Personal Identification System Based on Rotation of Toilet Paper Rolls

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***Abstract*—Biological information can easily be monitored by installing sensors in a lavatory bowl. Lavatories are usually shared by several people, so users need to be identified. Because of the need for privacy, using cameras, microphones, or scales is not appropriate. Though personal identification can be done using a touch panel, the user may forget to use it because the action is not necessary. In this paper, we focus on the differences in the way of pulling a toilet paper roll and propose a system that identifies individuals based on features of rotating of toilet paper rolls with a gyroscope. The evaluation results revealed that 83.9% accuracy was achieved for a five-person group in a laboratory environment, and 69.2% accuracy was achieved for a five-person group in a practical environment.**

I. Introduction

Lavatories are strongly associated with human health; for example, excreta can be used as a health indicator. To take an actual example, eating habits and the condition of bowels can be estimated from the color and shape of feces [1], [2]. Kidney disease can also be detected in its early stage by examining urine [3]. In Japan, Intelligence Toilet II[1], which records and analyzes important data such as weight, blood pressure, urinary sugar, urinary temperature, and body mass index (BMI), was developed. Intel's survey indicates that more than 70% of people globally are receptive to collecting personal health data by using toilet sensors[2]. Reflecting these facts, various sensors will be installed in lavatories in the near future.

For data to be collected in lavatories, the provider of the data has to be identified because lavatories are common facilities. User identification can be done with deoxyribonucleic acid (DNA) extracted from feces [4], which is technologically possible but takes much time and money. Using a camera or microphone for user identification is also possible. However, either device is not appropriate in a lavatory due to privacy concerns. Buttons or a touch panel to input a user ID can be installed in a lavatory. However, it is not appropriate to force the users to input an ID every time they use a lavatory because it is an unnecessary action for them. Therefore, user identification through sensing actions we ordinarily do, such as opening a toilet door, sitting on a toilet seat, pulling a toilet paper roll, and flushing the toilet, is desirable.

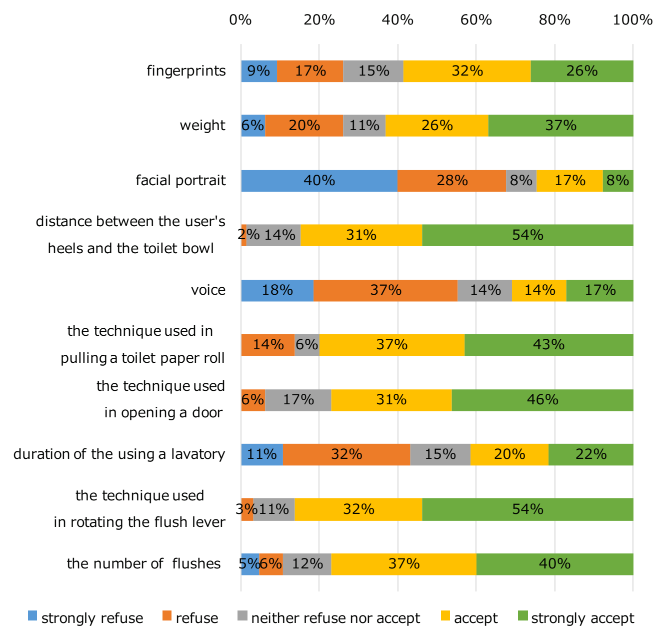

Fig. 1. The results of a questionnaire on acceptance of data collection in a lavatory.

We conducted a questionnaire survey examining to what degree lavatory users would accept collecting data there. 33 males and 32 females aged 15–41 years (average: 24.8, standard deviation: 4.86) answered the questionnaire. In the questionnaire, we asked the respondents about the possibility of using a lavatory that had sensors to collect data for health monitoring, such as the monitoring of urinary sugar. The respondents answered questions about accepting collection of ten kinds of data to link health information and the user: fingerprints, weight, a facial portrait, the distance between the user's heels and the toilet bowl, voice, the technique used in pulling a toilet paper roll, the technique used in opening a door, the duration of using a lavatory, the technique used in rotating a flush lever, and the number of flushes. They answered with a five-level Likert scale: strongly refuse, refuse, neither refuse nor accept, accept, and strongly accept. The results are shown in Figure 1. Approximately 80% of the respondents answered

[1]Intelligence Toilet II: https://www.daiwahouse.co.jp/release/20081224111714.html

[2]Technology Inspires Optimism for Healthcare: http://newsroom.intel.com/community/intel_newsroom/blog/2013/12/09/the-world-agrees-technology-inspires-optimism-for-healthcare

"strongly accept" or "accept" to the data of the distance between the user's heels and toilet bowl (84.6%), the technique used in pulling a toilet paper (80%), the technique used in opening a door (77%), the technique used in rotating a flush lever (86.1%), and the number of flushes (76.9%). However, fewer respondents answered "strongly accept" or "accept" to the data on fingerprints (58.5%), weight (63.1%), facial portrait (24.6%), voice (30.7%), and the duration of using the lavatory (41.5%). The results indicated that we found the data that can easily be associated with a person is not acceptable.

Personal traits are more likely to appear in the way of pulling a toilet paper roll because most of us have never watched someone pulling a roll or never learned how to pull one. In this paper, we propose a system that recognizes individuals based on how they pull a toilet paper roll. The rest of this paper is organized as follows. The next section introduces related work. Then, our proposed identification system is explained, followed by an evaluation of our method. The last section concludes this paper.

II. Related work

A lot of studies have been conducted on user identification based on features of human activity. Hayashi et al. [5] proposed user identification based on body segment lengths and hand-waving gestures. These methods are not reliable enough when they are used separately; however, using both of them can achieve high performance. This system uses a hand waving gesture lasting two seconds. In a lavatory, hand waving is an unnecessary action. Furthermore, this system uses Microsoft Kinect to capture depth images, and capturing such images is not desirable from the viewpoint of privacy protection. An et al. [6] proposed human identification using visible light communication (VLC). This system consists of VLC-enabled LED lights on the ceiling emitting light beacons and of photodiodes on the floor capturing a continuous stream of shadow maps, each of which correspond to an LED light. Installing this system in a lavatory or a corridor is difficult because it uses many LEDs and photodiodes and requires enough space. Watanabe et al. [7] proposed a lifelog system that records activities, people nearby, and location with sound information only. The user of this system has to wear an ultrasound speaker and a voice recorder. The system recognizes user activity on the basis of the volume of the received sound and the Doppler effect. Moreover, ultrasound speakers playing their IDs are attached to the user and environment. The system estimates the person and the place the user visited. Gang et al. [8] proposed user identification based on floor pressure sensed while walking. Users need not carry any devices, but pressure sensors have to be embedded under the floor, requiring large refurbishment of the residence.

III. Proposed system

The proposed system extracts feature values from the rotation of a toilet paper roll, such as the length of paper used and the maximum rotation speed. Then, the system identifies the user with the feature values. This section explains the system requirements, design, and identification method. Note that the lavatory we assume is one where a toilet paper roll is installed. In other words, a urinal is not our target in this work.

A. System requirements

User identification in a lavatory requires consideration of user privacy. Recording by cameras or microphones is not acceptable for lavatory users. A lot of work on lifelogs uses wearable sensors. Tamura et al. [9] showed precise identification by having the user carry devices with an assigned ID. Though we usually carry devices such as smartphones and watches, they are put away at home. Thus, installing sensors in the environment is more realistic than having the user carry devices.

Logging and analyzing daily health data is useful for early detection of diseases. Therefore, systems that can be used over the long term habitually are advisable to create a lifelog for optimal health care. Some actions that are not necessary for using a lavatory, such as operating a touch display or a button, may irritate users or be often forgotten. However, a personal identification system based on actions involved in using a lavatory, e.g., opening or closing a door, pulling a toilet paper roll, and flushing, is acceptable. These actions can be obtained through sensors installed in a lavatory, thereby preventing embarrassment. The action of pulling out a toilet paper roll may include new information on user contexts such as the amount of paper used. In addition, most people have not learned how to use a toilet paper roll and have not seen others using a toilet paper roll in a lavatory because a lavatory is a very private room; therefore, individual differences would be evident in the way of pulling a toilet paper roll. For these reasons, individual differences may appear in the usage of paper, such as the length of paper per pull and the rotation speed of the paper. In this paper, we propose a personal identification system focusing on the differences in the technique used in pulling a toilet paper roll.

B. System design

The proposed method uses a wireless gyroscope (TSND121 by ATR Promotions Inc.), which is inserted into a toilet paper roll with a cylindrical attachment. The size of the sensor is W46 x H37 x D12 (mm), and its weight is 22 g. To prevent the attachment from running idle, nonskid rubber is set into the attachment. This device is easy to attach and detach. Moreover, it can be applied to common toilet paper holders that hold a paper roll on both sides. The Bluetooth module in the gyroscope does not have enough distance coverage, so a relay is used to receive data with Bluetooth and to send data to a server with Wi-Fi. First, the gyroscope sends acquired data to a relay with Bluetooth. Then, the relay sends the data to a server via Wi-Fi. Finally, the data is analyzed on the server.

The method uses one-axis angular velocity heading to the rotation of the paper roll. User privacy is protected because only angular velocity is obtained. The system identifies the user based on how the toilet paper roll is pulled, which is a natural movement, and the user does not have to be aware

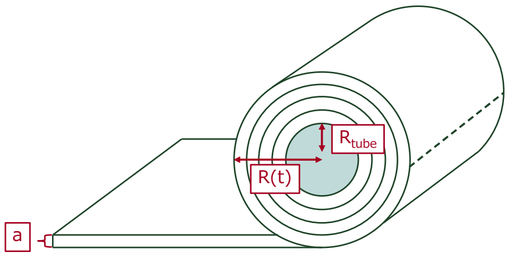

Fig. 2. Layered cylindrical paper model.

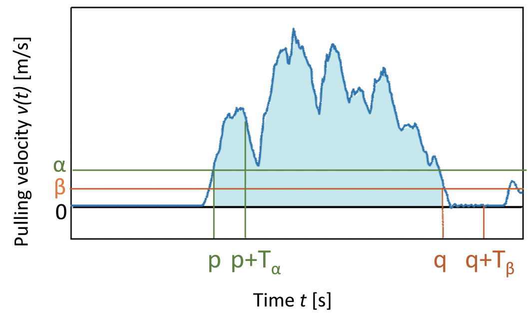

Fig. 3. An example of a waveform of the pulling velocity when pulling a paper.

of the system. In addition, the user does not have to carry any devices because the system is completely installed in the environment.

C. Identification method

The pulling velocity, which is the velocity of pulling the paper roll, is first calculated from the angular velocity obtained with the gyroscope. The starting point and endpoint of pulling the paper are detected from the change in the pulling velocity. Then, the data ranging from the beginning of pulling the paper to the tearing of the paper are segmented. Five kinds of feature values are calculated over the extracted data and standardized. Finally, the standardized feature values are compared with the training data labeled with the user ID, and the user of the lavatory is determined. If the user pulls and cuts the paper multiple times, conclusive results are obtained with majority votes of the results.

1) Pulling velocity: Even if the length of pulled paper per unit time $v(t)$[m/s] is the same, the angular velocity increases as the radius of the paper roll decreases along with using the paper. Accordingly, the pulling velocity is calculated with the angular velocity as follows.

At time t, the pulling velocity $v(t)$[m/s] is given by

$$v(t) = R(t)\omega(t), \tag{1}$$

where $\omega(t)$[rad/s] is the angular velocity and $R(t)$[m] is the radius of the toilet paper roll. Then, the length of the paper pulled between $t-1$ and t is given by

$$L(t) \approx R(t)\omega(t)\Delta t, \tag{2}$$

where Δt[s] is the sampling interval of the gyroscope. Moreover, as shown in Figure 2, a toilet paper roll is regarded as a layered cylindrical model because $R(t)$ changes slightly. In other words, $R(t)$ does not change during one revolution.

The initial total length of the toilet paper roll L_0[m], the initial outer radius of the toilet paper roll R_0[m], and the inner radius of the toilet paper roll R_{tube}[m] are fixed in each product; therefore, these parameters are known in advance. Here, n_0 defines the initial number of turns of the paper, a[m] is the thickness of the paper, and L_0 and R_0 can be expressed with

$$R_0 = R_{tube} + n_0 \cdot a \tag{3}$$

$$L_0 = \sum_{i=1}^{n_0} 2\pi(R_{tube} + i \cdot a). \tag{4}$$

By deforming these equations, a is obtained as follows:

$$a = \frac{(R_0 - R_{tube})(R_0 + R_{tube})}{\frac{L_0}{\pi} - R_0 + R_{tube}} \tag{5}$$

The cumulative number of paper revolutions $n_{used}(t)$ is given by

$$n_{used}(t) = \left\lfloor \frac{d(t)}{2\pi} \right\rfloor, \tag{6}$$

where $d(t) = \sum_{i=0}^{t} \omega(i)$[rad] is the accumulated value of the angular velocity obtained from the gyroscope. Here, we get the radius of the toilet paper roll at time t as follows:

$$R(t) = R_0 - n_{used}(t) \cdot a \tag{7}$$

By substituting Eqn. (7) for Eqn. (1) and Eqn. (2), the pulling velocity $v(t)$ at time t and the length of paper pulled between time $t-1$ and t are obtained as follows:

$$v(t) = \{R_0 - n_{used}(t) \cdot a\}\omega(t) \tag{8}$$

$$L(t) = \{R_0 - n_{used}(t) \cdot a\}\omega(t)\Delta t \tag{9}$$

The preliminary experiment revealed that the deviation between the actual length of a whole paper roll and the theoretical value calculated by Eqn. (9) was less than 1%.

2) Data segmentation: The system conducts identification for one pulling action. In this paper, we define a pulling action as a segment from the start of pulling the paper to the tearing of the paper, so the system detects the starting point and endpoint of a pulling action. Figure 3 shows an example of a waveform of pulling velocity $v(t)$[m/s] when pulling a toilet paper roll. The area that should be clipped from the wave is emphasized by shading. If the condition $v(t) > \alpha$ is first satisfied from time p for time T_α, the proposed system judges that the pulling action began at time p. Then, if the condition $v(t) < \beta$ is satisfied from time q for T_β, the system judges that the pulling action finished at time q. α[m/s] and β[m/s] are the threshold of beginning and ending of the pulling action.

3) Feature extraction: Five kinds of feature values are calculated over one pulling action: the length of used paper $Used$[m], the duration of pulling the paper $Time$[s], the maximum pulling velocity Max[m/s], the average pulling velocity Ave[m/s], and the variance of the pulling velocity Var[m^2/s^2].

4) Standardization: After the feature extraction, the system creates a feature vector $\boldsymbol{X} = \{Used, Time, Max, Ave, Var\}$. Then, $\boldsymbol{X}$ is standardized using the following equation because the scales of the feature values are different. $\boldsymbol{Z} = \frac{\boldsymbol{X}-\boldsymbol{M}}{\boldsymbol{S}}$, where $\boldsymbol{Z} = \{z_1, z_2, z_3, z_4, z_5\}$ is a standardized feature vector whose average and variance are 0 and 1, respectively, and $\boldsymbol{M} = \{m_1, m_2, m_3, m_4, m_5\}$ and $\boldsymbol{S} = \{s_1, s_2, s_3, s_4, s_5\}$ are the average and standard deviation of $\boldsymbol{X}$ over the training data.

5) Comparison with training data: The system identifies the user with a K-nearest neighbor algorithm after calculating the Euclidean distance between the input data and training data labeled with user ID. Specifically, the Euclidean distance between the i-th training data $X_i = \{x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}\}$ and input data $Y = \{y_1, y_2, y_3, y_4, y_5\}$ is calculated using $Euclid_i = \sqrt{\sum_{j=1}^{5}(x_{ij} - y_j)^2}$. $Euclid_i$ is calculated for all the training data, and the user is identified by the majority votes of the labels of the top-K training data. K was set to 1 in this paper.

6) User identification from multiple pulling actions: Users often pull, tear, and use a paper roll multiple times between entering and exiting a lavatory. More accurate identification can be achieved with these data than with a single pulling action. Our system makes a conclusive decision with a majority vote of the results of the single pulling action. If the user is not determined by the majority vote, the result of the smallest Euclidean distance is utilized.

IV. Evaluation

We evaluated our system in a laboratory environment and a practical environment. The experiment in the laboratory was performed to prove the hypotheses that individual traits may appear in the way of pulling paper, and we evaluated the accuracy of user identification with the data of just pulling actions, e.g., without defecation. In the practical environment, we evaluated the accuracy of the user identification with the data of pulling actions when a lavatory was used, i.e., for a case of defecation.

A. Experiment in a laboratory environment

1) Experimental Environment: Data of pulling actions were captured 20 times each from 27 males and 14 females participants aged 19–28 years through the system installed in the toilet booths at one of the university buildings. We used two toilet booths located near our laboratory. One of the booths is for men, and the other is for women. A new toilet paper holder was installed on the left of the booths, although each already had toilet paper holder on the right. This was done because exchanging paper rolls in the other holder was problematic. We used one-ply toilet paper rolls 60 m long, with a tube radius is 19 mm and an initial radius of 58.5 mm.

We evaluated the accuracy by changing the number of people from 2 to 41. The average accuracy of all combinations was calculated if the number of combinations of x people out of the 41 people was no more than 10,000. Otherwise, the average accuracy of the 10,000 combinations was randomly

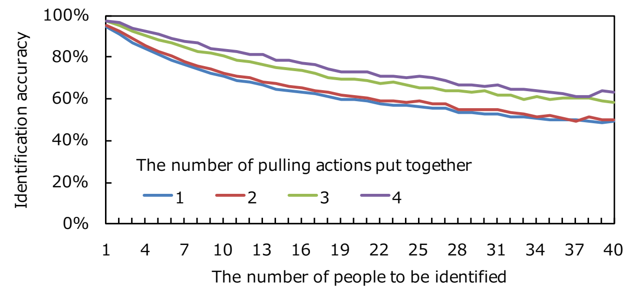

Fig. 4. Identification accuracy vs. the number of participants in the laboratory environment.

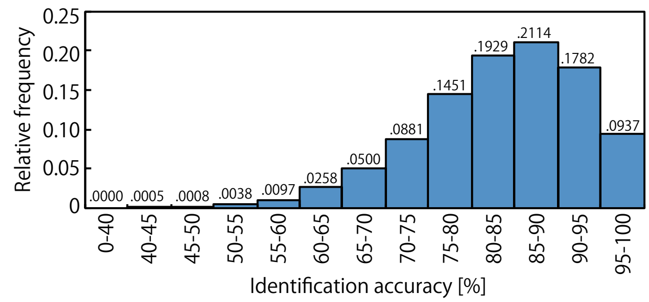

Fig. 5. Identification accuracy in the laboratory environment for the five-person group.

chosen. The identification accuracy was evaluated using a 10-fold cross-validation for all user combinations. To test the efficiency of identification based on multiple pulling actions and single pulling actions, we evaluated our system using two to four folds of cross-validation together with the method shown in section 3.

2) Results: The results of the experiment are shown in Figure 4. In each set of results, over 70% accuracy was achieved when the number of users was 11. Thus, these results demonstrate that individual differences appear in the technique used in pulling paper. In addition, the more the number of the results put together increased when using multiple pulling actions for identification, the higher the identification accuracy became.

We assumed that the system was used by a family of five, with the accuracy distribution of 10,000 combinations of 5 people out of the 41 shown in Figure 5. The horizontal axis indicates the identification accuracy, and the vertical axis indicates the relative frequency. For example, the label 75–80 in the vertical axis means more than 75% and 80% or less in this section. The average and the standard deviation of identification accuracy over the user combinations were 83.9 % and 9.2%, respectively. The maximum accuracy was 100%. The accuracy changed according to the combinations. Figure 6 and 7 show the distribution of feature values in cases where identification accuracy was 41.0% and 100%, respectively. Figure 6 indicates that distributions of feature values overlapped among the participants. However, Figure 7 shows that the distributions of feature values did not overlap.

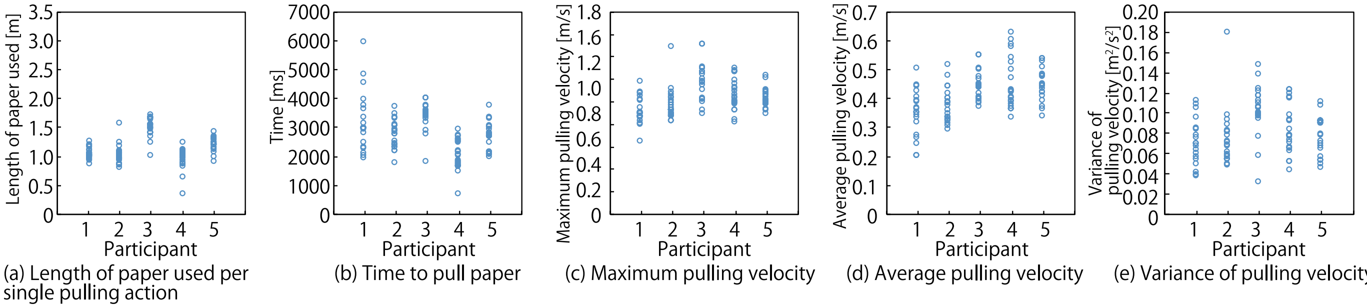

Fig. 6. Distribution of feature values for the group whose identification accuracy was 41.0%.

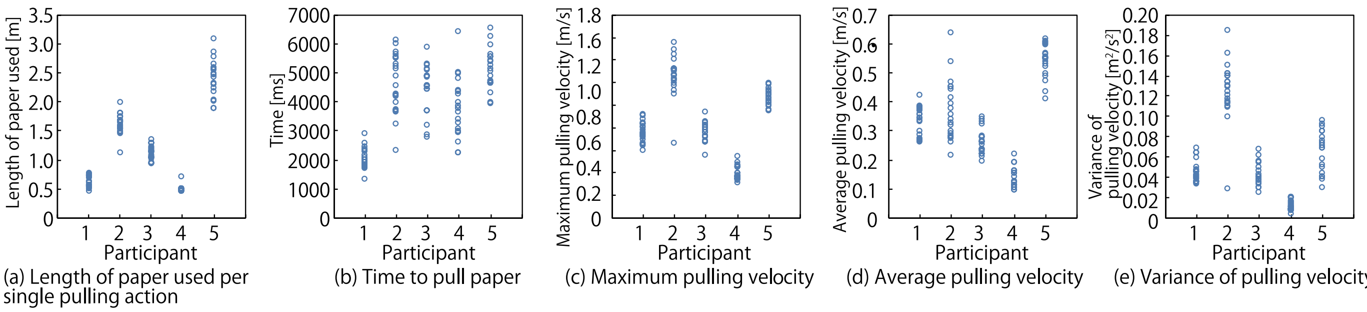

Fig. 7. Distribution of feature values for the group whose identification accuracy was 100%.

TABLE I
IDENTIFICATION ACCURACY VS. THE NUMBER OF PULLING ACTIONS.

The number of actions	Accuracy[%]			
	Average	Max	Min	SD
1	84.0	100	41.0	9.2
2	85.3	100	34.0	10.0
3	90.3	100	40.0	8.9
4	92.5	100	44.0	7.9

Identification accuracies using multiple pulling actions are shown in Table I. In these results, the average identification accuracy improved as the number of actions increased. However, the minimum accuracy decreased when using two or three pulling actions compared with single pulling actions. The reason for the decline in accuracy is that correct identification results turned into incorrect ones because of a majority vote. Therefore, identification using multiple pulling actions may not work well if the identification accuracy based on single pulling actions is below 50%.

To confirm the possibility of identification with multiple pulling actions, 7 males and 7 females (13 were original participants and one was new) recorded the number of pulling actions when using a lavatory to urinate or defecate for a week. The number of pulling actions per use of a lavatory is shown in Figure 8. “M” and “F” in the horizontal axis refer to “Males” and “Females”, respectively. The results indicated that 12 of 14 respondents used paper more than twice on average when they excreted; therefore, identification based on multiple pulling actions can be applied to most users when excreting, bringing high and stable identification accuracy. However, men hardly use paper and women use paper 1.41 times on average when urinating. Identification with our method is difficult for men. Accordingly, designing another identification method such as manual input is desirable for applications where personal identification is required even when urinating. For women, identification based on multiple pulling actions is less effective when urinating than when excreting.

B. Experiment in a practical environment

1) Experimental Environment: An evaluation experiment in a practical environment was conducted to investigate the efficiency of the proposed system in practical use. Data of pulling actions were collected over one month from 13 male participants aged 21–28 years with our system installed in the same mens toilet booth as the laboratory experiment. The participants were asked to report the time they used the toilet booth and their name. Data gathered in this experiment were identified using 20-sample data of pulling actions collected in advance as training data. These training data were taken during the experiment in the laboratory environment from the same participants. The identification accuracy of this experiment was evaluated by changing the number of target people from 2 to 13.

In this experiment, the proposed device was not able to be installed continuously for a month due to privacy concerns; therefore, data on women were not collected. However, the results of the questionnaire demonstrated the feasibility of identification based on multiple pulling actions during defecation. Similar results to men would naturally appear for women because no great difference existed in the way of pulling the toilet paper roll between men and women.

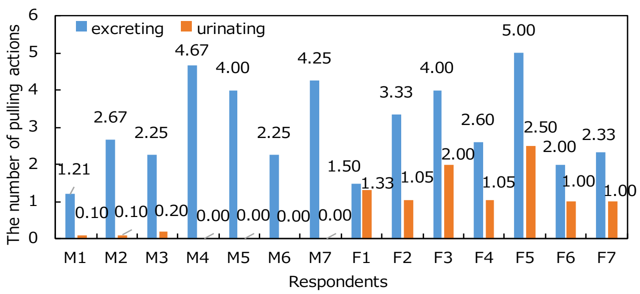

Fig. 8. The number of pulling actions per use of the lavatory.

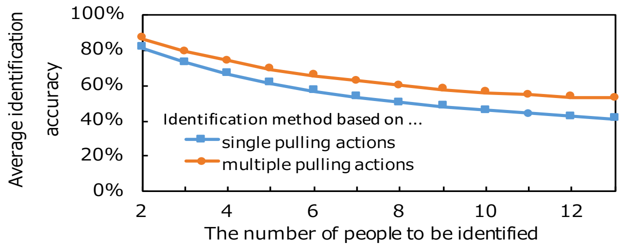

Fig. 9. Identification accuracy vs. the number of participants in the practical environment.

2) Result: The averaged identification accuracy is shown in Figure 9. The horizontal axis indicates the number of people to be identified, and the vertical axis indicates the average identification accuracy. For each population, the accuracy achieved over 50% when using identification based on multiple pulling actions. Here, we assume that the system with the identification method based on multiple pulling actions is used by a family of five. The distribution of the identification accuracy of ${}_{13}C_5$=1287 combinations of five people out of the 13 is shown in Figure 10. The average identification accuracy and the standard deviation of combinations were 69.2% and 11.5%, respectively. The minimum accuracy was 33.3%. The maximum accuracy was 93.3%. When using an identification method based on single pulling actions, the average identification accuracy and its standard deviation were 61.2% and 11.7%, respectively. The minimum accuracy was 25.0%. The maximum accuracy was 89.1%. The cumulative frequency in Figure 10 indicated that the identification accuracy achieved over 50% for about 70% of all combinations. The identification accuracy in this experiment decreased by 10% in comparison with the accuracy in the other experiment. In the practical environment, the amount of paper used varied depending on the condition of excretion. Accordingly, the feature of pulling actions also varied more than they did in the laboratory environment.

V. Conclusion

We designed a user identification system based on the rotations of a toilet paper roll. The proposed system identifies the users of a lavatory using only an installed gyroscope in a toilet paper roll. We conducted an experiment in a

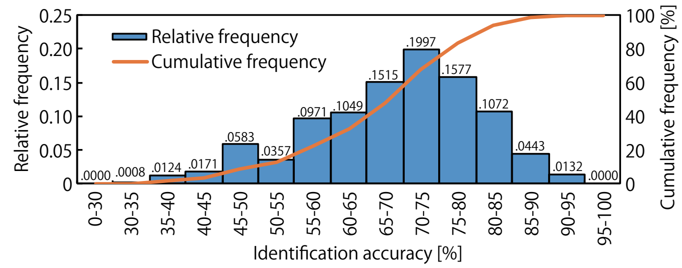

Fig. 10. Identification accuracy in the practical environment for the five-person group.

laboratory environment, in which the identification accuracy was evaluated for data of pulling actions when defecation was not involved, and an experiment in a practical environment, in which the identification accuracy was evaluated for data of pulling actions when defecation was involved. The average identification accuracies using single pulling actions for a five-person group in the laboratory environment and for a five-person group in the practical environment were 83.9% and 69.2%, respectively. We will take measures to address low identification accuracy for some user combinations in the future, such as using other feature values.

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