Development of a WLAN Based Monitoring System for Group Activity Measurement in Real-Time

Hiroshi Tsunoda, Hidehisa Nakayama, Kohei Ohta, Akihiro Suzuki, Hiroki Nishiyama, Ryoichi Nagatomi, Kazuo Hashimoto, Yuji Waizumi, Glenn Mansfield Keeni, and Yoshiaki Nemoto

Abstract: **In recent years, there has been a rise in epidemiological evidence suggesting the health benefits of a physically active lifestyle. However, it is not always easy for individuals to personally recognize the optimal conditions for exercise and physical activity. Wearable acceleration-based pedometers have become widely used in estimating the amount of physical activity, and to a limited extent, providing information regarding exercise intensity, but they have never been used to assess adaptation to exercise. In order to realize simultaneous activity monitoring for multiple users exercising outdoors, we developed a prototype wireless local area network (WLAN) based system. In our system, a WLAN is deployed outside, and a user wearing a smart phone and monitoring device exercises freely within the coverage area of the wireless network. By doing so, the developed system is able to monitor the activity of each user and measures various parameters including those related to exercise adaptation. In a demonstration experiment, the developed system was evaluated and used to monitor users enjoying a Nordic walk, after which users were immediately able to receive their exercise report. In this paper, we discuss the requirements and issues in developing an activity monitoring system and report the findings we obtained through the demonstration experiment.**

Index Terms: **Activity monitoring system, multiple simultaneous monitoring, Nordic walking, outdoor wireless local area network.**

I. INTRODUCTION

A lifestyle of fitness is becoming more important throughout the world; many people enjoy jogging and walking as a daily exercise to improve their health. In recent years, group exercise activities have become more popular, and many people have established groups to exercise together. Stabilizing exercise habits is a key for health enhancement, and the measurement and visualization of the benefit of the exercise encourages more people to start physical exercise. Consequently, the development of such a measurement system is eagerly anticipated [1].

In light of this situation, we aimed to develop measurement systems for supporting the stabilization of exercise habits. We defined the following requirements for such a system.

1. The system can measure users exercising outdoors.
2. The system can measure multiple users simultaneously.
3. The system can summarize the measurement data and generate a report immediately after the exercise.

Since many daily exercises such as jogging and walking are outdoor exercises, it is natural that the measurement system should work outdoors. As previously mentioned, some people enjoy exercising together in groups. In such group activity, providing measurement results for all users in the group will be useful for motivation. The measurement data give valuable feedback to motivate users and is useful for instructors when advising student users. Therefore, the measurement data should be provided as soon as possible after the exercise.

In order to fulfill these requirements, the measurement system should effectively utilize advanced networking technologies. These are vital for real-time measurement and can be used to ease restrictions on the measurement environment. Even now, the effect of exercise can be measured and evaluated in detail by using dedicated laboratory equipment. However, it is not feasible to use such equipment for the purpose of stabilizing exercise habits. On the other hand, cellular and smart phones with accelerometeres are becoming popular as a kind of advanced pedometer. These devices can send measurement data via 3G cellular data communications, and thus real-time activity monitoring for outdoor user exercise is possible. However, this system is not designed for monitoring group activity but for personal use only. When monitoring group activity, users receive heterogeneous measurement results if they do not have identical devices. Additionally, since monitoring devices such as accelerometers are integrated into the phone, the types of exercise that can be measured are limited because new sensors cannot be easily added to the phone.

Therefore, we assumed that a communication device and a sensor should be separated for monitoring multiple users exercising outdoors simultaneously. Based on this concept, we developed a prototype monitoring system using wireless local area network (WLAN) and Bluetooth technologies. Fig. 1 illustrates the overview of the developed system. A smart phone works as the communication device for sending the data to the server via WLAN, and the activity monitoring device, “Imoni” [2], serves as the sensor. The smart phone and Imoni are communicated via a Bluetooth connection. The separation of devices is useful for

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H. Tsunoda and H. Nakayama are with the Faculty of Engineering, Tohoku Institute of Technology, Sendai, Miyagi, Japan, email: {tsuno, hidehisa}@m.ieice.org.

K. Ohta and G. M. Keeni are with the Cyber Solutions Inc. Sendai, Miyagi, Japan, email: {kohei, glenn}@cysols.com.

A. Suzuki is with I. T. Research Co., Ltd, Sendai, Miyagi, Japan, email: asuzuki@itresearch-itr.com.

H. Nishiyama, Y. Waizumi, K. Hashimoto, and Y. Nemoto are with the Graduate School of Information Sciences, Tohoku University, Sendai, Miyagi, Japan, email: bigtree@it.ecei.tohoku.ac.jp, wai@ecei.tohoku.ac.jp, kh@aiet.ecei.tohoku.ac.jp, nemoto@bureau.tohoku.ac.jp.

R. Nagatomi is with the Graduate School of Biomedical Engineering, Tohoku University, Sendai, Miyagi, Japan, email: nagatomi@med.tohoku.ac.jp.

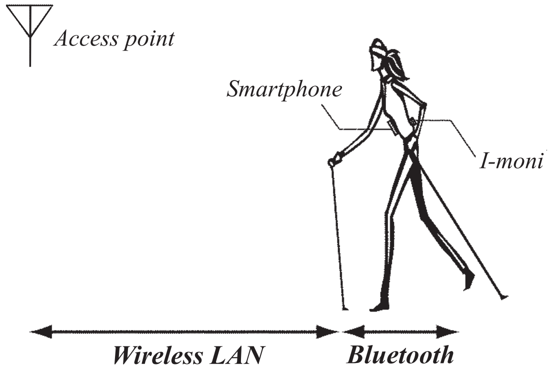

Fig. 1. Overview of activity monitoring system for Nordic walking.

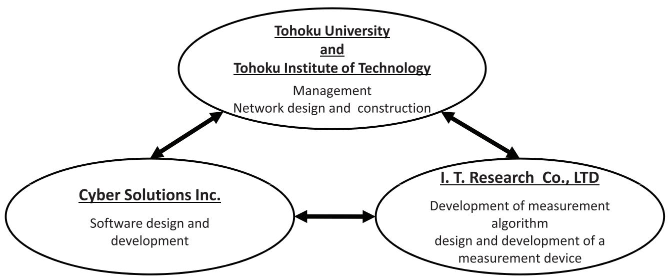

Fig. 2. Industry-university cooperation framework for research and development.

improving the flexibility of the system.

Using multiple WLAN access points, we can flexibly connect the measurement environment in an outdoor location. Users can freely exercise within the coverage of the access points and enjoy the benefits of the measurement services.

Imoni can measure the stride length as well as other usual measurements such as the number of steps taken and caloric expenditure. Because a user's stride length tends to slowly increase with exercise rather than quickly in a short time, stride length serves as a good metric for evaluating a user's exercise proficiency.

In order to validate the efficiency of the system, we conducted a demonstration experiment with Nordic walking [3], a type of fitness walking which uses specially designed walking poles[1]. As one of the fastest growing recreational field sports in the world, Nordic walking is an appropriate model for evaluating the system.

This work was supported by the greater Sendai area knowledge cluster initiative (GSAKCI) of the knowledge cluster initiative (2nd stage) [5][2] in Japan, and we developed the system via industry-university cooperation as shown in Fig. 2.

The reminder of the paper is organized as follows. Section II discusses the requirements for a real-time measurement system for group activity. In Section III, we describe the architecture and characteristics of our system in detail. Section IV presents an overview of the demonstration experiment and network configuration used in the experiment. Section V gives the experimental results and shows the validity of the system. Finally, conclusions are drawn in Section VI.

[1]Nordic walking originally began as a way for cross-country skiers to train during the summer in the early 1930s, and has grown in popularity since then as an important training method.

[2]Knowledge cluster initiative (2nd stage) [4] has been implemented by the Ministry of Education, Culture, Sports, and Technology Japan. The GSAKCI aims to better understand the health of the region's citizens and establish a health service cluster in collaboration with industry, academia, and the government.

II. REQUIREMENTS FOR THE MEASUREMENT SYSTEM

We developed the requirements for the measurement system according to advice received from an investigation with the Japan Nordic Fitness Association (JNFA), which is a member of the International Nordic Walking Federation (INWA) [3].

A. Measurement Environment

Since Nordic walking is an outdoor sport, the measurement environment must be assumed to be outside. Moreover, Nordic walkers enjoy exercising not only individually but also in a group. Therefore, we summarize the requirements for the measurement environment as follows.

- The measurement system can work under outdoor conditions.
- The measurement system can monitor at least 10 exercisers simultaneously.

In addition, minimization of user operation is also desired because groups of all ages can be users of this system.

B. Measurement Items

Using the advice we received from the JNFA, our system was designed to measure the following items.

- Change in and total caloric expenditure,
- total number of steps,
- total walking distance,
- change in average stride length,
- change in average walking speed.

The caloric expenditure, number of steps, and walking distance provide meaningful information and typical pedometers measure these items, which are useful for users to quantify their exercise achievements. Stride length and walking speed are appropriate parameters for estimating the proficiency in Nordic walking because a proficient user can efficiently push his/her body forward by using the poles, which increases these values.

The innovation of our system is the measurement of stride length, to the best of our knowledge, there are no simple system that can measure stride length like ours. In existing systems for measuring daily activities, stride length is not a measurement item but a value input by a user to calculate walking distance. In the commercial systems for training use, an additional dedicated device is required for measuring stride length. Our system only needs a single device for measuring all of the above-mentioned items. Moreover, the measurement accuracy of the stride length is the same or better than that of the existing systems for training (see Appendix).

C. Providing Measurement Results

The requirements for providing measurement results are as follows.

(1) A user can receive the exercise results immediately after the exercise.
(2) A user can check the current status of his/her progress during the exercise.
(3) An instructor can check the current status of a user's progress during the exercise.

A user's interest in the results peaks immediately after exercise. However, the disadvantage of conventional systems is that the system cannot output exercise reports on the same day because it takes time to retrieve the monitoring devices, read the measurement data, and analyze it. Therefore, the most important requirement is to give exercise reports to users immediately after they finishing.

In addition, users will be motivated if they can check their current status during the exercise. Instructors can also give effective advice to users in real-time according to their current status.

III. REAL-TIME MEASUREMENT SYSTEM FOR GROUP ACTIVITY

By using wireless links to gather measurement data, we developed a measurement system that realizes simultaneous activity monitoring for multiple users exercising outside. The measurement data are gathered through wireless links in real-time. Both users and instructors can see the current status of their exercise progress.

Fig. 3 depicts the architecture of the measurement system. The smart phone serves as a relay point for the measurement data; i.e., the measurement data from various monitoring devices are aggregated to a smart phone. A monitoring device and a smart phone are connected via Bluetooth, and a smart phone sends the accumulated data to the server via WLAN.

In this architecture, a smart phone has considerably more resources than the monitoring device; it is in charge of gathering, storing, and processing the measurement data. As a result, the requirements of each monitoring device can be reduced to only measurement and short-range Bluetooth communication. Consequently, monitoring devices can be simplified, and energy consumption can be decreased. Moreover, the system can flexibly adapt to changes and the addition of other monitoring devices.

Since we focused on future expandability, we used a WLAN system instead of 3G cellular data communication for transmitting measurement data from the smart phone to the server. The reasons are as follows.

- If we need to transmit data from the server to smart phones (e.g., push notification) in the future, such transmission will be realized by using the Internet standard.
- The bandwidth of WLAN is wider than that of 3G cellular data communication, and the system provides scalability to handle increases in the amount of measurement data in the future.

A. Portable Measurement Set

The portable set consists of a smart phone and Imoni, which is a motion-monitoring device that utilizes accelerometers and a barometer.

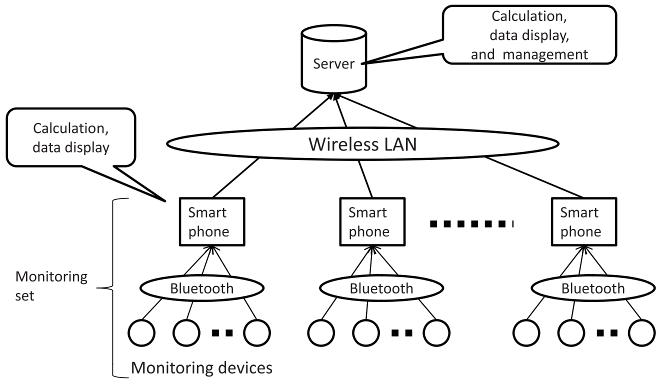

Fig. 3. System architecture.

Fig. 4. Smart phone (left) and monitoring device "Imoni" (right).

Imoni was developed in the first stage of the knowledge cluster initiative by I. T. Research Co., LTD. Imoni can automatically classify ambulatory movements and can measure the walking speed, number of steps, and intensity of exercise based on the classification results. In developing this measurement system, we modified the measurement algorithm of Imoni for Nordic walking and appended the Bluetooth module to Imoni.

We used the Nokia E61 smart phone. The operating system for E61 is Symbian [6] and the application platform is S60 3rd edition [7]. E61 provides WLAN, Bluetooth, and 3G phone functionalities.

B. Software of the Measurement System

B.1 Overview

The data collection server was implemented as a web application server using Apache Tomcat and also works as a manager of the entire measurement system. Considering the portability, we implemented the software on a smart phone as a MIDlet, which is a Java mobile information device profile (MIDP) [8] application.

The server consolidates information about events, users, smart phones, and Imoni devices. Fig. 5 shows a list of registered users. The system operator can add a new user or delete a registered user through this screen. The operator can browse through the personal exercise history for each user.

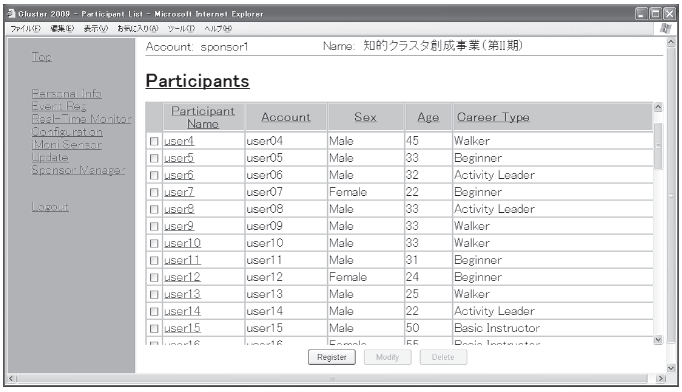

Fig. 5. User list view in the developed system.

Fig. 6. Display on a smart phone.

Moreover, the server analyzes the measurement data received from smart phones and generates a graph view that displays the current exercise status in real-time. After the exercise, the server outputs the exercise report summarizing the results. In this way, the measurement system fulfills requirements (1) and (3) as described in subsection II-C.

A smart phone not only sends measurement data to the server via WLAN but also performs statistical processing of the measurement data before showing it on the display as depicted in Fig. 6. Users can find out the elapsed time, average stride length, average velocity, caloric expenditure, total number of steps, and total walking distance using this display. Thus, this display fulfills requirement (2) as described in subsection II-C.

Since the ”power” method Math.pow() is not supported in Java ME, we have to use an approximation [9] for statistical processing. The algorithm used for the approximate calculation is the decay algorithm estimation because using it yielded the least amount of error in the preliminary experiment.

B.2 Dynamic Bluetooth Pairing Between a Smart Phone and Imoni Device

As previously mentioned, the communication device (i.e., smart phone) and monitoring device (i.e., Imoni) are separate. Thus, we have to establish a one-to-one relationship between the smart phone and Imoni to prevent confusion when simultaneously monitoring activity for multiple users. In addition, since a Bluetooth pairing must be created between these devices, the pairing operation should be simplified as much as possible.

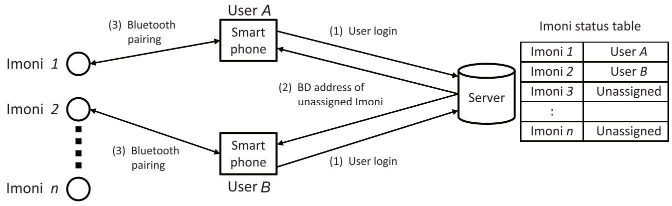

Fig. 7. Pairing between a smart phone and Imoni.

If we focus on only keeping a one-to-one relationship between devices, the simplest solution is that the system operator defines the static pairs of devices and keeps one of the pairs close to the other. However, this approach is not scalable against the number of portable sets, and the overhead cost for the operator is unacceptable if several types of monitoring devices are introduced. Human error with regard to Bluetooth pairing must also be considered as an additional factor complicating device management.

To address these issues, we implemented the dynamic pairing shown in Fig. 7. In this system, a user operates a smart phone in order to login to the server and download his/her personal data (e.g., sex, age, height, and weight) to the smart phone (Fig. 7(1)). At that time, the server checks the table for managing the usage of Imoni and gives the smart phone the Bluetooth device (BD) address of an unused Imoni with the requested personal data (Fig. 7(2)). The smart phone then automatically establishes a Bluetooth pairing to the device with BD addresses given to it from the server (Fig. 7(3)).

This approach alleviates the significant burden of managing each smart phone and Imoni pair since the latter are governed by the server. In addition, a user does not need to conduct the pairing explicitly because the pairing operation is automatically done. In particular, this is good for users who are unfamiliar with information communication techologiy (ICT) devices, and will encourage more users to participate.

B.3 Transferring Measurement Data

In this system, we use well-proven Internet standards instead of an original protocol.

Transmission control protocol (TCP) and user datagram protocol (UDP) are the standard protocols for the transport layer in the TCP/IP protocol suite. TCP provides reliable transport, and UDP is often used for real-time applications. This system supports both TCP and UDP, and we can select either of them. Since the measurement data are gathered via lossy wireless links, we used reliable TCP in the demonstration experiments unless otherwise specified.

Application layer protocols that use TCP and UDP are simple object access protocol (SOAP)/hypertext transfer protocol (HTTP) and Syslog, respectively. SOAP/HTTP is used for transmitting extensible markup language (XML)-based messages and goes well together with web applications. Syslog is widely used for transmitting log information for management purposes, and free-format data can be included in the payload of the Syslog message. Both SOAP/HTTP and Syslog have flexibility for

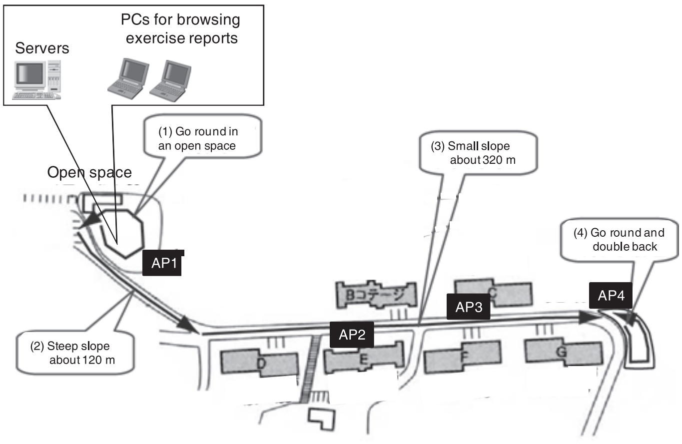

Fig. 8. Simplified map of the course and access point locations.

Table 1. Equipments used for the experiment.

Equipments	Model number
WLAN access point	ICOM SB-510EA
Omni-directional antenna	ICOM AH-151VR
Data collection server	Dell Vostro 420 Desktop
Syslog server	PDX Japan Mini-1R5U/S
PC used for browsing exercise reports	Acer TM5320-301G12
Printer	Canon PIXUS iP100, LK-62
Switching hub	CentreCOM GS916XL
Switching hub	ELECOM LAN-SW05P/PB
KVM switch	ELECOM KVM-NVP4

data in the message payload, and thus we can adapt the system to changes in the amount and type of measurement data. Since there are privacy issues for the user information, the system provides secure socket layer (SSL) support to SOAP/HTTP/TCP transmission and uses advanced encryption standard (AES) encryption to secure the payload of Syslog/UDP transmissions.

IV. NETWORK ARCHITECTURE OF MEASUREMENT SYSTEM IN THE DEMONSTRATION EXPERIMENT

Fig. 8 illustrates the walking course where users walked. There is a flat open space, steep slope, and small slope along the course. The total length is 450 m, and participants walked the entire course on a round trip. Hence, users walked about 1 km for a total time of about 10–15 min.

We deployed the network for the measurement system using the equipment listed in Table 1. The network topology is illustrated in Fig. 9. As shown in the figure, the experimental network was composed of a data collection server, Syslog server, several laptop PCs for browsing exercise reports, and four WLAN access points (APs) (AP1–AP4 in Fig. 8). The four APs are cascaded via a wireless link using the wireless distribution system (WDS) function; only AP1 is also connected to the server segment via a wired local area network (LAN).

Table 2. Performance of a WLAN access point.

	Results of preliminary experiments
Maximum communication range between two access points (APs)	430 meters (line-of-sight)
Maximum communication range between an AP and an smart phone (SP)	260 meters (line-of-sight)
The number of terminals that can connect to an AP	20

The wireless standard used was IEEE802.11g, and the same wireless channel was used for all APs in order to enable wireless interconnection between them. In addition, the wired equivalent privacy (WEP) was used to secure the network with a 128-bit WEP key due to the limitations of the Nokia E61.

In our preliminary experiments, we found the communication performance of an AP to be as summarized in Table 2. In the demonstration experiment taking into account various obstacles on the course such as trees and road signs, we positioned the APs to best meet these conditions. In Fig. 8, AP1–AP4 indicate the location of each AP.

- The neighboring APs were located within half of the maximum communication range.
- Every smart phone on the walking course was within half the coverage distance of any AP.

The maximum number of terminals for an AP was 20, and 10 terminals are recommended according to the manual. Therefore, we limited the number of users measured simultaneously, to typically less than or equal to 10. Even when such limitations was difficult, we limited the number of users to a maximum of 15. Since the amount of data sent by one smart phone to the server is around 2.7 kB, the total amount of data is around 40.5 kB (324 kb) data if 15 smart phones send data simultaneously. An IEEE 802.11g WLAN system has enough bandwidth for transmitting this amount of data.

Note that neighbor APs within a two-hop distance (e.g., AP2 and AP4 in Fig. 8) can directly communicate if the radio conditions are good. In such a case, a loop of APs is constructed and causes a broadcast storm. In order to avoid the loop and broadcast storm, we enable the spanning tree protocol (STP) function on every AP.

All APs are deployed on the roadside, and thus the power is supplied with battery boxes made by a participant company. The capacity of each battery is 12V 8Ah, which is enough for eight hours continuous AP operation.

V. DEMONSTRATION EXPERIMENT AND RESULTS

The demonstration experiment was held as a part of a Nordic walking event co-hosted by the JNFA [10] and the health, fun, and fitness net [11] on 15 March 2009. In the demonstration experiment, nine users measured their activities during the morning and 13 users did so during the afternoon. The measurement time was around 10–15 min.

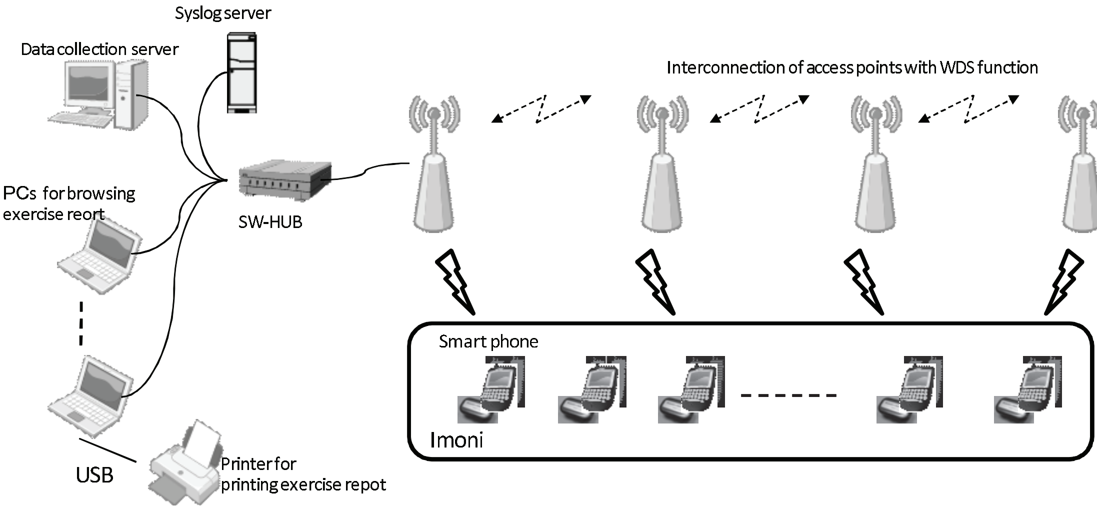

Fig. 9. Network topology for the experiment.

A. Processing Time in Smart Phones

Fig. 10 depicts the percentage of processing time in smart phones. As mentioned in subsection III-B.1, a smart phone retrieves the measurement data from Imoni every minute and sends the data to the server. Then, it peformes statistical processing for displaying the current status of the exercise. As shown in Fig. 10, the statistical processing accounted for more than 70% of the processing time. On the other hand, the time for data transmission to the server was only one-eighth that of the statistical processing.

We show the time distribution for the statistical processing and data transmission in Fig. 11. In this figure, we see that 80% of the transmission finished in 1 s and 95% finished within 3 s. Although 85% of the statistical processing for the data over 1 min finished within 5–10 s, 15% required about 20 s due to the load on the smart phone.

This suggests that statistical processing can become a bottle neck for the system if the amount of measurement data is increases with the addition of more monitoring devices. There could be a risk that the statistical processing of 1 min worth of data may require more than 1 min to process. On the other hand, the performance of this experimental network is enough in terms of both bandwidth and delay that the network can tolerate the increase in data if the data were sent directly to the server for processing.

Consequently, in order to improve system scalability, particularly with less capable phones or with sensors that produce more data, statistical processing should be offloaded to the server where possible. In this configuration, smart phones focus on passing data to the server, and after processing, the server returns the data back to the smart phone.

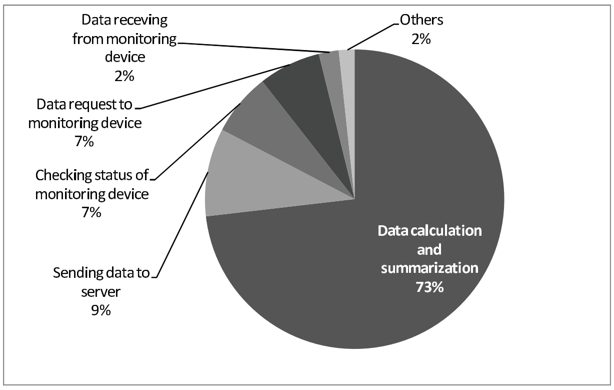

Fig. 10. Percentage of processing time in smart phones.

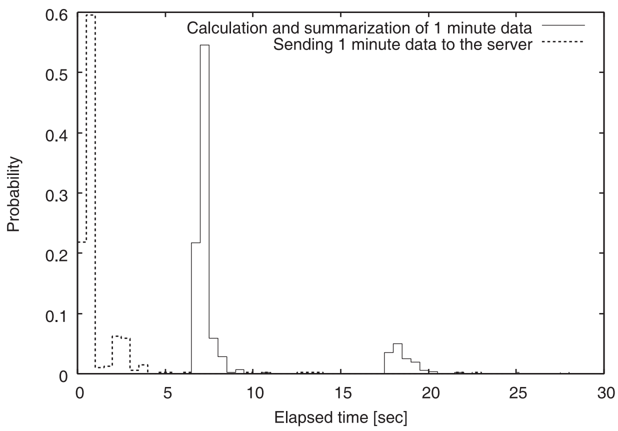

Fig. 11. Distribution of processing time in smart phones.

B. Measurement Results of Exercise Data

Since one of the important requirements is to allow users to check their data immediately after the exercise, we presented the exercise report using laptop PCs and gave an explanation about the exercise based on the report. After that, we provided a printout of the report to the users. This approach was received well by both users and the event organizer, and we found that Nordic walkers were very interested in the measurement data for themselves.

After the experiment, we handed out a questionnaire to sur-

Fig. 12. Photo of the participants who check their exercise reports.

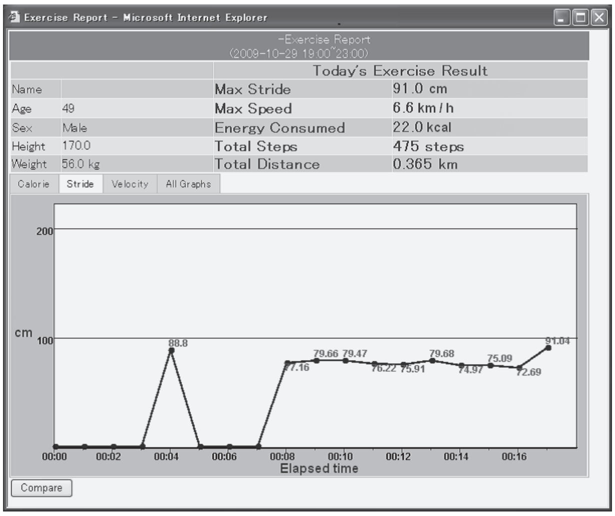

Fig. 13. A sample of exercise report

Table 3. Questionnaire result for "Did the measurement equipment become an obstacle for your exercise?".

Smart phone		Imoni	
Not at all	15	Not at all	15
Rarely	1	Rarely	1
Sometimes	1	Sometimes	1
Often	0	Often	0
No answer	1	No answer	1

vey users for their opinions on the measurement system; there were 18 respondents, and the results of the questionnaire are summarized in Tables 3 and 4.

According to Table 3, the portable equipment used for measuring the exercise was acceptable to almost all of the users. Table 4 indicates that almost all users were interested in their stride length and walking speed as we expected. The number of users interested in caloric expenditure was less than that for stride length and walking speed because of the short measurement time.

Fig. 14 shows the questionnaire result about future needs of

Table 4. Questionnaire result for "Is the information in your exercise report useful?".

	Stride length	Speed	Caloric expenditure
Useful	15	15	13
A little useful	1	1	4
Not so useful	1	1	0
Not useful	0	0	0
Did not see	0	0	0
No answer	1	1	1

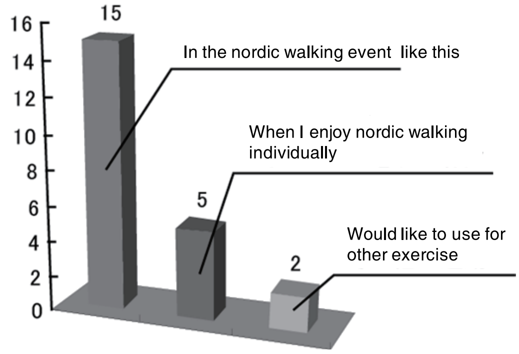

Fig. 14. Questionnaire result for "How do you want to use this type of service? (multiple answers allowed)".

the measurement system. The activity monitoring for multiple users like in this demonstration experiment almost meets the needs of Nordic walkers. In addition, we found that there is a demand for such a system for personal and daily use.

In addition, we received the following requests.

- I would like the ability to measure a longer time.
- I would like to know even more detailed data on my exercise.

We will improve the monitoring device and measurement algorithm in order to meet these requests.

The final goal of our project is to realize request below.

- I would like to know the difference between my results and average data.
- I would like advice about the most appropriate way to exercise based on my measurement results.

We will continue ahead with the research and development of this measurement system toward this goal.

VI. CONCLUSION

In our research, we developed a measurement system for monitoring multiple users exercising outdoors based on WLAN and Bluetooth technologies. In order to show the validity of the system, we conducted a demonstration experiment for Nordic walking users in an event organized by the JNFA. The system was received well by both users and the event organizer.

However, the system is still in the prototype phase, and we are planning to improve the system by taking into account the following issues that emerged during the demonstration.

- Consruction of body sensor network (BSN) for connecting various types of sensors. This enriches measurement items such as skill level, degree of fatigue, cardiac rate, and blood

Table 5. Measurement results of Imoni and an existing product.

	Distance [m]	Avg. stride length [cm]	Average speed [km/h]	Error in avg. stride length
Imoni	787.5	81.4	5.23	3.33 %
Product	762.4	78.8	5.08	6.45 %
Actual value	815.0	84.2	5.43	-

pressure by introducing additional sensors and analysis algorithms.

- Reconsideration of role sharing between a server and smart phones when handling huge amounts of various data.
- Modifying the system for personal use regarding the use of 3G wireless links and simplification of the system equipment.

Moreover, the integration of the body sensor network and social networks should provide more intelligent and autonomous applications [12]. Thus, we would like to provide the measurement data to users via social networks in future work.

APPENDIX

In this Appendix, in order to show that Imoni can appropriately estimate the stride length of users, we compare the measurement data of Imoni with an existing commercial product for training use. The commercial product requires a dedicated sensor attached to the instep of a shoe for measuring the stride length, and thus we measured the exercise of a subject wearing both Imoni and the dedicated sensor.

The test course was an open space 163 m around. The subject traveled around the space five times, at the constant pace of about nine steps per 5 s. The subject walked 815 m in 540 s and the number of steps was 968. Based on these results, we calculated the actual value of the average stride length and average walking speed.

Table 5 summarizes the measurement results of Imoni and the existing product. As shown in Table 5, the measurement error of both devices for the average stride length is less than 10%, and both devices can precisely measure stride length. It should be noted that the error of Imoni was less than that of the existing product. Figs. 15 and 16 show the 5 s average value of the stride length and walking velocity, respectively. In both figures, the dotted straight line means the actual value.

As an overall trend, the existing product underestimated the stride length and walking speed, but the line graph of Imoni fluctuated around the actual value. Note that the stride length and speed periodically drop for the line graph representing the existing product. Each periodical drop means that the subject stopped for a moment at the end of each lap. From these results, we believe that Imoni has shown the ability to measure the stride length more precisely when the subject walks at a constant pace.

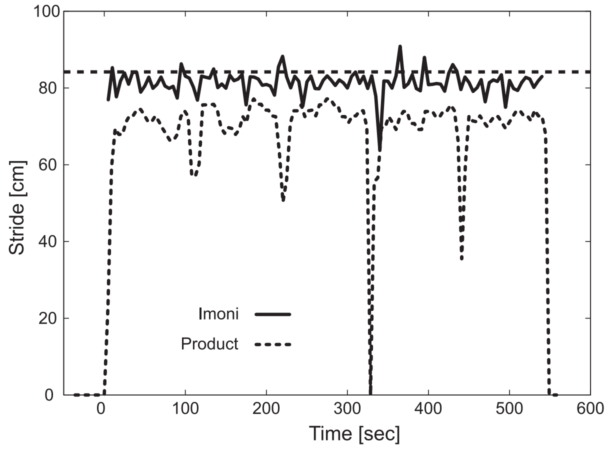

Fig. 15. Stride measured with Imoni and the existing product.

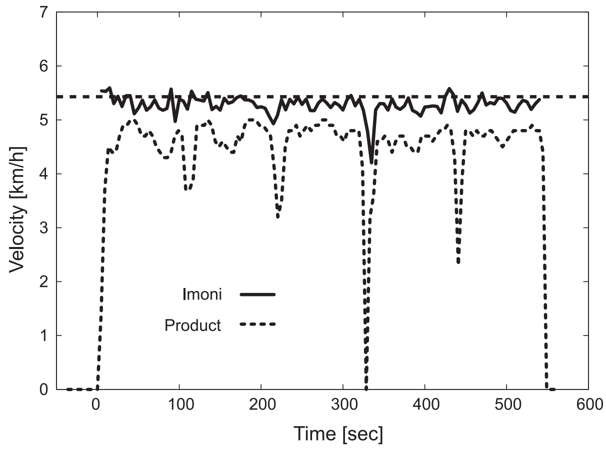

Fig. 16. Velocity measured with Imoni and the existing product.

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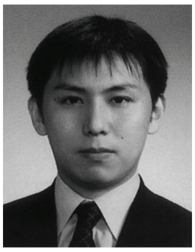
Hiroshi Tsunoda received his B.E. degrees from the Department of Information Engineering at Tohoku University in 2000, the M.S. and Ph.D. degrees from the Graduate School of Information Sciences at Tohoku University in 2002 and 2005, respectively. From April 2005 to March 2008 he was an assistant professor in the Graduate School of Information Sciences, Tohoku University. He is now a Senior Assistant Professor in the Department of Information and Communication Engineering, Tohoku Institute of Technology. His research interests include wireless networking, network management, and network security. He is a Member of the IEICE, IPSJ, and IEEE.



Hidehisa Nakayama received his B.E. degrees from the Department of Information Engineering at Tohoku University in 2000, the M.S. and Ph.D. degrees from the Graduate School of Information Sciences (GSIS) at Tohoku University in 2002 and 2005, respectively. He joined the GSIS of Tohoku University as Assistant Professor in 2005. He has been Senior Assistant Professor in the Department of Electronics and Intelligent Systems at Tohoku Institute of Technology since 2008. He has been engaged in research on intelligent sensor technology, wireless mobile ad hoc network, computer networking, character string analysis, pattern recognition, and image processing. He is a member of IEEE Communications Society, the Institute of Electronics, Information and Communication Engineers (IEICE), and the Information Processing Society of Japan (IPSJ). He received the Paper Award for Young Researcher of IPSJ Tohoku Chapter in 2000, the Best Paper of Pattern Recognition Award in SCI 2003, the 8th Network System Award of IEICE Technical Committee on Network Systems in 2009, the 20th NEC TOKIN Contribution Award in 2010, and the Best Paper Award of IEEE GLOBECOM 2010.

Kohei Ohta received the M.S. and Ph.D. degrees from the Graduate School of Information Sciences, Tohoku University, Sendai, Japan, in 1995 and 1998, respectively. He is currently R&D manager of Cyber Solutions Inc., Sendai, Japan. He has been engaged in research on network and security management. He is also a Researcher of Security Economics Laboratory & Planning Group, IT Security Center, Information-Technology, Promotion Agency (IPA), Japan.

Akihiro Suzuki received the M.S. degree from the Graduate School of Information Sciences, Tohoku University, Japan in 1995. Currently, he is working toward the Ph.D. degree with the Graduate School of Biomedical Engineering, Tohoku University. He established I. T. Research Co., Ltd in 2000, and he is a board member of the company. His research focuses on a novel method of monitoring daily physical activity with a wearable sensor device.

Hiroki Nishiyama received his M.S. and Ph.D. in Information Science from Tohoku University, Japan, in 2007 and 2008, respectively. He was a Research Fellow of the Japan Society for the Promotion of Science (JSPS) until finishing his Ph.D, when he then went on to become an Assistant Professor at the Graduate School of Information Sciences at Tohoku University. He has received Best Paper Awards from the IEEE Global Communications Conference 2010 (GLOBECOM 2010) as well as the 2009 IEEE International Conference on Network Infrastructure and Digital Content (IC-NIDC 2009). He was also a recipient of the 2009 FUNAI Foundation's Research Incentive Award for Information Technology. His active areas of research include, traffic engineering, congestion control, satellite communications, ad hoc and sensor networks, and network security. He is a Member of the Institute of Electronics, Information and Communication Engineers (IEICE) and an IEEE member.

Ryoichi Nagatomi received his M.D. and Ph.D from the Graduate School of Medicine at Tohoku University in 1984 and 1994, respectively. He is currently a Professor in the laboratory of Health & Sports Science, Division of Biomedical Engineering for Health and Welfare, Graduate School of Biomedical Engineering of Tohoku University. His research interests include physiological, kinesiological and epidemiological assessment of human movement that contributes to human health, as well as the mechanism of skeletal muscle adaptation and repair. He is also a Guest Professor of Division of Health Science, School of Public Health, Jilin University, China. He is the President of Japanese Society of Exercise & Immunology and is a Fellow Member of Japanese Society of Clinical Sports Medicine and Japan Heart Club.

Kazuo Hashimoto was born in Tokyo in 1953. He received his Ph.D. degree in Information Science from Tohoku University in 2001. He is currently a professor at the graduate school of information sciences of Tohoku University, directing the theoretical and practical study of web communication. He won the Incentive Award from the Japanese Society for Artificial Intelligence in 1999, the Best Paper Award in the field of Artificial Intelligence from the Institute of Electronics, Information and Communication Engineers in 2001, and the achievement award from the Association of Radio Industries and Businesses in 2002. He is a Member of IPSJ, IEICE, AAAI, and IEEE.

Yuji Waizumi received his B.E., M.S. and Ph.D. degrees from Tohoku University in 1996, 1998, and 2001, respectively. Now he is an Associate Professor with Graduate School of Information Sciences, Tohoku University. He has been engaged in research on computer networking, network security, pattern recognition, and neural networks.

Glenn Mansfield Keeni received his Ph.D. in Logic programming from Tohoku University, Japan. He is currently President/CEO of Cyber Solutions Inc. Sendai, Japan. His research interests include expert systems, computer networks and their management, security, etc. He is a Member of the ACM, IEEE Computer Society and is an active Member of the IETF.

Yoshiaki Nemoto received his B.E., M.E., and Ph.D. degrees from Tohoku University in 1968, 1979, and 1973, respectively. He was a Full Professor with the Graduate School of Information Sciences until 2008. Currently, he is serving as the Senior Vice President of Tohoku University. He has been engaged in research work on micro wave networks, communication systems, computer network systems, image processing, and handwritten character recognition. He is a co-recipient of the 1982 Microwave Prize from the IEEE MTT society, the 2005 Distinguished Contributions to Satellite Communications award from IEEE Com-Soc society, FUNAI information ScienceAward 2007 and several prestigious awards from Japanese Ministries. He is a Senior Member of IEEE, and a Fellow Member of IEICE and IPSJ.