Auto-leveling Radar Sled for the Identification of Annual Layers of Snow Over Sea Ice

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Introduction

The mapping of near-surface internal layers of snow over land ice is necessary for modeling snow accumulation from year to year. This information can help model the mass balance of the ice sheets so that accurate conclusions can be made about potential fluctuations in sea level. Sleds equipped with radar antennas are commonly used to collect data about snow thickness and internal layers.

The objective of this project was to design a sled to identify the annual layers from radar returns. Accumulation rates can then be calculated by comparing the radar data to ice cores. The goal is to identify internal firn layers to a depth of 15-20 meters that correspond with 15-meter firn cores that will be drilled. While specialized sleds to collect these data have been built and deployed in Greenland and Antarctica in the past, they were not capable of consistently pointing at nadir due to their inability to adjust to undulations along the snow surface (sastrugi). Some previously designed sleds were also quite heavy and complex in their designs. This is a disadvantage out in the field where the sled frame must be hauled around and assembled. The structure is composed of an aluminum tube truss structure topped with a platform of fiberglass grating to support the antennas. This provides a stable, lightweight, non-interfering platform from which to hang the Vivaldi and horn antenna arrays. In the event that the design needs to be modified, the grating provides the flexibility to mount a variety of antennas as the need arises. The end result is a sled which is light, strong, easy to assemble, and efficient at collecting accurate data without the issue of structural interference.

Background

In 2003, at the Center for Remote Sensing of Ice Sheets (CReSIS), a sled was build to traverse and measure the depth of snow over Antarctic sea ice. This particular sled was used to image the snow-ice interface and map internal layers and was equipped with an ultra wideband frequency-modulated continuous-wave radar system. This type of radar is able to map air-snow and snow-ice interfaces which aids in the estimation of snow thickness over large areas [1]. This design was a major improvement over the previous method of gathering snow thickness data, which involved using meter sticks during ship cruises [1]. The radar used at the time operated over the frequency range from 2-8 GHz (S-band and C-band), which yielded a vertical resolution of approximately 3 cm. The sled itself had a one-piece base structure that held a cantilevered beam equipped with horn antennas off to one side.

In another previous sled design which was developed in part by Ryan Cummings, a previous REU student, a very large (16 feet on a side) aluminum truss structure mounted on snowboards was towed behind a rover. It held a synthetic aperture radar system consisting of eight transmit and eight receive antennas. Because of the short spacing and the proximity to the metal frame, there was the danger of bandwidth degradation [2]. The sheer size and complexity of the sled also presented problems when out in the field.

Design Methodology

It was determined that the new sled should utilize design aspects of previous sleds that were successful, while improving upon the overall weight, ease of assembly, and ability to dynamically point at nadir. The antennas themselves are each mounted to a specialized gimbal system that keeps the antennas pointed at nadir. By mounting them in this way, inertial navigation system data is not required for post-processing. Otherwise, the inertial navigation system data would be necessary to correct the antenna positioning along the measurement track. Therefore, the ability of the antennas to aim at nadir reduces the need for post-processing and makes the collection of accurate data much simpler.

The existence of antennas in close proximity to a metallic structure can affect the return loss of the antennas, which affects operational bandwidth. It also has the potential to skew the far-field radiation pattern of the antennas. For this reason, the mounting platform for the antennas consists only of a fiberglass grating material. This material was chosen not only for its electromagnetic transparency, but also because it is strong and lightweight. The grating allows the gimbaled antennas to be rearranged as needed. The body of the sled consists of four eight-foot aluminum truss sections that were used successfully in a previous sled design. The trusses are fastened at the corners by removable legs that are approximately two meters long and gusseted for added strength. The entire structure rides on four snowboards, which are sprung so that the tip of the board has the tendency to point upward. This allows the snowboards to efficiently glide over sastrugi. Since the sled itself consists of only a few parts, it is easy to transport and assemble in environments where the end-user would be wearing bulky gloves or mittens that impede dexterity.

On the underside of the sled, two horn and four, 16-element Vivaldi antenna arrays (operating at frequencies of 12-18 GHz and 2-8 GHz, respectively) are mounted on the gimbal system attached to the grating so that the antennas sit two meters above the ground to ensure that the surface and internal layers are in the far-field. Mounting the antennas in this way allows for the accurate prediction of the interaction of the RF wave at each internal interface through standard equations for reflectivity and transmissivity as well as attenuation through firn as a function of frequency. Performing far-field measurements ensures that the RF waves are classified as plane waves. This is a benefit when it comes to modeling the interaction of the waves with dielectric interfaces, since modeling this same interaction with spherical waves (from near-field measurements) is a difficult task. In order to determine the efficacy of the proposed structure as a platform to mount these antennas, HFSS can be used to simulate the antenna structures in free space and attached to the sled. Comparing the two simulation results allows for mitigation of any unforeseen issues in the design phase.

Other Considerations

Another proposed design for this sled involved placing pneumatic linear actuators on the legs in lieu of a gimbal system on the antennas. This system would require an accelerometer such as the Analog Devices ADIS16201 that would sense roll and pitch in the sled. The sled itself will be towed at approximately 6 mph, so the actuators would have ample time to react. The main, previously mentioned design hinges on the development or purchase of a gimbal system with nonmetallic components. If this cannot be done, the linear actuator and accelerometer system is the next best option.

Conclusion

This sled will be used in future trips to Antarctica beginning November 2010. The sled is designed to be robust such that it can withstand travel, assembly and disassembly, cold temperatures and vibrations induced by movement over uneven terrain. The structure will provide a sturdy platform for the Ku, S and C-band radar it was intended for, but could eventually be modified to fit other types of radar for other measurements.

References:

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