

Research Article

Wireless Sensor Networks for Vital Signs Monitoring: Application in a Nursing Home

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This study evaluated the application of a wireless sensor network (WSN) on a web-based vital signs monitoring system to nursing homes in Taiwan. The applicability assessment focused on the timely provision of information, information accuracy, system usability, and system accessibility of healthcare systems using a wireless sensor network. Experiments were performed under Internet-based network conditions to verify the timely information provision, especially for a web-based system, including Ajax technology. The accuracy of the information was verified from statistical analyses of the residents' daily vital sign measurements. A comparison was performed between having and not having a healthcare monitoring system in nursing homes for system usability, system accessibility, and system efficacy. The results indicate that the successful application of a WSN healthcare monitoring system is feasible for use in nursing homes in Taiwan.

1. Introduction

As the number of elderly people in Taiwan has continued to increase in recent decades, the percentage of persons aged 65 and older has increased from 7.1% in 1993 to 9.9% in 2006 [1]. It is estimated that Taiwan will become an aged society in 2017, when elderly people will account for more than 14% of the entire Taiwanese population. Thus, health-related issues are becoming increasingly important for this segment of the population. The needs for medical care and long-term care, as well as their linkage with the National Health Insurance (NHI) program for elderly people, should be considered. It is also expected that the costs of long-term care for older people will increase [1].

Besides, one of the severe problems for long-term patient care is the shortage of human resources and the growing needs of health workers [2]. The adoption of information

communication technology (ICT) may help to alleviate some parts of this problem. Additionally, a higher quality of nursing service may be achieved. A vital signs monitoring system with wireless sensor networks (WSN) may be a key solution for long-term care. A wireless sensor network monitoring system not only avoids the high cost of devices and installation but also preserves the resident's comfort and privacy [3]. These sensor networks are designed to be self-management and self-healing and are installed to gather data in places where the use of cabled sensors is undesired [4, 5]. Many advantages of healthcare monitoring systems based on wireless sensor networks (WSNs) have been reported [6, 7]. To improve the throughput of WSN, a DSP-based WSN platform was proposed [8]. To enhance the performance of communication, an integrated wireless health service system with 3G/3.5G and mobile devices was revealed in some researches [9–13]. Impacts of monitoring system to

elderly people were also evaluated in some researches [14–17]. The results showed that most of elderly people have positive attitude to wireless health monitoring systems. These applications help medical caretakers in hospitals to obtain patients' electronic records anytime and anywhere. Further, as mentioned in a previous study [16, 17], a ZigBee-based healthcare service system can provide significant satisfaction for the community care. The results also suggest that a telecare system will not be accepted without an auxiliary medical service. This may be especially true for a new technology, where users have to trust the system by seeing that it meets their expectations and delivers satisfaction [18]. Additionally, people may lack confidence in such a healthcare monitoring system if it includes no medical service provided by physicians or nurses. Because of Chinese traditional concepts, when they feel sick, many older people hope to talk to doctors face-to-face to meet their psychological needs. A successful line of business (LOB) application for home healthcare monitoring systems in Taiwan should take this into consideration. In this study, we suggest that a successful healthcare monitoring system should be combined with a nursing/medical service. In the present environment in Taiwan, such a system would probably be implemented in nursing homes or clinics because those facilities can provide nursing/medical services. When all nursing homes and clinics use healthcare monitoring systems in their daily work, they can ask their residents/patients to use healthcare monitoring systems at home. Then, the nursing service provided by nursing homes and medical services provided by clinics can be extended to home. However, it is obvious that a feasible strategy for replacing the old system with a new one should provide a seamless transition and should not change the workflow too much. This development should provide caregivers more time and reduce the routine loading. After trust in the new healthcare monitoring system has been established, it will be possible for the users, including residents and caregivers, to accept the change. Because of limitations in medical law, telemedicine remains impermissible in Taiwan presently. However, the healthcare monitoring system we propose can be used as part of a care service, combined with traditional nursing service in nursing homes and long-term healthcare institutions. Thus, this study focused on assessing the applicability of a wireless sensor network (WSN) healthcare monitoring system for nursing homes, from the viewpoint of software development and deployment [19]. The results of our 3-month clinical experiment may lead to a better understanding of the feasibility of a telecare business model in Taiwan. The objectives of this study were as follows:

- (i) to evaluate the timely provision of information, information accuracy, system usability, and system accessibility of a WSN healthcare monitoring system in daily healthcare measurements,
- (ii) to provide WSN healthcare monitoring system implementation and assessment in nursing homes,
- (iii) to provide results indicating user satisfaction with a WSN healthcare monitoring system in nursing homes.

This paper describes the design and implementation of a WSN healthcare monitoring system for the care of elderly people living in nursing homes, using a clinical experiment to evaluate the system.

2. Research Methodology

2.1. System Architecture of Healthcare Platform. The design and implementation of a WSN healthcare monitoring system was required for this study because no web-based healthcare monitoring system with WSN offering daily vital signs measurement is currently commercially available. The system architecture we designed is shown in Figure 1. The wireless sensor network consists of a Personal Area Network (PAN) coordinator, routers, and end devices. The end devices of the wireless sensor network include a temperature sensor and a blood pressure sensor. The vital signs detected by the sensors are transmitted from the devices. When the router receives data from the associated device, it immediately sends data to the associated PAN coordinator. The PAN coordinator then sends it to the UART connected by a gateway. Java program was developed to transmit vital signs data from the gateway to the remote database server via the Internet using a client-server access method [20]. These WSN components and gateway were set up at the Haechun Nursing Home, located in Taichung, Taiwan, and were connected to the Internet with an ADSL broadband connection at a connection speed of 2 M/256 kbps (downstream/upstream). An independent global web and database server was constructed and set up at the Central Taiwan University of Science and Technology (CTUST), about 10 km from the Haechun Nursing Home. The web-based healthcare service management platform was hosted on a web server. Client-side users, for example, the caregiver, physician, or a resident's family member, can access the vital signs data through the Internet. Three web-based modules were provided to client users: the Daily Vital Signs Recording Module (DVSRM), the Caregiver Signature Form Printing Module (CSFPM), and the Historical Record Plotting Module (HRPM). Each resident had to have basic physiological signals measured once a day, including temperature, heart rate, and blood pressure. The DVSRM can receive vital signs data from the sensor and store data on the database server. Caregivers can use the CSFPM to print out and sign the daily vital signs' records of the residents. The physician and the resident's family members can use the HRPM to view the resident's vital signs record history and know his health status.

2.2. A Wireless Sensor Network Layout in a Nursing Home. The wireless sensor network was built at the Haechun Nursing Home. At the time of the study, 94 beds were housed in the six-floor building. A total of 10 residents on the fifth floor cared by one were chosen by convenience sampling to participate in this experiment. The complete WSN layout is shown in Figure 2. The wireless sensor network consists of a Personal Area Network (PAN) coordinator, routers, and end devices. A microcontroller unit built in the device with a ZigBee RF chip selected one of the routers that had the shortest distance between the router and the end device.

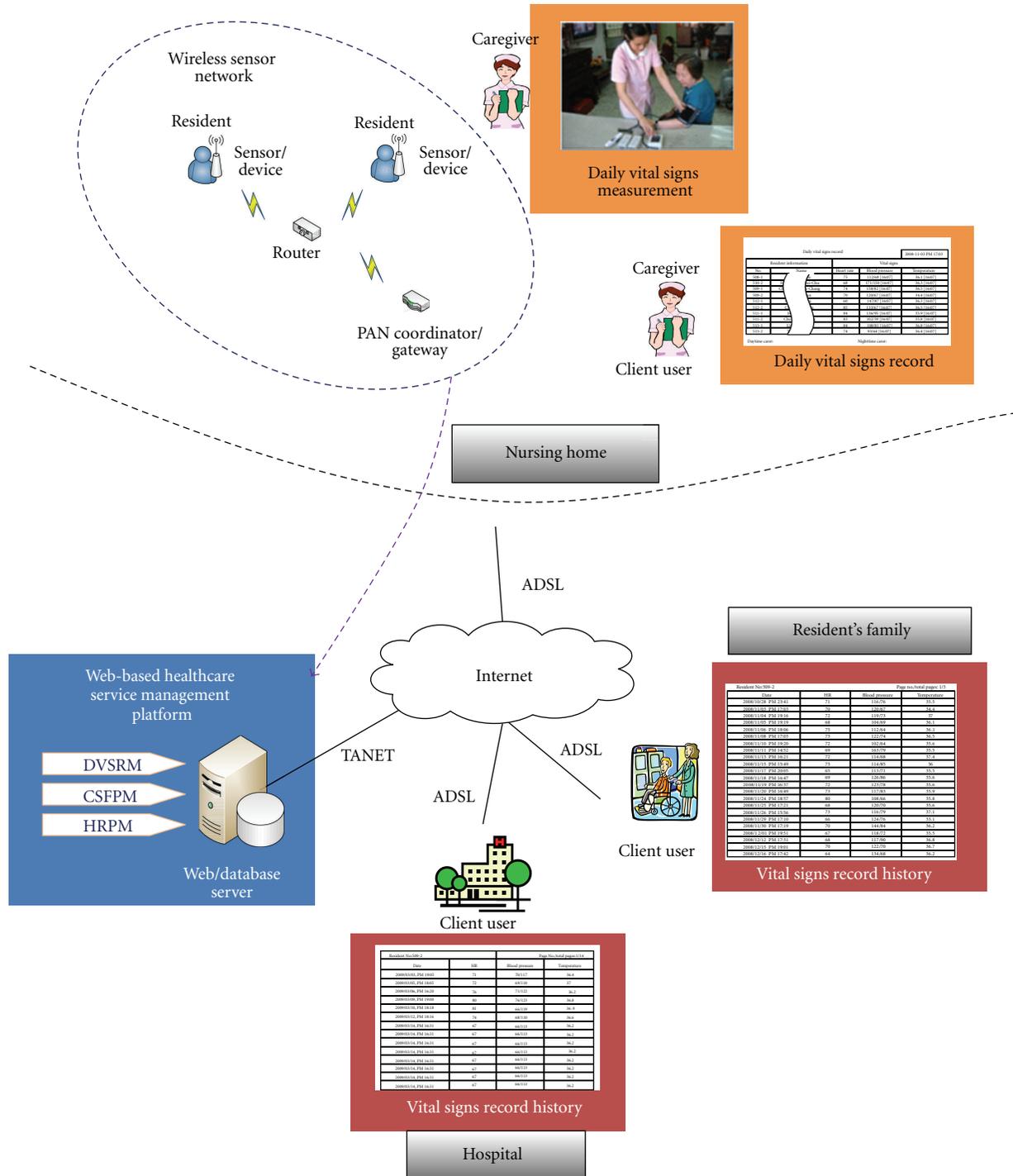


FIGURE 1: System architecture of the WSN healthcare monitoring system designed in this study.

When the device joined a router, it began retrieving vital signs data from the sensor and sent the data to the router. When the router received data from the associated device, it immediately sent data to the associated PAN coordinator. The PAN coordinator then sent the data to the UART connected with a gateway. The gateway then sent data to the remote database server by a client-server program built in a gateway via the Internet.

The detailed description of the components is as follows.

- (1) Internet connection: Haechun Nursing Home was connected to the ISP HINET by an ADSL broadband network at a connection speed of 2 M/256 kbps (downstream/upstream). The caregiver can also access the healthcare platform via this broadband network connection.

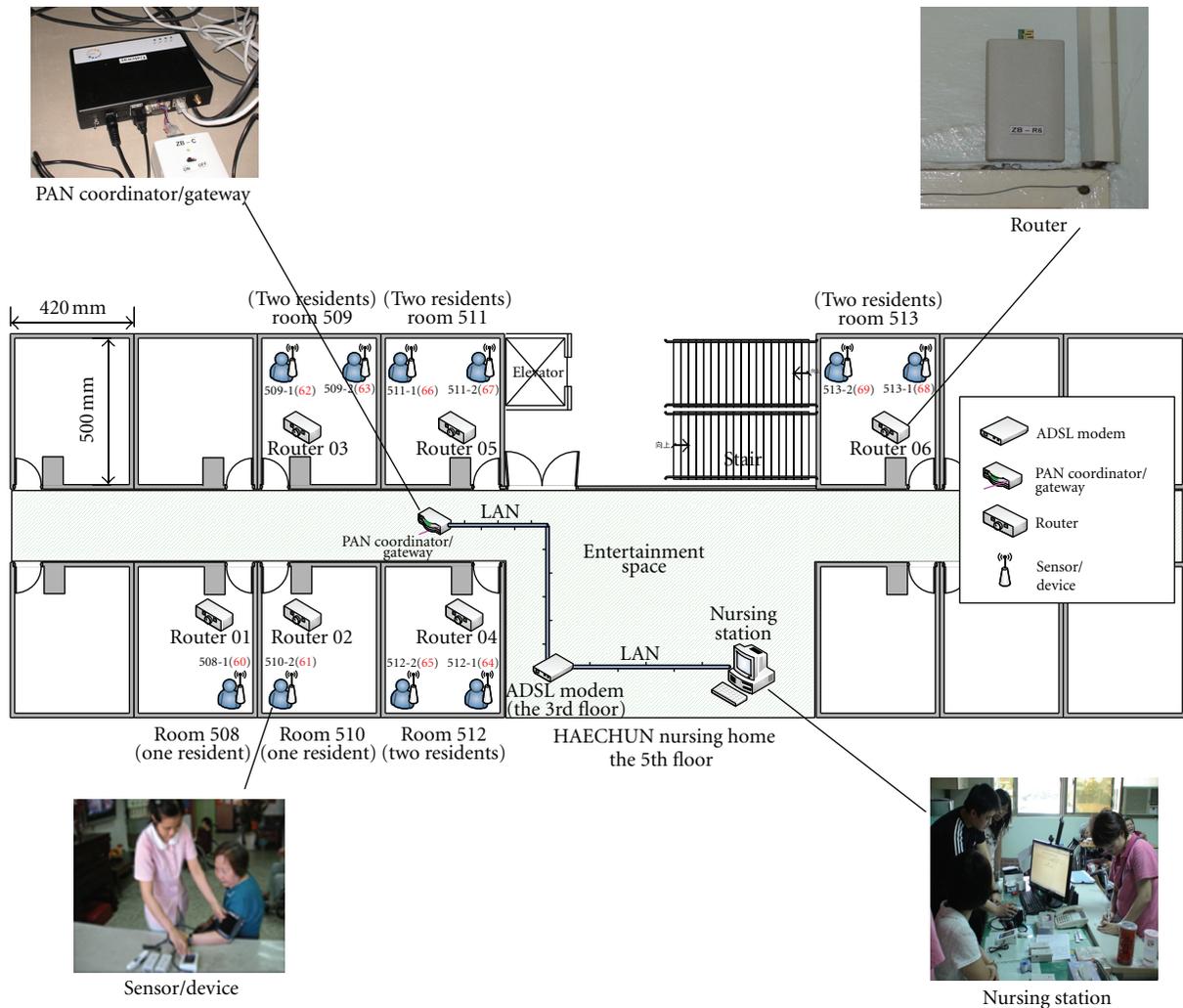


FIGURE 2: Complete wireless sensor network layout in the nursing home.

(2) Gateway and PAN coordinator: the gateway and the PAN coordinator ZB-C were placed in the ceiling of a corridor (Figure 2). Only one gateway and a PAN coordinator were needed on each floor. The gateway and the PAN coordinator are shown in Figure 3(a). The circuit board in the gateway and PAN coordinator is shown in Figures 3(b) and 3(c), respectively. An embedded platform, provided by the Rosonix Technology (Rosonix Technology Inc., Taipei, Taiwan), was used to develop the gateway. The platform uses the ARM9 processor (Samsung 2410) with 64 Mbyte NAND Flash and two 128 Mbyte memory modules on board. Embedded Linux 2.4 was installed, and C/C++ language was used to develop the gateway client module. This sensor gateway was connected to the PAN coordinator through a UART. The WSN components, including the PAN coordinator, router, and device, were homemade. The Texas Instruments TI-MSP430F1611 (Texas Instruments, Dallas, TX, USA) was chosen as the core control unit, because

of its ultra-low-power consumption, and the UBECE ZigBee module UZ2400 (Uniband Electronic Corp., Hsinchu, Taiwan) was chosen as the RF module for its stability and design flexibility. Different firmware versions were used with the PAN coordinator, router, and device, depending on the application. The design of the WSN hardware platform was described in detail previously [21, 22].

(3) Router: one router, ZB-R, was installed in each room on top of the door (Figure 2). The router received vital signs data from the device and transmitted the data to the PAN coordinator. The router and circuit board are shown in Figures 4(a) and 4(b), respectively.

(4) Device: the ZigBee Device ZB-T and ZB-P can retrieve vital signs data from the thermometer and sphygmomanometer, respectively, and transmit data to the router ZB-R. Each resident had his/her own device for the different sensors in which a specified

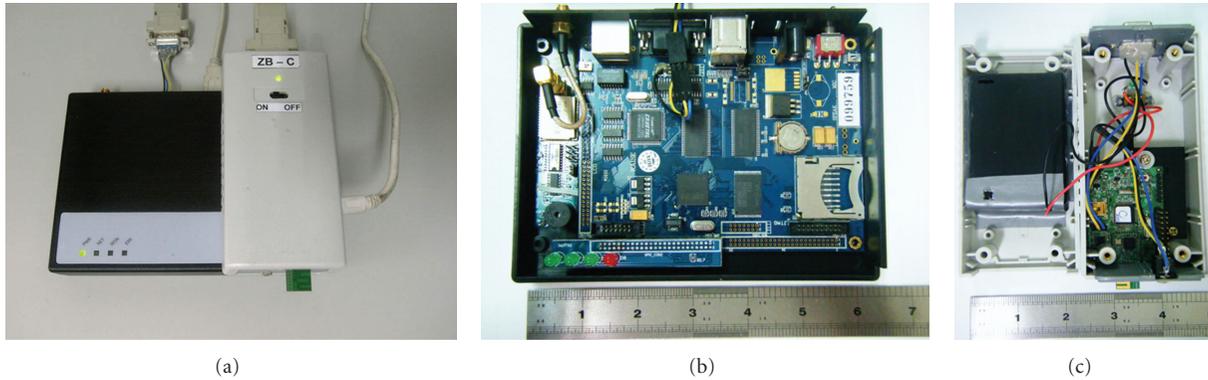


FIGURE 3: Photographs of (a) gateway and PAN coordinator ZB-C, (b) circuit board in gateway, and (c) circuit board in PAN coordinator.

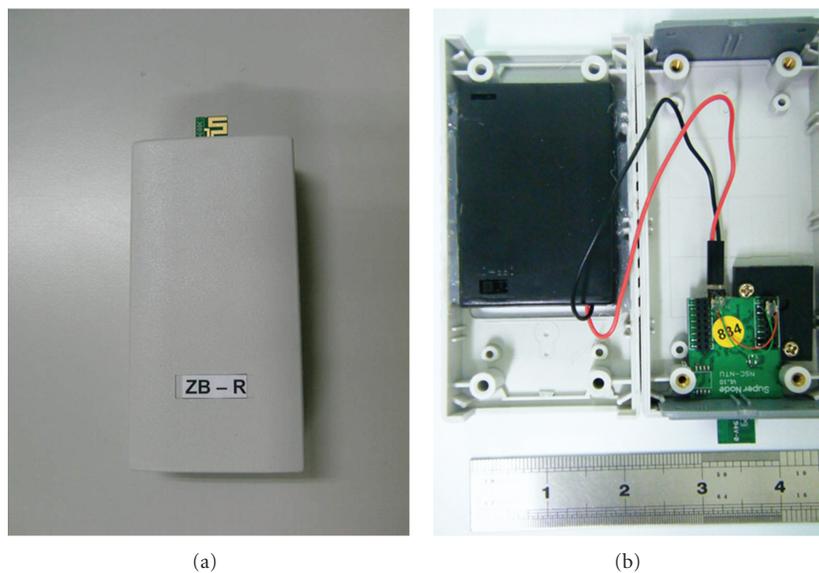


FIGURE 4: Photographs of (a) router ZB-R and (b) circuit board in router.

sensor ID was recorded in the firmware. Each device had a unique resident ID in this wireless sensor network. An LED light was designed to indicate data transmission status. Photographs of the devices for temperature and blood pressure are shown in Figures 5(a) and 5(b), respectively. A photograph of the circuit board in the device is shown in Figure 5(c).

- (5) **Sensor:** two sensors, a thermometer and a sphygmomanometer, were used to measure three vital signs, temperature, heart rate, and blood pressure. The thermometer used in the WSN healthcare monitoring system was a TD1261A (TaiDoc Corporation, New Taipei City, Taiwan), as shown in Figure 5(a). The sphygmomanometer used in the WSN healthcare monitoring system was the TD3250B (TaiDoc Corporation), as shown in Figure 5(b).
- (6) **Web/Database Server:** A “WAMP” (Windows, Apache, MySQL, PHP) system was set up to manage the vital signs data. The web-based healthcare service

management platform was hosted on a web server, and it provided the aforementioned three modules to client users. The web/database server was located at the CTUST and connected to the TANET at a connection speed of up to 1,000 Mbps.

2.3. Evaluation Methodology. To evaluate the system in clinical practice, a clinical paired-comparison experiment was designed [23]. Ten residents cared by one caregiver were selected by convenience sampling to participate with their agreement. For convenience, they were cared for by the same caregiver and were located on the same floor. In the nursing home, every resident has to have his/her vital signs measured at least once a day. The daytime caregiver and the nighttime caregiver have to write down the results of the measurement on a signature form and sign the form (Figure 6). The caregivers who take care of these residents in the nursing home were most concerned about whether the vital signs data could be recorded automatically, and the most important issues were that the vital signs data were

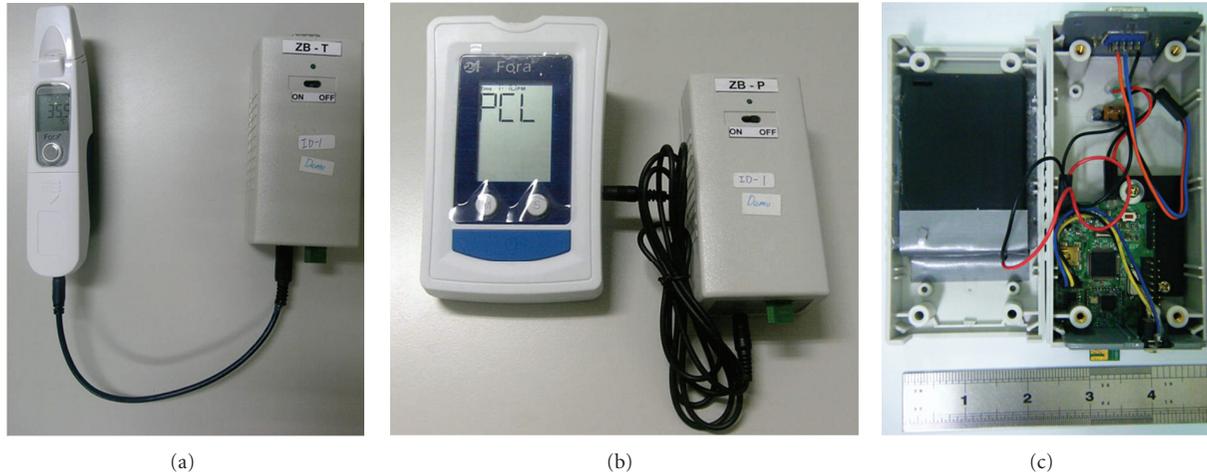


FIGURE 5: Photographs of the sensor and device. (a) Thermometer and device, (b) sphygmomanometer and device, and (c) the circuit board in device.

Daily vital signs record					2008-11-03 PM 17:03
Resident information			Vital signs		
Number	Name		Heart rate	Blood pressure	Temperature
508-1		en	75	112/68 (16:07)	36.1 (16:07)
510-2	H	hui-Chu	68	171/150 (16:07)	36.3 (16:07)
509-1	Ch	n-Chang	74	158/82 (16:07)	36.5 (16:07)
509-2		un	70	120/67 (16:07)	34.4 (16:07)
512-1	C	u	60	147/87 (16:07)	36.3 (16:07)
512-2	Ch	n	85	133/67 (16:07)	36.5 (16:07)
511-1	H		84	136/95 (16:07)	35.9 (16:07)
511-2	Cher	g	83	102/59 (16:07)	35.8 (16:07)
513-1	Lir		84	108/81 (16:07)	36.8 (16:07)
513-2	T		74	93/64 (16:07)	36.4 (16:07)

Daytime carer:

Nighttime carer:

FIGURE 6: Signature form for the daily vital signs record.

always correct and that they were not lost through wireless transmission. In addition, the nurses in the nursing home had to collate each resident’s daily vital signs record into a vital signs history record (Figure 7). Periodic routine visits by physicians were scheduled once a month. The physicians needed to review the resident’s historical vital signs record during each visit. This WSN healthcare monitoring system can help nurses generate reports with vital signs history records and can enhance the efficiency of the nurses’ work. Thus, the aim of the experiment was to evaluate the timely provision of information, information accuracy, system usability, and system accessibility of a WSN healthcare monitoring system in daily vital signs measurement. One caregiver measured vital signs of these 10 residents using conventional equipment and without the WSN healthcare monitoring system. Another caregiver measured the vital signs of the same 10 residents using the WSN healthcare monitoring system. The experiment lasted 3 months. The detailed evaluation method is described as follows.

(1) Timely provision of information: the total time it took to display the residents’ sensor-measured vital signs on the user’s screen was calculated. Time1, Time2, and Time3 were measured to obtain the mean and standard deviation for each experiment (Figure 8) [24]. Thus, the total time is equal to the sum of Time1, Time2, and Time3. This represented the timely provision of information. Time1 included device processing time, transmission time from device to router, router processing time, and transmission time from router to gateway. Time2 included gateway processing time and transmission time from gateway to database server. Time3 included web page processing time and data transmission time from database server to a web page browsed by client users. An Internet broadband network connection with a connection speed of 2Mbps/256 kbps (downstream/upstream) was chosen for client users because such an Internet broadband network connection is popular, with its usage exceeding 66% by families in Taiwan Network Information Centre.

Resident number: 509-2 Page number/total pages: 1/3

Date	HR	Blood pressure	Temperature
2008/10/28 PM 23:41	71	116/76	35.5
2008/11/03 PM 17:03	70	120/67	34.4
2008/11/04 PM 19:16	72	119/73	37
2008/11/05 PM 19:19	68	104/69	36.1
2008/11/06 PM 18:06	75	112/64	36.1
2008/11/08 PM 17:03	73	122/74	36.5
2008/11/10 PM 19:20	72	102/64	35.6
2008/11/11 PM 14:52	69	163/79	35.5
2008/11/13 PM 16:21	72	114/68	37.4
2008/11/15 PM 15:49	73	114/85	36
2008/11/17 PM 20:05	65	113/71	35.5
2008/11/18 PM 16:47	69	126/86	35.6
2008/11/19 PM 16:37	72	123/78	35.6
2008/11/20 PM 16:49	73	117/83	35.9
2008/11/24 PM 18:57	80	108/66	35.8
2008/11/25 PM 17:21	68	120/70	35.6
2008/11/26 PM 15:56	73	116/79	37.1
2008/11/29 PM 17:10	66	124/76	33.1
2008/11/30 PM 17:19	70	144/84	36.2
2008/12/01 PM 19:51	67	118/72	35.5
2008/12/12 PM 17:31	68	117/90	36.8
2008/12/15 PM 19:01	70	122/70	36.7
2008/12/16 PM 17:42	64	134/68	36.2

1 2 3

FIGURE 7: Vital signs record history of a resident (only some records were shown here).

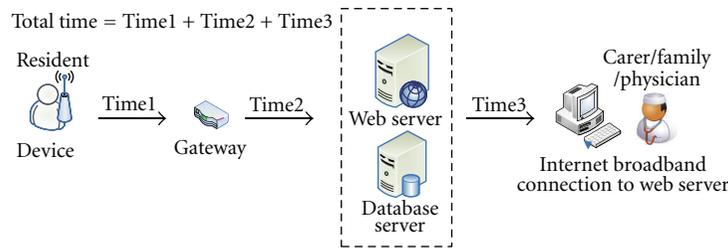


FIGURE 8: Diagram depicting the experimental design for timely delivery of information.

(2) Information accuracy: when a new technology is adopted, users generally ask whether they can trust the technology. Thus, we wanted to compare the two methods for measuring residents' vital signs. A paired experiment was designed to test for differences between the two measurement methods. One caregiver used conventional sensors to measure 10 residents' vital signs. The thermometer used was an OMRON MC-110B (OMRON Healthcare Inc., Kyoto, Japan) and the sphygmomanometer used was the Spirit ck-101 (Hsing Sheng Medical Goods Inc., Taipei, Taiwan). Another caregiver repeated the measurements on the same 10 residents' vital signs using the WSN healthcare monitoring system. The sensors used with the WSN system were a thermometer, TD1261A, and a sphygmomanometer, TD3250B, both from the TaiDoc Corporation (TaiDoc Corporation, New Taipei, Taiwan). The two values, the paired data, were recorded and a paired *t*-test statistical analysis was conducted to compare the two measurement methods.

(3) System usability: the main reason for applying usability in the development of a healthcare monitoring system is to increase user satisfaction and acceptance. Even when our system was deployed at the Haechun Nursing Home, we continued with our system modifications. Some system usability issues were considered:

- (i) provide obvious visual indicators when the system is retrieving and transmitting data,
- (ii) provide a standard operational procedure (SOP) that users can follow,
- (iii) reform the user interface for the sensor device to make it easy for the user to understand the status of the sensor device,
- (iv) redesign the workflow for daily measurements to save the user time [19].

TABLE 1: Results of experiments on the timely attainment of information.

Time1* ¹ (second)	Time2* ² (second)	Time3* ³ (second)	Total time (second)
0.006 ± 0.000	0.228 ± 0.030	0.586 ± 0.040	0.82 ± 0.128

*¹ Average time of 30 times experiments, and each experiment 10,000 row data: average time ± standard deviation.

*² The connection speed from the nursing home to Internet is 2 M/256 k.

*³ The connection speed from the resident's family to Internet is 2 M/256 k.

TABLE 2: Data for different measurement techniques.

Residents			Conventional method				Sensors with a WSN healthcare monitoring system			
Number	Age	Gender	HR	Systolic BP	Diastolic BP	Temperature	HR	Systolic BP	Diastolic BP	Temperature
508-1	50	M	80	110	60	36.0	75	109	74	36.5
509-1	85	F	80	130	90	36.0	67	115	71	36.4
509-2	74	F	68	110	80	36.0	68	112	76	36.1
510-2	54	M	88	160	90	36.2	80	147	67	36.4
512-1	76	F	66	130	60	36.7	59	121	67	36.2
512-2	88	F	98	130	80	36.6	97	96	63	36.3
511-1	52	F	80	110	60	35.4	73	122	87	35.6
511-2	74	F	70	90	70	35.5	89	96	71	35.7
513-1	61	M	80	100	60	36.2	74	108	73	36.6
513-2	87	M	84	120	86	37.2	90	117	87	36.6

(4) System accessibility: some features were customized to caregivers' and client users' needs to promote system accessibility. A web-based graphic user interface (GUI) was designed to make the system easy to use. The user simply opens the browser and each of the processes was performed, including the printing of the daily vital signs record, monitoring of the physiological status of the residents, and viewing of the vital signs history records of residents.

After the experiment, user satisfaction was investigated to understand the intended use of the WSN healthcare monitoring system.

3. Results and Discussions

3.1. Attainment of Timely Information. The results of the measurements for the timely provision of information in this experiment are shown in Table 1. The average duration of Time1 was 0.006 ± 0.000 seconds. Time1 was primarily affected by two factors. First, the number of sensor nodes transmitting data concurrently affected transmission time. As a complication, an increase in the number of sensor nodes increased the possibility of a collision of packets. Second, the priority of each packet affected the waiting time for transmission if two or more sensor nodes were transmitting data concurrently. In this study, only one sensor node transmitted data at any time.

The average duration of Time2 was 0.228 ± 0.030 seconds. Time2 was primarily affected by two factors [25]. First, the network connection speed from the gateway to the database server affected the transmission time. In this study, the Haechun Nursing Home used an ADSL connection with a connection speed of 2 M/256 kbps (downstream/upstream). Second, the access method from the gateway to the database

server affected transmission performance. According to a previous study [25], we adopted the client-server access method to achieve better transmission performance.

Time3 is the time needed for the client users to inspect the vital signs' records of the residents. A web-based interface was designed for client users in which Ajax was used to retrieve data from the remote web server. However, the asynchronous JavaScript function did not display the results on a web page until a response was received from the server. This response time affected Time3. Due to the low data transmission rate needed by Ajax technology, a different network connection speed for the client side did not affect Time3. The Internet broadband network connection with a connection speed of 2 Mbps/256 kbps (downstream/upstream) was chosen for client users. In a total of 30 experiments, with each experiment involving transmission of 10,000 data records, the average total time for transmission from device to client users was 0.82 ± 0.128 seconds (Table 1). The results showed that whenever the vital signs were measured, the data were immediately recorded into the database. This means that any client user can inspect the data at once. This provides physicians the opportunity to monitor residents' health status remotely via the Internet.

3.2. Information Accuracy. To convince caregivers and residents to trust the vital signs' values measured by the sensors of the WSN healthcare monitoring system, a paired *t*-test statistics analysis was conducted. Table 2 shows the paired data measured by the two different methods. A total of 107 data records were used in the calculations, but only one day's record is presented. Table 3 shows the paired *t*-test results for the two different measurement techniques. For all vital signs

TABLE 3: Paired *t*-test results for different measurement techniques.

		Conventional method		Sensors with WSN healthcare monitoring system		<i>t</i>	<i>P</i>
		M	SD	M	SD		
Vital signs	HR	78.07	9.321	79.64	10.229	-1.788	0.077
	Systolic BP	119.81	13.666	120.92	17.888	-0.861	0.391
	Diastolic BP	77.16	8.306	75.55	9.550	1.802	0.074
	Temperature	36.18	0.508	36.10	0.5	1.199	0.233

TABLE 4: Questionnaire responses (*n* = 162).

Question	User score					Mean
	A1 <i>n</i> (%)	A2 <i>n</i> (%)	A3 <i>n</i> (%)	A4 <i>n</i> (%)	A5 <i>n</i> (%)	
(1) To use WSN healthcare monitoring system in your job would make it easier to accomplish care work.	20 (12.3)	75 (46.3)	50 (30.9)	14 (8.6)	3 (1.9)	3.59
(2) To use WSN healthcare monitoring system would improve care.	19 (11.7)	80 (49.4)	45 (27.8)	15 (9.3)	3 (1.9)	3.60
(3) To use WSN healthcare monitoring system would make it easier to conduct care work.	20 (12.3)	76(46.9)	52 (32.1)	11 (6.8)	3 (1.9)	3.61
(4) You would find WSN healthcare monitoring system useful to conducting care work.	17 (10.5)	87 (53.7)	45 (27.8)	10 (6.2)	3 (1.9)	3.65
(5) You would be clear and understandable with WSN healthcare monitoring system.	16 (9.9)	83 (51.2)	49 (30.2)	11 (6.8)	3 (1.9)	3.60
(6) To learn how to operate WSN healthcare monitoring system is easy for you.	19 (11.7)	77 (47.5)	52 (32.1)	10 (6.2)	4 (2.5)	3.60
(7) I think it is easy for me to become familiar with WSN healthcare monitoring system after learning and practice.	19 (11.7)	83 (51.2)	51 (31.5)	7 (4.3)	2 (1.2)	3.68
(8) I think WSN healthcare monitoring system is easy to use.	18 (11.1)	75 (46.3)	58 (35.8)	9 (536)	2 (1.2)	3.60
(9) I am willing to use the WSN healthcare monitoring system in my work.		YES: 135 (83.3)		NO: 27 (16.7)		

A1: strongly agree; A2: agree; A3: neutral; A4: disagree; A5: strongly disagree.

measured in this study, heart rate, blood pressure, and temperature, the *P* values were greater than 0.05. Thus, we are confident that there was no statistically significant difference between the two measurement methods. Additionally, these data were reviewed by physicians and nurses, who claimed that these data were routine. Thus, caregivers can trust the WSN healthcare monitoring system to perform daily vital signs measurements.

3.3. System Usability. Caregivers rely on technology to perform their daily vital signs measurement. Information accuracy affects their confidence in using the technology [18, 19]. For the wireless sensor network, the transmission distance between sensor nodes affected the packet loss rate (PLR), which consequently affected the accuracy of our data. This study included an experiment on PLR in the indoor space. The experiments used a transmitter node and a receiver node; the transmitter node continuously sent one hundred full packets to the receiver node. The receiver node checked how many packets were received after varying

the distance between the transmitter node and the receiver node and repeating the experiment 10 times at a given distance, as follows:

$$\text{Packet Lost Rate (PLR)} = \frac{100 - \text{Received Packets}}{100} \times 100\%. \quad (1)$$

Figure 9 shows that the packet loss rate was less than 2.5% when the transmission distance was less than 18 m. Serious data errors may occur when the packet loss rate increased. We are not able to control the packet loss rate because the wireless environment differs, case by case. To avoid data transmission errors, a specially designed indicator of the data transmission status was guaranteed to correct data storage on the database server. An LED light was used to display the data transmission status. When the device was turned on, initial test data were sent to the gateway, and the LED light flashed continuously until the device received a message from the gateway to ensure that vital signs data were stored in the remote database. If the response revealed the

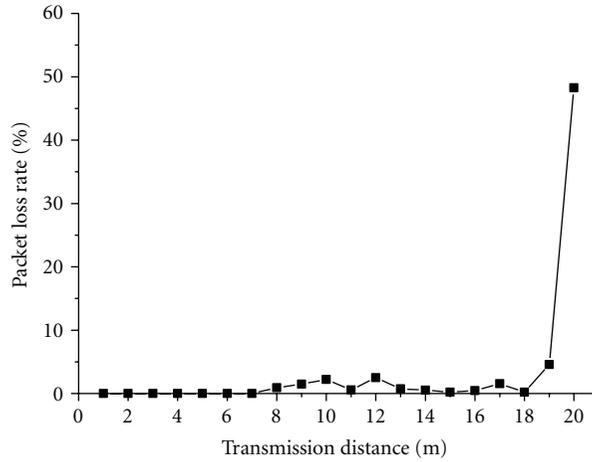


FIGURE 9: Packet loss rate versus transmission distance (meter).

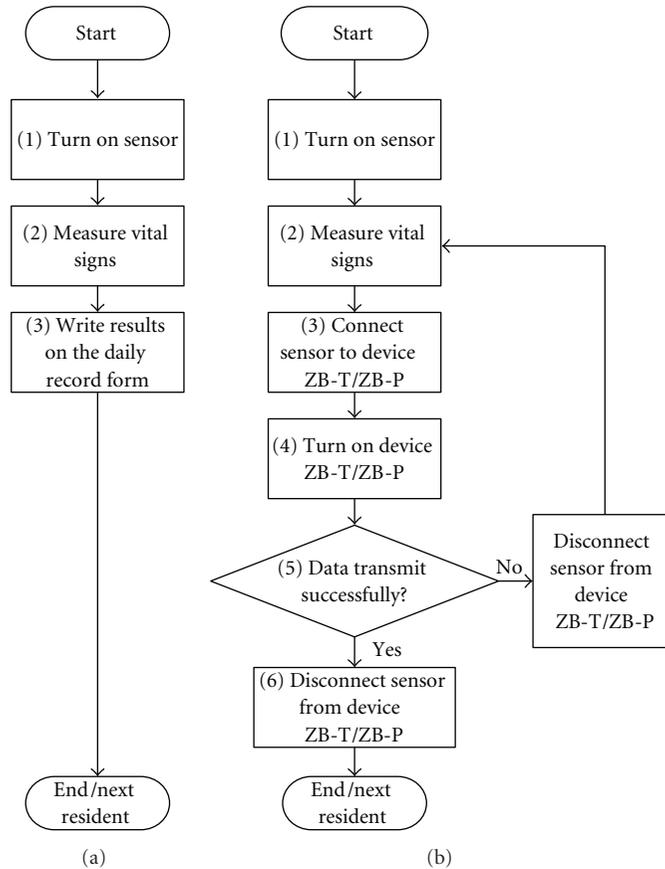


FIGURE 10: (a) Conventional workflow and (b) new workflow for vital signs measurement procedure.

transmission was correct, the LED light turned off and waited for the caregiver’s immediate measurement. When the next vital signs were measured, the LED light again lit up and the process was repeated. The data were correctly measured and stored if the caregiver followed the SOP. This LED indicator made users more confident in performing their daily vital signs measurement and enhanced the usability of the WSN healthcare monitoring system.

3.4. System Accessibility. A similar workflow process for caregivers to measure vital signs of residents using the WSN healthcare monitoring system enabled the caregivers to transfer seamlessly from the conventional measurement technique to a new one. Figure 10 depicts the conventional and new workflow procedures for measuring vital signs. Compared with the conventional workflow, three extra steps (steps 4–6) were needed for the new workflow; however,

these added steps took less than 30 s. Moreover, the caregivers did not need to write down their retrieved results on the signature form of the daily vital signs record. Following the SOP also reduced typing errors. From the physician's point of view, it is possible to review any resident's health status every day via the Internet using only a browser, thus reducing scheduled clinic visits for residents. Additionally, unexpected health alarms can be sent immediately, if needed.

3.5. Costs. The cost for developing the system designed in this study for nursing home was minimal, because the workflow already existed. The training course can also be accomplished easily. The calculated costs included an equipment cost of one gateway (US \$514), one PAN coordinator (US \$29), six routers (US \$174), and 20 devices (US \$580), for a total cost of US \$1,297, or an average of US \$130 per resident. The director of the nursing home states that this cost would be acceptable if the WNS healthcare monitoring system could increase the residents' satisfaction. Of course, such costs can be reduced when the equipment is mass produced and purchased in bulk.

3.6. User Satisfaction. This WSN healthcare monitoring system was demonstrated to 130 nurses and 32 physicians; all 162 users responded to the user satisfaction questionnaire. Table 4 shows the percentage of the nurses and physicians who were satisfied and dissatisfied. Overall, the nurses and physicians were satisfied with the WSN healthcare monitoring system. About 61.1% of the users agreed that the WSN healthcare monitoring system can improve care. 57.4% of the users agreed that the WSN healthcare monitoring system was easy to use. However, 62.9% of the users agreed that it was easy to become familiar with the WSN healthcare monitoring system only after learning and practice. Finally, 135 (83.3%) users were willing to use the WSN healthcare monitoring system.

4. Conclusion

Based on the seamless transfer from a conventional workflow to a new one, the WSN healthcare monitoring system was found acceptable by the nursing home caregivers in this study. As opposed to the conventional procedure in which a caregiver has to spend time collecting daily vital signs data from residents, the new WSN healthcare monitoring system collected all the needed vital signs data automatically, emphasizing that caregivers do not need to change their work habits to use the new technology. This is a key point in whether a new system can be successfully introduced. Additionally, it was demonstrated that the system could provide near real time performance and was sufficient for nursing home use. Adequate distance in the deployment between sensor nodes and specially designed indicators guaranteed the data to be correct in its transmission and storage in the database server. The study also convinced users to trust the new WSN healthcare monitoring system, especially following a comparison between the new measurement method and the conventional one. Moreover, a clear SOP for the measurement of vital signs gave the

users confidence in conducting care work, which made the system more accessible. With the use of the WSN healthcare monitoring system, the extent of nursing services for residents actually remained the same. However, the residents felt that higher quality services were provided. In conclusion, with the WSN healthcare monitoring system, the caregivers' load of routine work could be reduced and quality of care could be improved. The results showed that the WSN healthcare monitoring system was applicable for use in a nursing home. After the healthcare monitoring system has been implemented successfully in nursing homes, elderly people and their families are likely to accept the healthcare monitoring system for use at home. The most important issue is to retain the linkage of nursing services provided by nursing homes and medical services provided by clinics or hospitals.

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