Theme Name	Nondestructive examination technology for inside of concrete by combining radar and tomography - detecting cavities and corrosions
Organization Name	University of Electro-Communications Graduate School of Informatics and Engineering Associate Professor Shouhei Kidera
Technical Field	IT, Manufacturing

Overview

The deterioration of social infrastructures such as roads, bridges, tunnels, etc. is an urgent critical issue closely related to The National Resilience Plan and the nondestructive examination technology is highlighted to examine the status of deterioration. In our laboratory, we have been studying a new nondestructive examination technology by combining UWB (Ultra-Wideband) radar and RPM(Range Points Migration) which is a unique technology as well as tomography technology in order to examine inside status (cavities, water distributions) of especially concrete construction materials exactly and efficiently for secured maintenance. Particularly, introducing the tomography technology can obtain information of permittivity and dramatically improve the accuracy of discrimination for cavities and corrosions.

We welcome companies that are willing to develop commercial products utilizing this research.

Simplified diagram

Nondestructive Examination Technology to Examine Inside of Concrete Constructers for Secured Maintenance by Combining UWB Radar, RPM Method, and Tomography Technology

UWB Radar can Penetrate Deep Inside of Concrete and Visualize Cracks, Cavities, Metals, Water by Utilizing Difference of Permittivity as Noncontact Examination

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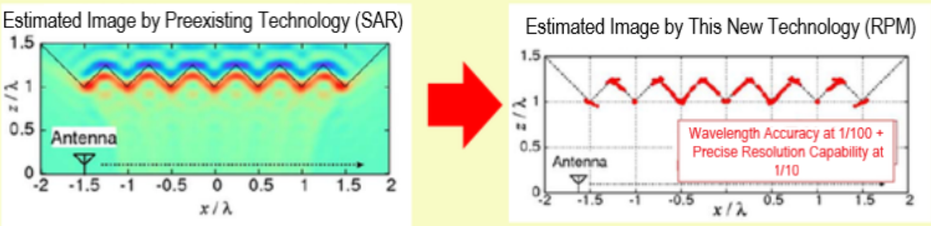
This New Technology(RPM) can Realize Wavelength Accuracy at 1/100, Precise Resolution Capability at 1/10 and Ultra-High-Speed Computer Processing



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Tomography Technology

Possibility for nondestructive examination technology which can realize secured maintenance precisely and efficiently compared with existing supersonic deep wound technology (High capability to Identify and discriminate cavities and water precisely)

Background

The deterioration of social infrastructures such as roads, bridges, tunnels, etc. is a critical issue closely related to The National Resilience Plan and the nondestructive examination technology is highlighted to examine the status of deterioration. The deterioration of infrastructure may cause big accidents like that of Sasago Tunnel on the central expressway. Since the examination requires huge cost and workload, the managers of local governments and local communities must control the maintenance work schedule under the limited budget and resources.

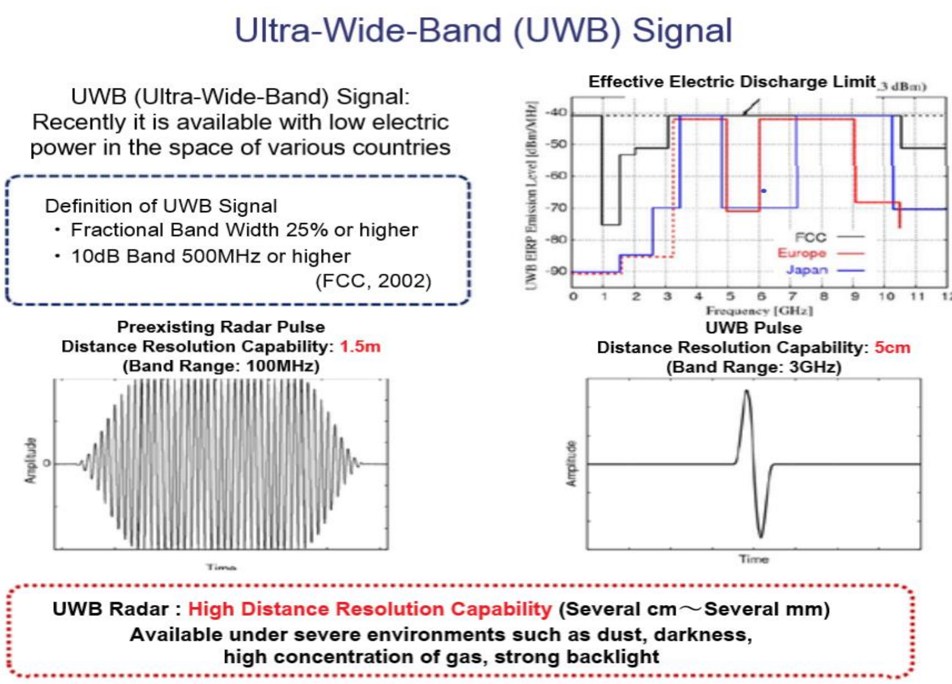
(Photo of ceiling collapse accident in Sasago Tunnel on the central expressway)

In our laboratory, we have been studying nondestructive examination technology which can realize infrastructure maintenance by examining the inside of concrete constructions precisely and efficiently.

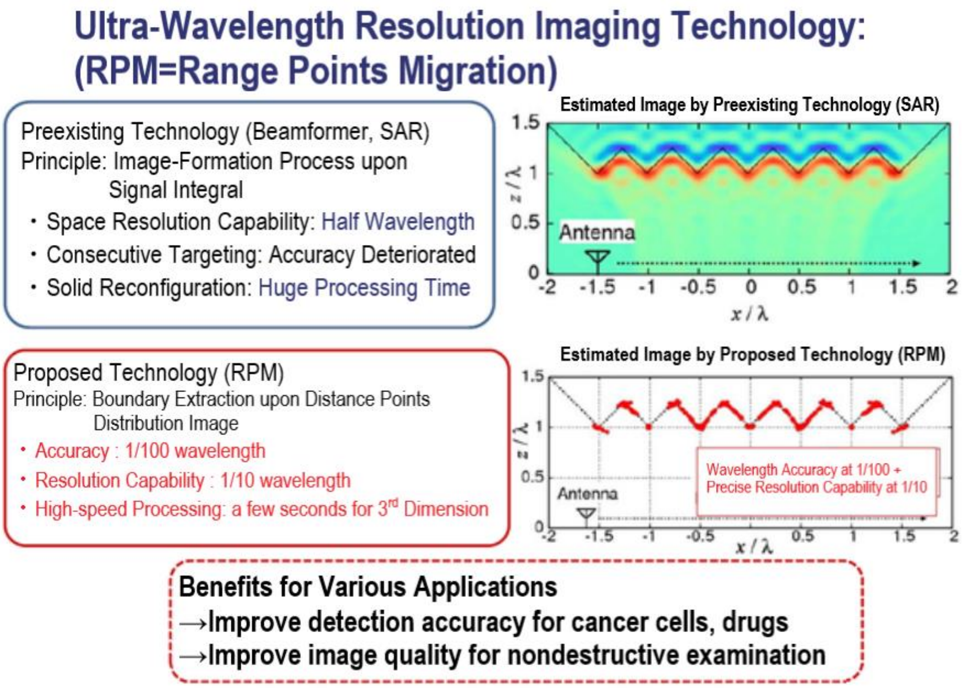
We welcome companies that are willing to apply this new technology to commercial products and popularize them.

Technical Content

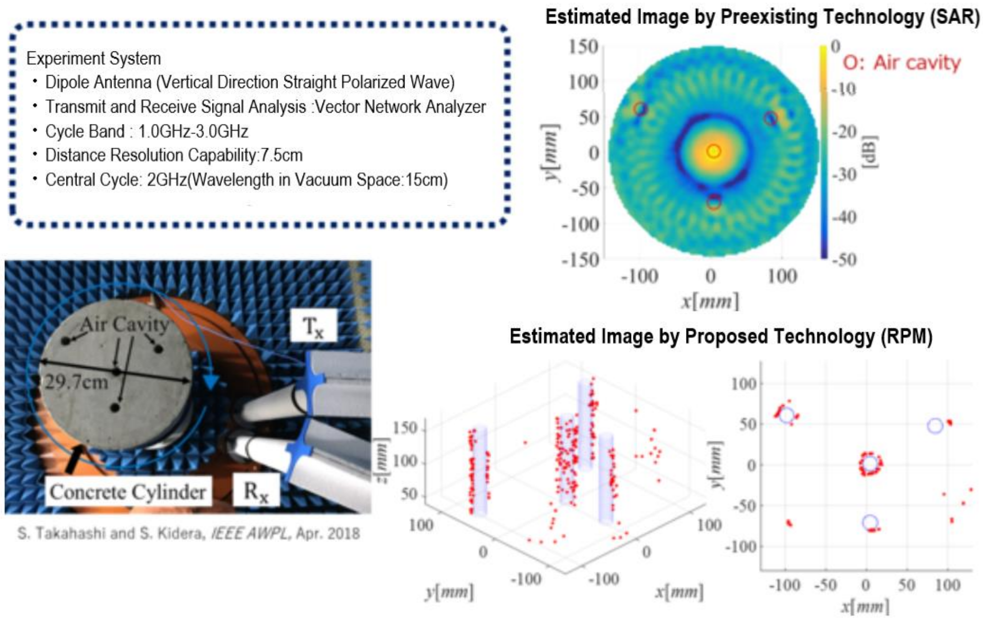
We have been studying radar measurement technology using UWB (ultra-wideband).Compared with the preexisting radar, UWB pulse has a characteristic that the distance resolution capability is higher at several centimeters to several millimeters. For example, when 3 GHz band is used, the distance resolution capability becomes 5 cm in free space, and 1 or 2 cm in concrete.



In imaging technology using radar, "Synthetic Aperture Radar (SAR)" was used as a conventional technology. In our study, we focused on a new technology called as RPM (Range Points Migration) method. When 100% monocycle pulse is used in the fractional band width, the accuracy is improved to 1/100 wavelength compared with the central wavelength and the resolution capability becomes 1/10 at high resolution ratio, consequently ultra-high-speed computer processing can be realized.

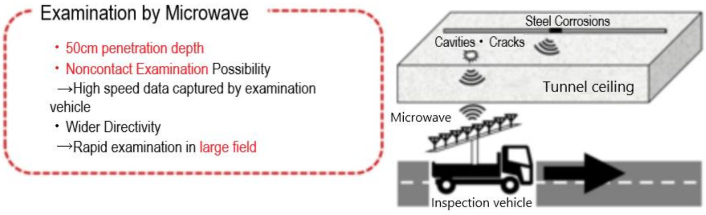


RPM method is a suitable technology for internal visualizing. The following diagrams show an experimental evaluation when 4 cylindrical cavities with several mm diameters are set in the cylindrical concrete. The upper right-hand diagram shows an estimated image by SAR which is the conventional examination method. A false image occurs due to the topology indeterminacy and the boundaries of cavities is unclear. This means the resolution capability is not enough. Also, it has been confirmed that the computation time is very large. The lower right-hand diagram shows an estimated image by RPM method, in which the boundaries of cavities became clear without false image by applying RPM method to the internal visualization. The shape can also be estimated very accurately. Therefore, it is possible to examine the internal status precisely.



S. Takahashi and S. Kidera, *IEEE AWPL*, Apr. 2018

Also, information about permittivity and conductivity is useful to identify corrosion of cavities and reinforcing steels.



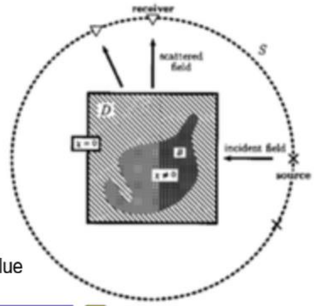
Complex permittivity comparison

f = 10GHz	$Re[\epsilon_r]$	$Im[\epsilon_r]$
Cavity	1	0
Concrete	7-8	0.01
Salinity Rust[1]	5-6	0.5
Red Rust[1]	8-10	1.0
Black Rust[1]	12-13	2-2.5

Therefore, tomography technology is effective to reconfigure permittivity. On the other hand, the ordinary tomography can measure data in all the directions, but the ordinary nondestructive examination can capture scattered data only obtained by limited illumination angles. Consequently, there is a problem that the preexisting technology cannot obtain enough accuracy for permittivity reconfiguration. In order to solve this problem, we have established a technology to estimate the distribution of permittivity at high precision by narrowing down the region of interest (ROI) and dramatically reducing unknown number to alleviate an ill-conditioned feature.

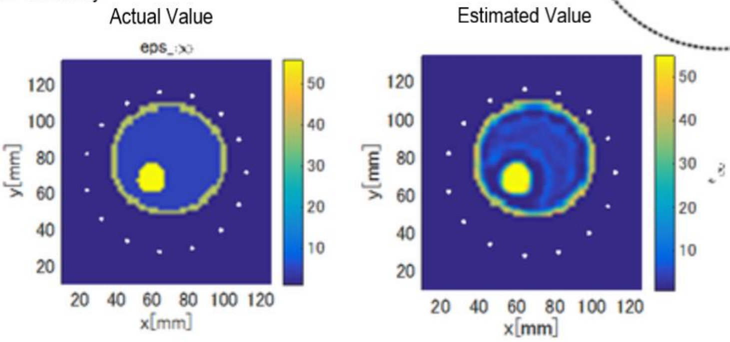
Field Integral Equation

$$E^{\text{scat}}(\boldsymbol{x}^R) = E^{\text{total}}(\boldsymbol{x}^R) - E^{\text{inc}}(\boldsymbol{x}^R)$$
$$= k_b^2 \int_D g(\boldsymbol{x}^R - \boldsymbol{x}')\chi(\boldsymbol{x})E^{\text{total}}(\boldsymbol{x})dv(\boldsymbol{x}')$$
$$\chi(\boldsymbol{x}) = \{\varepsilon_r(\boldsymbol{x}) - \varepsilon_b\}/\varepsilon_b$$



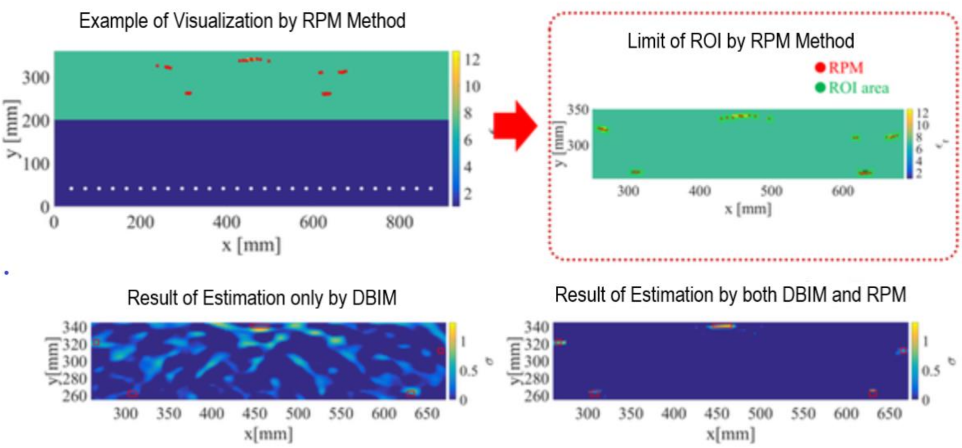
DBIM(Distorted Born Iterative method)による

Result of Estimated Permittivity



Disadvantage: Dispersed data is required from all the directions and computation cost is high

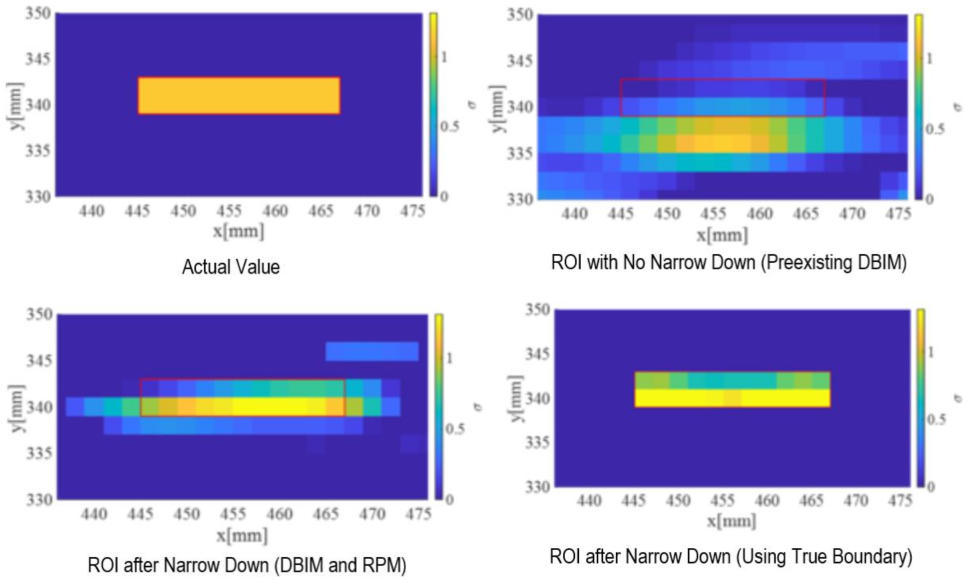
It is important to narrow down ROI data precisely, and in this study, we have succeeded to estimate relevant ROI by using Bayesian approach. If we look at the following diagrams, it's clear that we could reconfigure the permittivity and conductivity very precisely, which are equivalent to cavities and steel corrosions by combining UWB radar, RPM method and tomography technology.



Estimated Accuracy: depending on narrowing down ROI

・introduced Bayesian approach (target distribution model)

The below diagrams are zoom up for the result of permittivity around the rusts. The result of tomography (DBIM method) indicates that the value of conductivity and the position of shape are shifted against the actual value in the left upper-hand diagram, on the other hand, the result after combining RPM method indicates that almost correct permittivity was reconfigured at the original position.

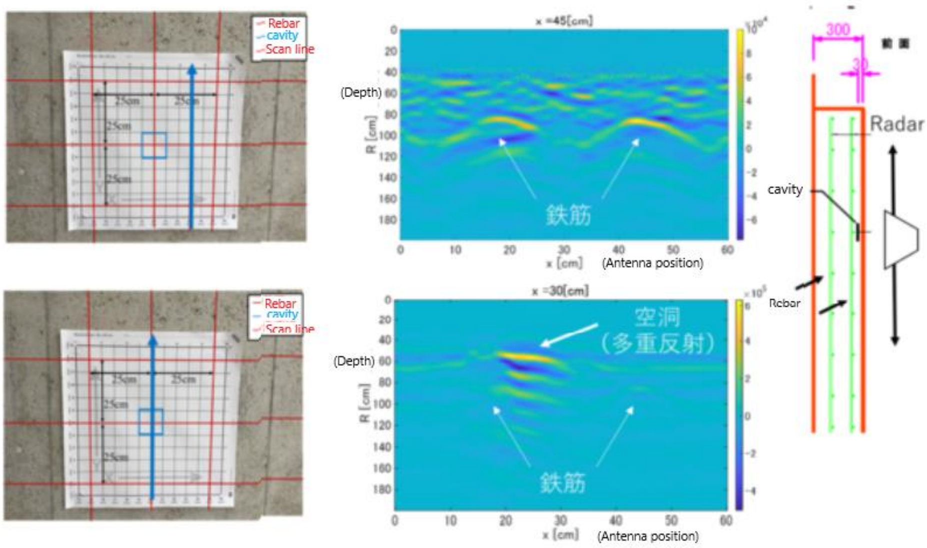


As shown in the diagram below, we conducted experiments using a test tunnel at Nagoya University. In the test tunnel, artificial cavities were intentionally placed in the concrete to fix the size and the position in advance, so it was possible to execute quantitatively accurate verification. In the diagrams below, if we look at the test with no cavities (upper diagram) and that with cavities (lower diagram), we could obtain meaningful reflection of cavities with 3mm thickness from the reinforcing steels and it's proved that the radar could detect exogenous materials.

Test Tunnel:

・Nagoya University New Bridge Concrete Test Tunnel

Cavity Size : 100mm×100mm×3mm



In our laboratory, we will go ahead with both multi-dimensional and highly precise microwave imaging technologies in terms of both hardware and software, including analysis of the above experimental data.

Strengths of the Technology and Know-How（Novelty, Superiority, Utility）

The development and practical application to product are ongoing as a nondestructive examination technology for concrete, etc.

1）Phased array ultrasonic deep wound method

This method can obtain cross-sectional views from the inside of contractures and identify the shape and size of wounds or cracks by taking the following processes.

(1) Arrange many ultrasonic oscillators in line or plane

(2) Adjust the respective oscillators

(3) Converge ultrasonic at the specific depth and position

(4) Process the image by scanning the position of convergence in upper, lower, right and left.

Since the same defects can be detected from many positions and directions, the detection accuracy is so high. Also, the operation is easy and safe because it does not use radiation for human body as well as there are no legal restrictions.

However, for concrete structures, attenuation of ultrasonic and pebbles in concrete cause big irregular reflections, so adjustment by image processing is important. Also, it requires much time and operational burden because the examination must be done by each contact.

２）Neutron transmission method

This is a nondestructive examination method utilizing large transmittance for iron and concrete.

It can visualize the part of iron and water in concrete by utilizing the difference of transmittance.

For practical applications, the beam intensity enhancement for small neutral resources and the improvement of detection sensitivity are issues to be solved.

Also, when it is used outdoors, radiation shield and area management are required.

３）Infrared thermography method

If there are peelings, cracks, and cavities on the concrete surface, the temperature of such parts is different from that of the other parts, infrared thermography can detect the difference of temperature and realize nondestructive examination. However, it’s impossible to detect those in the deep part of concrete from the surface.

In our new technology, as the characteristics of the UWB radar, it can realize contactless penetration into the wide and deep part of concrete and obtain the information of permittivity by utilizing RPM method and tomography, so it can examine inside of concrete precisely. That’s why this technology is advanced and better than other preexisting technologies.

Image of Collaborative Companies

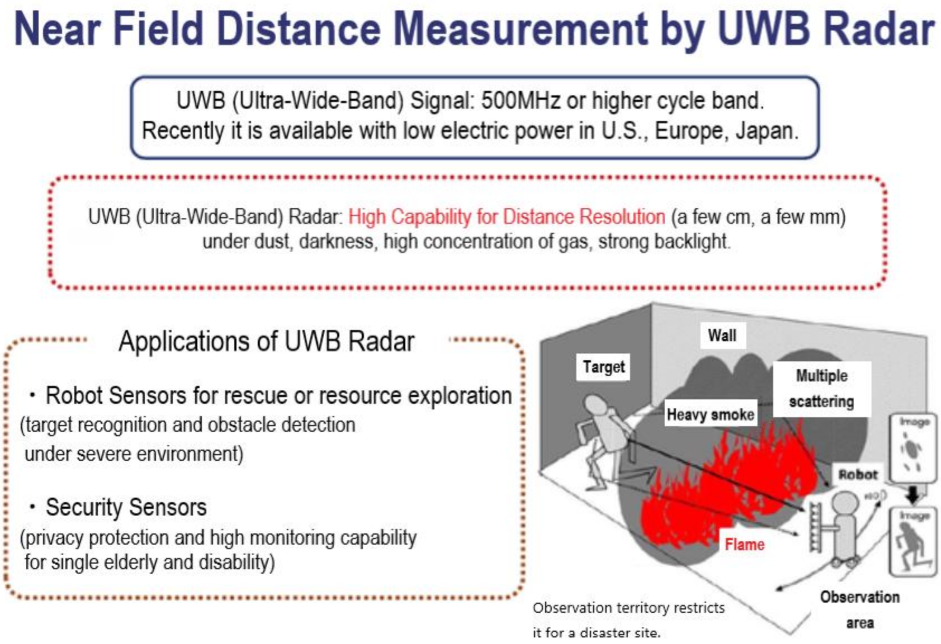
We welcome companies that currently develop, manufacture, sell infrastructure maintenance equipment or nondestructive examination apparatus and are willing to commercialize and populate our new apparatus. We also welcome interests for developing a new nondestructive examination apparatus not only for concrete constructions but also in any categories by utilizing the characteristics of UWB radar.

Since we have knowledges about radar, tomography, microwave imaging technology, and electromagnetic field analysis is in our laboratory, it is possible to cooperate with any companies without those knowledges.

Utilization of Technologies and Know-How (Images)

As described previously, basically it can be utilized for nondestructive examinations on concrete constructions such as roads, bridges, and tunnels. It can visualize the images of cracks, metals, water and so on by optimizing the difference of permittivity between concrete and target objects. In this explanation, concrete is cited as a typical example, but it can be applied to other materials and can be used for any nondestructive examination apparatuses for other objectives. Since it can examine in non-contact and high-speed real-time manner, it is workable even in the case that workers only move in the tunnel taking the UWB radar examination apparatus to complete the examination. In recent years, robot technology is highlighted for infrastructure examination, so it can be used as a sensor for the robot as well.

UWB radar is workable even under the bad conditions such as dust, darkness, high concentration of gas, and strong backlight as indicated in the following diagrams.



This technology is applicable to detect buried objects underground and explore resources like metals by utilizing its high penetration capability.

Flow of Technology and Know-How Application

If you are interested in this technology, please feel free to contact us. We will provide a detailed explanation about UWB radar using demonstration apparatus and technology contents.

Description of the Technical Terms

【 UWB (Ultra-Wideband) 】

UWB is one of the radio communication systems, which can send and receive data dispersing into wide range of cycle band around 1 GHz. Since the data transmitted to each cycle band has small intensity at noise level, so it does not cause confusions with other radio equipment using the same cycle band, and the electric power consumption is small. UWB has 3 functions such as position measurement, radar, and radio communication as a unique radio application technology.

【 Radar 】

Radar is an apparatus that clarifies the distance and direction of object by sending radio wave toward the object and measuring the reflected radio wave. Radar is used for recognizing and indicating the positions of aircrafts / ships, measuring rainfall cloud quantity, speed of movement as well as detecting obstacles by measuring the distance between objects with radio wave.