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

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*Abstract*— **In recent years, epidemiological evidence suggesting the health benefits of a physically active lifestyle has risen. It is, however, 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 LAN based system. In our system, a wireless LAN is deployed outside, and a user wearing a smart phone and monitoring device exercise 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 measure 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 able to receive their exercise report immediately. In this paper, we discuss the requirements and issues in developing an activity monitoring system and report our findings obtained through the demonstration experiment.**

## I. Introduction

A lifestyle of fitness has been becoming more important in the world, many people are enjoying 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 key for health enhancement, and the measurement and visualization of the benefit of the exercise will encourage more people to start physical exercise. Consequently, the development of such measurement system is eagerly anticipated [1].

In light of the situation, we aim to develop measurement systems for supporting the stabilization of exercise habits. We define the following requirements for such 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 outdoor.

As previously mentioned, some people often enjoy exercise together as a group. In such group activity, providing a measurement of the results for all users in the group will be useful for motivating. The measurement data gives 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 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, a cellular phone and smart phone embedding accelerometers are becoming popular as a kind of advanced pedometer. These devices are capable of sending measurement data via 3G cellular data communications and thus a real-time activity monitoring for outdoor user exercise is possible. However, this system is not designed for monitoring group activity, but is designed for personal use only. In the case of monitoring group activity, users will receive heterogeneous measurement results if they do not have identical devices. Additionally, since monitoring devices such as an accelerometer 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 consider that a communication device and a sensor should be separate for monitoring multiple users exercising outdoor simultaneously. On the basis of this concept, we develop the prototype of the monitoring system using wireless LAN (WLAN) and Bluetooth technologies. Figure 1 illustrates the overview of the developed system. A smart phone works as the communication devices for sending the data to the server via WLAN, and activity monitoring device, “Imoni” [2], served as a sensor. The smart phone and Imoni are communicated via Bluetooth connection. The separation of devices is useful for improving the flexibility of the system.

Using multiple WLAN access points, we are able to flexibly construct the measurement environment in an outdoor location. Users can freely exercise within the coverage of the access

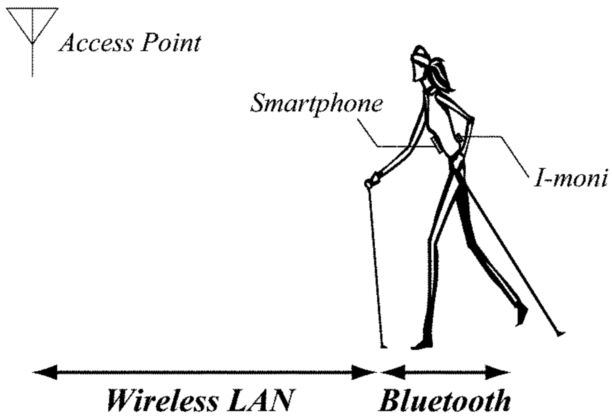


Fig. 1. Overview of activity monitoring system for Nordic Walking

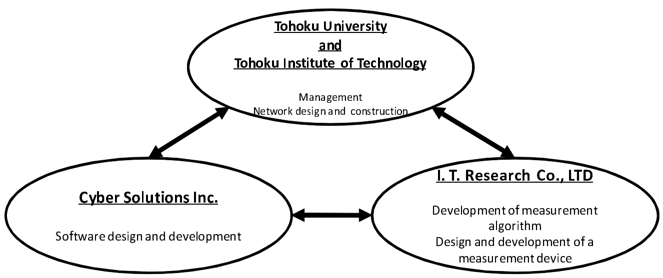


Fig. 2. Industry-university cooperation framework for research and development

points and enjoy the benefits of the measurement services.

Imoni has the ability to measure 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 as their skill in the exercise improves, rather than widening in a short time span, 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 fitness sports in the world, Nordic Walking serves as an appropriate model to measure the system.

This work is supported by the Greater Sendai Area Knowledge Cluster Initiative (GSAKCI) of 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 of a real-time measurement system for group activity. In Sec. III, we describe the architecture and characteristics of the our system in detail. Sec. IV presents an overview of the demonstration experiment and network configuration used in the experiment. Section V gives experimental results and shows the validity of the system. Finally, conclusions are drawn in Sec. 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 Greater Sendai Area Knowledge Cluster Initiative (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, a measurement environment must be assumed to be outside. Moreover, Nordic Walkers enjoy exercising not only on an individual basis but also in a group. Therefore we summarize the requirements of the measurement environment as follows.

- The measurement system is capable of working in outdoor conditions.
- The measurement system can monitor the exercise of at least 10 users simultaneously.

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

### B. Measurement items

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

- The change and total caloric expenditure
- The total number of steps
- Total walking distance
- The change in average stride length
- The change in average walking speed

Caloric expenditure, the number of steps, and walking distance provide meaningful information and typical pedometers measure these items, which are useful for users to quantify the achievement of their exercise. Stride length and walking speed are appropriate parameters for estimating 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 our system. In the existing systems for measuring daily activities, stride length is not a measurement item but an input value by a user. It is used for calculating walking distance. In the systems for training, an additional dedicated device is required for measuring stride length. Our system only needs a single device for measuring all the above-mentioned items. Moreover, measurement accuracy of stride length is the same or more than that of the existing system for training (see Appendix).

### C. Providing measurement results

There are three requirements for providing measurement results:

(1) A user can receive the exercise report 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 users' progress during the exercise

A users' interest in the results will be peaked immediately after the 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 finishing.

Additionally, users will be motivated by checking their current status during the exercise. Instructors can also give effective advice to users in real-time according to their current status.

## III. A REAL-TIME MEASUREMENT SYSTEM FOR GROUP ACTIVITY

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

Figure 3 depicts the architecture of the measurement system. The smart phone serves as a relay point of the measurement data, and measurement data by 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 and it is in charge of gathering, storing, and processing the measurement data. As a result, the requirements of each monitoring device can reduced to only the measurement and a short-range bluetooth communication. Consequently, monitoring devices can be simplified and energy consumption can be decreased. Moreover, the system has flexibly adapt to change and the addition of other monitoring devices.

Since we focus on the future expandability, we use a WLAN system instead of 3G cellular data communication for transmitting measurement data from a 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 the 3G cellular data communication, and the system provides scalability to handle increases in the amount of the measurement data in the future.

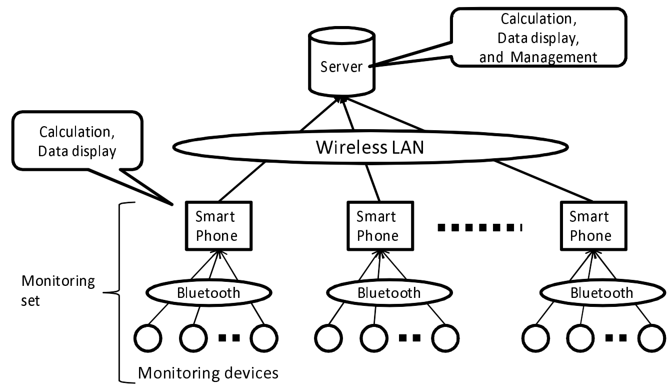


Fig. 3. System architecture

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

### A. A portable measurement set

A portable set is composed of a smart phone and Imoni, which is the motion monitoring device utilizing accelerometers and a barometer.

Imoni was developed in the 1st stage of the Knowledge Cluster Initiative by I.T.Research Co., LTD. Imoni can automatically classify ambulatory movements and can measure walking speed, the number of steps, and the intensity of the exercise based on the classification results. In developing this measurement system, we modify the measurement algorithm of Imoni for Nordic Walking and append the bluetooth module to Imoni.

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

### B. Software of the measurement system

*1) Overview:* The data collection server is 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.

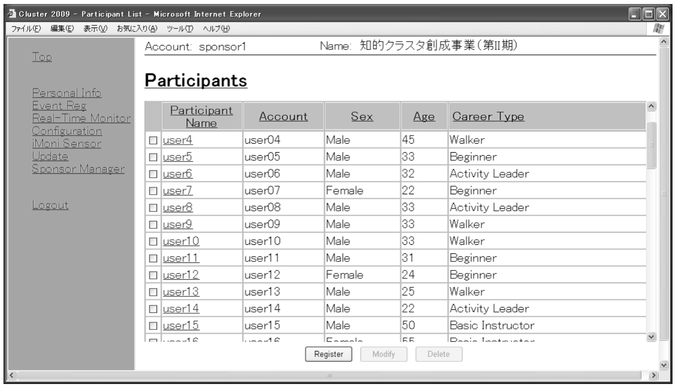


Fig. 5. User list view in the developed system


Fig. 6. Display on a smart phone

The server consolidates information about events, users, smart phones, and Imoni devices. Figure 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 is able to browse a personal history of exercise for each user.

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

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

*2) Dynamic bluetooth pairing between a smart phone and an imoni device:* As previously mentioned, the communication device (i.e. a smart phone) and the 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 bluetooth pairing must be created between these devices, the pairing operation should be simplified as much as possible.

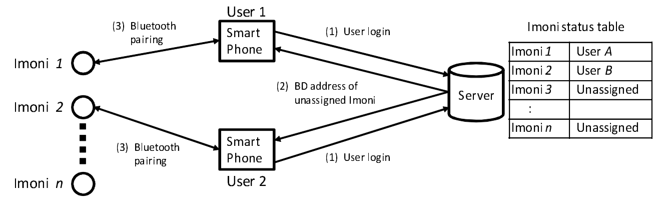


Fig. 7. Pairing between a smart phone and Imoni

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 will be unacceptable if several types of monitoring devices are introduced. Human error with regard to bluetooth pairing must also be considered as an additional factor to complicate the management of devices.

To address these issues, we implemented a dynamic pairing which is 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 which has the BD addresses given to it from the server (Fig. 7(3)).

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

*3) Transferring measurement data:* In this system, we use the well proven Internet standards instead of an original protocol.

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

Application layer protocols that use TCP and UDP are SOAP/HTTP and Syslog, respectively. SOAP/HTTP is used for transmitting XML-based messages and goes well together with Web applications. Syslog is widely used for transmitting

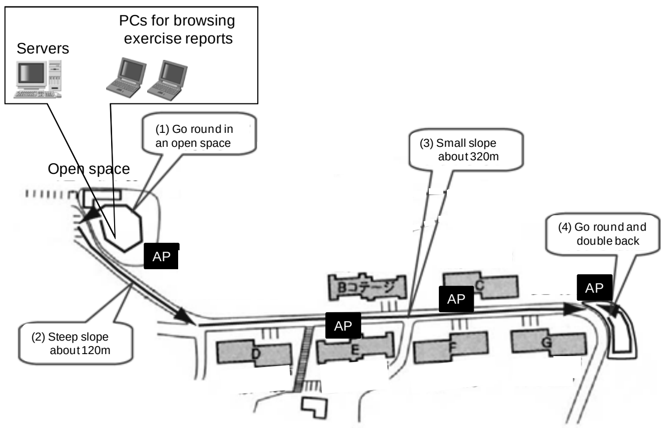


Fig. 8. Simplified map of the course and access point locations

TABLE I
PERFORMANCE OF A WLAN ACCESS POINT

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

AP: Access Point, SP: Smart Phone

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 the data in the message payload, and thus we can adapt the system to the change of the amount and type of measurement data. Since there are privacy for the users' information, the system provides SSL (Secure Socket Layer) support to SOAP/HTTP/TCP transmission and uses AES encryption to secure the payload of Syslog/UDP transmissions.

## IV. NETWORK ARCHITECTURE OF MEASUREMENT SYSTEM IN THE DEMONSTRATION EXPERIMENT

Figure 8 illustrates the walking course where users walk. There is a flat open space, a steep slope, and a small slope in the course. The total length of the course is 450 meters, and participants walk the entire course round trip. Hence users walk about 1 kilometer for a total time of about 10 minutes to 15 minutes.

We deployed the network for the measurement system using the equipment listed in Table II. The network topology is illustrated in Fig. 9. As shown in Fig. 9, the experimental network is composed of a data collection server, a syslog server, several laptop PCs for browsing exercise reports, and four WLAN APs (AP1 $\sim$ AP4 in Fig. 8). The four APs are cascaded via a wireless link using the WDS (Wireless Distribution System) function, and only AP1 is also connected to the server segment via a wired LAN.

The wireless standard used is IEEE802.11g, and the same wireless channel is used for all APs in order to enable wireless interconnection between them. Additionally, 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.

TABLE II
EQUIPMENTS USED FOR THE EXPERIMENT

| Equipments | Model number |
|---|---|
| WLAN access point | ICOM SB-510EA |
| Omni-directional antenna | ICOM AH-151VR |
| | 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 |

In our preliminary experiments, we found that the communication performance of an AP as summarized in Table I. 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, AP2, AP3, and AP4 indicate the location of each AP.

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

The maximum number of terminals for an AP is 20, and 10 terminals are recommended according to the manual. Therefore, we limit the number of users that are measured simultaneously, typically less than or equal to 10. Even when such limitation is difficult, we limit 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 kilobytes, the total amount of data is around 40.5 kilobytes (324 kilobits) 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 in two-hops distance (e.g. AP2 and AP4 in Fig. 8) can directly communicate if the radio conditions are good. In such case, a loop of APs is constructed and causes a broadcast storm. In order to avoid the loop and the broadcast storm, we enable the STP (Spanning Tree Protocol) 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 and it is enough for eight hours continuous AP operation.

## V. DEMONSTRATION EXPERIMENT AND RESULTS

The demonstration experiment is held as a part of a Nordic Walking event co-hosted by Japan Nordic Fitness Association (JNFA) [10] and Health, Fun, and Fitness Net [11] on Mar. 15th 2009. In the demonstration experiment, nine users measured their activities during the morning and 13 users during the afternoon. The measurement time was around 10 to 15 minutes.

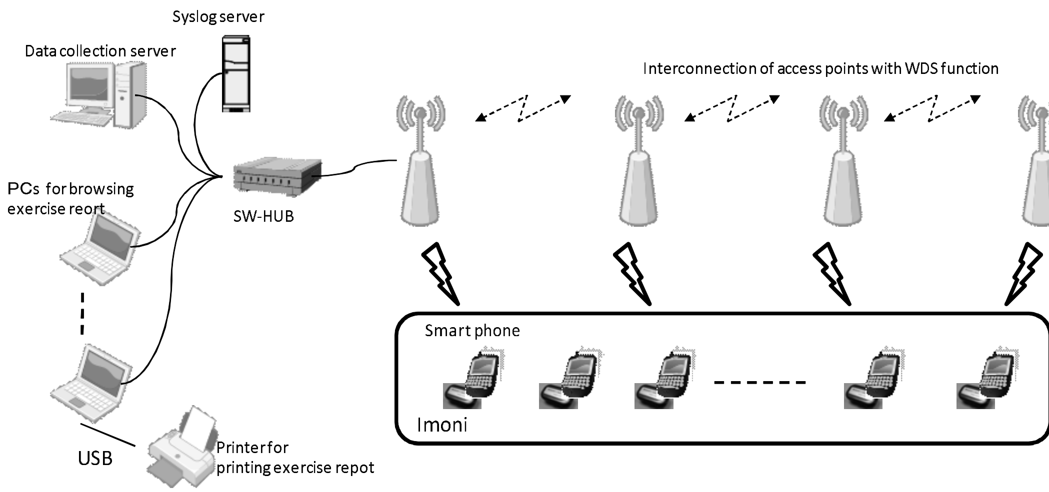


Fig. 9. Network topology for the experiment

### A. Processing time in smart phones

Figure 10 depicts the percentage of processing time in smart phones. As mentioned in III-B.1, a smart phone retrieves measurement data from Imoni once a minute and sends the data to the server and performs statistical processing for displaying the current status of exercise. As shown in Fig. 10, statistical processing accounts for more than 70% of the processing time. On the other hand, the time for data transmission to the server is only one-eighth of the 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 finish in one second and 95% finish within three seconds. Although 85% of the statistical processing of one minute data finish within from five seconds to ten seconds, 15% of that requires about 20 seconds 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 increased with the addition of more monitoring devices. There could be a risk that the statistical processing of one minute worth of data could require more than one minute 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 would focus on passing data to the server, and after processing, the server would return the data back to the smart phone.

### B. Measurement results of exercise data

Since one of the important requirements is to allow users to check their data immediately after exercise, we presented the exercise report using laptop PCs and gave an explanation about the exercise based on the report. After that we provided

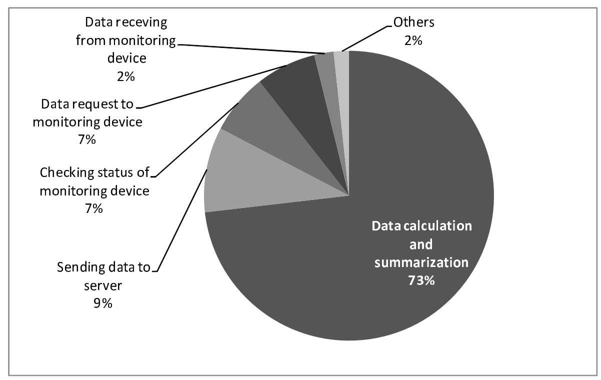


Fig. 10. Percentage of processing time in smart phones

a print of the report to 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 conducted a questionnaire to ask users for their opinions on the measurement system, and there were 18 respondents. The results of the questionnaire are summarized as Tables III and IV.

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

Fig. 14 shows the questionnaire result about future needs of the measurement system. The activity monitoring for multiple users like this this demonstration experiment almost meets the needs of Nordic walkers. In addition, we find that there is a demand for such a system for personal and daily use.

Additionally, we received the following requests:

- I would like the ability to measure a longer time.

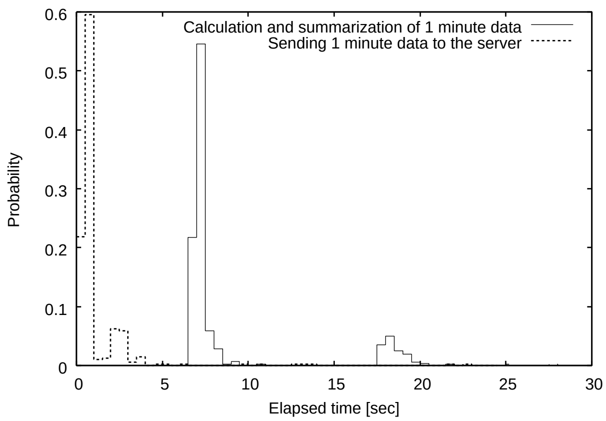


Fig. 11. Distribution of processing time in smart phones

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

- 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 the event organized by the Japan Nordic Fitness Association. The system was received well by both users and the event organizer.

The system is however 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.

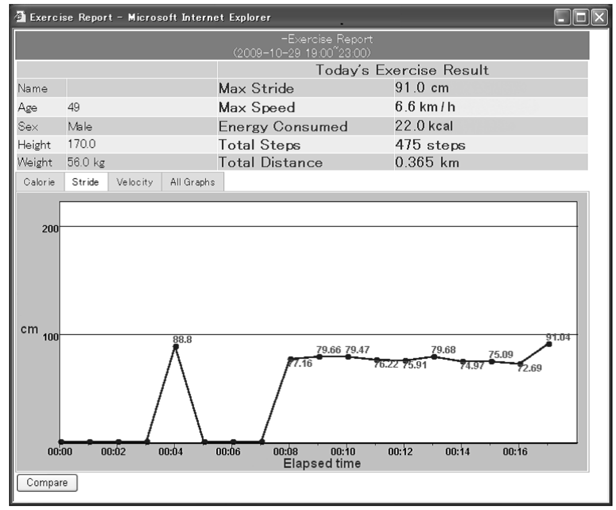


Fig. 13. A sample of exercise report

TABLE III
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 |

- Enrichment of measurement items such as skill level, degree of fatigue, cardiac rate, and blood 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 following points:
  - Use of 3G wireless links
  - Simplification of the system equipment

## Acknowledgment

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TABLE IV

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 |

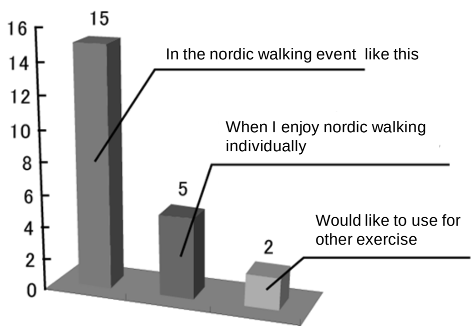


Fig. 14. Questionnaire result for "How do you want to use this type of service? (multiple answers allowed)"

[3] International Nordic Walking Federation (INWA) http://www.inwa-nordicwalking.com/
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[10] Japan Nordic Fitness Association http://jnfa.jp/ (in Japanese)
[11] http://www.wakuwakugenki.net/ (in Japanese)

## APPENDIX

In this appendix, in order to show that Imoni can appropriately estimate 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 which is attached to the instep of a shoe for measuring stride length, and thus we measure the exercise of a subject wearing both Imoni and the dedicated sensor.

The test course was an open space 163 meters around. The subject traveled around the space five times, at the constant pace of about nine steps per five seconds. The subject walked 815 meters in 540 seconds 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 summarizes the measurement result of Imoni and the existing product. As shown in Table , the measurement error of both devices in average stride length is less than 10%, and both devices can precisely measure stride length. It should be noted that the error of Imoni is less than that of the existing product. Fig. 15 and Fig. 16 show the five-second average value of stride length and walking velocity, respectively. In both figures, the dotted straight line means the actual value.

As an overall trend, the existing product underestimates the stride length and the walking speed, but the line graph of Imoni fluctuates around the actual value. Note that the stride length and the speed periodically drop for the line graph by the product. Each periodical drops means that the subject stops for a moment at the end of each lap. From these results, we consider that Imoni has the ability to measure the stride length more precisely in the case that the subject walks at a constant pace.

TABLE V

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 | - |

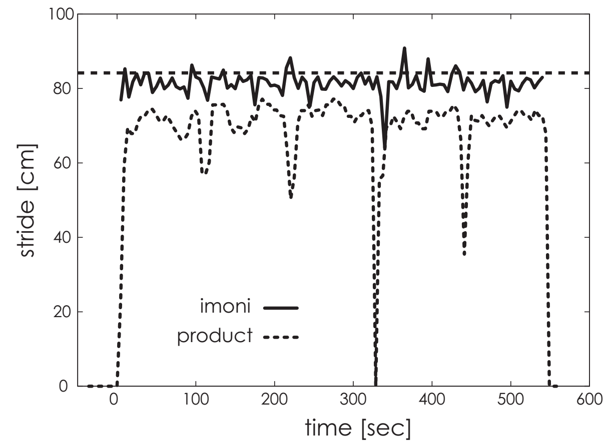


Fig. 15. Stride measured with Imoni and the existing product

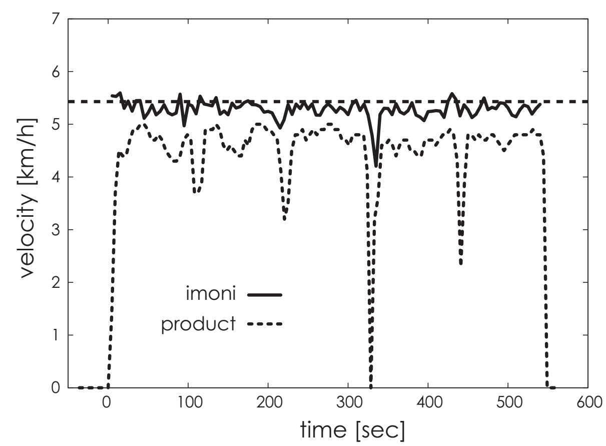


Fig. 16. Velocity measured with Imoni and the existing product