NTT R&D of Systems and Devices for Safety

Kimihisa Aihara† *and Naoya Kukutsu*

Abstract

In this article, we introduce NTT's research and development (R&D) of imaging and sensing technology for *making the hidden visible* in order to make our lives safe.

1. Introduction

Since the major earthquake that occurred in eastern Japan last year (on March 11, 2011), expectations for technology that supports safety in our lives have increased. NTT has long been engaged in four broad fields of research and development (R&D) related to imaging and sensing technology to support safety from the viewpoints of meeting current needs and sowing seeds for the future (**Fig. 1**).

Representative of the former viewpoint is R&D of facility management for the maintenance and management of basic communication facilities, particularly aiming for greater accuracy and efficiency in the inspection and diagnosis of concrete structures such as concrete poles, cable tunnels, and office buildings.

For the latter, there is R&D of new imaging and sensing technology that uses terahertz waves, which occupy a frequency band that is currently undeveloped for basic communication technology. Lying between radio waves and visible light in the electromagnetic spectrum, terahertz waves hold promise for contributing to a safer and more secure society through skillful use of the features of both radio and light. They allow the implementation of new application fields that have previously been impossible, such as remote gas sensing and spectroscopic analysis [1], [2]. Another example is technology for detecting harmful substances based on NTT's own µTAS (micro-total analysis system), which uses ultraviolet region spectroscopic analysis technology [3]. In those R&D activities, repeated simulations based on theory and measurements are used to understand electromagnetic wave propagation or gas flow path behavior for application in device design and manufacture. Furthermore, the sensitivity of sensing and analysis is improved by the addition of signal processing, with the result that these various systems are almost ready for use.

In this article, we describe our efforts in the above-mentioned areas.

2. Concrete structure crack detection technology

NTT maintains a nationwide network of concrete poles, cable tunnels, office buildings, and other concrete structures that support communication services. Those facilities were mainly constructed during the period of rapid growth, so many of them are over 40 years old and are beginning to deteriorate. This situation has made facility management an important issue.

The position of current concrete pole inspection methods and current R&D of new inspection methods is illustrated in **Fig. 2**. Here, we introduce image analysis and millimeter-wave imaging techniques for crack detection.

Surface cracking in concrete structures allows moisture to enter and corrode the iron reinforcement bars inside, reducing the strength of the structure. For that reason, information about the presence of surface cracks and their number, widths, and lengths is important for structural integrity evaluation.

† NTT Microsystem Integration Laboratories
Atsugi-shi, 243-0198 Japan

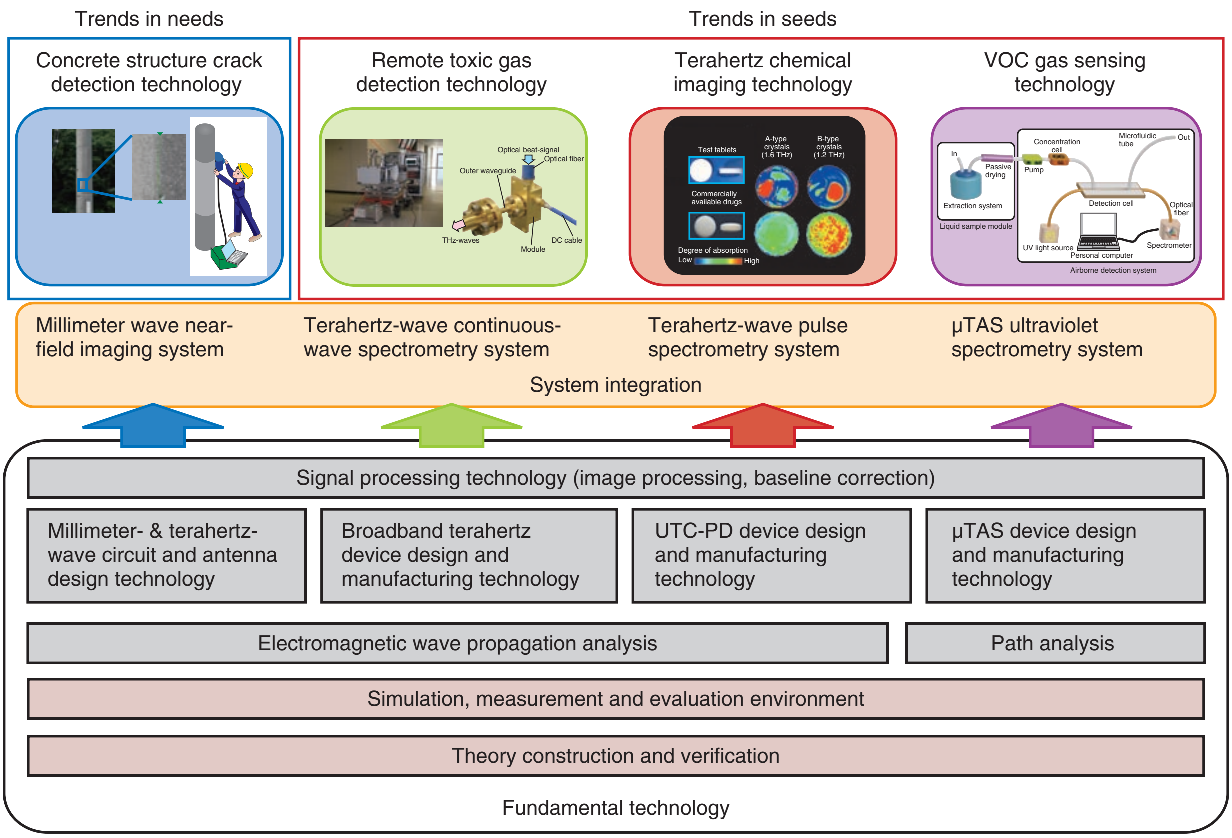
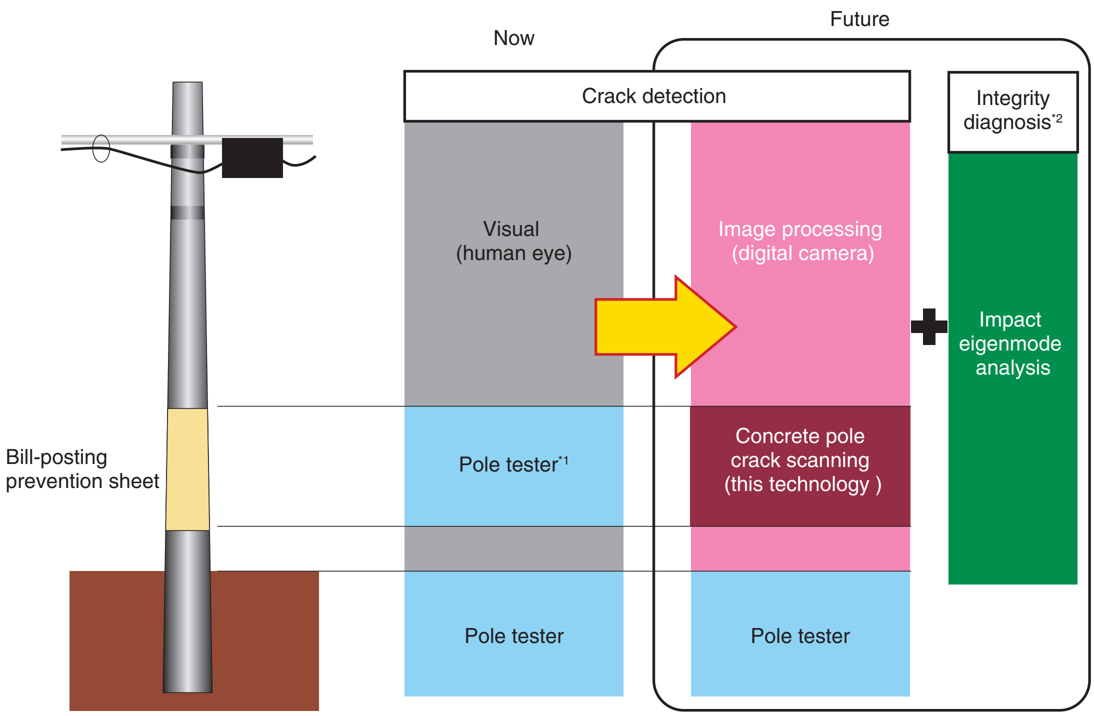


Fig. 1. Imaging and sensing technology supporting safety and security.

NTT EAST and NTT WEST together manage about 11.85 million concrete poles. Because pole inspections to detect cracking are currently done visually by workers, there is a need to develop a more efficient inspection method. Automatic crack detection by image analysis is a technique that could meet this need. However, concrete poles have foot pegs, belts, plates, and other items attached to them that hinder image analysis, so commercial software has a high rate of error in crack detection.

To solve that problem, NTT is developing automatic crack detection software that can reduce the detection errors caused by such obstacles by applying an obstacle removal algorithm and a neural network for crack shape recognition. That R&D is described in detail in the Feature Article “Detection of Cracks in Concrete Structures from Digital Camera Images” in this issue [4].

Some concrete poles have plastic sheeting attached to them to prevent unwanted posters being pasted there (bill-posting prevention sheets). Since the sheeting blocks the concrete surface from view, ultrasonic inspection equipment (pole tester) is used. However, ultrasonic inspection has difficulty detecting fine cracks. Moreover, the surfaces of many concrete structures other than poles are often painted, wallpapered, tiled, or covered with reinforcing material that makes visual inspection difficult. Techniques for detecting cracks below such coverings include the use of ultrasonic waves and x-rays, which can pass through the coverings. Ultrasonic waves are used to measure cracks that are more than one millimeter wide, but that resolution is insufficient for early detection of cracking in concrete poles, which requires the detection of submillimeter cracks. X-rays have an extremely short wavelength that allows high resolution, but x-ray inspection requires the object to be inspected to be located between a transmitter and a receiver. Moreover, x rays are harmful to humans, so x-ray equipment is difficult to use for



*1 Probes are positioned above and below the bill-posting prevention sheet, but this results in a long ultrasonic wave propagation path (about 2 m), so the accuracy is low and it is difficult to detect fine cracks.
*2 Broken rebar diagnosis equipment that uses impact eigenmode analysis is currently being developed by NTT Access Network Service Systems Laboratories.

Fig. 2. NTT concrete pole inspection technology.

inspections conducted in the field.

To solve that problem, NTT has investigated imaging techniques that use millimeter waves (77-GHz-band electromagnetic waves) to *see* what is hidden from the unaided eye. That work has resulted in the development of a portable scanner that can observe the condition of the pole surface lying beneath a bill-posting prevention sheet or other such covering. This R&D is explained in detail in the Feature Article "Millimeter-wave Imaging for Detecting Surface Cracks on Concrete Pole Covered with Bill-posting Prevention Sheet" [5]. It introduces technology for detecting surface cracks in concrete structures caused by broken rebar, but NTT Access Network Service Systems Laboratories has also been developing techniques that use impact mode analysis for diagnosing rebar deterioration.

3. Basic technology for terahertz wave signals

Terahertz waves are electromagnetic waves in the frequency range from 300 GHz to 3 THz (wavelength: from 100 µm to 1 mm). They have the ability to pass through some materials and exhibit absorption lines that are specific to the material. These characteristics can be used to identify materials. Another feature is that this radiation is not as harmful to the human body as x-rays are. If these features can be applied to imaging and sensing, they will make it possible to obtain new data that cannot be gathered by conventional techniques that use x-rays, infrared radiation, or microwaves, and we can expect many applications. What has prevented industrial applications so far is that it is very difficult to generate sufficiently strong terahertz waves over a wide frequency range by using electrical technology. The reason is that no efficient means of generating terahertz-band electromagnetic waves has been established because these waves exceed the operating frequencies of transistors and other active devices [6].

NTT has applied many years of optical communication R&D to develop new technology that uses a uni-traveling carrier photodiode (UTC-PD). The UTC-PD, which features an extremely fast response,

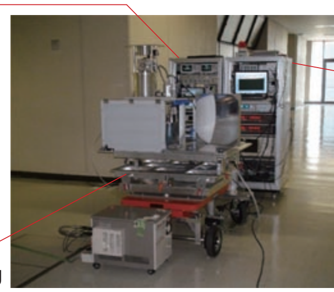


Fig. 3. Remote gas detection equipment.

was originally developed for use in communications to convert an optical signal into an electrical signal. The new UTC-PD-based terahertz-wave generator uses a UTC-PD to convert an optical signal into an electrical one, which is then converted to produce terahertz waves [7]. This technique uses the stable, broadband, ultrahigh-frequency characteristics of photonics to generate terahertz-band electromagnetic waves for various applications. In this way, imaging and sensing with this frequency band is made feasible. This R&D is explained in detail in the Feature Article “Development of Terahertz-wave Photomixer Module Using a Uni-travelling-carrier Photodiode” [8].

4. Remote detection of dangerous gases with terahertz waves

At the site of fires or other disasters, a rapid response is needed to prevent secondary damage. There is thus a pressing demand for the development of systems that can detect carbon monoxide, hydrogen cyanide, and other dangerous gases from a remote location.

NTT is engaged in R&D for applying its terahertz-wave generation technology to the remote detection of dangerous gases (**Fig. 3**). Terahertz waves differ from light in that they are not scattered by dust or smoke and they can propagate through a fire without any significant attenuation. Moreover, because terahertz waves resonate at a frequency of rotation and vibration of gas molecules, dangerous gases have specific absorption spectra for this frequency band, and the absorption line patterns can be used to identify the types of gases present. These properties can be used to detect toxic gases from a safe distance, even under conditions of extremely low visibility due to smoke etc.

NTT has developed a prototype system for remotely detecting dangerous gases under a commission from the National Institute of Information and Communications Technology and in cooperation with the University of Tokyo, the National Institute of Advanced Industrial Science and Technology, the Spectra Design Company, and others. This system was tested and evaluated in a full-scale simulated fire environment at the Fire Research and Test Laboratory of Tokyo University of Science. The tests verified the system’s effectiveness for remotely detecting hydrogen cyanide gas as an example of a dangerous gas. This R&D is described in detail in the Feature Article “Remote Detection of Hazardous Gases in Full-scale Simulated Fire by Using Terahertz Electromagnetic Waves” [9].

5. Terahertz spectroscopy

Terahertz spectroscopy is an analytical chemistry technique that identifies substances by detecting hydrogen bonds and hydrate bonds and their interactions with other molecules [2] (**Fig. 4**).

By improving the latest terahertz-frequency components such as ultrashort-pulse lasers and photoconductive antennas, we are approaching realistic terahertz chemical imaging (TCI) and analysis technology. Because TCI can clarify the distribution of hydrogen bonds and molecular networks, it is expected to be a powerful tool for biology, pharmacology, and the life sciences. TCI technology can determine the two-dimensional distribution of molecules on the basis of molecular networks revealed by terahertz-wave absorption spectra. As an application to actual pharmaceutical molecules, two polymorphs of famotidine, a component of histamine receptor antagonist (H2 blocker) antacids, have been distinguished in pills. Polymorphs are composed of the same

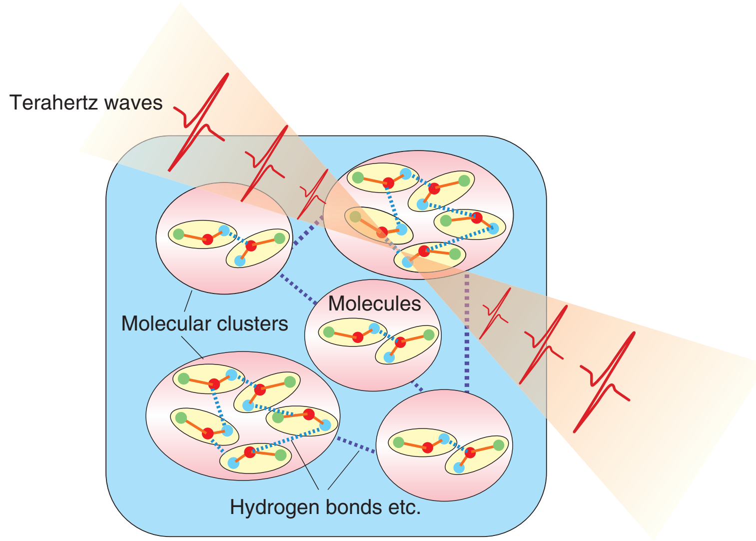


Fig. 4. Concept of terahertz spectroscopy.

molecules, but differ in how these molecules are linked. Large differences in the effectiveness of polymorphic drugs due to differences in chemical properties have been reported. New detection methods thus have major significance for the development of even safer pharmaceuticals.

This R&D is described in more detail in the Feature Article "Visualization of Pharmaceutical Drug Molecules by Terahertz Chemical Imaging" [10].

6. VOC gas sensing by ultraviolet absorption spectrometry

The Ministry of the Environment has established standards for benzene, toluene, xylene, and other highly toxic, aromatic, volatile organic compounds (VOCs) as dangerous gases in our environment besides combustion gases such as carbon monoxide and hydrogen cyanide to which terahertz waves have been applied for remote detection. The sources of those toxic gases include gasoline stations, printing shops, paint shops, and other small-scale facilities as well as large-scale facilities such as chemical plants, steelmaking plants, oil refineries, and power plants. Such facilities may release even larger amounts of dangerous materials into the atmosphere during an earthquake or fire. Those pollutants, together with radioactive pollution, are becoming a cause of serious environmental pollution. Besides earthquakes and other disasters, the deterioration of gasoline station facilities with age and other such situations present the danger of toxins leaking onto the ground surface or into groundwater. The methods of detecting such dangerous substances have generally been analytical ones that combine gas chromatography and mass spectroscopy. Such methods are performed in laboratories and require a large amount of equipment. They also rely on manual collection of gas samples. All of these factors hinder immediate and continuous measurement and increase costs, making them unrealistic for constant monitoring of the environment.

For these reasons, NTT has developed a compact and highly sensitive gas sensor system, which uses NTT's own μTAS together with ultraviolet spectroscopic technology. Even though the system's structure is simple, its sensitivity to minute quantities of gas is 1000 to 10,000 times greater than previous methods and it can perform continuous monitoring.

Recently, we have also achieved a detection sensitivity of 1 ppb or better for benzene in water by adding a liquid sample module based on newly developed bubbling and pervaporation methods [3] (**Fig. 5**). This R&D is described in detail in the Feature Article "Portable Sensor for Determining Benzene Concentration from Airborne/liquid Samples with High Accuracy" [11].

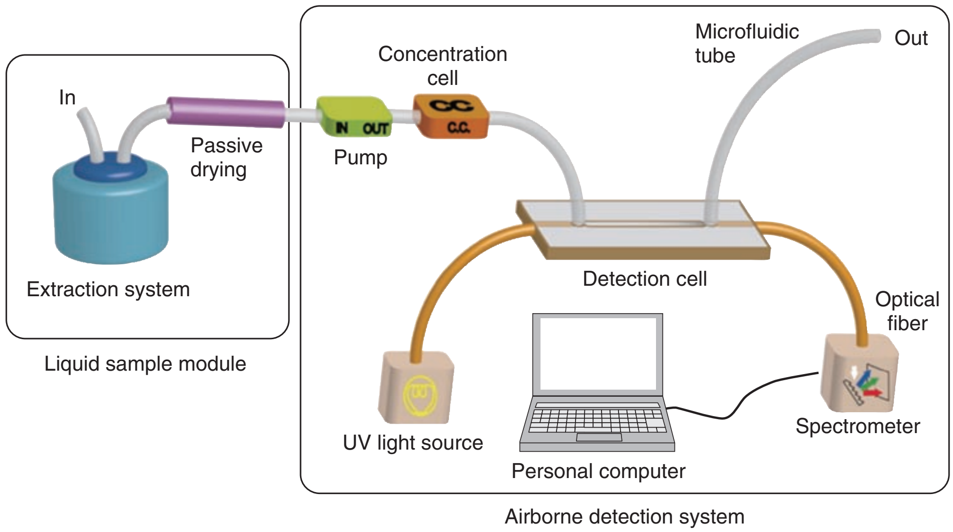


Fig. 5. Equipment for detecting benzene in water.

7. Conclusion

We have presented an overview of the work on imaging and sensing technology for safety that is underway in NTT. Efforts to improve the practicality and performance of the technology introduced here are continuing. Our objective is to achieve a safe and secure society by timely response to needs both within and outside NTT and by creating new technology.

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Kimihisa Aihara
Director, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.E. degree in electronics from Keio University, Kanagawa, in 1984. He joined Nippon Telegraph and Telephone Public Corporation (now NTT) in 1984. He is currently responsible for ubiquitous communications appliance technologies at NTT Microsystem Integration Laboratories. He is leading R&D projects on sub-terahertz-wave wireless communications, ultralow-power network appliances and electrical near-field communication for human area networks. He is a member of IEEE and the Institute of Electronics, Information and Communication Engineers (IEICE).

Naoya Kukutsu
Senior Research Engineer, Supervisor, Group Leader, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.E., M.E., and D.E. degrees in electrical engineering from Hokkaido University in 1986, 1988, and 1991, respectively. His D.E. dissertation described research for a time-domain electromagnetic wave numerical analysis method. In 1991, he joined NTT Applied Electronics Laboratories in Musashino. His current research involves millimeter-wave and terahertz-wave transmission, as well as imaging systems. He is a member of the IEEE MTT and COM Societies and IEICE.