Rescue Radar System with Array Antennas

Toshio Takeuchi*, Hideo Saito*, Yoshimitsu Aoki*, Akihisa Ohya†, Fumitoshi Matsuno‡, and Iwaki Akiyama§
*Keio University, Yokohama, 223–8522, Japan
Email: takeuchi@ozawa.ics.keio.ac.jp, saito@ozawa.ics.keio.ac.jp, yaoki@njima.elec.keio.ac.jp
†University of Tsukuba, Tsukuba, 305–8571, Japan
Email: ohya@cs.tsukuba.ac.jp
‡The University of Electro-Communications, Chofu, 182–8585, Japan
Email: matsuno@hi.mce.uec.ac.jp
§Shonan Institute of Technology, Fujisawa, 251–8511, Japan
Email: akiyama@elec.shonan-it.ac.jp

***Abstract*—The purpose of this study is to improve rescue radar system with array antennas so that it can quickly identify far-off survivors under rubble. Authors focused on time-variable elements from the respiration of a survivor awaiting rescue in order to remove clutter components, such as the rubble. Authors propose the method which identifies the location of the survivor in three dimension by using the two dimensional array antennas. The experimental results of measurement for subjects location by the proposed method agreed with the actual location of the subjects.**

I. Introduction

The purpose of this study is to improve performance of rescue radar system with array antennas so that it can quickly identify the existence and location of survivors confined in rubble due to an earthquake or other disaster. Conventional CW radar unit with individual antennas detects their respiration based on time variation of the received signals to identify survivors in rubble within a few meters radius of the antennas[1,2], however it is difficult to measure the distance from the antennas to survivor. We have developed a rescue robot with UWB pulse radar system that can detect a moving object in response to the distance from the antenna to measure the distance[3,4]. This system enables the operator to identify survivors buried under rubble from any position by remotely controlling the robot. This system detects the respiratory of the subject approximately 2 meters under rubble and measure the three dimensional location of the survivors by controlling the robot to cover the search area within an hour. We developed the Radar system which consist of 5 antennas[5]. This system detects respiratory variation from a low SNR by utilizing the properties of the variation and 5 antennas information.

In this article, we propose the rescue radar system with two dimensional array antennas which extends the radar system of 5 antennas. This system detects the respiration of survivor 3 meters under rubble and measures the three dimensional location of the survivor. In this article, we propose the method that detects the survivor and measures the location of the survivor by using the 9 modules, which consists of 5 antennas. To detect and measure experimentally, we built the tower structure platform. It was 3 meters in height. We send microwave from top to subject and measured the effectiveness of this method.

II. Detection of respiratory variation by radar

Radar detects the object by sending microwave and receiving the reflected wave from the object. In this research, we detect the survivor by removing the reflected wave of rubble from received wave and extracting the reflected wave from the survivor. To remove the wave from the rubble, it is necessary to utilize the difference of the rubble and the survivor's reflected waves. Static objects, such as rubble, never change the frequency of reflected wave, however vibrating objects, such as survivors, change the frequency of reflected wave. Therefore, by extracting the area that frequency does not change, we can get only the reflected wave of vibrating object. The experiment showed that the frequency of respiration is from 0.2 to 0.5Hz[5], therefore extracting that area we can distinguish vibration of respiration from other vibration.

There are two type of radar for rescue. They are CW radar and pulse radar. CW radar cannot get the distance information, because it continuously transmits the microwave. However CW radar can obtain broad area information and can easily detects the respiration variation compared with pulse radar. Pulse radar can get the distance information, because it intermissively transmits the microwave. However pulse radar can obtain only narrow area information, and it is difficult to obtain the respiration variation of survivor comparatively. The information obtained by one antenna is not the direction to the object but the distance from the object. To solve this problem, first it is useful to utilize the CW radar to detect the presence of survivor, and next it is useful to utilize pulse radar by array antennas to measure the distance and location of the survivor. In proposed system, we detect the survivor under the rubble by array antennas. Fig.1 shows the outline of this system.

III. Radar system with array antennas

A. Specification of the radar system

Radar of proposed system can switch between CW radar and pulse radar. Therefore, we utilize the CW radar to detect the presence of the survivor. When the survivor exists, we utilize the pulse radar to measure the three dimensional location of the survivor.

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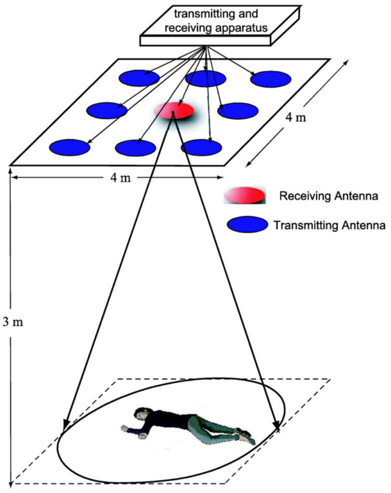

Fig. 1. Schematic illustration of searching survivor using rescue radar system with 2D array antennas.

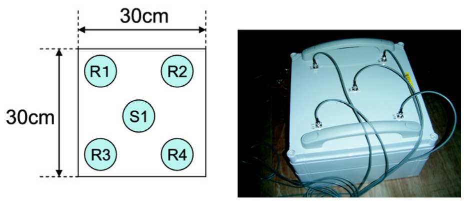

Fig. 2. Module which consists of 5 antennas.

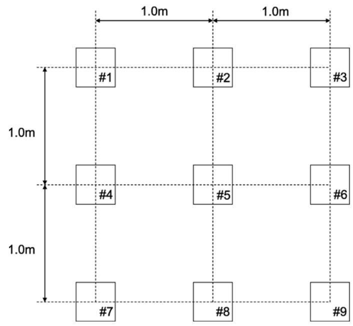

Fig. 3. Arrangement plan of the array antennas.

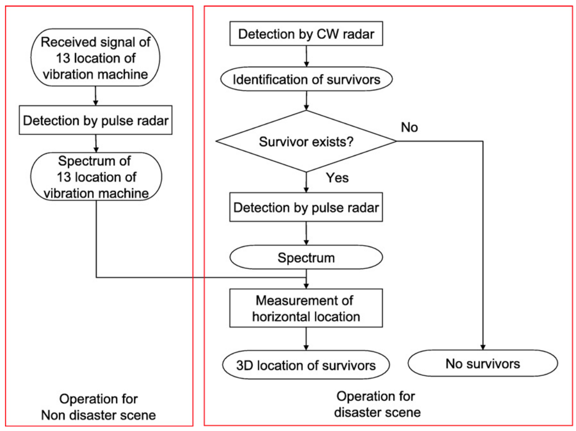

Fig. 4. Flowchart of signal processing of this system.

B. Forty five antennas divided into nine modules of five antennas

In this study the detection capability is improved by use of forty five antennas, however it is difficult for an actual rescue scene to locate all the antennas at the appropriate position within a few minutes. Then, as a module with antennas of a minimum number considered the portability of this system, we compose module with five antennas, which is one transmitting antenna and four receiving antennas.

Fig.2 shows the each module of this system. It is 30cm in length and breadth and one transmitting antenna, four receiving antennas. From R1 to R4 show the receiving antennas and S1 shows the transmitting antenna. Antennas are spiral antennas that have a wide band in which they center on 1.2GHz. Signals received by four antennas are sampled about 50psec period and A/D is done and it is accumulated in the memory of the same personal computer.

C. Array antennas configuration

We utilize modules described above to compose the array antennas that can detect the presence of the survivor and measure the location of the survivor. However the accuracy will go up by utilizing a number of modules, we use 9 module, minimum number of module, to detect the minimum performance. By installing the 9 module as Fig.3, we can measure the horizontal location.First, we transmit microwave of 1.2GHz from module No.5 and receive the reflected waves from inside the shielding platform by an antenna in each module. The received signals include subject respiratory information under the array, because the CW radar detects all the moving objects under the antennas. The sampling speed of the data in nine modules are so faster compared with respiration variation, we can obtain the same data with respiration variation.

IV. PROPOSED METHOD

Fig.4 shows the flow of the proposed method. In the place that is not the disaster scene, special characteristics data of the phase and of receiving antennas are obtained beforehand by utilizing the vibrating object. These data are utilized to measure the location survivors by pulse radar. Then in the place of disaster scene, first the presence of the survivor is detected by CW radar. If the survivor exists, the three dimensional location of survivor is measured by pulse radar. In that time, it utilizes the data gotten by vibrating object beforehand.

A. Detection of the presence of the survivor by CW radar

We utilize electromagnetic radiation survivor inquiry device Life Detector[6] to process the signal of CW radar. CW radar radiate continuous wave, therefore it detects the moving by canceling the reflected wave from the statistic object and extracting the reflected wave from moving object. Then, fourier transform of the obtained signal is done. If the amplitude of the respiration frequency is the most highest, it determines the presence of the survivor.

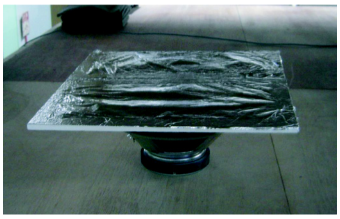

Fig. 5. Vibrating object.

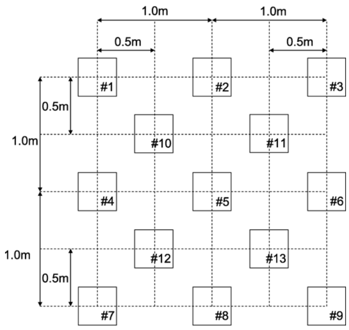

Fig. 6. Arrangement of the nine modules for the reference data by using the vibrating object.

B. Reference data by using vibrating object

Array antennas usually detect the location of the object by utilizing the phase and strength of the receiving signal of modules. However the received shape of wave in each module changes by the distance from transmitting antenna and distance from the object. The amplitude of the received wave also changes by the characteristics of receiving antenna and attenuating by the rubble. Therefore, we obtain data when the vibration object exists in various positions beforehand. Then we calculate the correlation coefficient between the data beforehand and the data obtained now. By the value of correlation coefficient, the location of the survivor is measured. We utilize the data beforehand as same vibration object, however the data is obtained at different place. Therefore we need same vibrating period object. Then, we used a speaker connected with polystyrofoam plate with aluminum foil as the vibrating object. Fig.5 shows the vibrating object of speaker. This object can change the frequency by changing the input frequency. Therefore it can move in various frequency.

We put the vibrating object of speaker on the first floor of tower structure platform. The place where we put the vibrating object is shown at Fig.6. We obtain nine module data for 13 different places. Details of tower structure platform are described at section V.A. These data are utilized for measuring the location by pulse radar.

C. Measurement of the location of the survivor by pulse radar

Signal processing to receiving signal is first done in each module, and then signal processing to 9 modules is done. Fig.7 shows the signal processing to each module. We perform quadrature detection to each receiving signal and cut off the discarded bounds. Then, MTI filter, which reduces average value of 8 to 16 seconds, is used to remove the reflection element from the geostationary object. After performing FFT to 1 minute of data, we multiple the spectrum of 4 received signals and calculate the absolute value. Then, we visually display the vertical axis as the range direction and the horizontal axis as the frequency spectrum. This signal processing corresponds to cross-correlation coefficient if it thinks in the time-domain. Thus, this processing and correlation coefficient of 4 signal spectrum are equivalent. By this processing, the depth distance and frequency of respiration variation are obtained. The purpose of this system is to detect the respiration variation. Therefore the frequency range of 0.1Hz or less that is outside the range and that is the range of the noise is cut off.

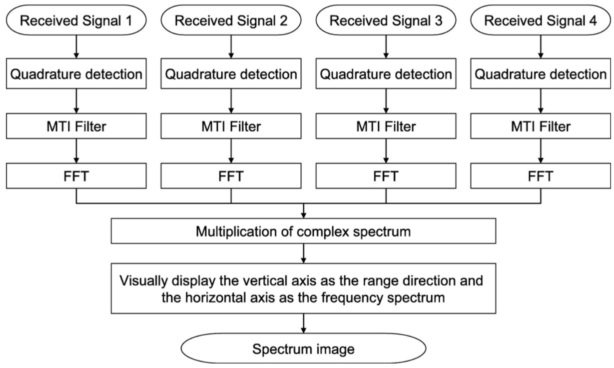

Fig. 7. Flowchart of signal processing of each module.

Then, we measure the horizontal location of the survivor. The data which are obtained by vibrating object beforehand are utilized, and we calculate the correlation coefficient and measure the horizontal location. We utilize that the value of correlation coefficient goes up when the phase and amplitude of the spectrum of the survivor resemblance to that of vibrating object. We determine the probability is high when the correlation coefficient is high. We calculate the 9 spectrum obtained by 9 module of the survivor and 9 spectrum times 13 location, then the probability presence in 13 location are obtained.

We descibe the detail expression. Max value, which is complex number, of location i of module j obtained by vibrating object is described as $p_{i,j}$. Max value of module j of survivor is described as q_j. The value of correlation coefficient M_i of location i is described as

$$M_i = \frac{\sum_{j=1}^{9} q_j \bar{p}_{i,j}}{\sqrt{\sum_{j=1}^{9} q_j^2}\sqrt{\sum_{j=1}^{9} p_{i,j}^2}} \quad (1)$$

The survivor is seemed to be present where the value of M_i is high, therefore probability distributions of the survivor existence of horizontal location are obtained by the value of M_i. By this process, the depth location and the horizontal location are obtained, thus we can measure three dimensional locations.

V. Experiment and Deliberation

A. Experimental environment

Fig.8 shows the tower structure platform which is utilized. A couple of volunteers helped the experiments as a human

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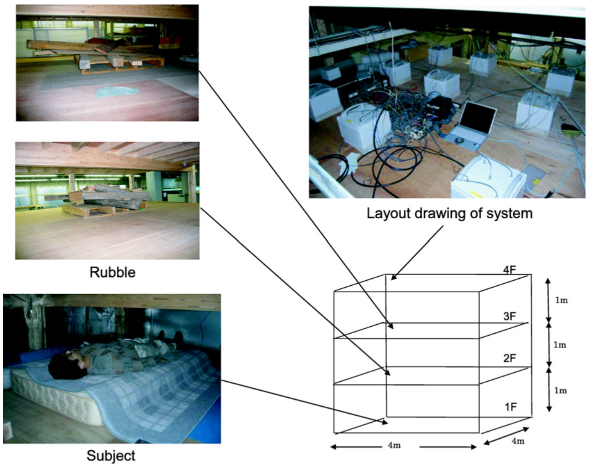

Fig. 8. Tower structure platform.

Fig. 9. Shield for tower structure.

subject. The subject lies with one's head back on the first or second floor of the tower and breathes normally. We transmit the microwave from the antenna which is put on the top of the tower to beneath. Fig.3 shows the location of the module on the top of the tower. The location of the survivor is arbitrarily-located. Then, to prevent the microwave being interfered by the outside environment, we cover the tower structure platform by electric reflective sheet as shown in Fig.9.

B. Detection of the presence of the survivor by CW radar

We put the additional concrete which is 10 cm thick under each module, and then we measure whether this system can detect the respiration variation of survivor who exists 3 meters beneath the antenna. The reflected spectrum where the survivor is beneath module No.5 is shown as Fig.10. There are nine graphs, they are the graph of nine modules. Fig.10 shows that results of each module have peak at the respiration variation range from 0.2Hz to 0.5Hz. This result shows that each module can detect the respiration of the subject, however when look the value of 0.2Hz to 0.5Hz, the value of them do not have enough difference to detect the horizontal location by the amplitude when utilize CW radar.

Then, we measure the change by the passage of time of two different situations when the subject exists beneath the module No.5 and none is there. Each figure shows the six period results of 50 seconds. Fig.11 shows every data when the subject exists shows the peak is in the frequency range of respiration variation of 0.2Hz to 0.5Hz. The spectrum obtained by the experiments without a subject is shown in Fig.12. The highest

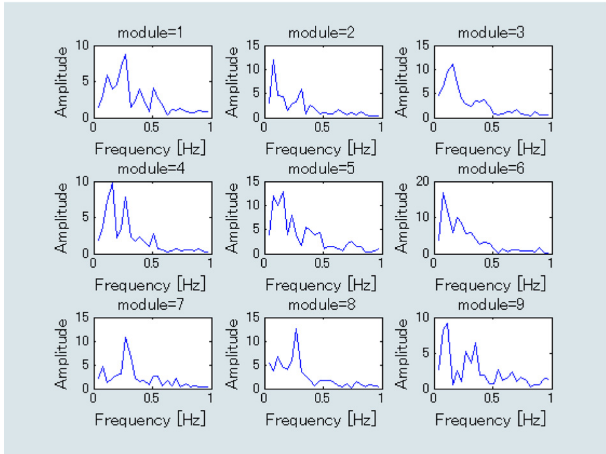

Fig. 10. Spectrum obtained by the experiments with a human subject three meters below the module No.5. Microwave of 1.2GHz is transmitted from an antenna in the module No.5. Reflected waves are received by an antenna in every nine modules.

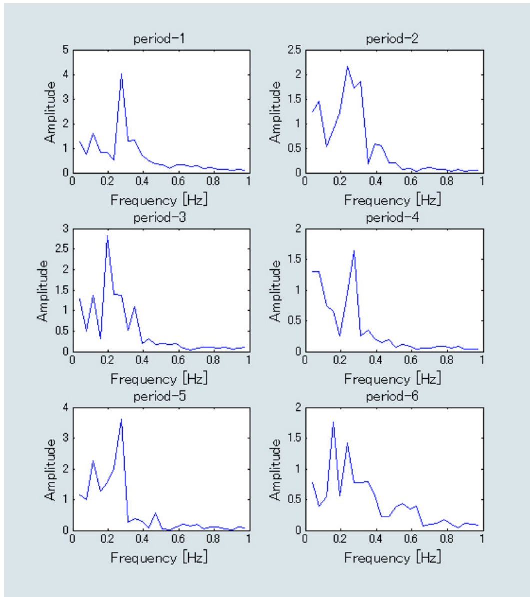

Fig. 11. Spectrum obtained by the experiments with a human subject three meters below the module No.5. Microwave of 1.2GHz is transmitted from an antenna in the module No.5. Reflected waves are received by an antenna in the module No.5. Measurement time for each spectrum is 50 seconds.

peak frequency is zero. Also this peak value is much higher than the values in the frequency range of human respiration as shown in Fig.11. By the difference of peak frequency, we can detect the presence of subject. The result shows that we confirm CW radar can detect the presence of the survivor.

C. Performance of pulse radar system

We measure whether pulse radar can detect the right frequency and depth of vibrating object of speaker when we vibrate the object at arbitrary frequency. Fig.13 shows the result of vibrating the object with 0.25Hz 3m beneath module No.5. This figure shows the amplitude by color. In a weak blue background, the depth of 3 meters and the frequency of 0.25Hz

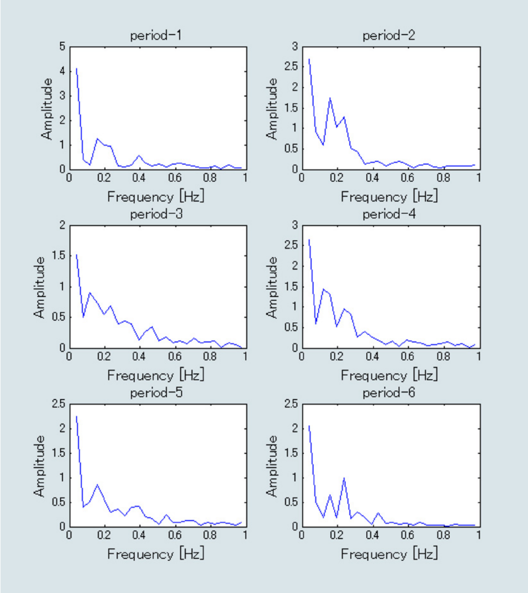

Fig. 12. Spectrum obtained by the experiments without a subject. Measurement time for each spectrum is 50 seconds. Pulses are transmitted from an antenna in module No.5 and the reflected waves are recieved by an antenna in module No.5.

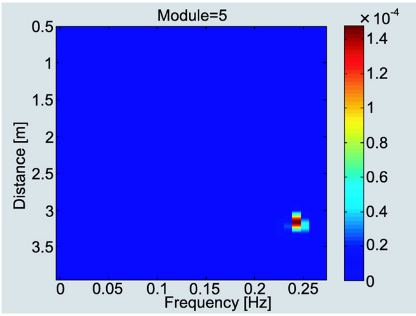

Fig. 13. Two dimensional maps of spectrum to distance from an antenna for a vibrating object located at three meters beneath the module No.5. Vibration frequency is 0.25Hz. Pulses are transmitted from an antenna in module No.5. Reflected waves are received by four antennas in module No.5.

point is red that means huge value. Therefore, the detection by pulse radar shows that it detects the object vibrating with 0.25Hz 3 meters beneath. This result shows that we confirm pulse radar can detect the reflected wave from vibrating object.

D. Measurement of the three dimensional location of the subject by pulse radar

First, we measure whether pulse radar can detect the subject at 3 meters beneath. We obtain two different data which the subject exists 3 meters beneath the module and none exists and compare them. Fig.14 shows the result when subject exists and Fig.15 shows the result when none exists. Fig.14 shows that red that is strong signal is detected within the breath frequency range of 0.2 to 0.5Hz and at depth 3 meters. This result shows that we confirm pulse radar can detect the respiration variation of the survivor.

We normalize the color scale by minimum and max value, therefore there are red signal at Fig.15. However if look at

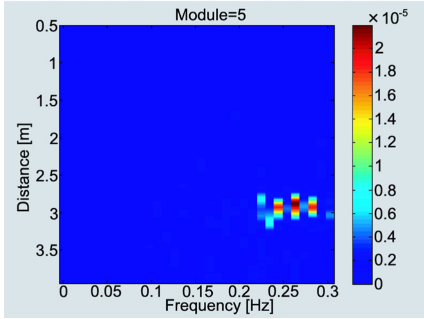

Fig. 14. Two dimensional maps of spectrum to distance from an antenna for a human subject three meters below the module No.5. Pulses are transmitted from an antenna in module No.5. Reflected waves are received by four antennas in module No.5.

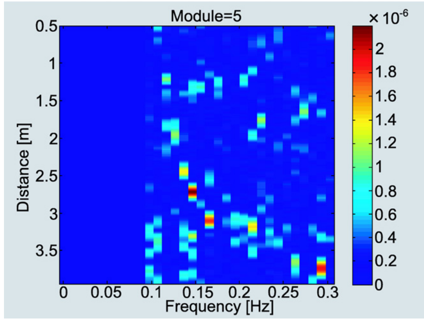

Fig. 15. Two dimensional maps of spectum without a subject. Pulses are transmitted from an antenna in module No.5. Reflected waves are received by four antennas in module No.5.

the color scale of them, the red signal at Fig.15 is same as blue signal at Fig.14. In other word, if use the same color scale, entire picture at Fig.15 becomes blue. These results show that only when the subject exists pulse radar obtains the strong signal at same distance of the survivor and the range of respiration frequency. Therefore, it detects the right depth.

Next, we measure the horizontal location by utilizing the data of 9 modules. Fig.16 shows the result of 9 module when the subject exists 3 meters beneath the module No.7. The result shows that module No.1 to No.3 cannot detect the respiration variation because the distance from the object is too far. However module No.4 to No.9 where the distance from object is not so far can detect peak 3 meters beneath and range of 0.25Hz. When display at picture, we use absolute value. Before calculating the absolute value, they are complex number. Thus they have phase and amplitude.

We can obtain the existence probability distributions by calculating the correlation coefficient between the data obtained by vibrating object at 3 meters beneath beforehand. Fig.17 shows result of the correlation coefficient of 13 different location. The location is same as Fig.6 and we show the correlation coefficient value at 13 different location. This result shows that about module No.7 has risen. At this time, the subject turned the head in the direction of the position of module No.4 by centering on module No.7 and lies. The subject exists between module No.7 and module No.4 and the

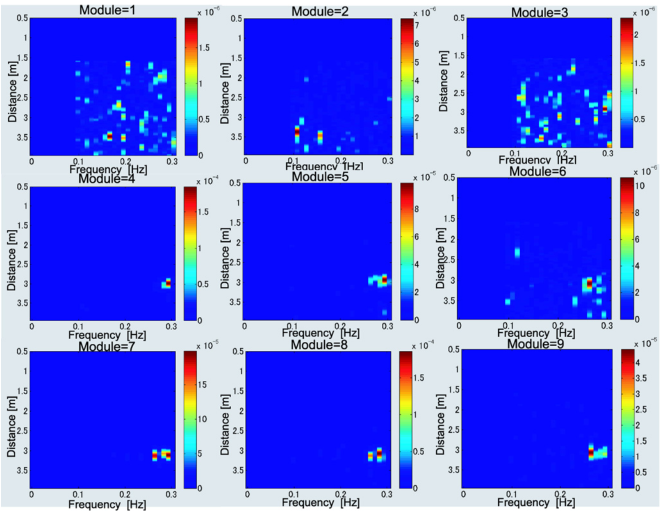

Fig. 16. Two dimensional maps of spectrum to distance from an antenna for a human subject three meters below the module No.7. Pulses are transmitted from an antenna in module No.5. Reflected waves are received by four antennas in each module.

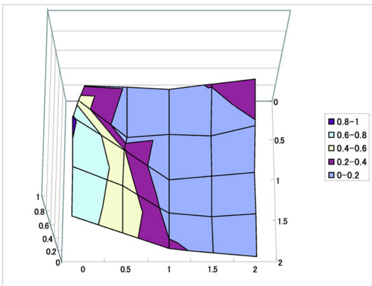

Fig. 17. Correlation coefficient between the reference data and the experimental outputs with a human subject three meters below the module No.7.

result shows the same shape. Therefore, it is confirmed that the value of the correlation coefficient expresses the shape of the object well.

Next, we measure whether we should obtain the vibrating object data at depth direction. Fig.18 shows the correlation coefficient between the data of vibrating object at 3 meters beneath when the subject exists at 2 meters beneath module No.7. This result shows that when subject exists at 2 meters beneath, value about module No.7 has risen. This result agrees with the fact that the subject turned the head in the direction of the position of module No.4 by centering on module No.7 and lied. The result shows only one depth data can enable the detection of horizontal location of subject.

VI. Conclusion

In this paper, we proposed the method for measurement of the three dimensional location of survivors under rubbles by using pulse radar system with two dimensional array antennas. We developed the experimental radar system consists of forty five antennas. All antennas divided into the nine antenna modules. Each of them consists of five antennas.

The experiments by using CW radar system showed that the respirations of subjects at 3 meters beneath the module through concrete block were measured in the frequency range of 0.2Hz to 0.5Hz.

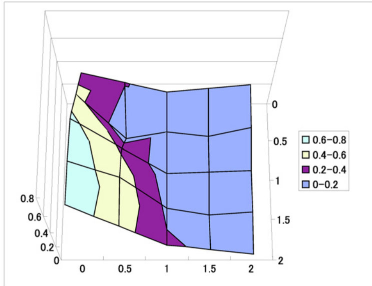

Fig. 18. Correlation coefficient between the reference data and the experimental outputs with a human subject two meters below the module No.7.

The experiments by using pulse radar sysytem demonstrated the following facts.

- The measured value of fluctuation frequency of the reflected waves from the vibrating object at 3 meters beneath the module agreed with the setup frequency.
- The measured values of respiration frequency of subjects at 3 meters beneath the antenna were in the range of 0.2Hz to 0.5Hz.
- The measured location of subjects at 3 meters and 2 meters beneath the antennas agreed with the actual location of subjects.

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