Array GPR system “Yakumo” and its applications

Motoyuki Sato
(1) Center for Northeast Asian Studies, Tohoku University, Sendai, Japan

Abstract
We have developed a multistatic GPR system “Yakumo”. “Yakumo” is equipped with 8-channel transmitter and receiver antennas, and has 2m width and operates at 50MHz-1.5GHz. It can acquire GPR data rapidly, and we have applied it to large scale GPR surveys, which include archaeological survey and Tsunami victims survey. Yakumo can obtain precise 3D GPR images using its multi-static antenna arrangement. We demonstrated that Yakumo can effectively detect objects buried 50cm – 1m in sand. The Yakumo system can also be used for CMP analysis, then vertical velocity profile can be obtained along with the conventional common offset data. We tested the estimation of vertical velocity profile in the test pavement, and we could demonstrated that we can see the structure very clearly.

1. Introduction

Last several years, several types of Array GPR systems have been introduced and they have been widely used. Most important application of this type of GPR system is inspection of road. In most cases, GPR array systems are equipped on a vehicle, and surveys while moving at high speed on a road. These types of array GPR systems can also be used for other purposes such as archaeological survey. GPR surveys in large areas are quite suitable for array GPR.

Most of archaeological sites in Japan are located in mountainous area, or the areas which are already highly developed and the survey site is normally not large. Therefore, we have not had chances to use this type of array GPR other than road inspection in Japan. However, due to the East Japan Great Earthquake and Tsunami on March 11th, 2011, many private houses must be relocated away from the coastal line, in order to avoid the further damage by Tsunami. Very rapid development for lands for houses are required, and demand of archaeological survey in large area suddenly appeared. Then we decided to develop an array type GPR system in order to support the archaeological survey in East and North Japan.

We developed 8-channel multi-static GPR system “Yakumo” in 2012, and started to operate for archaeological survey. Along with these surveys, we learned that many local people are still trying to find any remaining objects of Tsunami victims. Then, we started to use “Yakumo” for the survey in coastal areas in East Japan with local police departments.

Yakumo can acquire GPR data sets by using 8 pairs of antennas, and data sets at different antenna offsets can be obtained at one time. This unique data sets can be used for CMP analysis, which can estimate the subsurface vertical profile of the EM propagation velocity. This approach is useful in Nondestructive Inspection (NDI) for concrete structures, too.

In this paper, we introduce the technical aspects of Yakumo system and then show the survey activities by using “Yakumo” system, and discuss the importance of multi-static GPR system.

2.“Yakumo” Array GPR system

2.1 System

We developed an array type GPR “Yakumo”. Yakumo is a SFCW radar system operating at 50MHz- 1.5GHz. It is equipped with 8 transmitting and 8 receiving antennas, having the swath width of 2m. The antenna arrangement is shown in Fig.2. By switching the antennas, multi-static data acquisition is possible, and we can acquire 8x8=64 channel data sets at every 1cm interval along the survey line. Several array type GPR systems have been introduced, and among them Yakumo is unique, because it was designed to optimize the performance in the frequency between 500MHz-1GHz, in order to achieve relatively deep penetration compared to other array GPR systems.

Figure 1 Array GPR “Yakumo”.
This multi-static data acquisition enlarges the possibility of advanced data processing. Each antenna pair can provide the conventional B-scan images along the multiple survey lines at the same time, and the multi-static data can directly be used for 3-dimensional migration.

In addition, we can use the data sets for CMP analysis, and can obtain the vertical profile of the dielectric constant. Fig.3 shows and example of antenna pairs, which acquire data simultaneously. CMP points can be selected in several locations at the same time by changing the combination of transmitter and receiver pairs.

2.2 Signal Processing

Fig.4(a) shows an example of such a CMP data set, acquired in a sandpit of our laboratory. The sandpit is filled with dry homogeneous sand, and the bottom of the sandpit is a flat concrete floor. Therefore we expect that CMP will image the bottom of the sandpit. Fig.4(b) shows the velocity spectrum obtained from the GPR data shown in Fig.4(a). The maximum velocity value and the corresponding two way travel time is 0.152m/ns and 13.6ns respectively, and the depth of the sandpit interface can be estimated as 103cm. Compared with the 99cm of the real depth, it has less than 4% error.

3. Survey of Tsunami Victims along Sand Beach

3.1 East Japan Great Earthquake and Tsunami

By the earthquake and tsunami on the 11th March 2011, more than 15,000 people were killed, mostly by tsunami, and still more than 2,500 people are missing, and we believe that most of them were flashed away by Tsunami. Local people, and local police departments are continuing their effort to find any remaining objects of the tsunami victims. After 6 years, unfortunately, we think detection of any part of body, i.e., bone is very difficult. However, GPR is capable of detecting buried objects in sand and soil, and if we could inspect these buried objects by plodding, if have a chance to find something.
month, we survey sand beach in this area by using Yakumo and conventional GPR (RAMC 500MHz) and metal detectors.

The thickness of the sediment layer carried by Tsunami is typically 30cm-1m. Objects still remaining are very different in each location. After the information of the locations where victims were found before provided by the local police station, we set a survey area for Yakumo. Typically it is larger than 50m by 50m. Yakumo acquires GPR data by 2m width, and after acquiring data along several survey lines, we merge the data and reconstruct horizontal images as shown in Fig.6. Typically, 50m by 100m area is chosen for one survey, and data acquisition and processing takes about one hour. Then we examine the data and detects anomalies and make a map indicating the possible buried objects. Typically, we have more than 5 points per 100m² area. Then, police men dig these locations.

![Figure 5](image1.png) **Figure 5** Horizontal GPR slice obtained by Yakumo in a sand beach.

## 4. Application in pavement inspection

We are now evaluating the performance of the GPR “Yakumo” for nondestructive inspection of pavement. Especially, we are testing GPR surveys in airports. The inside pavement structure can be damaged by the heavy load of aircrafts, and currently visual inspection and acoustic inspection by hitting the pavement surface by a metal rod are widely used. We think high resolution GPR can be a good alternative to the existing technologies.

![Figure 6](image2.png) **Figure 6** Vertical structure of the test lane in in the Nobi site of the Port and Airport Research Institute.

Figs.7 show the vertical profiles of GPR acquired in this test site. In order to compare the performance, the data was acquired by a commercial GPR (RAMC 500MHz) and Yakumo. Both GPR system can visualize the voids and horizontal structure of the pavement.

![Figure 7](image3.png) **Figure 7** GPR vertical profile

Yakumo has a capability to process the data for CMP analysis to obtain the vertical profile of the pavement. Fig.8 sows one of the examples of the vertical velocity profile obtained by Yakumo. Data acquisition is done every 1cm along the survey line, therefore the vertical velocity profile is also obtained every 1m along the survey line.
From Fig. 8, we can understand that the velocity in the pavement structure is almost uniform except some position. The right part of the profile in Fig. 8 is partially damaged by the heavy vehicle. The pavement surface has some groove, therefore the CMP analysis can be affected by the surface condition. We think we have to investigate the influence of the ground surface flatness to the CMP analysis. However, the velocity difference between two horizontal layers could be observed, and we think this technique is very sensitive to the conditions of pavement structure.

5. Conclusion

We have used array type GPR “Yakumo” for the survey of Tsunami victims in east Japan. We demonstrated that Multi-static GPR system “Yakumo” which operates at 50MHz-1.5GHz is quite useful for detecting objects buried 50cm to 1m by Tsunami. The survey of a 50m by 100m area takes about one hour and can point out locations of the buried objects. We have worked with local police in Iwate, Miyagi and Fukushima prefectures for the survey since August 2014, and we think this is a good example of GPR survey for contribution to local society.

Then we demonstrated the capability of CMP data acquisition and estimation of the vertical profile of the velocity. We think this approach is quite useful for Nondestructive Inspection, which include road and pavement inspection.

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7. References