NEW APPLICATIONS OF RADIO WAVES IN PHYSICAL SENSING

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Abstract

The popularity of Cyber-Physical Systems, which aims to optimize real-world information in cyberspace to control physical spaces efficiently, is expected to grow. In order to advance them, improved sensors are necessary to capture real-world information. Although various sensors using various media such as ultrasonic and infrared waves have been developed in the past, research on new sensing methods that utilize radio waves is ongoing. This article introduces our current research on proximity and paper-thin sensors that use radio waves and discusses the future challenges for these sensors.

Introduction

Sensing technology is getting more and more important for automating our societies. Its demand is rising with the growing popularity of Cyber-Physical Systems (CPS) in various fields such as optimizing factory production lines and public transportation systems.

Sensors come in contact and non-contact types, and the latter has advantage of detecting objects without wearing and tearing on the contact surface, dirt transfer, and fast-moving objects. Different sensor types based on physical phenomena have distinct strengths and weaknesses. For instance, sensors using magnetic forces can only detect metal, while those using light cannot detect transparent objects.

Recently, attention has shifted towards sensing methods using radio waves, which realize new sensing technology. Traditional radio wave sensors include touch sensors that use electrostatic capacitance and distance detectors using radar, which is now also being applied to vital sign detection in recent years. Moreover, the research aims to add sensing capabilities to Wi-Fi devices has been emerging [1].

Radio waves offer physical properties that enable to measure phenomena that were difficult to be measured by the existing approaches. Compared to the light and laser commonly used in the current sensing technology, radio waves are less affected by color and surface treatments. Furthermore, radio waves can pass through objects, allowing non-destructive detection of internal states. For example, non-contact detection of pressure ulcers within human body is under investigation [2].

Radio waves require antennas to radiate, and their shapes can be flexibly designed such as thin wires or plates on substrates, flexible films, and transparent antennas. Thus, new installation methods are possible.

However, using radio waves for sensing technology has some drawbacks, such as the potential for false detection due to strong electrical noise from nearby devices and unexpected reflections from objects. Nonetheless, selecting an appropriate frequency band with less interference and employing narrow-band filters can reduce interference, and lead to novel sensing technologies.

Our research focuses on detecting instantaneous changes of environment in the vicinity by monitoring antenna impedance, which changes in response to environmental changes. This article introduces our method and its use in proximity and paper-thickness sensors, and discuss future challenges.

Detecting Environmental Changes through Antenna Impedance Monitoring

This method utilizes an oscillator to generate a sine wave fed into an antenna through a feeding line. It measures the complex voltage reflection coefficient of the feeding line when a weak radio wave is emitted into space (see Fig. 1). By monitoring changes in the complex voltage reflection coefficient, the system can detect instantaneous variations of environment in the vicinity. After being radiated into space, the weak radio wave passes through or reflects off objects around the antenna and returns to the oscillator through the antenna and feeding line. Therefore, the strength and phase of the reflected wave vary depending on the characteristics of the object, and this variation is utilized for sensing.

We can convert the complex voltage reflection coefficient to the antenna impedance if the impedance of the feeding line is known. This method is, therefore, equivalent to measure the antenna impedance.

A sensing circuit based on this method has been designed as shown in Fig. 2. The circuit sets the frequency difference between the feeding frequency and the local oscillator to 5 kHz. The mixer always outputs a signal that is down-converted to 5 kHz, which is then input to the bandpass filter, thereby suppressing interference at frequencies other than the feeding frequency. We are reducing the number of circuit components by implementing IQ conversion in software processing.

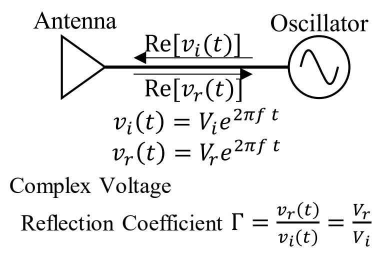

Fig. 1 Sensing Model

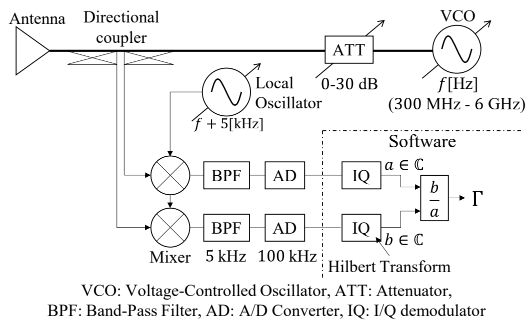

Fig. 2 Block diagram of sensor circuit[4]

Examples of Sensing Applications using Monitoring Antenna Impedance

· **Proximity sensor**

A proximity sensor detects the presence or movement of an object without physical contact and converts it into an electrical signal. Unlike contact-based sensors, such as limit switches, proximity sensors do not cause wear and tear on the object or the sensors themselves.

Various proximity sensors include induction, magnetism, electrostatic capacitance, ultrasonic sound wave, infrared wave, and even cameras or radars. For example, active infrared sensors emit near-infrared light and detect its reflection or blocking to detect objects. However, this method cannot detect transparent objects and is susceptible to false detection under sunlight.

Radio wave impedance detection is also applicable to a proximity sensor [3-5]. This method emits weak radio waves from an antenna and detects their reflection by the object being detected. The strength and phase of the reflected waves differ depending on the object's presence, allowing for detection by monitoring the difference from the case when no object is present.

We evaluated this method using a sensor with a microstrip antenna resonating at 2.58 GHz in an anechoic chamber (see Fig. 3). We measured its characteristics using a phantom block that simulated the dielectric constant of the human body. We confirmed that a strong response is obtained when the antenna and the phantom were close to each other, and it can be used as a proximity sensor at distances of a few centimeters (see Fig. 4).

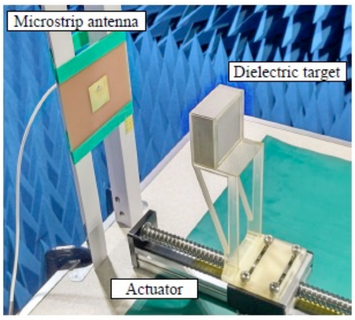

Fig.3 The experimental scene on the proximity sensor. [5]

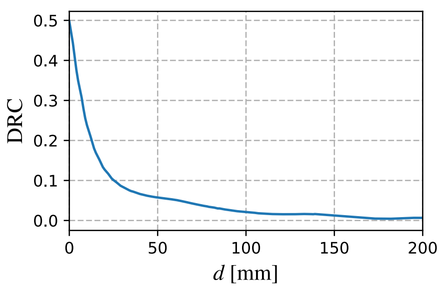

Fig. 4 Detection characteristics with respect to the distance between the antenna and the object (vertical axis: distance of reflection coefficient with and without the object)

・Paper Thickness Sensor

Paper thickness sensor is a non-contact type of sensor commonly used in paper manufacturing, printers, and scanners to detect the thickness of paper. Detecting paper thickness is important to avoid printing failures and scan errors caused by multiple sheets passing through simultaneously. Traditionally, paper thickness was detected by mechanically clamping paper, but this method has wear and tear on the mechanical components and thus leads to a short lifespan of the sensor.

Non-contact methods, such as ultrasonic, optical, and laser methods, have been developed, however they have some limitations such as requiring stationary paper and being affected by its surface properties. We propose using radio waves to detect paper thickness [5-6]. This approach involves creating a gap between an antenna and a metal plate, and measuring the complex voltage reflection coefficient. When paper is inserted into the gap, changes in the complex voltage reflection coefficient caused by the presence or thickness of the paper can be converted into the change of paper thickness measurements (see Fig. 5).

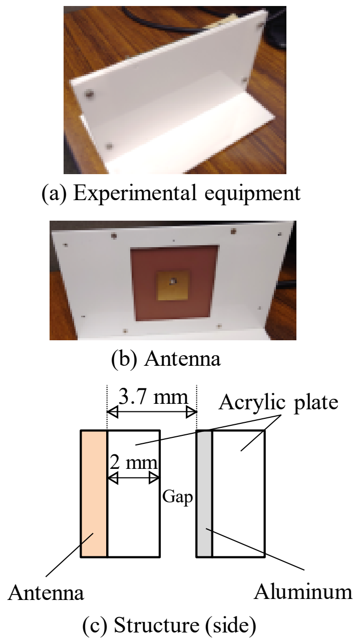

Fig. 5 Paper Thickness Measurement Equipment

Since radio waves are less affected by surface properties than light, this method is applicable to detect various types and conditions of paper. However, this method may not measure the thickness of paper with ink that contains a large amount of metal. Fig. 6 plots the complex reflection coefficient for various paper thicknesses when inserted into the gap. This figure shows that the reflection coefficient exhibits different responses depending on the paper thickness, demonstrating that this sensor can detect even small changes in paper thickness.

This radio wave-based method for paper thickness detection is promising due to its non-contact nature and potential to detect various types and conditions of paper. Future research will analyze this method to improve its accuracy and reliability further.

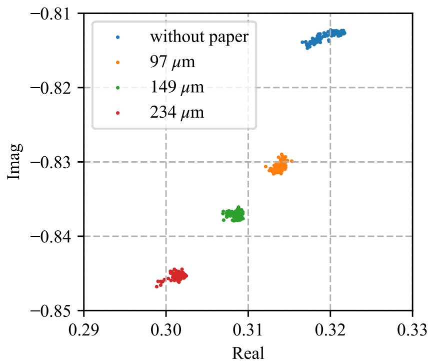

Fig. 6 Characteristics of complex reflection coefficient versus paper thickness

Future Challenges

To further advance and promote the practical applications of this sensing technology, it is essential to analyze its principles and establish a design methodology, as we currently demonstrate its effectiveness through experiments in an anechoic chamber and FDTD analysis. Currently, in this method, suitable shapes of antennas, frequencies of the emitted radio waves, and ambient conditions are needed to be selected by experts according to their application and location. Therefore, we will need further analysis of the principles to allow non-experts to determine suitable configurations for this method.

We will try to expand the scope of our method to emerge new applications. For instance, proximity sensors can expand their scope with distance detection capabilities.

While the principles of the paper thickness sensors have validated, many factors, such as vibration, ambient conditions, and mechanical structure, must be considered to design them for industrial applications. We strive to overcome these challenges, and develop stable and robust technology.

Acknowledgments

This research and development work was supported by the MIC/SCOPE #JP196000002.

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