dealing with Optical Communication, however, is the required pointing accuracy of the system: it must point at the ground station with a sensibly higher accuracy with respect to the one required by state-of-the-art communication systems, i.e. Radio Frequency (RF). For this reason, we developed Ronza, an innovative Optical Communication-based system that is able to autonomously locate and point with the required accuracy the target ground station through the use of machine learning algorithms. Our team performed a proof-of-concept in December 2019 where an artificial intelligence-based version of the algorithm was successfully tested, while we worked on the development of the machine learning-based algorithm in the first part of 2020. The objective of this test was to show that the prototype was able to recognize and point to the target ground station while a picture of the area where the ground station is was shown to the camera. All the tests that were performed were successful, testifying the validity of the solution we are proposing.

Key Words

Optical Communication, CubeSats, New Space Economy, Machine Learning, Artificial Intelligence



CAD representation of Ronza.


Data transfer
How is data downloaded?
Radiofrequency
Optical Comm.
Low cost
Low data rate
High data rate
High pointing accuracy required
Looks
Thinks
Spots
Steers

Project description written by the Principal Academic Tutor

In the context of the New Space Economy, gathering data from space to make it valuable on the Earth has assumed an increasing importance. Moreover, the CubeSats technology is gaining attention from all the major public and private companies in the sector: the Hera Mission of the European Space Agency is just one of many examples. It is likely that private companies will invest more and more money on CubeSats mission, because they are cheap, easy to develop and simple to operate. Therefore, particular attention must be given to these small satellites. In addition, spacecrafts are producing more and more data since the sensors are becoming more efficient even for small and nano satellites. In the light of these considerations, the team has investigated deeply the state-of-the-art technology regarding satellite communication systems, and, thanks to the different backgrounds of the team members, they found that a possible disruptive innovation can happen if CubeSats could use optical communication. Consequently, they developed an innovative attitude sensor to increase the pointing accuracy when communicating via optical links, because they understood that is the key factor to achieve an high data rate and data volume. Thanks to different skills inside the team, they were able to design a functioning prototype to demonstrate that an artificial intelligence algorithm is able to recognize the ground station receiver position from an orbital altitude and point the satellite to the desired position.

Team description by skill

Our team is composed of four Space Engineering students, one Aeronautical Engineering student, one Computer Engineering student and one Engineering Physics student.

Being our project a technical one, the presence of a significant number of components with many hard skills has been of paramount importance. The major technical skills our team had available are:

- **Expertise in the Aerospace sector**: Andrea Forestieri, Andrea Carlo Morelli, Fabio Ferrari, Riccardo Masiero, Tommaso Tassi.
- **Expertise in optics and optical systems**: Stefano Palladino.
- **Expertise in programming and Machine Learning**: Alessandro Rosso.

Nevertheless, our team needed also a considerable amount of soft skills: as we applied for different calls, including the Telespazio Space Contest, and we presented our product during the proof-of-concept event held in December 2019 (where by the way we were elected as the winning team), we were also required to have capabilities of oral presentation, creativity, time managing and fluency in spoken English.

Goal

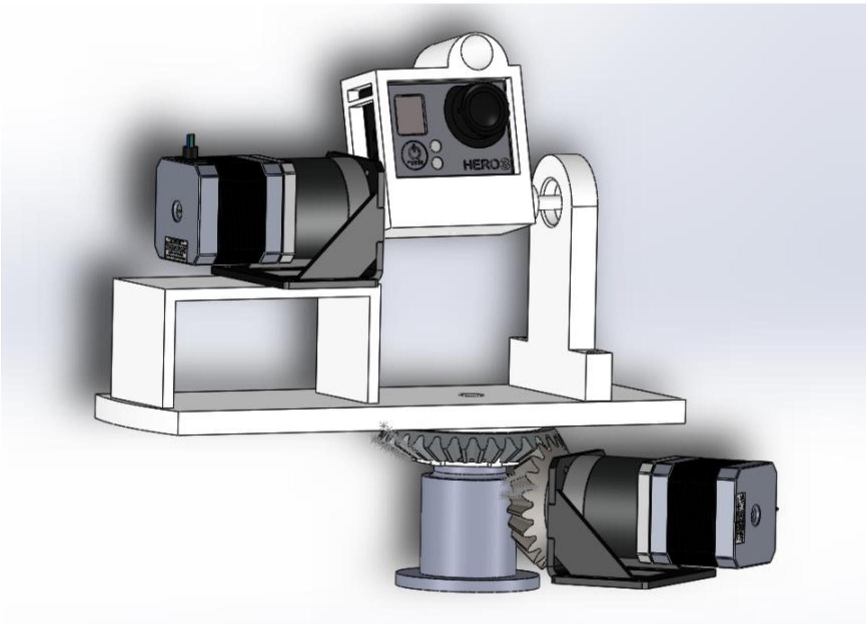
During the last decades, the amount of data produced onboard commercial and scientific spacecrafts increased due to the higher performances of cameras and sensors. However, the actual telecommunication systems, used for satellites communication, exploit the old Radio Frequency (RF) technology, which has a data rate, i.e. the amount of data transmitted in the unit, in the order of kbps (kilobits per second). The volume of data transmitted from space to ground is the product between the data rate and the communication time window. Therefore, both a new communication technology and a higher number of ground infrastructures are needed to increase the amount of data transmitted. Our goal was the development of an advanced communication solution for micro/nanosatellites and/or between micro/nanosatellites and ground stations. This challenge reflects the needs of the space community, that want to increase the amount of data downloaded from space to enable new innovative services.

Understanding the problem

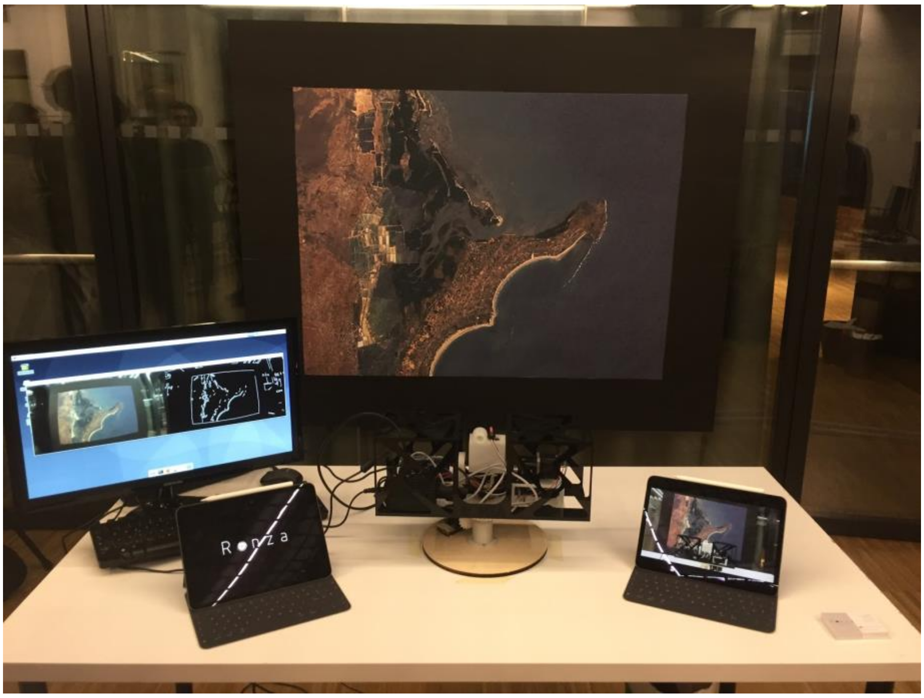
In this decade we are realizing that the human activity is changing dramatically the equilibria in our ecosystem. “From space we can clearly see only one fundamental boarder in our world: our atmosphere”, said astronaut Paolo Nespoli during one of his press conferences at the end of his last mission on the International Space Station. The space community realized that understanding the behaviour of our planet is as important as discovering new planets and asteroids in our solar system. Therefore, this strong vision induced the scientific community to design new innovative missions to study the changing in oceans, glaciers, forests, rivers, and many other natural environments. This process induced engineers to push beyond the limits of technology and to develop cheaper and more accessible space missions. Launchers manufacturers increased the efficiency and lowered the cost per launch.

In 2015, SpaceX landed for the first time in history a first stage of an orbital launcher that usually is dropped in the ocean. Moreover, the entering in the market of private actors, stimulated by public fundings, increased the competitiveness reducing the access cost of space technologies to other industries. The average launch cost for a Low Earth Orbit mission in 2000 was 18.5 k$/kg that now is reduced by a factor of 7 to 2.6 k$/kg. Furthermore, the miniaturization phenomenon is happening also in satellites’ manufacturing. The majority of launched spacecrafts in 2020 are in the nanosat’s category, i.e. their wet mass is below 50 kg. They are designed using the Cube-Sat standard, a modular approach where the spacecraft is composed by cubes with a volume of 1 dm^3 and a mass of 1.3 kg.

This trend is caused by the increased performances of electronic components that are able to acquire a large amount of data with low power needed. As an example, the satellites of the Copernicus program produce 12 Terabytes of data every day, that could be used from every European citizen to get valuable information. As a result, a new economy arises based on the usage of space-borne data. In the New Space economy many innovative start-ups base their business models on space data mining to help energy, agriculture, and maritime industries to monitor and predict with higher accuracy their infrastructures. However, this massive amount of data that is produced inside the spacecraft’s payloads needs to be transmitted to Earth’s data repositories. This is the biggest bottle neck in the space industry nowadays.



3D CAD representation of the prototype.

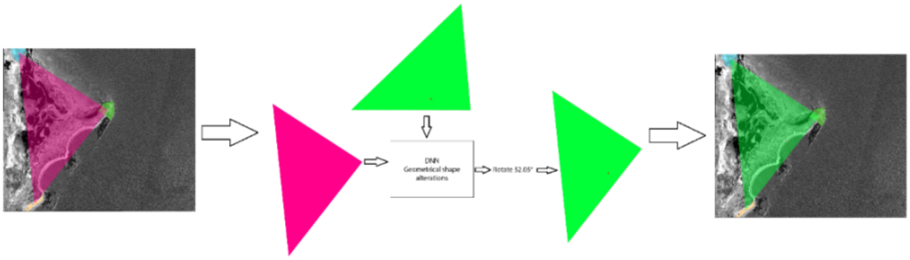


Prototype testing at the Product Demo Day in Torino.

Exploring the opportunities

The primary function that our solution has to satisfy is to transmit data from a nano-satellite to ground using an optical communication link. We focused on this technology because optical communication has an higher data rate with respect to the old radio frequency one. However, this technology opens to new functionalities. In fact, it requires a very high pointing accuracy to decrease the communication errors and achieve the highest data rate. Therefore, the functions needed to guarantee a precise pointing are:

- Turn the satellite towards the Earth surface
- Identify the ground station
- Steer the beam toward the ground station
- Stabilize the attitude to maintain a continuous contact



Artificial Intelligence algorithm.

Generating a solution

Ronza, our prototype, works in a very simple way and it has four main functions. It looks at ground, it is able to think and spot the ground station and it steers the satellite towards the desired position. The idea is that by taking a lot of pictures of the ground at every second, through a pre-trained neural network our product knows exactly where the ground station is almost continuously. It has a built-in pointing software that receives this information as an input and controls the satellite. The pictures come from a high-resolution commercially available camera. It is then processed by the first neural network that is capable of detecting big features of the ground. The detected objects are then used as vertices of a 2D geometrical shape. A similar one is stored inside an internal database and it is used as a reference, since the displacement of the ground station with respect to the center of the shape is known.

Now it is just needed to understand how the two shapes differ. That's the job for the second neural network, a 3D pose estimator, that outputs the alterations in the 3D space needed to apply to the reference shape to make the two equals. Finally, knowing this last information and the center of the computed shape, it is possible to output the correct position of the target, even if it is not directly visible. In order to steer the satellite, on-board attitude control devices are used.

As for the communication system, there is a modulator which electronically control the seed laser with a pulse position modulation format; then the beam is amplified by an optical amplifier, which is an erbium doped amplifier and finally goes in a collimator, which is a Cassegrain telescope which transmit a beam with a diameter in the order of 1 cm.

Our pointing system is based on the machine learning algorithm which figures out the position of the ground station by recognizing the main features of the Earth surface. Therefore, our solution is cheaper than other state of the art solutions but allows it to achieve the same performance in terms of pointing accuracy. The receiver is simply a telescope with a diameter of about 30 – 40 cm which collects the light beam and sends it to a detector.

Main bibliographic references

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