2-D and 3-D Near Range SAR Imaging

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***Abstract*— In this report, we demonstrate some near range radar systems and their applications, which have been conducted in our research projects. The first example is GB-SAR working at Ku-band, which has been used for long-term land slide monitoring,. We will demonstrate the status of observation in 2 land slide sites in Japan. They have been implemented in an early warning system for local inhabitants. GB-SAR can be also used for infrastructure monitoring including road and airport taxiway inspection. Then we introduce results from a project for non-destructive inspection of wooden houses. In this project we developed a 1-D linear array, and MIMO GB-SAR and 2-D sparse array radar systems, which operate at 10-20GHz.**

Keywords*— radar; GB-SAR; MIMO GB-SAR; 2-D Sparser array radar; Compressive Sensing; Landslide monitoring; Infrastructure monitoring

I. Introduction

Space borne and airborne synthetic aperture radar (SAR) has been utilized for many applications. In these systems, the radar target to be imaged are very far from the radar sensor. Recently, we have investigated near range SAR, which include Ground Based SAR (GB-SAR) and other radar sensors which use SAR image processing for image reconstructions. If the targets are very far from the radar sensor, the area to be imaged is located within narrow angle from the radar antenna, and we can use some approximations in imaging algorithms. However, if the target is in near range, we have to use more accurate algorithm to obtain well focused images. This means, the near range radar imaging is more complicated than that for far range imaging. However, on the other side, if the target is in near range, radar can observe the target from different incident angles, and we can obtain more rich information about the target.

II. GB-SAR and Its Applications

Ground Base Synthetic Aperture Radar (GB-SAR) is a technique of Synthetic Aperture Radar imaging using radar data sets acquired by a radar sensor set on a fixed position on the ground. Compared to airborne and Space borne SAR, GB-SAR has advantages in continuous monitoring of targets, which is advantageous, for example for landslide monitoring. Currently, a few commercial GB-SAR systems area available, and most of them have a fixed rail having 2m length and a radar sensor moves on the rail to acquire SAR data, and operate at Ku –band (17GHz). In the last decade, this type of GB-SAR has been used for ground surface displacement monitoring for land slide observation or safety monitoring for mining production in open pits.

A. Land Slide Monitoring

We are now conducting a few GB-SAR campaigns. One of the first, and still continuing is the landslide monitoring at Aratozawa-site, Miyagi, Japan [1]. A 17GHz GB-SAR was installed in 2011 and monitoring the ground surface condition by Interferometry SAR, and the real-time information is sent through Internet for early warning to the local government. We have conducted this monitoring for over 5years, and could obtain rich experience. Then in January 2017, we started GB-SAR landslide monitoring at Minami-Aso, Japan. Fig.1 shows the GB-SAR system installed at Minami-Aso, and an example of the Interferometric SAR images is shown in Fig.2.

Fig. 1. GB-SAR installed at Minami-Aso.

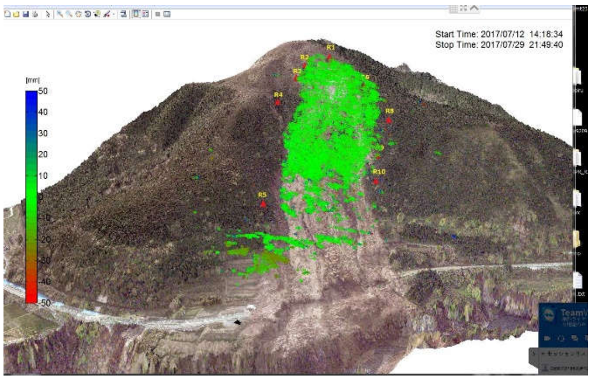


Fig. 2. GB-SAR Interferometry at Minami-Aso.

The area which we are monitoring by the GB-SAR is about 400-800m range distance. It is well known that the electromagnetic wave propagation in air has strong effect to the SAR interferometry. We found that the atmospheric effect is not negligible even in this relatively short range distance. The Minami-Aso site is located in a mountainous area, where the weather condition changes quite quickly, and a conventional atmospheric correction method which assume a homogeneous atmospheric model cannot work well. Then we proposed a 2-stage model for modeling the atmosphere conditions and found it works much better than the conventional method [2].

The SAR interferometry image in Fig.2 shows the displacement of the ground surface, which was obtained by the 2-satge model of atmosphere condition. We think continuous observation of displacement can be used for the prediction of large scale landslide.

B. Pavement Inspection in Airports

Infrastructure monitoring is an important issue in many countries including Japan. Now we are testing the use of GB-SAR for pavement inspection. Especially, now we are testing the observation of the surface pavement movement at Tokyo International Airport (Haneda). The data acquisition for the project has started in 2016, and now we are continuing this analysis.

Fig. 3. GB-SAR system installed at Tokoyo Interantional Airport (Haneda).

Fig. 4. SAR Interferometry at Haneda airport taxiway

The commercial GB-SAR system which we are using can acquire one set of SAR data in 10sec., because it requires time for moving the sensor head for 2m span. The SAR images can be created every 10sec., but we cannot obtain quick movement of the target from these images. The PRF (Pulse Repetition Frequency) of the radar system used for GB-SAR is higher than a few hundred Hz, and can acquire very fast vibration. If we use real aperture radar (RAR) mode instead of SAR mode, we can measure vibration of objects by interferometric technique. We have used this method for monitoring of vibration of bridges, and found it quite successful.

C. MIMO GB-SAR

However, if we use RAR mode observation, we cannot obtain 2-D SAR image and we have to determine the observation points of the vibration monitoring only from the range information measured from the radar antenna, and it can contain ambiguity of the position.

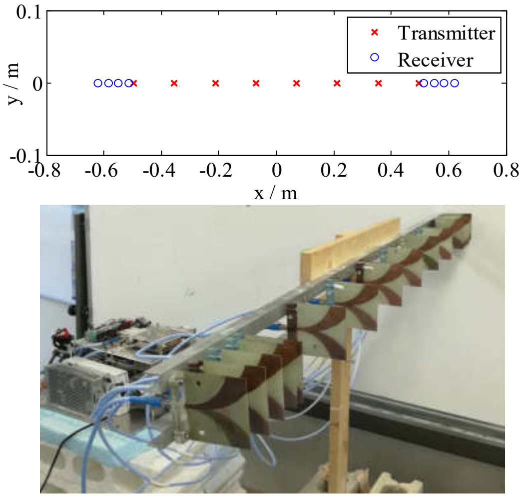


Fig. 5. 1-D MIMO GB-SAR array operating at 4-8GHz [3].

Although increasing the speed of mechanical movement of the radar antenna of a GB-SAR is not easy, we can use 1-D antenna array to replace them. However, in order to have a focused image of SAR, the antenna spacing is normally limited by the Nyquist theorem and we have to have the antenna spacing less than the half wavelength to avoid artifact in SAR images. This condition required quite dense antenna array. However, this condition can be relaxed, if we use MIMO (Multiple Input and Multiple Output) configuration for GB-SAR. Fig. 5 shows the 1-D antenna array, which we use for MIMO GB-SAR [3]. This radar stem is consists from 8 transmitting and 8 receiving antennas. The radar has one transmitter and one receiver unit and antennas are connected through a switching matrix, and operates at 4-8GHz.

By using the MIMO configuration, we can obtain the focused SAR images and about 10 images per second can be obtained. Therefore, we can observe a vibrating target up to a few Hz in the 2-D SAR image.

Then, we investigated the use of Compressive Sensing (CS) algorithm for image reconstruction. In the conventional CS applied to the radar image reconstruction, we assumed that the reflectivity from a target is always constant, which is independent of the observation angle, however, if the targets are located close to the radar antennas, the reflectivity from one target may have incident angle dependency. We proposed a block sparsity based CS algorithm and found it works better than conventional CS [3].

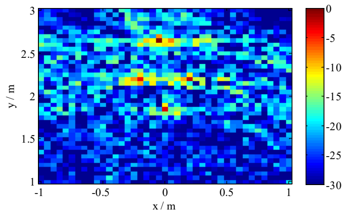


Fig. 6. Reconstructed image by FDBP method.

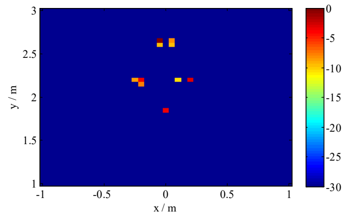


Fig. 7. Reconstructed image by the conventional CS method with 1/8 data

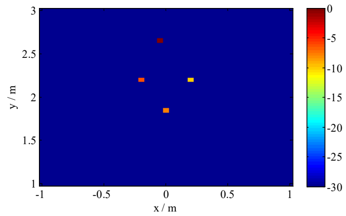


Fig. 8. Reconstructed image by the proposed method with 1/8 data

Figures 6-8 show the images of 4 metallic spheres observed by the 1-D MIMO radar system shown in Fig.5. Fig.6 was reconstructed by back projection algorithm. By using the same data set, Fig.7 was obtained by using conventional CS algorithm and Fig.8 was obtained by the proposed block sparsity based CS algorithm. We found it gives better focused images.

III. Imaging Radar for Nondestructive Testing

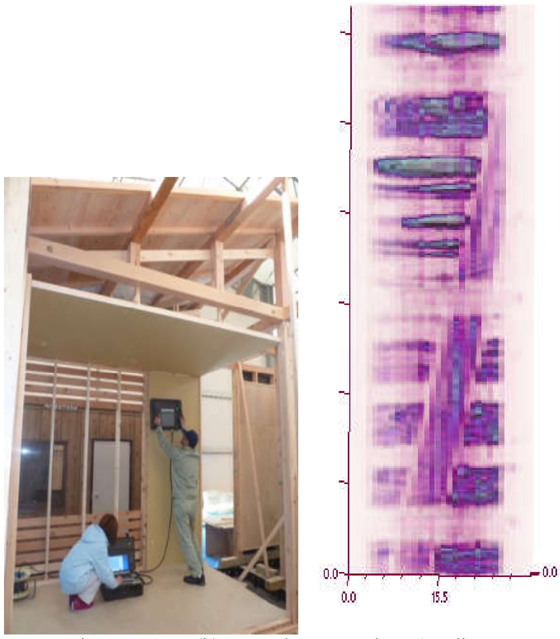
East Japan was suffered from large Earthquake and Tsunami on March 11th, 2011. Most of the Japanese private houses are made of wood, and by the strong shake of earthquake, the structure of the wooden houses could be damaged, but it is very difficult to inspect it from outside the wall, because the wooden structure is covered by the surface wall. We stared a project to inspect the inside structure of wooden houses by radar. Radar developed for concrete structure inspection is already commercially available, but the wooden structure is more complicated than concrete structure, and we needed the higher resolution.

A. Monstatic Radar

Radar systems developed for concrete structure inspection is already commercially available. Most of these radar systems work at 1-3GHz, and one pair of transmitter and receiver antennas are installed in a hand-held radar system. This kind of "concrete radar" is quite useful for detecting steel bars in concrete, however, the wooden structure is more complicated than concrete structure, and we need higher resolution.

B. 1-D Linear Array Radar

One of the challenging task in this research project is the use of operation frequency up to 20GHz. The electromagnetic wave attenuation through material increases when frequency increases. Therefore, most of the subsurface radar and GPR systems uses frequency lower than 10GHz.



(a) Experiment setup (b) Imaged structure by a 1-D linear array radar.

Fig. 9. Inspection of a model wall by a 1-D linear array radar

However, in our project, we have to achieve high resolution, so that we can see the inner structure of wooden building, and larger frequency bandwidth was required. We evaluated the penetration of EM wave through the wooden structure and found that 20GHz can also be used for this purpose. Fig.9 shows the wall inspection by using the radar system which we have developed. This system has 32 transmitter and receiver antennas in 1-D linear array configuration and works at 10-20GHz [4]. By scanning the antenna as shown in Fig.9(a), we can obtain 3-D images as shown in Fig.9(b).

C. 2-D Sparse Array Radar

Figure 9 shows a high resolution 3-D image of inner structure of a wooden wall, however, data acquisition is not easy, if the wall is not completely flat as is the case shown in Fig.9 (a).

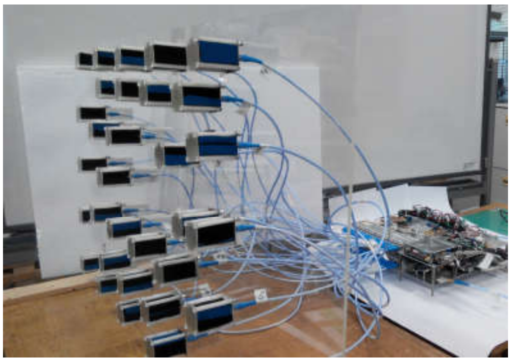


Fig. 10. 2-D sparese arry radar

In oredr to solve this problem, we developed a radar system which has a 2-D antenna array. We employed the MIMO antenna configuration, and the antenn spacing could be much larger than conventional antenna array. Fig.10 shows the antenna array that we have developed [5]. This radr system operate at 10MHz to 8GHz and 16 transmit and 16 receive antennas are equipped.

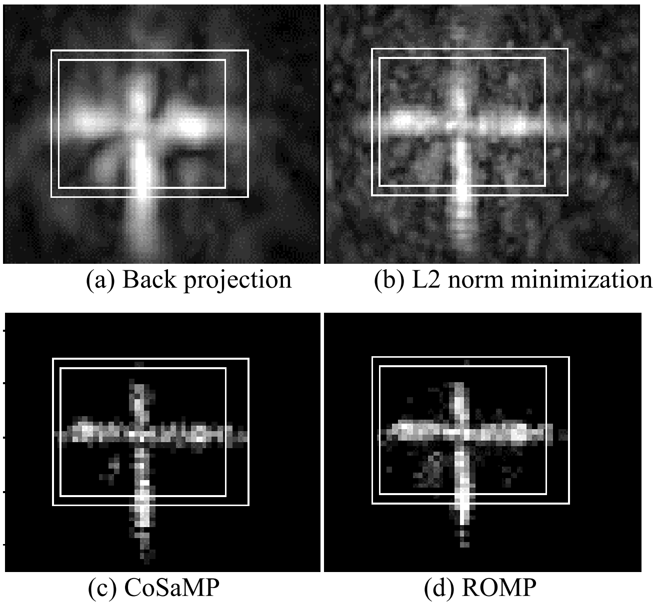


Fig. 11. The reconstructed image of the wooden cross target.

From one time data acquisition, we obtain 16x16 signals and can reconstruct a 3-D image. Fig.11 shows the images reconstructed by using different imaging algorithms. In this study, we tested various image reconstruction algorithms including Compressive sensing (CS).

The reconstructed images using the experiment data showed that the L2 norm minimization method always provides better image quality than the conventional back projection method. It is applicable for simple targets as well as for more complicated structures. In contrast, the ROMP and CoSaMP methods are able to suppress artifacts very efficiently. The matching pursuit methods optimize the sparse solution that means it gives the best resolution on the reconstructed images. Despite that, these methods produce another type of artifacts that are caused by the inaccuracy of the input data and the operators that was used [5].

We think that image reconstruction algorithm dependent on the target type must be investigated.

IV. Conclusion

We demonstrated near range radar imaging by using GB-SAR, 1-D and 2-D array radar systems. We think this type of new radar systems can be used for new applications.

Acknowledgment

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