Synthetic Aperture Radar for UAVs

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Abstract

Synthetic aperture radar (SAR) is a technology used for generating large radar imagery using relatively small hardware. SAR works by taking a lot of small measurements while moving, and merging them all together to generate one large image.[1] It is useful for environmental monitoring, resource mapping, military systems, and more. Traditional SAR systems are expensive and designed to fit on a full-size plane. In contrast to visible light imaging systems, radar works at night and in adverse weather conditions. This enables detailed imaging through clouds, dust, and smoke. Having an easily deployable SAR imaging system would be useful in many fields. For example, a UAV with SAR could be utilized in search and rescue operations when typical camera vision is obscured. Similarly, SAR can see through trees and foliage to detect airplane crash sites.[4]

Methods

The beginning of this project consisted of background research and determination of the state of the art of Synthetic Aperture Radar. The research includes basic understanding of radar terminology and acronyms, such as pulse repetition frequency (PRF), as well as formulations for basic radars that extends into the realm of synthetic aperture radar. One example of such an equation is the radar range equation:

\[ P_R = \frac{P_t G_b G_r k \lambda^2}{(4\pi^3)^2 R^4} \]

Once the preliminary research was completed a careful disassembly of the MIT Candar project was performed. This project was done at MIT, with the focus on the physical construction of the Radar system. This physical design was backed up with a corresponding electrical system. Both the physical design and electrical setup were studied.

A thermal noise calculation was performed on the MIT Candar to inspect the signal to noise ratios using the selected components. This was done first on paper, then in an excel format allowing for components to be easily added or modified. The results of this analysis fed directly into the selection of radar components for the UAV SAR system.

Results

The basic concept behind radar is in fact relatively easy to understand. It is easiest to explain when the concept of radiation is simplified to a physical phenomenon. Imagine that a radar casts instead of radiation small rubber balls that fly in perfectly straight lines at a given speed until they hit another object, and then when they do bounce off of that object and go back the way that they came. The simplest radar spins in a circle and casts a set number of these balls per second. The balls bounce off objects and then return to the radar and the signal to noise ratio from got it to go out and then come back the radar knows where it was pointed at that time and how long it took the ball to come back, so it knows that there is an object in the direction that it was pointed at a certain distance.

This works well for simple radars, but it is too simplified to explain synthetic aperture radar. Synthetic aperture radar works on a similar concept, but expands the functionality greatly. The most simple synthetic aperture radar emits a slow series of pulses as it moves in a known path. The radar receives signals for each pulse essentially showing how much occlusion there is at what distance from the radar based on the amount of energy received over time. Since the radar knows how it is moving and how much occlusion there is at what distance along its path it can construct a cohesive map of where the occlusion is in space.

This technology is extraordinary because it allows small low power radars to construct high fidelity occlusion maps. Previously this would require highly directional antennas and large transmission power. Due to the iterative nature of the algorithms allowing the fidelity of the map to be improved by increased PRF, rather than higher transmission power and directionality.

In the background research only one other project of similar scope and goals was discovered. The Binghamton University SAR, YINSAR project was a project that aimed to create a miniature SAR system for UAV imaging purposes. Their initial testing proved successful, however their implementation left much to be desired. Their UAV was a large (6 ft wingspan) plane. This platform, while much smaller than traditional platforms, is still quite large and lacks maneuverability and flexibility.

In addition to the platform shortcomings the unit was still prohibitively expensive. Many custom boards and expensive components drove the cost of this unit up. The UB SAR system has sought to address this problem through designing around COTS components. Additionally we will be utilizing a different processing system to both lighten and simplify the payload. The improvements to microprocessors in recent years allow our processing be done faster and utilizing less power.

Preliminary range calculations were programmed into an excel spreadsheet, allowing for the calculation of signal to noise ratio from given distances, component selection, and environmental validation. This spreadsheet uses mainly thermal noise temperature calculations, and additionally the radar range equation. Through this spreadsheet we were able to estimate the range of the MIT radar as a function of transmission power, required SNR and target radar cross section.

Further Work

There is still a large amount of work to do on this project. The first step towards a working unit is to create a simulation in Matlab for transmission and receiving of radar signals. This model will allow the testing of algorithms for both generating the signals, as well as processing the input signals. A comparison of actual input geometry with geometry synthesized using synthetic aperture radar would verify the processing algorithms. In conjunction with the algorithm development the physical radar will also be developed further.

The purchased components will be carefully characterized and the actual output of the radar will be compared to the simulation. These characterizations will ensure the validity of the calculations and algorithms backing the radar. Once the radar is characterized a mobile mount will be employed to begin testing the synthetic aperture radar algorithms.

Finally once the synthetic aperture radar algorithms are verified on the ground an air-based platform will be developed capable of knowing its location to within several centimeters. This will be accomplished through use of an IMU and a phased array GPS unit.

Discussion

Preliminary research and analysis shows that there is a large opportunity to improve the state of the art of small-scale synthetic aperture radar enabled UAVs. This concept is not only possible, it has the possibility to revolutionize the way we image the ground. These platforms would be more economical than space based or large scale terrestrial or air based platforms and allow for a distributed network of imagers to collect simultaneous data.

The concept for SAR from a small UAV has been shown to work previously as discussed, however there are still many improvements to be made, namely scale, cost and functionality. The Brigham Young University MicroSAR project was an impressive demonstration of the viability of the micro UAV platform for SAR, however it failed to account for platform drift, still used many custom boards and was still a large UAV. It used many expensive custom boards and was too expensive for distributed applications.

The Buffalo SAR project must strive to minimize cost through using primarily COTS parts, while keeping scale and complication down. The platform drift can be compensated for by using, as stated earlier a phased array GPS system in conjunction with a full IMU. This allows the platform to be both smaller and more flexible.

Works Cited

http://searchandrescue.gsfc.nasa.gov/techdevelopment/sar2.html