professional and the patient may lead to more successful management by the professional and increased adherence by the patient.[1] Thus, the aim of the present study was to assess the feasibility of a low-cost, email-based system for SBPM. In addition, long-term SBPM data obtained using this system were analysed taking into consideration a seasonal temperature change.

Methods

Ten elderly volunteers, including four married couples, were enrolled. All subjects received an explanation of the purpose of the study and provided written informed consent. Ethics permission was not required. The subjects started BP measurement on 15 August 2002. After completion of their participation in the study, they provided their assessment of the SBPM system by interview.

The wrist cuff oscillometric BP monitor (HEM-637IT, Omron, Tokyo, Japan) consisted of a microprocessor, an electric pump, a pressure sensor, an LCD screen and a wrist cuff. It also included an advanced positioning sensor (APS) and a universal serial bus (USB) interface. The APS served to verify that the wrist was placed properly at heart level, and the USB interface served to transfer BP data from the internal memory of the BP monitor to the subject's personal computer (PC). A BP monitor was given to each subject, and the subjects were instructed in its proper use. The subjects placed the wrist cuff around the left wrist, after which the APS guided the wrist to the proper placement at heart level by means of an arrowhead, which appeared on the LCD screen. When the wrist is held at heart level, cuff inflation starts automatically, and the systolic and diastolic BP readings are displayed on the LCD screen together with the date and time. The BP monitor automatically stores these data in its internal memory, which has a recording capacity of 90 measurements.[12]

All subjects, including those without prior experience of SBPM, learned to use the BP monitor properly after 10 min of training. After completion of training, the subjects measured their BP twice a day (just after waking in the morning and just before going to bed at night), and were asked to continue measurement as long as possible, at least for 30 consecutive days. The BP readings with the date and time were transferred weekly from the internal memory to the PC by a software program (BI-LINK version 1.0.0, Omron) and stored as a comma-separated values (CSV) file. The file was sent by email each month to one of the authors. In each married couple, at least one partner was familiar with email, and the data for both partners were sent together. The other two subjects, who had no experience with email, were helped by their children to send the data.

The procedure is summarized in Figure 1.

Analysis

Each CSV file received was converted to a spreadsheet (Excel, Microsoft), and the morning and evening systolic and diastolic BP data were plotted separately as a function of the time of day. The hourly regional outdoor temperature in the district where the subject lived was obtained from the meteorological data reference Website of the Japan Meteorological Agency,[13] and the regional outdoor temperature at the time closest to that of BP measurement was also plotted with the BP data.

The BP and temperature data were fitted with smooth curves, using a weighted curve fitting method[14] (KaleidaGraph version 3.51, Synergy Software, Reading,

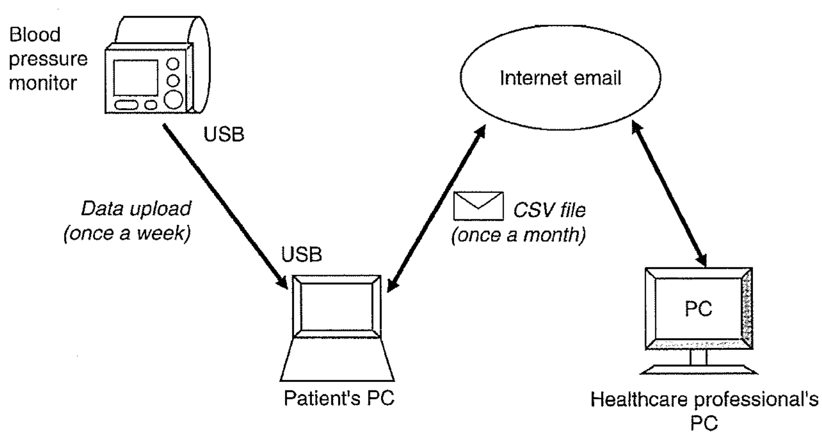

Figure 1 Low-cost email-based system for SBPM

PA, USA). The smoothing coefficient in the weighted curve fit method was 33% of the data range. The correlation between BP and outdoor temperature data was calculated from the fitted curves.

Results

Monitoring period and percent achievement of measurement

The monitoring period ranged from 35 to 502 days, with a mean period of 207 days (SD 149) days (Table 1). The mean numbers of morning and evening measurements were 181 (SD 142) and 179 (SD 144), respectively. Monitoring was incomplete in most subjects: only Subject 10 recorded two measurements per day throughout the monitoring period. Figure 2 shows the relationship between the percent achievement of measurements (ratio of the total number of measurements carried out to twice the number of days in the monitoring period) and the monitoring period. The regression line indicates that subjects who were monitored for long periods had a high percent achievement of measurements. The mean percent achievement of measurement in all 10 subjects was 84% (SD 12). In hypertensive subjects ($n=3$), the mean percent achievement was 93% (SD 7), and in the normotensive subjects ($n=7$), it was 81% (SD 13). The difference between the hypertensive and normotensive subjects was significant (t-test, $P<0.01$).

Evaluation by subject

All 10 subjects were interviewed after the study. The three subjects whose percent achievement of measurement was less than 80% were asked about the reason for their low percentages. Subject 3 did not trust the BP monitor because her BP readings fluctuated more than she expected. Subject 9 was not interested in the BP measurements, and did not measure his BP every day. In addition, he was in the habit of waking up late, and sometimes missed his BP measurement time in the morning. In the case of Subject 4, the battery in her BP monitor was low from the beginning of the 208th day, and she did not obtain a replacement for 24 days. Finally, our interviews showed that eight of our 10 subjects (all except Subjects 3 and 9) approved of the proposed SBPM using the wrist monitor with the APS. They also mentioned that the weekly transfer of BP data from the internal memory of the monitor to their PCs and the monthly email of the BP data to one of the authors were not stressful, and gave a favourable evaluation of the utility of the proposed SBPM system.

Physiological data

Figure 3 shows an example of BP in the morning and outdoor temperature in Subject 5. The seasonal variation in systolic and diastolic BP was inversely correlated with temperature. The correlation coefficients were −0.95 for systolic BP and −0.96 for

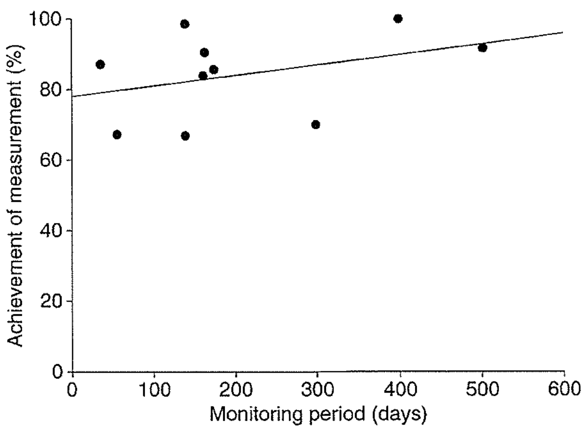

Figure 2 Relationship between percent achievement of measurement and the monitoring period in 10 subjects. The solid line is the regression line

Table 1 Personal details, monitoring period and number of blood pressure measurements for each subject

						Number of measurements		
Subject	Age (years)	Sex	Location (city, prefecture)	Hypertension	Monitoring period (days)	Morning	Night	Total
1	60	M	Obu, Aichi		35	30	31	61
2	60	F	Ube, Yamaguchi		161	138	132	270
3	62	F	Seki, Gifu		139	97	89	186
4	63	F	Kyoto, Kyoto		299	227	192	419
5	65	M	Suzuka, Mie	Yes	502	453	468	921
6	66	M	Ube, Yamaguchi		163	141	154	295
7	67	M	Seki, Gifu		139	135	139	274
8	68	F	Obu, Aichi	Yes	174	156	142	298
9	69	M	Kyoto, Kyoto		55	31	43	74
10	72	F	Niigata, Niigata	Yes	399	399	399	798

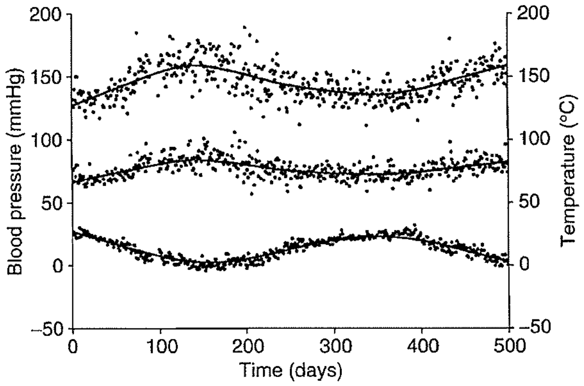

Figure 3 An example of the seasonal BP variation in Subject 5. There is an inverse correlation between BP and outdoor temperature. The upper, middle and lower points with their best-fit lines indicate the systolic BP, diastolic BP and outdoor temperature, respectively. Abscissa, time in days from the beginning of measurement (15 August 2002)

diastolic BP. In the other seven subjects whose monitoring periods were longer than 130 days, BP variations with an inverse correlation to seasonal temperature variations were also observed. The mean correlation coefficients in these eight subjects were −0.70 (SD 0.36) for systolic BP and −0.79 (SD 0.25) for diastolic BP.

Discussion

In the present study, the mean percent achievement of measurement in the 10 subjects was 84%. Eight of the 10 subjects evaluated the system favourably. The results demonstrate that the email-based SBPM system is easy to use and is acceptable to elderly people, especially to those with hypertension who require long-term monitoring of their BP.

Telecare, telenursing and telemonitoring systems using the Internet, ISDN lines and the telephone network have been developed to monitor and manage the health condition of patients with hypertension or chronic disease. Cost is an important factor in patients' perceptions of such systems. Aris *et al.*[15] developed an Internet-based blood pressure monitoring system. However, special hardware was required to link the output of the BP monitoring device (automatic sphygmomanometer) with a PC. Unlike this system, the monitor used in the present study could transmit BP readings automatically via the built-in USB interface. In addition, our system used email to send the monthly reports of BP data. The cost of email is relatively low, involving only the cost of the provider. Therefore, the present system can be implemented at a low cost.

The accuracy of self BP measurements using wrist monitors has been discussed in previous studies.[9,11] One cause of inaccurate BP measurements in wrist monitoring is the possibility of incorrect wrist level positioning during measurement. The wrist monitor used in the present study includes a positioning system that guides the wrist to the heart level. Recently, Yarows[9] demonstrated that the present wrist monitor with the APS measured BP more accurately than the same model with the APS turned off. Nolly *et al.*[11] also evaluated the accuracy of the wrist monitor with the positioning sensor in comparison with the standard mercury sphygmomanometer, and found excellent agreement between them.

The physiological BP data obtained in the present study showed seasonal variation with an inverse correlation to seasonal outdoor temperature variation. The relationship between BP and seasonal temperature variation has been examined in many studies, and it has been confirmed that BP has seasonal variations with an inverse correlation to seasonal temperature variation.[16,17] Therefore, the seasonal BP variation seen in the present study may be taken as a reflection of the accuracy of BP measurements using our monitoring system.

The results of the present study demonstrate the feasibility of our email-based system for SBPM. It can be incorporated easily into the homes of patients or elderly people. It may have widespread application in future home telecare studies.

Acknowledgements: This work was supported in part by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science to KN (17510121).

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Smart Homes and Beyond
C. Nugent and J.C. Augusto (Eds.)
IOS Press, 2006

A Smart House for Emergencies in the Elderly

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Abstract. An automated monitoring system characterised as a smart house and called the Welfare Techno House (WTH) has been designed for home health care to prevent disease and improve the quality of life in the elderly. In this paper, we describe the smart house project in Japan and evaluate its effectiveness. The WTH concept involves a monitoring system for the continuous measurement of physiological parameters. Using this system, we collected physiological data and then analysed the key features of the data with regard to health monitoring. We review the previous 10-year trial of the WTH experimental project and discuss future developments.

Keywords. Smart house, wireless LAN, automatic health care system, ad hoc network

Introduction

Given the increase in elderly people in our society, a need exists for the promotion of new methods of disease prevention using information and communication technology. Consequently, several "smart houses" have been developed worldwide that use applied information technology to measure daily health activity at home. Epidemiological research is also needed to assist in the prevention and identification of diseases such as diabetes and hypertension, but this research requires long-term monitoring [1]. Our proposal is to use a smart house to monitor physiological parameters noninvasively. The ability to monitor physiological and vital signs without attaching sensors and transducers to the body is preferable especially in emergency cases. Thus, fully automated measurements are needed to acquire data in a noninvasive manner and minimise procedures for subjects. An experimental project on noninvasive automatic monitoring of a patient's daily physiological status during bathing, elimination, and sleep was conducted at the Welfare Techno Houses (WTH) in Japan.

In this paper, we present the current home health care technology at the WTH and propose new, simple technology for installation at this facility.

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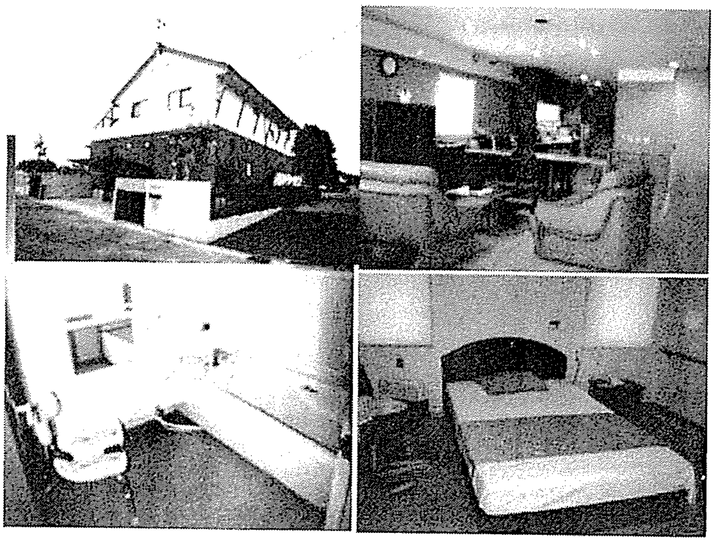

Figure 1. Welfare Techno House in Mizusawa. Overview (top left) of a barrier-free living room with an infrared sensor on the ceiling (top right), bathroom with an electrocardiogram (bottom left), and bed with an electroconductive sheet.

1. Welfare Techno House

1.1. Health monitoring

In 1995, the Japanese Agency of Industrial Science and Technology, under the auspices of the Ministry of International Trade and Industry (MITI), and the New Energy and Technology Development Organizations (NEDO) collaborated to support the construction of 13 demonstration and research houses across Japan, known as WTHs. After a few years, three more houses were built for a total of 16 WTHs. The concept of these experimental houses is to promote independence for elderly and disabled persons and to improve their quality of life. The houses provide the opportunity for clients and caregivers to explore issues concerning accessible design and to participate in trials that enable them to meet their own specific needs; the WTHs are therefore used for testing and exhibiting new products and design concepts. Elderly and disabled people may stay in the houses for several days to try out the facilities. In addition, manufacturers are able to test their equipment, although no accreditation is given based on this use.

The Ministry of Health, Labor, and Welfare supports the integration of information technology with health care. Consequently, we have developed an electronic healthcare system for the WTH.

Three of the 16 houses were built as smart homes. The Mizusawa Techno House (Fig. 1) was designed to accommodate two generations of people as a two-story building with an area of 400 m^2, which is greater than the average Japanese house. This facility incorporates a range of features that relate to the approach to the house, orientation and movement within the house, and building management. These features are integrated to provide flexibility of use and to meet a variety of individual needs, particularly for elderly who require care. The floor has a cushioning effect and under-floor heating, and a home network system was installed as part of the smart house control and communication network to provide for the control of lighting, curtains, and windows. Furthermore, the security system has a video phone connected to the front door. The future of the Mizusawa Techno house involves the introduction of automatic health care facilities as shown in Fig. 1.

The concept of an automatic health care monitoring system has been published elsewhere [1–5]. For example, automated electrocardiogram (ECG) measurements can be taken while a subject is in the bed or the bathtub without the subject's awareness and without using body surface electrodes. Furthermore, body weight can be monitored by the toilet. To evaluate these automated health monitoring systems, overnight measurements have been performed to monitor the daily health status of both young and elderly subjects [6].

Simple physical sensors, such as pyroelectric sensors and magnetic sensors, have been installed inside rooms, and the number of activations or switches are counted to monitor the movement of subjects [7].

1.2. Data analysis

Several attempts for long-term monitoring and epidemiological study have been performed to evaluate the health effects of the monitoring, and simple histograms have been produced to present the data based on the average activation per unit time [8].

We applied imaging technology to monitor the well-being of occupants. We focused on the use of the television, and the on/off switching time was plotted as shown in Fig. 2. A regular signal output is shown in Fig. 2(a), while an irregular signal output is shown in Fig 2(b). We can evaluate the well-being of a subject with this simple monitor [9]. We were able to detect an irregular condition at an early stage before hospitalisation was required.

2. Further development of smart house projects

Over the last 10 years, our group and colleagues have attempted to create several sensors, such as temperature and optical flow monitors located in the bed, as well as software.

The WTH concept is a valuable contribution to the development of accessible domestic dwellings and the integration of these structures with the information technology infrastructure and daily living products. The WTH technology will facilitate independence and improve the quality of life for elderly and disabled people in Japan. Although few reports have been published on the Japanese smart house project, we have proposed innovative new projects and products; however, only two have been made commercially available (Sekisui and Panasonic, Japan), and the system was not implemented in private homes.

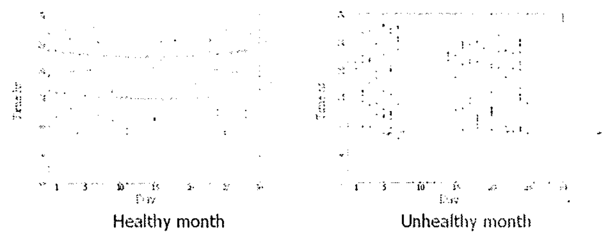

Figure 2. The time course of the TV on/off switch use. The left panel shows data from normal daily life, and the right panel shows an irregular pattern before hospitalisation.[9]

In terms of a business model and integration, the proposed system is very useful for elderly subjects. The clients typically only require this type of monitoring once a week or during an emergency. The questionnaire given to these subjects indicated that continuous monitoring was not required [10]. The proposed system, however, must be refined to meet their needs better.

Issues of privacy and ethics are also critical in this system. The elderly were not comfortable with the idea of continuous monitoring, which seemed to rob them of their privacy.

The main disadvantage of this system is that it must be installed when a house is being built, and the installation is expensive and time-consuming. For emergency cases, such as sudden illness, we will sometimes need to install this type of system in an existing house; therefore, a monitoring system should be easy to install and remove. Furthermore, the system must be evaluated through evidence-based health care (EBHC).

3. Wireless network and wearable sensor

The integration of wireless data communication technologies such as wireless LANs, Bluetooth, ZigBee, MOTE, and other radio frequency systems with a sensor unit for data collection is effective for introducing health monitoring systems into ordinary houses in a short time.

New technology will provide advanced computational capabilities and reliable healthcare monitoring at locations where the number of caregivers and their time are limited and where biomedical analysis-and-decision-making computing devices are urgently needed to assist the medical staff.

The network chip that we are now developing will be deployed as a medical sensor-network for home health care. In this scenario, a patient would have biomedical transducers attached to their body that measure an ECG 1 lead and oxygen saturation in the blood (SpO_2) noninvasively for several days. Different sensors in turn would be connected wirelessly to a wearable network chip that collects different parameters and performs filtering, complex calculations, and analysis of received information to identify the state of the patient. The collected and analysed data will then be transmitted wirelessly (GPRS, 3G) to a hospital where physicians and nurses can follow-up on the patient's condition. The medical parameters are sent in real time from home appliances and/or medical equipment to the network chip for processing and real-time analysis of large amounts of data. For example, an ECG for heart monitoring may produce megabytes of data by monitoring for only half an hour. Thus, a real-time analysis solution becomes crucial, and the network chip would be used, i.e., for fast complex computations to deliver results within an acceptable period of time, especially in an emergency. In normal monitoring situations (i.e., nonemergencies), the processed and analysed data would be sent from the network chip to the hospital three or four times per day or at a rate based on the individual case.

4. Conclusions

We developed a fully automatic health care monitoring system for use in a WTH that effectively collects physiological data. However, the problem of implementing this system in the real world is difficult to resolve. We are now developing a simple and highly specific health monitoring device to use in the home for evaluating the personal health status and daily activity level without the use of invasive measurements.

Acknowledgements

This work was supported by grants from the Ministry of Health, Labor, and Welfare, Longevity Sciences, and by the CREST project of Chiba University, Japan.

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Smart Homes and Beyond
C. Nugent and J.C. Augusto (Eds.)
IOS Press, 2006

Easily Installable Sensor Unit Based on Measuring Radio Wave Leakage from Home Appliances for Behavioural Monitoring

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Abstract. This paper describes a sensor unit used in a behavioural monitoring system for ordinary houses. This unit has been developed to obtain information on the usage of home appliances by measuring the radio waves leaking from these appliances. Since the unit employs a device that uses weak radio waves for transmitting the obtained data, the unit is ready for use by simply attaching it to an appliance. A simple evaluation test revealed the applicability of the sensor unit.

Keywords. Sensor, behavioural monitoring, home appliance, radio wave leakage

Introduction

Preventive medicine is one of the types of health care for the elderly. Obtaining continuous physiological information will be useful for health care since quantitative information is very important for physicians in order to make a diagnosis and suggest treatments. Furthermore, due to an increase in the elderly population, the investigation of preventive and epidemiological medicine is important to reduce the costs incurred in medical insurance and health care. Because of the large medical costs incurred due to a large number of patients, the reduction in medical costs is a crucial issue.

Recently, behavioural information has been shown to be effective for maintaining and improving the quality of life [1–8]. It is known that both the physical and mental conditions of elderly people are reflected in their behaviour. The elderly are somewhat conservative and their day-to-day activities do not differ significantly; these activities may include preparing food and watching TV regularly. This pattern will be different when they are not healthy [8]. Many behavioural monitoring systems have been developed thus far. However, these systems consist of many physical sensors such as drawer sensors and movement sensors, and wiring is required to connect these sensors with a computer that stores their status. Therefore, most of these systems are installed when a house is being newly built or reconstructed. In reality, the installation is

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expensive and time-consuming. For the elderly who live alone, we sometimes need to install such systems in their houses in case of sudden illnesses or emergencies. Therefore, such a system should be easy to install and remove [6, 7]. Recently, a behavioural monitoring system based on radio-frequency identification (RFID) was proposed as one of the low-cost and easily installable monitoring systems. The generality and the applicability of the system are remarkable; however, it is difficult to analyse the obtained data since the target and number of the attached RFID tags are different for each subject and a generalized analysis method has not yet been designed.

Recent studies have revealed that the usage statistics of home appliances, which fall under behavioural information, are useful for estimating the health conditions of the elderly by evaluating their daily activities [5, 8]. For the detection of the usage of home appliances, an electric current detector is used; this monitors the total amount of electric power in the power plug. Ideally, the integration of wireless data communication technologies such as wireless LANs, Bluetooth, ZigBee and other RF systems with the sensor unit for data collection is effective for introducing such systems in ordinary houses in a short time. Unfortunately, no studies have been performed thus far to monitor and transmit physiological parameters. Furthermore, since the electric current detector requires access to a power plug, some of the advantages of a wireless system will be lost. The design of both the monitoring system and the sensor needs to be improved for facilitating their easy installation and removal.

In this study, we built an ad hoc wireless behavioural monitoring system that was technically similar to that built by Mote [9]. A wireless system is very important for the temporal construction of a monitoring system in ordinary houses since it does not require any wiring. In addition, we developed a sensor that detects the usage of home appliances. The sensor was designed to be usable by simply attaching it to an appliance. The unit employs a device that uses weak radio waves for transmitting the obtained data, and it detects whether an appliance is in use by measuring the radio waves leaking from it. Therefore, engineering expertise is not necessary to install the unit.

1. System Structure and Apparatus

1.1. Behavioural Monitoring System

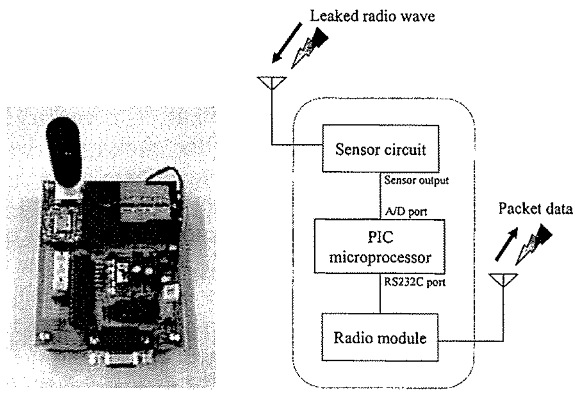
The system developed in this study comprises a data storage terminal and many measuring units. The units automatically sample the outputs of the sensor circuit and transmit the obtained data to a server via a radio module. The radio network, i.e. data relay path, is automatically constructed and modified when a relay failure occurs.

Figure 1 shows the circuit board and the schematic diagram of the sensor unit. The unit shown in Figure 1(a) has an RS232C-type communication port in order to directly connect it to a personal computer (i.e. the unit can also act as a radio interface for the server). A 1/4-λ antenna (Diamond RH-3) makes the radio communication more reliable than the previously developed pattern antenna [9].

1.2. Sensor Circuit

1.2.1. Television Sensor

For developing a sensor that detects the usage of home appliances, we first focused on



(a) Circuit board (b) Schematic diagram

Figure 1. Sensor unit for behavioural monitoring

Table 1. Definitions of conventional colour television formats

Format	Scanning line N (lines/frame)	Frame rate f_V (Hz)	Horizontal scanning frequency f_H (kHz)
NTSC	525	29.97	15.734
PAL (PAL-M, PAL60)	625 (525)	25 (29.97)	15.625 (15.734)
SECAM	625	25	15.625

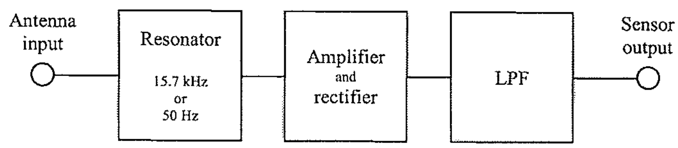


Figure 2. Schematic diagram of the sensor circuit

the television set. This is because the habit of watching television is always associated with the type of programme, and this habit is strongly influenced by the physical and mental conditions of the subject [8]. The image on a television screen is composed of a number of horizontal lines (scanning lines). By displaying different images at a certain frame rate, the television displays a moving picture. The number of scanning lines N and the frame rate f_V of conventional television formats are shown in Table 1. The horizontal scanning frequency f_H can be calculated as the product of N and f_V. The scanning in a conventional television set comprising a cathode ray tube (CRT) is performed by driving an electromagnet near the electron gun in the CRT. The electromagnetic activity near the CRT during the operation of the television can be detected by obtaining the leaked radio (electromagnetic) waves from the electromagnet. In this manner, information on the usage of a television set may be gathered.

Figure 2 shows the schematic diagram of a television sensor. The leaked radio waves from the television set are extracted by the resonator. Since f_H is almost the same among the television formats, the resonance frequency was set as 15.7 kHz, which is also the intermediate frequency. The amplified and rectified signals are then low-pass filtered (LPF) in order to determine whether the television set is on or off by very low frequency sampling. Generally, a comparator circuit is necessary for the on/off distinction. However, because the output voltage of the circuit may be affected by the placement of the unit, a comparator circuit, which requires a constant threshold, was not introduced in this study. The distinguishing of the on/off status can be performed following the raw sampling of the sensor unit output by using the software in a PIC microprocessor unit that employs the variable threshold technique.

1.2.2. General-purpose Sensor for Home Appliances

A television sensor uses a special resonance frequency at which it does not respond to waves from other appliances such as video tape recorders or AV amplifiers. In other words, depending on the type of electromagnetic waves radiated by an appliance, the sensor unit can be adapted to receive waves from almost all appliances; this can be done by tuning the resonance frequency of the resonator and the gain of the amplifier.

In this study, we also developed a general-purpose sensor that responds to a resonance frequency of 50 Hz, which is the power-line frequency of commercial electric power systems in Eastern Japan. The frequency of leaked radio waves can be observed in almost all appliances since most of the appliances have power transducers, i.e. a (electromagnetically) coupled transformer.

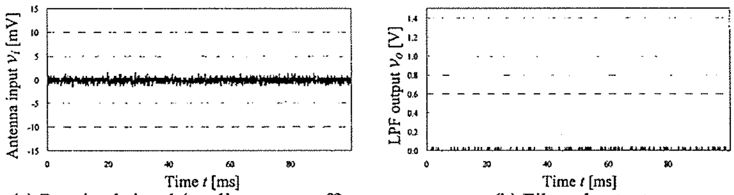
2. Experiments

To assess the applicability of the sensor developed in this study, we conducted simple experiments. The sensor unit was placed on the target appliance, and the data storage server was placed at a distance of ~2 m. The sensor output was automatically sampled by the PIC microprocessor installed in the sensor unit at a sampling frequency of 10 Hz and a sampling resolution of 8 bits. A reference voltage of 5.0 V was used for the A/D converter. The data obtained was then transmitted to the server. A simple handshake protocol was employed in this experiment. In the case of a transmission error (when the sensor unit was unable to receive an acknowledge (ACK) packet from the server), the unit retransmitted the data without any limitation on the number of retransmissions.

During the first evaluation, based on the output of the sensor, we confirmed that no appliances were in use (i.e. the sensor circuit measured the environmental noise).

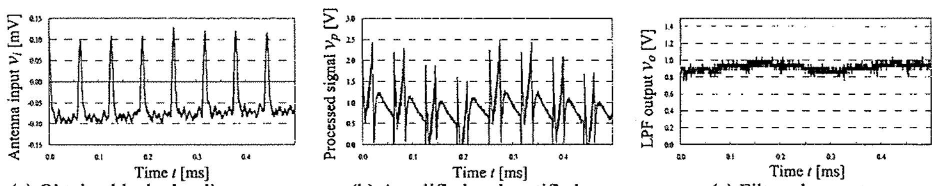
To confirm the behaviour of the proposed sensor circuit, we observed the obtained raw signal (leaked radio waves from the television set), processed signal (resonance, amplification and rectification) and filtered sensor outputs. These signals were recorded using Tektronix TDS210. The A/D converter in 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. Further, we confirmed the dependency of the sensor output on the screen size; several conventional television sets that comprised CRTs were evaluated in this study.

For the evaluation of the general-purpose sensor, we selected a microwave oven as one of the home appliances; this is because the magnetron used in a microwave oven is driven by a voltage-doubled half-wave-rectified power generated by a high-voltage transformer.



(a) Received signal (appliances are off) (b) Filtered output

Figure 3. Environmental noise and sensor output.



(a) Obtained leaked radio wave (b) Amplified and rectified (c) Filtered output

Figure 4. Signal processing of television sensor.

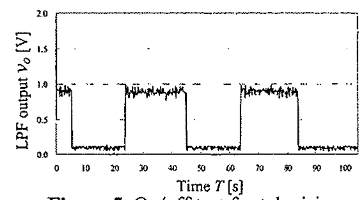


Figure 5. On/off test for television.

Table 2. Dependency of sensor output (television sensor) on screen size

Screen size (inches)	14	24	27	33
Year of manufacture	1995	1995	1989	1989
Power consumption at rated value (W)	67	131	153	169
Average sensor output (V)	1.01	1.01	0.97	0.92

3. Experimental Results

3.1. Electric Appliances in the Switched-off State

Figure 3 shows the result of the case when the appliances (i.e. the television set and the microwave oven) were not in use. Figure 3(a) shows the signal received by the antenna of the sensor circuit; no significant component exists in this signal. The very small component of the power-line frequency of commercial electric power systems will be observed anywhere in the house; however, the gain of the amplifier is not high. Thus, this type of 'noise' is ignored. As a result, the filtered output is almost 0 V.

3.2. Television Sensor

Figure 4 shows the signals at each point of the sensor circuit when the television set is in use. Figure 4(a) shows the leaked radio waves that are received. The signal mainly consists of 15.7 kHz pulses. These pulses are extracted by the resonator and subsequently amplified and rectified (Figure 4(b) shows the signal processing result). Figure 4(c) shows the filtered output of the signal shown in Figure 4(b). When the television set is in use, the sensor output increases to ~0.95 V.

Figure 5 shows the result of the on/off test for the television. During the experiment, on an average, approximately ten retransmissions and one instance of data corruption occurred for each data transmission. Since the data recorded at the server comprised several duplicate data entries obtained from the sensor unit, most of the retransmissions were assumed to be caused by packet losses. However, based on this result, we can estimate the duration of use of the television set; thus, the sensor unit is suitable for practical use.

Table 2 shows the evaluation result of the dependency of the sensor output on the screen size. The average voltage of the sensor output is inversely proportional to the screen size even though the power consumption of the television set is directly proportional to the screen size. This tendency is attributed to the following reason: the radio wave leakage is directly proportional to the power consumption. However, the distance between the source of radio wave leakage and the antenna of the sensor circuit also increases with the cabinet size of the television. As a result, an increase in distance decreases the intensity of the received signal.

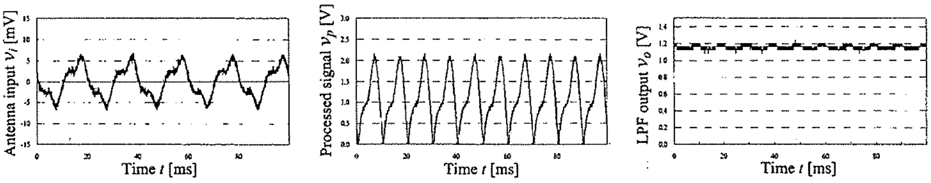
3.3. General-purpose Sensor

Figure 6 shows the experimental result obtained by using the general-purpose sensor with a microwave oven. Figure 6(a) shows the obtained radio wave leakage. The signal mainly consists of 50-Hz waves. Since the radiated waves are not sinusoidal, the microwave oven evaluated in this experiment may also have radiated other frequency components (harmonics). This phenomenon should be thoroughly investigated for the development of a microwave-oven-specialized sensor. Figure 6(b) shows the signal processing result. The filtered output (Figure 6(c)) shows that when the microwave oven is in use, the sensor output increases to ~1.18 V.

Table 3 shows the evaluation result of several microwave ovens. It is difficult to observe a tendency based on the number of trials in this experiment; however, the result shows that the output voltage is almost 1 V when the microwave oven is in use.

4. Discussions

The electromagnetic phenomenon is widely used in electronic/electrical machines, including home appliances, such as motors, transformers and relay switches. Furthermore, there is also an electromagnetic field around an electric wire when the connected appliance is in use. A clamp meter focuses on and uses this phenomenon for estimating the amount of electric current in an electric wire. The sensors developed in this study can also be considered as one of the applications of the clamp meter; the only difference is that the sensor extracts a specific frequency of the electric current.



(a) Obtained leaked radio wave (b) Amplified and rectified (c) Filtered output

Figure 6. Signal processing of general-purpose sensor (microwave oven).

Table 3. Output voltage of general-purpose sensor (microwave ovens).

Year of manufacture	1994	1996	1997
Power consumption at rated value (W)	960	920	1000
Radio frequency output (W)	500	500	500
Average sensor output (V)	0.86	1.18	1.00

Investigating the cause of packet loss and increasing the efficiency of the wireless network system are still the objectives of our study. In most of the cases, the packet losses are caused by dropping the first byte of the packet. By devising an appropriate structure for the data packet, this problem may be solved. We are also considering changing the radio module for addressing this problem.

The main aim of our study is to evaluate how the sensor output reflects the physical activity and health of an elderly person. Nambu et al. [8] proposed an algorithm for evaluating the health of the elderly. In their study, they focused on the running monitor of television since television was common to most of the subjects. Further, since it is considered that the habit of watching television depends on the programmes, it is thought that this habit is strongly influenced by the physical and mental conditions of the subject. The algorithm was applied to the data that had been acquired in a continuous period of seven months, and the result indicated the changes (randomness) in the time when a subject began watching television expressed the health condition of the subject fairly well. We need further studies for the confirmation of this fact; however, our study believes in the monitoring of television for estimating the health condition of a subject.

As described in section 1.2.2, the general-purpose sensor responds to the power-line frequency of the commercial electric power system. Thus, the sensor can be adapted to almost all appliances that have a built-in transformer, provided the transformer consists of coils. A simple evaluation showed that the sensor could also work for the following appliances: electric pot (Zojirushi CD-LE40, CD-GS50, 985 W maximum power consumption), coffee maker (Sanyo, SAC-MST6, 850 W), electric fan (Yamazen, BX-A252, 42 W), humidifier (National, FE-KHA05, 433 W) and note book computer (IBM X31, Toshiba DynaBook CX/E216L). The sensor can work even when the area around these appliances where the electromagnetic signal can be detected is relatively small. This area may be enlarged by increasing the amplifier gain; however, such an increase also amplifies the noise that results from the power lines in the house, as mentioned above and in section 3.1. Introduction of an automatic gain controller (AGC) or variation of the gain is required to solve this problem; on the other hand, a small detectable area may prevent the contamination of the signal by signals from other appliances.

5. Conclusion

In this study, we developed a monitoring system and a sensor unit to be used in a behavioural monitoring system for ordinary houses; this sensor unit fulfils the requirements of simple installation and removal. The television sensor and general-purpose sensor developed in this study appear to be suitable for practical use. Developing specialized sensors (for specific devices) and performing further clinical evaluations are topics for future studies.

Acknowledgements

The authors are grateful to Mr. Haruhisa Naganokawa for technical support. This study was partly supported by a Grant-in-Aid for Scientific Research (16700429) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan and Grants-in-Aid from the Ministry of Health, Labour and Welfare, the National Center for Geriatrics and Gerontology, and Chiba University.

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Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

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.

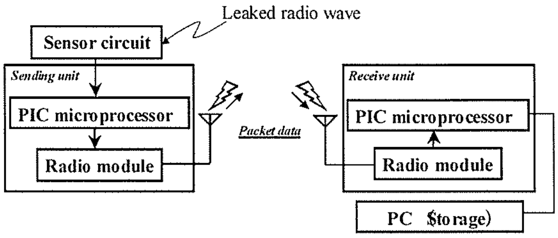

Fig. 1. Schematic diagram of the system.

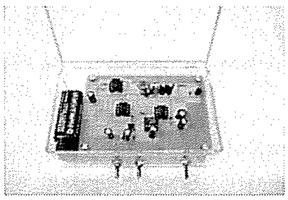

Fig. 2. Sensor circuit.

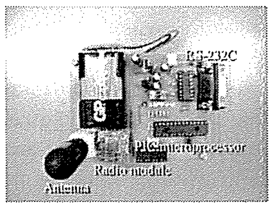

Fig. 3. Processor board (transmitter/ receiver unit).

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

Manuscript received April 3, 2006. This study was partly supported by a Grant-in-Aid for Scientific Research (16700429) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan and Grants-in-Aid from the Ministry of Health, Labour and Welfare, the National Institute for Longevity Sciences, and Chiba University.

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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

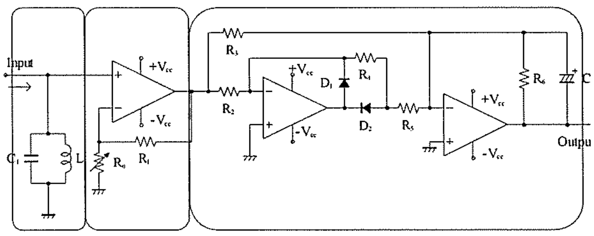

Fig. 4. Circuit diagram of television sensor.

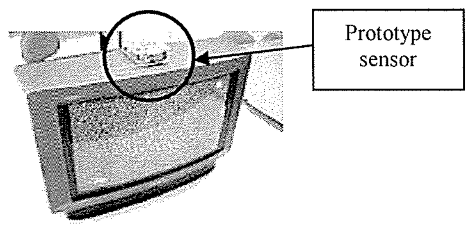

Fig. 5. Arrangement of television sensor.

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.

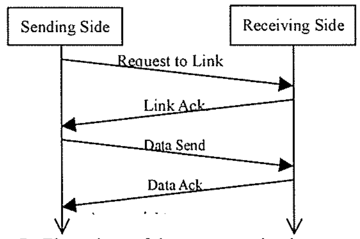

Fig. 7. Flow chart of data communication process.

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.

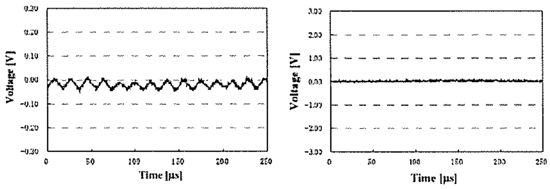
(a) Input waveform (b) Output waveform

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

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.

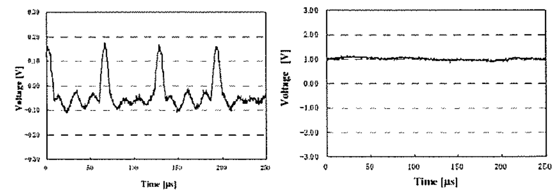
(a) Input waveform (b) Output waveform

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

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.

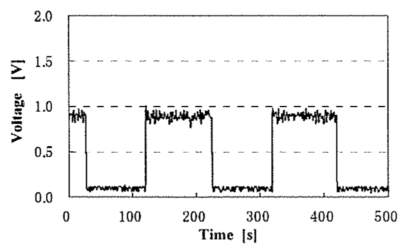

Fig. 10. Television on/off test.

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.