Novel sensing techniques of chipless RFID sensor for infrastructure

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Abstract:
Monitoring applications using sensors are being led by the government to address the problem of aging infrastructure in Japan. There are various methods for sensing but the durability of general infrastructures and buildings have already exceeded 30 years which makes it difficult to address the issue. As one of the solutions we focused on the technology of "Chipless sensor" that applies “Chipless RFID” technology composed only of metal patterns without using electronic components such as IC chips. This report describes a sensor that can detect moisture with just metal patterns by supplying power from the reader.

Keywords: Chipless RFID, sensor, moisture detection, infrastructure
Classification: sensing

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1 Introduction

With the expansion of IoT technology, various products equipped with communication and sensor functions have been introduced. Under such circumstances, RFID technology that can operate under a little power solely by radio waves is attracting attention, and expected to be introduced into infrastructure facilities due to its little energy operation [1]. On the other hand, the durability of infrastructure and buildings has already exceeded 30 years, so even a battery-less RFID sensor is difficult to meet the durability. In order to solve this challenge, we looked into a possibility of “Chipless RFID sensor (Chipless sensor)” [2] technology that can detect the sensor value only with metal pattern. By irradiating electromagnetic waves, the metal pattern resonates and can detect the sensor value. There is no need for electronic components such as IC chips on the tag side. Therefore, long-term durability can be expected. In this paper, we report a sensor that detects the moisture by “Chipless sensor” technology in the real environment. And those researches would pave the way for detecting water leakage of the infrastructure over long period.

Fig. 1. a) Overview of Chipless sensor, b) Overview of Chipless Tag, c) Tag peak of when Tx:pararell /Rx:Orthogonal and Tx/Rx:Orthogonal
2 Chipless Sensor Detection System

Fig. 1 (a) shows the configuration of the chipless sensor system. The tag has a metal etched pattern on the base material. In these researches, we adopted the frequency-domain system where IDs are generated as resonance peaks in specific frequency band [2]. Electromagnetic waves were irradiated toward the chipless sensor using a network analyzer (KEYSIGHT: E5071C), and the reflected waves were detected as resonant peak of Radar Cross Section value using reference sphere. Since the wide frequency band could generate multiple resonance peaks, the UWB band (7 to 10 GHz) is utilized which is legally allocated wide band frequency in Japan. Horn antenna is used for Tx and Rx antenna (Band: / Gain15dBi @ 10 GHz).

2.1 Chipless Tag

Details of the tag are shown on the Fig. 1(b). The tag has a three-layer structure composed of copper foil and low dielectric loss material. A low dielectric loss material (MEGTRON6 R-5775N: 250 μm thick) sandwiches the copper pattern and solid copper foil (Copper: 18 μm thickness). Electromagnetic waves coming from Tx antenna resonate with each chipless sensor, and each reflects waves received by Rx antenna. The reflected wave is not modulated and is disturbed by the attached material and the surrounding environment. Since the tag has a sandwich structure for generating an electric field between the upper and lower copper foils, the influence on the back side is mitigated [3].

2.2 A depolarizing chipless RFID tag for robust detection

However, when a tag is attached on the actual objects such as wood wall, cardboard box and concrete blocks, tag peaks are buried by standing waves of objects. Thus, technologies that mitigate the effects of standing waves have been proposed [4, 5]. By making Tx and Rx orthogonal, each electric field plane also becomes orthogonal, making the standing wave of the object smaller, and the tag peak clearly detectable. Fig. 1(c) indicates two tag peaks of the Tx and Rx electric field in parallel (V) and orthogonal (H) to each other, and the parallel is flat and almost has no peak, while the orthogonal is above the peak at around 8.6GHz. It is, therefore, easy to detect the peak by making Tx and Rx orthogonal.

3 Angle Control for Fine Detection

Fig. 2 (a) shows a chipless sensor that consists of 12 elements in one plane, assuming moisture detection such as a water leakage. The Radar Cross Section results of the electromagnetic simulation (ANSYS Electronics) are shown on the right side of the Fig.2 (a), and it can be confirmed that 12 peaks appear between 7.5 and 9.5GHz. For easy understanding, red dots are marked on the each peaks at Fig.2 (a). However, in actual measurement, Tx and Rx are broadband horn antenna, the distance between the antenna and the tag is 50 cm, and the transmitted and received angle is set at 30 degrees. As shown in Fig. 2(c), the transmitted and received angle is defined with reference to a line passing through the center of objects. As a result is shown in Fig.2 (b), sensor peak could not be detected well,
especially on the high frequency side. Because of the frequency characteristic, it is assumed that there is an influence of object reflection. Therefore, we tried to confirm the reflection of the tag and the object. The reflection intensity was measured by changing the transmitted angle, fixed with received angle as 30 degrees. The result shown in Fig.2 (d), confirmed that the tag had a strong peak at the 0° direction, whereas the object had directivity at the 30° direction. In order to evaluate the angle effect of the chipless sensor as shown in Fig.2 (d), the reflection intensity was read by placing the Rx so that received angle was 0°, 30°, and 60° in front of the Tx toward the object. When it was set at 0°, 12 peaks could be clearly detected. On the other hand, at 30° and 60°, the peaks at low and high frequencies were particularly dull. This is because some sensor elements at both ends carrying low frequency and high frequency side could not be received by the surrounding noise.

**Fig. 2.** a) 12elements of sensor tag(tag components, simulation results ), b) 12elements of sensor tag peak of actual environment, c) Overview of directivity measurement, d) Reflection intensity of Tag and Cardboard , e) 12elements of sensor tag peak when transmitted angle 0, 30, 60 degree
4 Water Detection on Concrete Blocks

Assuming installation on an infrastructure, the chipless sensor tag were attached to 300 \( \times \) 300 \( \times \) 50 mm concrete block. As shown in Fig. 3 (a), when water droplets were dropped on several sensor elements, the sensor value could be detected as lost peaks. In this system, the peak of the element with water disappears, and the peak without water remains unchanged, so the position with water can be clearly detected. Sensors using RFID could also perform water detection due to the loss of tag functionality [8], however chipless sensors could identify the position of water adhesion. And this is the key feature of chipless sensor.

Furthermore, when a large amount of water is dripped on the assumption of water leakage, the sensor value as shown in Fig.3 (b) was confirmed. It was found that even when water entered the back of the element, since the floor level was not greatly lowered, moisture on the surface alone could be detected accurately.

![Water droplet](image1.png)

![Water leakage](image2.png)

**Fig. 3.** a) Sensor Peak when assuming of dripping water,
b) Sensor Peak when assuming of water leakage
5 Conclusion
In this paper, we showed the possibility of utilizing chipless sensor for infrastructure by adjusting the reading angle.

In the future, it will be necessary to structure a system that can detect the peak in concrete or in some other objects in consideration to embed in the structures.

In addition, since the outdoor use of the UWB band investigated this time is legally limited to few frequencies, it is necessary to solve this point and problems when using it in infrastructure applications.

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