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Proposal of Wireless Behavioral Monitoring System with Electric Field Sensor

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***Abstract*— This paper describes a wireless behavioral monitoring system equipped with an omnidirectional electric field sensor. The system can be installed by individuals in their residences. It is composed of a sensor circuit, wireless data transmitter, and receiver that is connected to a personal computer for data storage. The sensor circuit has been designed to obtain information on the usage of domestic appliances by measuring the electric field around them. It is assumed that the usage statistics provide information on a type of indoor behavior of the subject. Since the system employs a device that transmits the obtained data through weak radio waves, the sensor unit, which is composed of the sensor circuit and wireless data transmitter, can be used by simply attaching it to an appliance. Simple evaluation tests confirm the practicability of the system.**

I. Introduction

Recently, ubiquitous networks have been applied to various fields, and a wireless sensor network technology has been introduced for home healthcare as a biomedical monitoring system [1]. The wireless biomedical monitoring system is an epoch-making system because it enables the collection of physiological data of individuals. On the other hand, a recent study has revealed that the physical and mental conditions of elderly people are reflected in their behavior; the pattern changes when they are unhealthy. Therefore, a domestic behavioral monitoring system can also enable the detection of a disease in its early stages [2], [3]. In addition, the recorded data may be used by a medical doctor to make a diagnosis and suggest treatment. The data may also be useful for self-health care and counseling in medical institutions.

Thus far, many behavioral monitoring systems have been developed (e.g., [3] and [4]). However, in the case of a sudden illness or an emergency, it is difficult to immediately install most of the conventional systems in residences. This is because wiring is required to connect many physical sensors, such as drawer sensors and movement sensors, with a computer that records their status. Moreover, engineering expertise is required for precise positioning of the sensors during installation. The design of both the monitoring system and the sensor must be improved in order to facilitate easy installation and disassembly.

In this study, a wireless behavioral monitoring system and a sensor for it are developed. The system can be installed by individuals in their residences.

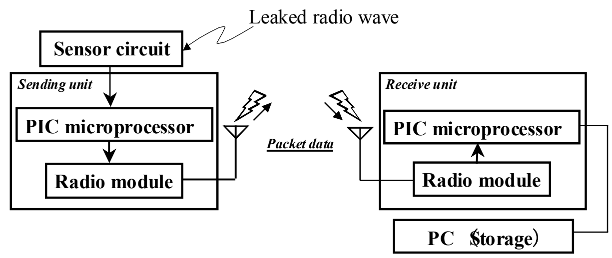

Fig. 1. Schematic diagram of the system.

Fig. 2. Sensor circuit.

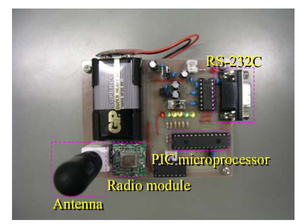

Fig. 3. Processor board (transmitter/ receiver unit).

II. Apparatus

A. System Structure

The system is composed of a sensor, data transmitter with a radio frequency (RF) module, and receiver. The data transmitter and receiver are composed of a PIC microprocessor and a low-power radio module. Fig. 1 shows the block diagram of the system, and Figs. 2 and 3 show prototypes of the sensor circuit board and data transmitter/receiver circuit board, respectively. The sensor circuit is equipped with an electric field sensor for monitoring

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the usage of domestic appliances. The microprocessor samples the analog output of the sensor. The obtained data are then transmitted to a receiver unit through the radio module. The PIC microprocessor in the wireless data receiver transmits the received data, which are the sampled outputs of the sensor, to a personal computer through an RS232C communication port. The personal computer records the sensor output as behavioral data.

B. Sensor Circuit for Television Set [5]

Most of the modern domestic appliances are based on electromagnetic phenomena. Therefore, the observation of electromagnetic waves may be useful for monitoring the usage of domestic appliances. In this study, we focus on monitoring the usage of a conventional television set.

A moving picture can be transmitted or displayed on the television in different formats. Table 1 shows the number of scanning lines, frame rate, and horizontal scanning frequency of each format. Although the number of scanning lines and frame rate of each format are different, the horizontal scanning frequency is almost the same (approximately 15.7 kHz). Moreover, scanning in a conventional television set that comprises a cathode ray tube (CRT) is achieved by driving an electromagnet near the electron gun in the CRT. Therefore, by monitoring the frequency of electromagnetic (radio) waves, information on the usage of the television set can be obtained.

Fig. 4 shows the circuit diagram of the television sensor developed in this study. After the extraction of the 15.7-kHz component in the resonator, the "signal" is amplified and rectified. Fig. 5 shows the arrangement of the prototype sensor unit on the television set.

C. Processor Unit

A wireless data transmitter and the receiver are composed of the PIC microprocessor and a low-power radio data communication module. Table 2 lists the specifications of the unit. The PIC microprocessor samples the analog output of the sensor circuit at a sampling resolution of 8 bits. It can also distinguish between the on and off states of the television set by evaluating the voltage level of the sensor output. The digitized value is then converted into a 16-bit data packet by Manchester coding and transmitted to the receiver unit through the radio module. A flag synchronization method is employed for radio communication. Fig. 6 shows the packet configuration for the radio communication. Two types of packets are used: negotiation and data packets. The negotiation packet is composed of the flag and status bits; it is used to determine the status of each unit. The data packet is composed of the packet number and data bits in addition to the negotiation packet.

Fig. 7 shows the flow chart of the communication process. It is based on the handshake protocol. First, the data transmitter (sender unit) transmits a negotiation packet to the receiver in order to determine the status of the receiver unit.

TABLE I VERTICAL RESOLUTION AND HORIZONTAL SCANNING FREQUENCY OF DIFFERENT TELEVISION FORMATS

Format	Scanning lines (frame, field)	Frame rate (Hz) (frame, field)	Horizontal scanning frequency (kHz)
NTSC	525, 262.5	30, 60	15.750
PAL	625, 312.5	25, 50	15.625
SECAM	625, 312.5	25, 50	15.625

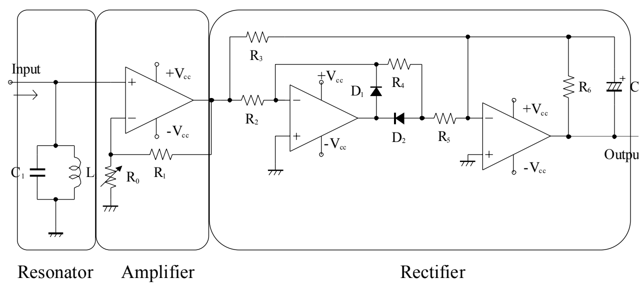


Fig. 4. Circuit diagram of television sensor.

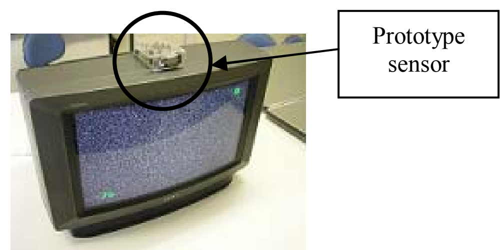


Fig. 5. Arrangement of television sensor.

TABLE II SPECIFICATIONS OF RF UNIT

Item	Specification
microprocessor	PIC16F876 (Microchip Technology Inc.)
processor clock	3.58 MHz
radio module	CDC-TR02B (Design Circuit Inc.)
radio frequency	315 MHz
radio antenna	RH3 (120–900 MHz, Diamond)
modulation	amplitude shift keying (Manchester coding)
transfer rate	115.2 kbps
unit weight	~250 g
size (H × W × D)	100 × 65 × 35 mm (antenna excluded)

FLAG	STATUS
16bit	16bit

(a) Negotiation Packet

FLAG	STATUS	Packet Number	Data
16bit	16bit	16bit	16bit

(b) Data Packet

Fig. 6. Packet configuration.

When the receiver responds with an ACK signal, the transmitter unit transmits a data packet. This packet is retransmitted until a DataAck packet is received. The process including the sampling of the sensor output is repeated at intervals of 1 s.

The receiver unit is connected to a personal computer via the RS232C interface. The unit transmits the received data to the computer that stores it for further evaluation.

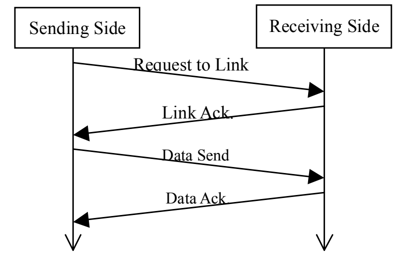


Fig. 7. Flow chart of data communication process.

III. Experiments

A. Practicability of Sensor Unit

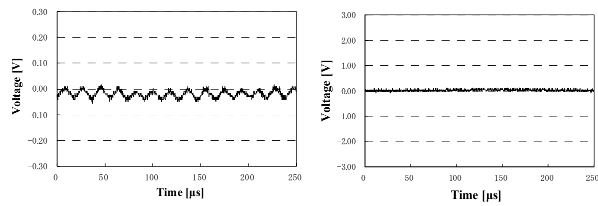
To confirm the behavior of the proposed sensor circuit, we observed the obtained raw signal (leaked radio waves from the television set) and the processed output (resonance, amplification, and rectification). These signals were recorded using a Tektronix TDS210. The A/D converter in the PIC microprocessor was not used in this experiment. The applicability of the television sensor was then evaluated by a simple television on/off test.

B. Evaluation of Low-power Radio Data Communication

The reliability of a wireless communication system is less than that of a wired system. Therefore, we performed a simple evaluation test for data transmission. Null data packets (Fig. 6(b)) were transmitted 1000 times from the sender unit. The receiver evaluated the authenticity of the packet in order to estimate the packet error rate. The handshake protocol was not used in this experiment. In order to determine the efficiency and wireless communication range, the evaluation was carried out 5 times for each distance between the sender and the receiver unit.

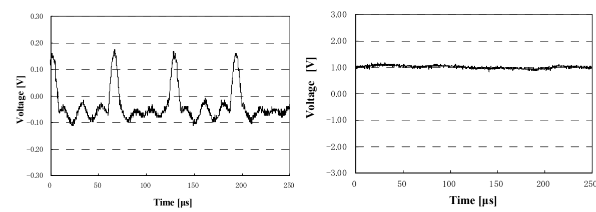
C. Data Comparison Test

A data comparison test was performed for verifying the function of the system developed in this study. The stored data (in the personal computer) was compared with the raw sensor output. In this experiment, the sensor unit was attached to the television set. The raw sensor output was measured with the digital oscilloscope (TDS210). The television set was switched on and off arbitrarily. The sensor output was also sampled and transmitted to the personal computer. The sampling resolution of the microprocessor was 8 bits and the sampling frequency was 1 Hz.



(a) Input waveform (b) Output waveform

Fig. 8. Input and output waveforms (television off).



(a) Input waveform (b) Output waveform

Fig. 9. Input and output waveforms (television on).

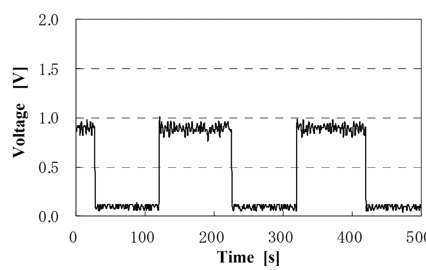


Fig. 10. Television on/off test.

IV. Results and Discussion

Fig. 8 shows the result obtained when the television set was switched off. Fig. 8(a) shows the signal received by the antenna of the sensor circuit. The very small component of the power-line frequency of commercial electric power systems can be observed in any part of the residence; however, the gain of the amplifier is not high. Therefore, this type of "noise" is ignored, and the filtered output is almost 0 V (Fig. 8(b)).

Fig. 9 shows the signals at each point of the sensor circuit when the television set is switched on. Fig. 9(a) shows the leaked radio waves that are received. The signal mainly comprises pulses of 15.7 kHz. Fig. 9(b) shows the filtered output. When the television set is switched on, the sensor output is almost 1 V.

Fig. 10 shows the result of the television on/off test. Based on this result, we can estimate the duration of the usage of the television set. Thus, the sensor unit is suitable for practical use.

Fig. 11 shows a screen shot of the data storage software developed in this study. This software has been developed using Microsoft Visual Basic 6.0. The received data are displayed on the screen along with the time of reception and recorded on the hard disk.

Fig. 12 shows the packet error rate. It is very small (~0.5%) even when the distance is 600 cm. This distance is appropriate for Japanese residences; however, the communication range should be investigated in order to evaluate the performance.

Fig. 13 compares the sensor output with the received RF data. Fig. 13(a) and (b) shows the raw sensor output recorded by the oscilloscope and the stored data, respectively. We have confirmed that the waveforms are almost the same. The PIC microprocessor connected to the sensor circuit samples the raw output with a resolution of 8 bits and a reference voltage of 5 V; the voltage resolution becomes approximately 0.02 V. Since the proposed sensor circuit outputs almost 1 V when an appliance is in use, this voltage resolution is rather appropriate for sampling the output.

In this study, the sampling frequency of the sensor output is set to 1 Hz. However, since we have not introduced time management systems in the unit, the actual sampling time may vary. This problem should be solved in the future.

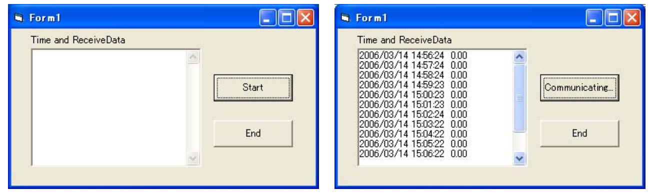


Fig. 11. Application developed for windows.

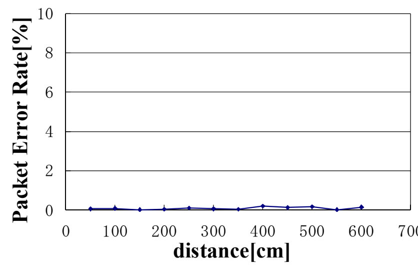
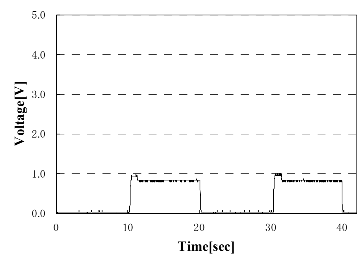
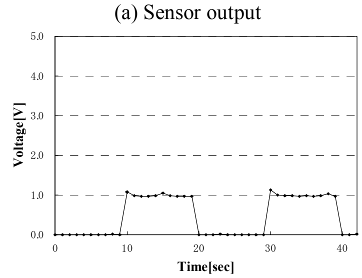


Fig. 12. Packet error rate of data communication.



(a) Sensor output



(b) Received RF data

Fig. 13. Comparison between sensor output and received RF data.

V. CONCLUSION

In this study, we proposed a wireless behavioral monitoring system equipped with an electric field sensor. A simple evaluation test revealed the practicability of the system. This system can be easily installed in residences by individuals since it does not require any engineering expertise. Moreover, it can be used in existing residences without requiring any reconstruction or new appliances with monitoring functions.

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