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Sensor Networking based on Two-Dimensional Signal Transmission Technology

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Abstract: This paper introduces our project of sensor networking technology called two-dimensional signal transmission (2DST). 2DST is a new form of room-size communication, in which the signal energy is confined in thin sheets. The sheet is composed of a dielectric layer sandwiched between a conductive mesh and a continuous conductive layer, typically. Signals are sent by microwaves propagating in the two-dimensional sheet. The electrical power for the device operation is also transmitted by microwaves. The prominent feature of 2DST is that it can integrate a large number of sensor chips without electrical contacts and efforts of wiring. The simplicity of the structure enables us to form the sheet on the surfaces of various materials of walls, desks, floors, and even clothing. We already developed some types of non-contact connectors to the 2DST sheet for wide band signal transmission.

Keywords: sensor network, two-dimensional communication.

1. INTRODUCTION

A challenge in sensor networking available in rooms, vehicles, and clothes is physical connection of a large amount of sensors. Radio is a useful, and in some cases, the only way to distribute sensors on large area of plants and farmlands. In those applications, the main theme of researches is communication protocols to save extremely the energy consumptions under limited batteries. In this paper, we introduce our project of two-dimensional signal transmission (2DST) that realizes a high density of sensor embedding. We show that there exists an alternative to radio for networking within room size.

In communication of 2DST, the sensor nodes communicate by microwave propagating in two-dimensional sheet. Sensor nodes connect to the 2DST sheet without electrical contact at any location on the sheet and also receive the power for operation from the sheet. The sheet structure is simple [4, 5], and the simplicity enables us to form the sheet structure on the surfaces of various materials of walls, desks, floors, and even clothing.

The idea of communication using two dimensional medium was originally proposed by us [1] and some other groups [2,3] at the early 2000s. In the researches [2] and [3], however, high speed communication through the medium was out of consideration. In addition, mechanical and electrical contacts of elements to the conductive layers were necessary.

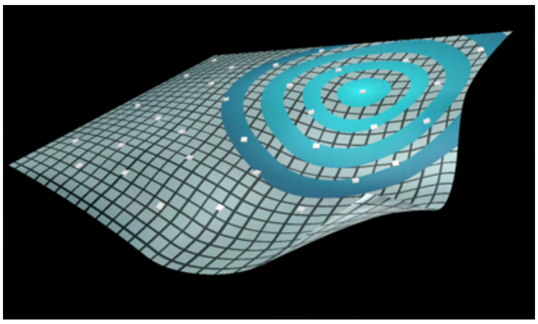
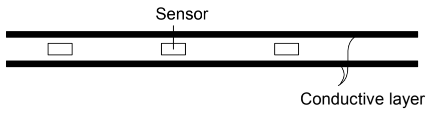


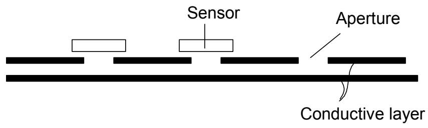
Fig. 1 The concept of 2DST. Sensor nodes send/receive packets through the 2DST sheet.

2. NON-CONTACT CONNECTION TO 2DST SHEET

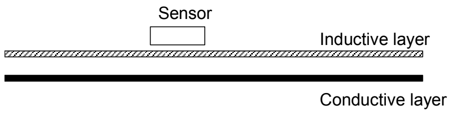
We can suppose at least four types of 2D connection as shown in Fig. 2. In the first form, the sensors are sandwiched by two conductive layers. In this structure the electromagnetic wave can be strictly confined within the sheet. TEM mode with the electric field vertical to the surface conveys the signals in this case. A small electrode on a sensor chip can obtain efficient



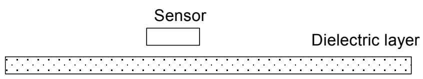
(a) Inside-connection [7]



(b) Aperture type



(c) Outside-connection [5]



(d) Connection by simple dielectric layer

Fig. 2 Cross-sections of possible types of 2DST. In our project, types (a) and (c) are intensively developed.

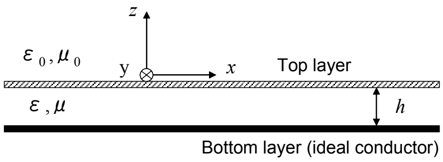


Fig. 3 Coordinate system and sheet parameters.

non-contact connection between the electrode and the 2DST sheet, although sensor chips have to be embedded inside the sheet in the production process. A method to make the electrode much smaller than the wavelength using resonance is described in [7]. The second type as shown in Fig. 2 (b) allows the sensor chips to be attached on the sheet after the sheet production. Electromagnetic waves are sent/received through apertures on the sheet.

Fig. 2 (c) realizes free location of the sensors on the sheet. The sensor can even move on the surface keeping the connection. In that system, communication is done by evanescent waves trapped around the surface [5]. Under the coordinate system shown in Fig. 3, the z component of electric field above the surface is written as

$$E_z = \frac{k_2^2}{k_1} V \exp(-k_1 z)\exp(-jkx)\exp(j\omega t) \quad (z > 0) \qquad (1)$$

$$\begin{cases} k_1^2 = (\mu\varepsilon - \mu_0\varepsilon_0)\omega^2 - \dfrac{j\sigma\varepsilon\omega}{h} \\ k_2^2 = \dfrac{j\sigma\varepsilon\omega}{h} \\ k^2 = \mu\varepsilon\omega^2 - \dfrac{j\sigma\varepsilon\omega}{h} \end{cases}$$

for the wave traveling toward $+x$, where μ and ε denote respectively the magnetic permeability and dielectric constant of the sheet, and μ_0 and ε_0 are those of the atmosphere. The parameter V is the voltage between the top layer and the bottom layer at $x = t = 0$. The equation is an approximation based on the assumption $|k_1 h| << 1$ and $|k_2 h| << 1$, where h is the dielectric layer thickness. The parameter σ is the sheet impedance of the top layer defined as

$$\sigma \equiv R + jX \equiv \frac{E_x}{i_x} \qquad [\Omega]$$

where E_x is the electric field along the x axis at the top layer and i_x is the current density [A/m] along x axis. We assume that the bottom layer is ideal conductor and that the top layer is sufficiently thin. If the top layer is ideal conductor, σ is equal to 0, which results in $E_z = 0$. We call a top layer whose sheet impedance is inductive as $X > 0$ an "inductive layer." An inductive layer can be realized by a conductor mesh with the period shorter than the wavelength. Electromagnetic wave can be sent/absorbed to/from the 2DST sheet by placing a conductive plate near the top layer, while the electromagnetic energy outside of the sheet remains small without the proximate conductive plate, for small σ. Proximity connection is obtained when the distance between the plate and the sheet is comparable to or smaller than the layer thickness h. An example of efficient connector is reported in [5]. One drawback of this system is that a certain amount of electromagnetic wave leaks into the atmosphere by scatterers on the sheet, which impairs the information security.

The last one is a simple dielectric layer as shown in Fig. 2 (d). A single layer of dielectric material which has a dielectric constant larger than that of the atmosphere can trap electromagnetic wave around the surface. In this case, however, most of the electromagnetic wave energy is in the outside space of the dielectric layer. In addition, a certain thickness of the dielectric layer comparable to the wavelength is necessary for effective wave trapping. In our project, types (a) and (c) are intensively studied.

3. MICROWAVE POWER TRANSMISSION

Since the 2DST sheet confines the electromagnetic energy inside the sheet, intense microwave is allowed to be radiated into the sheet. Microwave power transmission is a robust way since a local short-circuiting between the conductive layers causes only local breakdown within the wavelength radius. That property makes it realistic to embed 2DST sheets on the desks, floors and walls. (In DC or low frequency AC power supply, only one point short-circuiting is fatal.) We experimentally confirmed 100 mW energy absorption by one node from 10 W power source through 50×95 cm^2 sheet, based on type (c) in Fig. 2. A technological challenge in microwave power transmission is to heighten the efficiency.

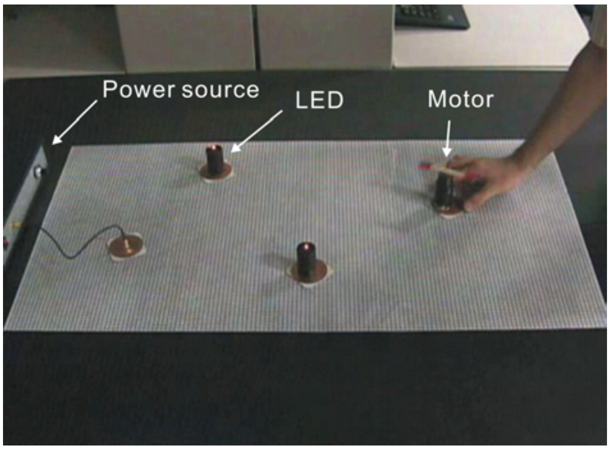


Fig. 3 View of power transmission experiment. The sheet size is 50×95 cm^2.

4. APPLICATIONS

2DST technologies have a wide variety of applications. If we can embed the 2DST sheet on the surface of the room, 2DST provides more efficient signal transmission than usual radio. The communication is more secure against information leak. Ubiquitous computing tools can obtain power from the 2DST sheet. 2DST sheet is also available as a medium for reading RFID tags.

The room-size equipment of temperature sensors on the wall and pressure sensors on the floor is also the first step of applications. The challenge resides in promoting the business to embed the 2DST sheet on the floors, walls, and desks.

Another application is to construct high density sensor network on an elastic and stretchable materials. In the current technologies, the electrical parts can be integrated on a rigid plate. Although bendable films are available as the substrate, it is difficult to mount them on stretchable materials. Since conductive fabrics can guide microwaves stably within 1 m distance, 2DST using conductive fabrics enables high density implantation of sensors on clothes.

As an interesting application of wearable sensors, an elastic device measuring myoelectric potential patterns has been proposed. EMG had been used in some special situations that allowed wearing complex devices. The device proposed in [6] enables EMG to be used for human interfaces in daily lives. A thin device that can be worn comfortably has a variety of applications as shown in [6]. Pressure sensors on a chair, acoustic devices on a curtain, and tactile elements in an artificial skin for a robot are also promising examples to be realized by 2DST technologies.

REFERENCES

[1] Mitsuhiro Hakozaki and Hiroyuki Shinoda: Digital Tactile Sensing Elements Communicating through Conductive Skin Layers, Proc. 2002 IEEE Int. Conf. on Robotics & Automation, pp.3813-3817, 2002.

[2] K. V. Laerhoven, N. Villar, A. Schmidt, and H.W. Gellersen: Pin & Play: The Surface as Network Medium, IEEE Communication Magazine, pp. 90-95, 2003.

[3] J. Lifton and J. Paradiso: Pushpin Computing System Overview: A Platform for Distributed, Embedded, Ubiquitous Sensor Networks, Proc. Perv. Comp., LNCS 2414, pp. 139-151, 2002.

[4] Kouta Minamizawa, Yasutoshi Makino, Hiroyuki Shinoda: Two-Dimensional Signal Transmission for Networked Sensing, Proc. SICE Annual Conf. 2005, pp. 3816-3819, 2005.

[5] Naoshi Yamahira, Yastoshi Makino, Hiroto Itai, and Hiroyuki Shinoda: Proximity Connection in Two-Dimensional Signal Transmission, Proc. SICE - ICCAS 2006.

[6] Yasutoshi Makino Akimasa Okada and Hiroyuki Shinoda: Measuring Myoelectric Potential Patterns Based on Two-Dimensional Signal Transmission Technology, Proc. SICE - ICCAS 2006.

[7] Hiromasa Chigusa, Yasutoshi Makino and Hiroyuki Shinoda: Resonant Proximity Connector for Two-Dimensional Sensor Implantation, Proc. SICE - ICCAS 2006.