New model simplifies orbital radar trade-off studies for environmental monitoring

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Skoltech researchers Alessandro Golkar and Ksenia Osipova, and former Massachusetts Institute of Technology (MIT) student Giuseppe Cataldo (now working at NASA's Goddard Space Flight Center) have developed, within the framework of a Skoltech-MIT collaboration, a model to help engineers create and select the most promising conceptual designs of satellite radar systems. By optimizing the design of these rapidly evolving instruments, the model promotes their faster and more cost-efficient introduction, leading to better maps and storm, flood, and landslide monitoring. The study came out in *Acta Astronautica*.

Satellite imaging of the Earth is used to monitor agricultural land use, ocean ice cover, coastal change, and hostile weather events. These observations are made in different bands of the electromagnetic spectrum, including radio waves. Unlike optical or infrared imagers, radars observe targets independently of their illumination, bypass clouds, and generally operate well in any weather.

However, in order to provide the same resolution as a shorter-wavelength instrument, the radar has to be physically larger, making it hard to fit on a satellite. One way around this is using synthetic aperture radars. SARS achieve high resolution by artificially increasing their aperture, or antenna "size." Mounted on a satellite, a SAR emits a radar pulse and travels a certain distance before the pulse returns and is picked up at a different location. The distance traveled then factors into the virtual size of the antenna, as if it were much larger, which translates into better image quality with a comparatively small antenna.

Despite this aperture inflation trick, SARS have been historically flown on large and expensive satellites, because radars were still fairly bulky and consumed a lot of power. This has been changing with the advent of smaller and lighter SARS. These are in the early stages of development but are evolving fast, already taking over such tasks as oil spill detection and surveillance.

As the number of ever smaller satellites in orbit is growing, SAR engineers wonder which of them are feasible carriers for the miniaturizing radars. This is particularly relevant as recent research suggests dozens of so-called micro- or nanosatellite-based SARS working together could vastly outperform conventional large SAR missions, if cost-efficiency is factored into the equation.

With the range of options extended, it is becoming increasingly challenging to balance radar performance characteristics against other parameters of a SAR launch mission. Some of the variables involved are the available orbits, radar and satellite models—with their physical dimensions and a host of characteristics, such as data rate and power consumption. This complexity calls for a computational approach to support the design of future SAR-based Earth observation missions.

To address this, a recent Skoltech-led study presents a mathematical model for creating optimal SAR conceptual designs. The model optimizes SAR characteristics with a method called trade space exploration. This term, which is a combination of "trade-off" and "playspace," implies that the model will help early-stage designers analyze the numerous trade-offs involved in the process, rapidly evaluating many design alternatives and identifying optimal solutions to pursue.

The paper demonstrates the utility of the model by looking at radar instruments on a broad range of small satellite platforms: 1,265 feasible radar designs are narrowed down to less than 44 optimal ones for different radio frequencies. The researchers conclude that small satellites are a feasible platform for the higher-frequency 8-12 GHz and 4-8 GHz radars, but not for the 1-2 GHz band. Conditions for making the latter type of SARS feasible are discussed, along with the feasibility bounds and technical constraints on the associated instrument and spacecraft requirements. Pulse repetition frequency emerges as the main limiting constraint on the SAR trade space. In other words, this characteristic is the most powerful factor—ahead of power consumption, antenna size, data rate, etc.—for narrowing down radar configurations to a limited set of feasible designs.

In a separate analysis, the team considers radars for the very small 3U CubeSat platform, identifying 44 optimal designs among about 13,000 feasible candidates. The study explores the operational constraints required for the development of such innovative miniaturized radars. The authors conclude that SARS for CubeSats are feasible from an instrument-level perspective and propose that their designs be now considered at the mission level—together with the implications for spacecraft design.

The model presented in the study applies to radar systems mounted on a single satellite. It could, however, be extended in the future to account for ways of combining SAR satellites into constellations.

More information: Alessandro Golkar et al, Small satellite synthetic aperture radar (SAR) design: A trade space exploration model, *Acta Astronautica* (2021). DOI: 10.1016/j.actaastro.2021.07.009

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