In-depth field insight

Drone-based radar facilitates crop monitoring, soil analysis, and the identification of underground mineral deposits, anthills, and bones

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To capture a broad view of the terrain, radar equipment is positioned on the underside of the drone

In agriculture, drones are used to distribute seeds or fertilizers with precision, saving both time and money. When combined with sensors and artificial intelligence, they can be used to perform remote sensing, similar to satellites and airplanes, monitor large crops, conduct detailed analyses of soil chemical elements, and identify issues such as erosion. One of the most advanced techniques in this field, synthetic aperture radar (SAR) was enhanced by Radaz, a startup founded in 2017 at the University of Campinas (UNICAMP) that is now based in São José dos Campos, São Paulo.

"It's an innovative technology with enormous potential to generate a wide variety of products, serving various market segments," says electrical engineer Hugo Enrique Hernández Figueroa from UNICAMP's School of Electrical and Computer Engineering (FEEC), who led the team responsible for developing radar equipment for mounting on a small drone. To achieve this, the team had to miniaturize the radar's electronic hardware and antennas. The idea behind SAR involves using a moving radar to simulate an antenna significantly larger than the physical components of the radar. As the antenna's directivity increases with its size, the system's resolution also improves.

Through its antenna, the radar emits pulsed electromagnetic waves that are reflected by obstacles on the ground. The waves are then detected by the antenna while the radar is in motion, whether on an airplane, satellite, or drone. The movement of the radar along its trajectory creates a large virtual antenna, allowing for high resolution and precise observations.

The operating principle of SAR is similar to that of interferometry, where the combination of multiple radio antennas simulates a single large antenna corresponding to the path traveled. If the drone moves 100 meters (m) in a straight line, the SAR can simulate a 100-meter aperture antenna; if the trajectory is circular, with a radius of 300 meters, the radar will simulate a spiral-shaped antenna with a 300-meter radius.

Developed in the United States in the 1950s and used in satellites and space probes since the 1960s, SAR has been employed to map the terrain of Venus, which is obscured by clouds made of microscopic drops of sulfuric acid and other aerosols. In the early 2000s, SAR was integrated into large drones for military purposes. With the growing miniaturization of electronic components and the proliferation of drones, it has become apparent that SAR systems can be attached to small, civilian devices.

"The challenge was to do it, and nobody was doing it," says Figueroa. The first recorded instance of SAR on a drone dates to 2016, at the University of Texas, United States, but this version was handmade and produced low-quality images. The São Paulo-based company took a different approach, developing a system with three spectral bands, including an advanced inertial navigation system (*see infographic*).

Working with his team, the UNICAMP researcher focused on reducing the size of a 100-kilogram (kg) device, only usable with airplanes, to one weighing 5 kg that could fit on small drones. Electronic engineer Laila Moreira, technical director of Radaz and a key contributor to the device's development at UNICAMP, notes that another critical modification was the in-

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corporation of computer programs designed for processing and interpreting the images, which were based on artificial neural networks.

FAPESP's support through the Innovative Research in Small Businesses (PIPE) program helped transform the prototype, completed in 2017, into a commercial device. The first results from monitoring of eucalyptus and sugarcane crops were published in February and April 2020 in the journal *Remote Sensing*.

The drone primarily follows two flight paths, namely, linear, in a single direction, and helical, in the form of a downward spiral, simulating a parabolic antenna to increase the radar resolution. The pulses emitted by the radar along the helical path and reflected by different underground structures provide precise data about the subsoil. This information is processed using the back-projection algorithm, typically used in CT scans, which reconstructs the reflected pulses into three-dimensional images.

The device is equipped with three antennas, each operating on a different band. The C-band collects information about the top of the vegetation and provides data on plant growth. The L-band penetrates beneath the treetops to measure the volume of a crop or, in helical flight, to capture data about the soil. The P-band penetrates the soil, extracting information up to 50 cm deep in linear flight and up to 100 m deep in helical flight. According to Radaz, no other device in the world has this configuration.

In a field test conducted in 2022, the P-band successfully detected leaf-cutter ant nests in eucalyptus and pine crops owned by paper manufacturer Klabin in Paraná. The equipment identified 29 previously unknown anthills, with areas ranging from 1 to 100 square meters (m^2), in a eucalyptus crop in Ortigueira, Paraná. The device showed that the ant nests were located at depths of up to 7 meters, as detailed in a *preprint* article submitted to the arXiv repository in December 2024.

"This was the world's first record of an anthill underground using this technology," said Bruno Afonso Magro, Klabin's forestry research and development manager, in an interview with *Agência FAPESP* in July 2022. Typically monitored through area sampling and human intervention, leaf-cutter ants create nests that can reduce productivity by up to 15%.

In another test, which was published in December 2024 on arXiv, the equipment successfully identified the height and growth stage of 340 sugarcane seedlings planted in a 20,000 m^2 experimental area at UNICAMP's School of Agricultural Engineering (FEAGRI). A report presented at a congress in Athens, Greece, in 2024 showed that the device achieved 100% accuracy in locating cow and pig carcasses buried 1.5 meters underground. The device can also record soil subsidence, erosion, and humidity.

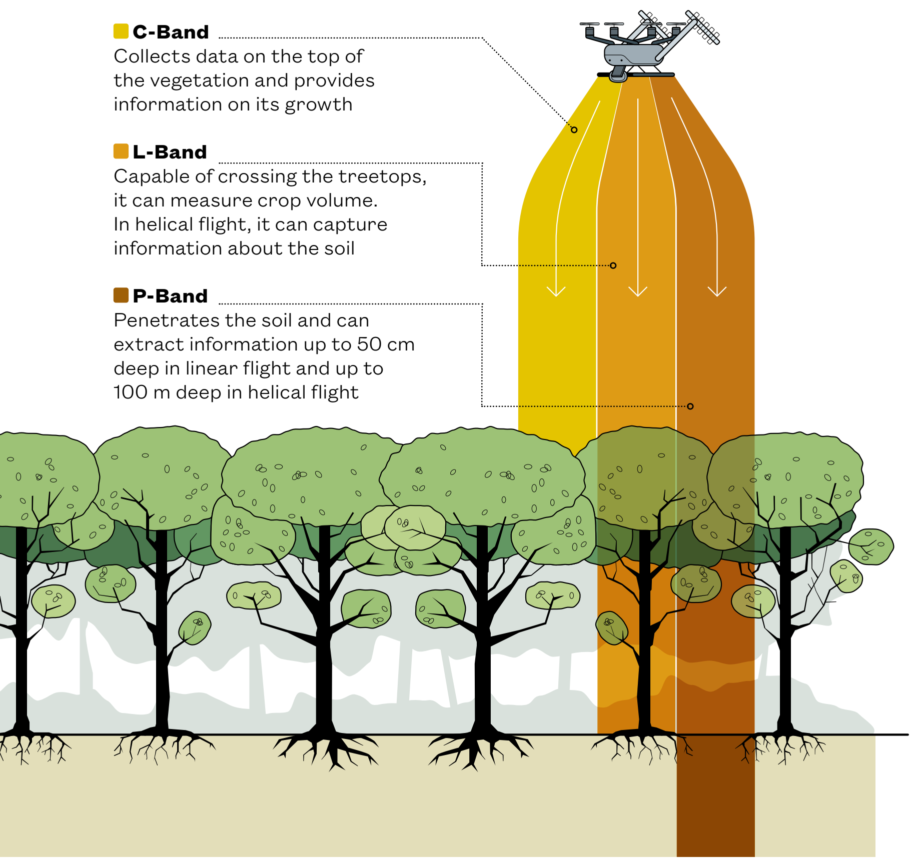
FOREIGN DEMAND

The Radaz system has also been successfully used to monitor the growth of sugarcane on a farm in São Paulo and to locate iron ore deposits, according to electronic engineer Fernando Ikedo, Radaz's commercial director. Owing to contractual stipulations, the names of the clients cannot be disclosed.

The market for remote sensing with drones appears to have significant growth potential.

Precise view

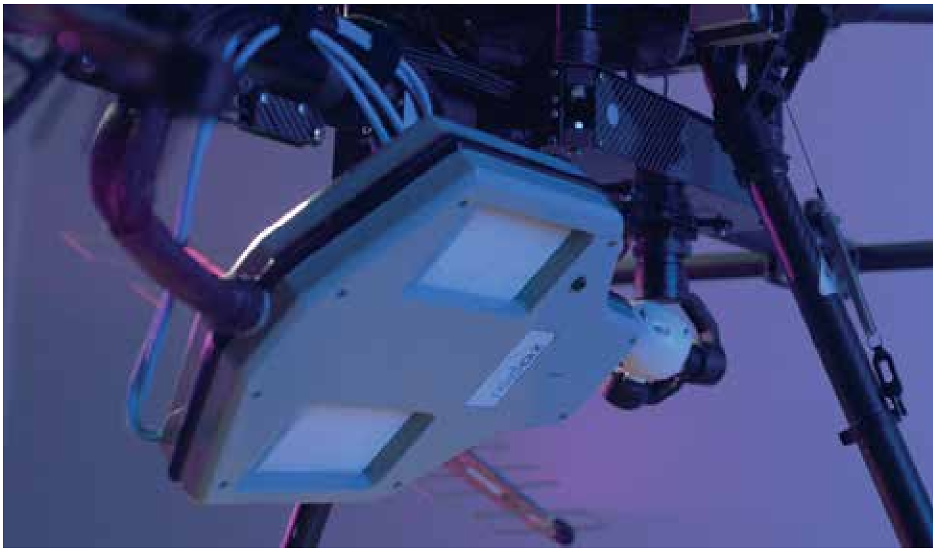
The synthetic aperture radar is equipped with three antennas operating in different spectral bands



Band	Wavelength	Frequency	Resolution
C	5.5 cm	5.5 GHz	2 cm
L	25 cm	1.2 GHz	6 cm
P	75 cm	400 MHz	18 cm

SOURCE RADAZ

Close-up images of the device attached to a drone (*on the right*) and the radar being tested in the startup's laboratories



According to Ikedo, the startup's revenue increased from R$1.1 million in 2022 to R$5.1 million the following year. In 2024, it reached R$17.3 million, with most of the revenue coming from international sales.

One of the clients is physicist Henrik Persson from the Swedish University of Agricultural Sciences, who uses a radar-equipped drone to assess the biomass and metabolism of trees, soil moisture, water tables, and underground rock layers. "The tomographic measurements have enabled new research into soil conditions, usually done by taking samples, which is expensive, tedious, and time-consuming," *Pesquisa FAPESP* reported.

The British company Surveyar acquired the innovative technology to map beaver dams, which cause losses to farmers by damming up waterways and flooding crops. According to the company's director, William Kirk—who discovered Radaz while reading articles by Brazilian researchers on anthill detection—the experiment was successful and led to the use of the technology for detecting soil and vegetation moisture, monitoring soil deformation, measuring biomass, and identifying buried objects.

CHALLENGES AHEAD

With no similar equipment available on the domestic market, the new technology faces the challenge of exploring new markets. Given the cost of the electronic components and the advanced technology involved, the complete equipment is sold for no less than R$1 million, excluding the cost of the drone. There are also other complementary technologies that are more affordable and can meet the specific needs of rural farmers, although none offer the same capabilities as the Radaz device does.

Depending on the objective, crop monitoring can be conducted with simple conventional cameras, such as RGB cameras, which capture only the visible spectrum and are priced between R$12,000 and R$60,000. Multispectral cameras, which cover other frequencies, such as infrared, can cost up to US$300,000 (approximately R$1.6 million). Devices of this type can provide satisfactory data on plant growth, biomass, and health status, according to environmental engineer Lucas Osco from the University of Western São Paulo (UNOESTE) and the Instrumentation unit of the Brazilian Agricultural Research Corporation (EMBRAPA) in São Carlos, who works with remote sensing.

Another alternative, according to Osco, is light detection and ranging (Lidar) technology, which uses laser beams instead of radar signals. With prices starting at R$100,000 and reaching R$1 million, it offers detailed three-dimensional mapping but has visibility limitations, leaving room for the use of SAR.

Innovative technology aimed at use in the field also faces challenges related to regulation and operator training. Additionally, there is resistance from Brazilian farmers, who, in the recent past, have seen results below expectations from drones that promised to increase production. "Farmers opt for technologies that are already established, with high and guaranteed returns. This makes it difficult to sell innovative products," notes agricultural engineer José Marques Júnior, from São Paulo State University (UNESP) Jaboticabal campus, a specialist in soil analysis. ●

The projects and scientific articles consulted for this report are listed in the online version.

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