Compact, low-cost synthetic aperture radar

David Long

The design of radar systems suitable for unmanned aerial vehicles represents both advances in technology and acceptable tradeoffs.

Synthetic aperture radar (SAR) is a powerful remote-sensing tool that can operate independent of solar illumination to produce radar images at night and under cloudy conditions. Using signal-processing techniques to generate high-resolution radar images, SAR systems operate from airborne platforms and spacecraft. Their operating frequency can be customized to enhance target characteristics. For example, low-frequency SAR can penetrate vegetation and dry soils, while high-frequency SAR emphasizes vegetation. Unfortunately, the complexity and high costs of SAR systems often preclude them from applications requiring long-term monitoring or frequent revisiting. Moreover, large size and power requirements have limited SAR to large and expensive platforms. There is a need for small, low-cost, high-resolution SAR systems designed for operation on small unmanned aerial vehicles (UAVs).

Faculty and students at Brigham Young University (BYU) have successfully developed a number of compact, low-cost, low-power SAR systems. These include an interferometric system known as YINSAR1 and a series of very small, ‘microSAR’ systems designed for operation on small UAVs.2

The BYU microSAR design represents a tradeoff between coverage and precision versus cost and size. It is an ultra-low-power system designed for ‘turn on and forget’ operation on a UAV with a 6ft wingspan. The system records data continuously on a pair of compact flash disks for over an hour. Post-flight, the flash disks are loaded onto a laptop and processed into images using SAR image-formation and autofocusing software. Real-time processing and image downlink capability are being developed (see Figure 1).

The microSAR system consists of a stack of $3 \times 3.4 \times 3$in. circuit boards and two flat microstrip antennas, each approximately $4 \times 12$in. (see Figure 2). Minimal enclosures reduce flight weight to less than 2lbs. Power consumption is 16W. With conventional SAR, short pulses are transmitted and separated by

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Figure 1. Shown is a micro-synthetic aperture radar (microSAR) block diagram.

Figure 2. The BYU microSAR system is suited to small unmanned aerial vehicles.

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In C-band microSAR images, the texture of fields reveals crop and plow conditions. Flight direction is right to left, with near range at the bottom. Manmade objects produce bright reflections. Paved roads show up as dark lines, while trees produce radar shadows. Surface lakes are black.

These photographs show (upper left) YINSAR radar hardware; (upper right) a Cessna Skymaster platform; (lower left) a laptop controller; (lower right) 12ft-long antennas mounted under the aircraft.

A receive interval. In contrast, with microSAR, transmission and receipt occur simultaneously via continuous-wave linear-frequency modulation, enabling low-power operation. To optimize performance, microSAR uses bi-static operation, in which transmission and receipt occur via different antennas. Designed for operation at 300–2500ft and 20–50m/s, microSAR has a swath width of 200–900m with a nominal one-look spatial resolution of ∼10 × 60cm, which is multi-look averaged to 1×1m in processed imagery. The averaging reduces the ‘speckle noise’ inherent in SAR images. Sample microSAR images are shown in Figure 3. The first microSAR operated at C-band (5.56GHz), but microSAR systems at other bands have also been built.

Shown are sample 3D YINSAR images (4×47-look SAR magnitude image draped over SAR interferometry-derived topography). Flight direction is right to left, with the near range at the back of the figure.

A sample 2D YINSAR image with 1×1m resolution shows a vegetated hill surrounded by fields with a creek running through them.

SAR imaging is coherent, using the phase of the radar echo. This can be exploited to infer topography as well as to generate images by combining data from multiple receive antennas separate.

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rated by a baseline. YINSAR uses two multiple antennas to enable extraction of surface topography from a small six-passenger Cessna 337M Skymaster (see Figure 4). Operating at 9.9GHz (X-band), YINSAR employs a 200MHz bandwidth chirp to achieve a single-look resolution of $60 \times 10$cm and a multi-look resolution of $1 \times 1$m with 1m height accuracy (see Figures 5 and 6). Cost was minimized by using a double-sideband (DSB) transmit chirp and an all-digital final intermediate frequency. The DSB chirp doubles the effective bandwidth of the transmit signal with only a small signal-to-noise ratio loss due to reduced carrier suppression. The bi-static antenna system consists of three identical waveguide-fed horn antennas with a baseline length of $\sim$1m. Aircraft altitude and motion data are used to compensate for aircraft motion in the post-flight processing.

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References