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A Device Specification Method by Describing a Circle in the Air

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Abstract: This paper provides a new device specification method, for file sharing among multiple partner devices on that spot (e.g., a meeting picture of a social gathering) and so forth. This is because the past representative solution of inputting or selecting the partner device address (e.g., e-mail address) sometimes irritates users and causes an operation error. The problem to be solved is the development of the method that satisfies the four requirements for the above use case: no need of awareness of the device address by users, simultaneous specification of multiple partner devices, differentiation of a device of a stranger, and no need for pre-planned infrastructure. To solve the problem, our method uses an operation of holding the user device in a hand and describing a circle in the air to surround the partner devices. During this operation, the devices exchange acoustic waves and generate the Doppler Effect. By analysis based on the Doppler Effect, the user can specify only the multiple devices that have been circled. Acoustic waves contribute to the relatively accurate detection of the Doppler Effect, due to their slower propagation velocity than that of electronic waves, e.g., Bluetooth and Wi-Fi. We explain the proposed method in detail, and measure its performance via an implemented application. The experimental results show that it enables the simultaneous specification of multiple devices located in the range within 10 degrees from the direction of the user operation, while distinguishing a device of a stranger located in the range larger than 45 degrees. In the above use case, after putting partner devices on a table, the proposed method of this performance satisfies the four requirements, even if a device of a stranger is located at the next table. Thus, this paper concludes that the proposed method is practical for the above use case.

Keywords: device specification, acoustic waves, Doppler Effect, smartphone

1. Introduction

In the case of file sharing among multiple devices, e.g., a smartphone or a feature phone, on that spot (e.g., a meeting picture of a social gathering or an alumni association), a user operation to specify partner devices is required. This operation enables the user device not only to identify partner devices, but also to avoid file sharing with an unwanted device (hereafter referred to as a non-partner device).

A commonly used operation is the specification of device addresses, e.g., an e-mail address, a BDA (Bluetooth Device Address), or a FQDN (Fully Qualified Domain Name). For example, by inputting e-mail addresses into the user device or selecting those from the address book, the user device can identify partner devices. However, this operation is sometimes irritating to users and may cause operation error.

For this reason, some device specification methods whereby users are unaware of the device address have been provided. One example is the operation to bring both devices close at fewer than several centimeters' distance enabling the user device to identify a partner device, by using NFC (Near Field Communication) or infrared rays. However, this operation must be repeated the same number of times as the number of partner devices for the above use case.

One of the ways to specify multiple devices simultaneously is the use of Bluetooth, Wi-Fi, or acoustic waves, which has a wider transmission range than NFC and infrared rays. Toneconnect [1] enables the user device to identify multiple devices located within the transmission range of acoustic waves at the same time. However, if a non-partner device is also located within the transmission range, the user device accidentally identifies and shares files with it. In the case of file sharing in a restaurant, a user may accidentally share a file with a stranger who is at a nearby table. To distinguish between a partner and a non-partner device, Toss-it [2] uses relative position information. When the user device is swung horizontally in a certain direction, it identifies the devices located in the direction of the swing. In this way, the relative position is a key to distinguish a non-partner device. However, infrastructure cameras are required to estimate the relative position, so the user cannot share files in places without infrastructure cameras.

Some methods provide a relative position by using acoustic waves without any pre-planned infrastructure [3], [4]. In general, the relative position can be accurately estimated with acoustic waves, because their propagation velocity is slower than that of electronic waves, e.g., Bluetooth and Wi-Fi. In particular, method [4] estimates the direction between two devices by using the Doppler Effect of acoustic waves. When one device is swung, it transmits acoustic waves. As a result, the other device observes the Doppler Effect. The direction is estimated by analyzing the Doppler Effect. However, the purpose of these methods is esti-

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Table 1 Outline of the related work regarding device specification.

	User Operation	Available Distance between Devices	Number of Devices Specified Simultaneously	Necessary Built-in Sensors or Actuators	Need Infrastructure or Server?
NFC	Bringing both devices close	Several centimeters	1	NFC	No
Infrared Rays	Bringing both devices close and tapping on either device	Several centimeters	1	Infrared rays	No
BUMP [5]	Bumping the user device against the partner device	0 meters	1	Accelerometer, GPS	Yes (Server)
SyncTap [6]	Tapping on both devices at the same time	Several meters	1	None	No
Point&Connect [7]	Pointing to the partner device with the user device	Several meters (*1)	1	Microphone, Speaker	No
Secure Device Pairing [8]	Capturing the partner device with the camera of the user device	Several 10 centimeters	1	Camera, LED	No
Toneconnect [1]	Tapping on the user device	Several meters (*1)	Multiple	Microphone, Speaker	Yes (Server)
Toss-it [2]	Swinging or throwing the user device towards the partner device	Several meters	Multiple	Accelerometer, LED	Yes (Infrastructure camera)

(*1)Transmission range of acoustic waves

mation of the relative position; therefore, these methods as they are cannot specify the devices.

In this paper, we newly propose a device specification method, which specifies multiple partner devices simultaneously, without any pre-planned infrastructure. The proposed method distinguishes between a partner and a non-partner device by estimating the relative position using the Doppler Effect of acoustic waves. In concrete terms, the user holds the user device and describes a circle in the air to surround the partner device. At the same time, both devices transmit and receive acoustic waves respectively in order to generate the Doppler Effect. Subsequently, both devices cooperatively estimate the change in the relative position, and the user device then identifies the devices that have been circled. Therefore, if a non-partner device is also located within the transmission range, the proposed method prevents identification and sharing files with the non-partner device. We analyze the resolution of the proposed method, which indicates the performance in distinguishing between a partner and a non-partner device. We implement the proposed method as an android smartphone application, and measure its actual performance from the viewpoint of resolution. Finally, we describe some issues to be discussed when providing applications using the proposed method.

This paper is organized as follows. Section 2 shows related work, while Section 3 newly proposes the device specification method and Section 4 analyzes its resolution. Section 5 describes the implementation of the proposed method, and Section 6 evaluates it via the implemented application. Section 7 discusses some issues and Section 8 concludes this paper.

2. Related Work

Some device specification methods that do not require a user to be aware of the device address have been provided, as shown in **Table 1**. All methods utilize a user operation, instead of a specification of device address. In addition, most of them use the built-in sensors and actuators or a pre-planned infrastructure, to detect the user operation. These device specification methods are classified into cases where the supposed number of partner devices is 1 or multiple.

In addition to NFC and infrared rays, the former case includes BUMP [5], which is a well-known application for file and data sharing. It requires the operation of bumping the user device against the partner device. After each device detects bumping via its accelerometer sensor, it notifies a server on the Internet of its location information. The location information is usually obtained via GPS (Global Positioning System). Subsequently, the server selects the pair of devices that detected bumping at the same time and location, and then notifies both devices of the pair information. However, it sometimes does not work well indoors, since availability of GPS is required. SyncTap [6] asks the user to tap on both devices concurrently for the same period. By exchanging the tapping period among all devices located nearby via Wi-Fi and so forth, the user device identifies the partner device. In Point&Connect [7], the user points to the partner device with the user device. At the same time, by transmitting and receiving acoustic waves, the user device estimates the change in distance between the user device and other devices located in the vicinity. Based on the feature whereby the change in distance between the user and the partner device peaks during the pointing operation, the user device identifies the partner device. Secure device pairing [8] requires the operation to capture the LED of the partner device with the camera of the user device. The partner device shows its own information via the LED emission pattern, and the user device obtains the information, so that the user device identifies the partner device. These methods [6], [7], [8] use only commercially available devices and their sensors and actuators, and do not require any pre-planned infrastructure. However, the operation must be repeated several times so as to specify multiple devices.

In the latter case, Toneconnect [1] asks the user to tap on the display of the user device. After the user device detects the tap operation, it transmits specific acoustic waves. The device that has received the acoustic waves notifies the server of the information on the received acoustic waves. Next, the user device inquires of the server information on the devices that have received the acoustic waves, and identifies the partner device. Although this method specifies multiple partner devices simultaneously, it

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cannot distinguish between a partner and a non-partner device if the non-partner device is located near the user device. In Toss-it [2], after the relative position among all devices is estimated, the user swings the user device horizontally in the direction in which the partner device is located, whereupon the user device identifies the devices from the relative position. However, infrastructure cameras are required to estimate the relative position, so an excessive initial cost causes a bottleneck. From the above, there is no device specification method that can distinguish between a partner and a non-partner device and specify multiple partner devices simultaneously without any pre-planned infrastructure.

3. Device Specification by Describing a Circle in the Air

In the supposed environment, Devices A and B are located within the transmission range of acoustic waves from the user device. Device A is assumed as the partner device with which the user desires file sharing. Device B is assumed as a non-partner device with which the user does not require file sharing. In addition, Devices A and B are collectively called neighborhood devices. For ease of understanding, the number of partner devices is set to 1 in the supposed environment. We discuss the case of multiple partner devices in the last part of Section 3.2.2.

We newly propose a device specification method that requires no pre-planned infrastructure. The proposed method is based on the following approaches.

- To distinguish between a partner and a non-partner device, we use the change in relative position among devices (see Section 3.2.2 for more details).
- To estimate the change in relative position, we use the Doppler Effect of acoustic waves (see Section 3.2.1 for more details). The use of acoustic waves also enables the simultaneous specification of multiple partner devices, due to their wide transmission range of several meters.
- To generate the Doppler Effect, user operation of describing a circle in the air to surround the partner device is used (see Section 3.1 for more details).

The rest of this section is organized as follows. Section 3.1 explains the operation to describe a circle and the basic idea of the device identification, while Section 3.2 mentions identification of the partner device based on the Doppler Effect. Section 3.3 explains the procedure for transmission and reception of acoustic waves, Section 3.4 mentions the procedure to detect the operation to describe a circle and Section 3.5 shows the entire procedure of each device.

3.1 Operation of Describing a Circle in the Air and Basic Idea of Device Identification

We focus on the operation to circle a target, which is sometimes used to specify things in our daily lives. For example, we circle an applicable item in a questionnaire. In concrete terms, the user holds the user device and describes a circle in the air to surround the partner device, while turning the display of the user device upwards, as shown in **Fig. 1**. We call this operation the circle operation.

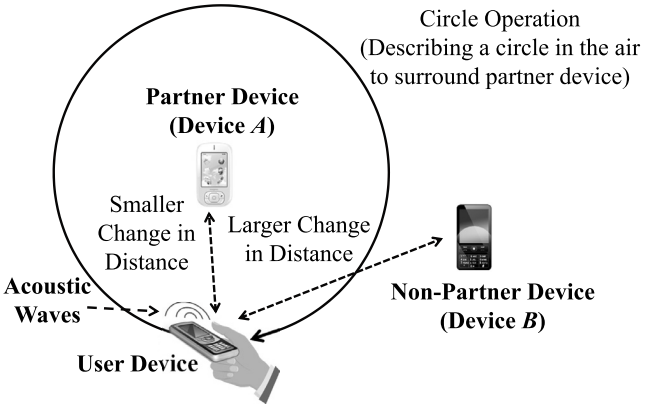


Fig. 1 Outline of circle operation for device specification.

We explain the basic idea of the device identification. During the circle operation, the user device moves in concentric circles above the partner device. Hence, there will be little change in distance between the user and the partner device. Conversely, the change in distance between the user and the non-partner devices would be larger. Therefore, the proposed method tries to identify the neighborhood device that has a smaller change in distance with the partner device. The procedure of identification is presented in Section 3.2.

3.2 Identification of a Partner Device Based on the Doppler Effect

During the circle operation, the user device transmits acoustic waves to generate the Doppler Effect. As a result, neighborhood devices receive the acoustic waves, and then estimate the change in distance based on the Doppler Effect. Finally, each neighborhood device judges whether it has been circled (specified) or not.

3.2.1 Estimation of Change in Distance Based on the Doppler Effect

The proposed method detects the Doppler Effect, using a similar procedure to the methods of Refs. [4], [9]. The details are as follows. During the circle operation, the user device transmits multiple pulse-type acoustic waves at a transmission interval. As a result, the neighborhood device receives these multiple acoustic waves at a reception interval, which may differ from the transmission interval. Subsequently, by calculating the difference between transmission and reception intervals, the Doppler Effect is recognized.

The number of acoustic waves transmitted by the user device is represented by n, and the i-th ($1 \leq i \leq n$) acoustic wave is expressed as A_i. Also, the transmission interval between acoustic waves A_i and A_{i+1} is denoted by $TI(i)$. The reception intervals of neighborhood device j ($j = \{A, B\}$) between acoustic waves A_i and A_{i+1} are represented by $RI_j(i)$. Neighborhood device j recognizes the Doppler Effect by calculating the difference between transmission interval $TI(i)$ and reception interval $RI_j(i)$. Here, transmission interval $TI(i)$ is notified by the user device in advance. Reception interval $RI_j(i)$ is calculated as described in Section 3.3. Finally, the change in distance $D_j(i)$ between the user device and neighborhood device j is calculated as follows.

$$D_j(i) = (TI(i) - RI_j(i)) * c. \quad (1)$$

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Variable c shows the propagation velocity of the acoustic wave.

3.2.2 Identification of a Partner Device Based on Change in Distance

Neighborhood device j performs a circle judgment regarding whether it has been circled by a user device or not, based on the feature of change in distance $D_j(i)$. If neighborhood device j has been circled, the absolute value of the change in distance $D_j(i)$ is 0 in the ideal case. Even if there is an error of the circle operation or calculation of reception intervals, the absolute value of the change in distance $D_j(i)$ would still remain small. Conversely, in the case where the neighborhood device j has not been circled, the absolute value of the change in distance $D_j(i)$ would be larger. In addition to this feature, for the non-partner device, the circle locus of the user device is divided into an approaching and withdrawing semicircle. In the approaching semicircle, the user device is approaching the non-partner device. Conversely, in the withdrawing semicircle, the user device is withdrawing from the non-partner device. To utilize this feature for the circle judgment, we use the maximum accumulated change in distance. The maximum accumulated change in distance between the user device and the neighborhood device j in approaching and withdrawing semicircles DA_j and DW_j are respectively calculated as follows:

$$DA_j = \max \sum_{k=l}^{m} D_{j(k)} \quad (1 \le l \le k \le m \le n, D_j(k) \ge 0). \tag{2}$$

$$DW_j = \max \sum_{k=l}^{m} (-D_{j(k)}) \quad (1 \le l \le k \le m \le n, D_j(k) \le 0). \tag{3}$$

In the case where the neighborhood device j is not circled, the change in distance $D_j(i)$ with the same sign will last in approaching and withdrawing semicircles, respectively. Hence, the maximum accumulated change in distance DA_j and DW_j becomes large. The circle judgment is performed based on the following equation.

$$(DA_j + DWj)/2 \le TH. \tag{4}$$

Parameter TH denotes a threshold for the circle judgment. If Eq. (4) is satisfied, neighborhood device j judges that it has been circled by the user device, which denotes that the neighborhood device j has been specified. For robust judgment, we use the average of the maximum accumulated change in distance DA_j and DW_j, so that the quantity of information used for the circle judgment increases. We discuss the decision of parameter TH in Section 4.

After neighborhood device j checks that Eq. (4) is satisfied, it tries to connect to the user device, using the notified user device address in advance. Then, the user device obtains the neighborhood device address and identifies it with the partner device. Moreover, when the non-partner device is also located within the transmission range, it does not try to connect to the user device. Thus, the proposed method does not identify and share files with the non-partner device.

If a malicious device, which is one of the non-partner devices and ties to be specified, performs a false judgment, the user device may incorrectly specify the malicious device. We discuss this point in Section 7.1.

Now, we describe the device specification for multiple partner devices. When circling multiple devices simultaneously, each neighborhood device j independently performs the circle judgment and tries to connect to the user device. As a result, the user device obtains their device address and identifies them with the partner devices. This implies that the proposed method can specify multiple partner devices simultaneously.

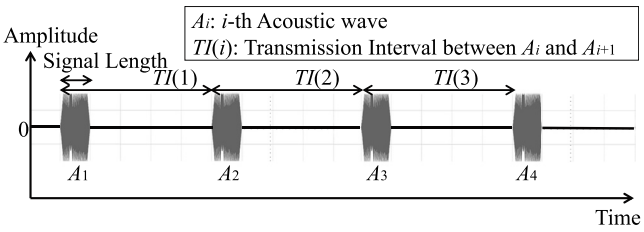


Fig. 2 Example of acoustic wave data.

3.3 Procedure for Transmission and Reception of Acoustic Waves

3.3.1 Procedure for Transmission of Acoustic Waves

Initially, the user device generates acoustic wave data that plays acoustic waves at transmission interval $TI(i)$. Subsequently, it transmits acoustic waves by playing the generated data. We show the example of the acoustic wave data in **Fig. 2**. This example includes 4 acoustic waves A_1, A_2, A_3 and A_4 and their transmission intervals are $TI(1)$, $TI(2)$, and $TI(3)$, respectively. Now, the transmission must be performed only when the user conducts the circle operation. This is because all neighborhood devices would satisfy Eq. (4), if the user device transmits acoustic waves when it stops. As a result, all neighborhood devices including a non-partner device are specified. One way to prevent such unwanted behavior is the detection of the circle operation. An accelerometer sensor of the user device can be used for the detection. The user device detects the start of the circle operation. After that, it continues to monitor whether the circle operation is lasting or not. Only when the circle operation is continued, the user device transmits acoustic waves. We will describe the concrete procedure to detect the circle operation in Section 3.4.

3.3.2 Procedure for Reception of Acoustic Waves

We describe how neighborhood device j calculates the reception interval of acoustic waves $RI_j(i)$. When neighborhood device j receives n acoustic waves, it calculates the reception time of each wave, and it then calculates reception interval $RI_j(i)$, using the same procedure in method [4].

The reception times are calculated using the cross-correlation function between the received data and a reference signal in the time domain. The reference signal is generated based on the acoustic wave information notified by the user device in advance. Basically, the time of the maximum peak of the cross-correlation function is concluded as being the reception time. After the calculation of n reception times, neighborhood device j tries to remove outliers, which is caused by reflection from obstacles or surrounding noise [4]. Finally, reception interval $RI_j(i)$ is calculated as the difference in adjacent reception time. **Figure 3** illustrates the example of the cross-correlation function in the actual environment. This example includes 4 acoustic waves A_1, A_2, A_3 and A_4.

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3.4 Detection of Circle Operation

The user device has to detect the circle operation, because acoustic waves should be transmitted only during the circle operation, as stated in Section 3.3.1. The user device uses its accelerometer to detect the circle operation. **Figure 4** illustrates the examples of acceleration when the circle operation is done in a horizontal direction and toward right under. We can see some features. For example, peaks appear at an interval in each axis, and the intervals of peaks are almost the same, regardless of axis X, Y and Z. In addition to that, we obtain information that a peak may appear only on 2 axes, depending on the degree of leaning of the user device. There is a noise, as we can see a notched curve of acceleration.

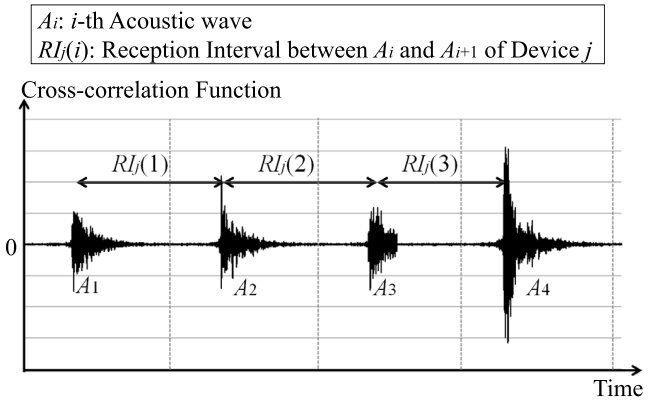


Fig. 3 Example of the cross-correlation function in an actual environment.

Based on these features, we describe the concrete procedure. The user device monitors its acceleration and uses a low-pass filter to remove a noise. If the user device finds peaks in at least 2 axes during the past T_1 [second], it detects the start of the circle operation. After that, it continues to monitor intervals in 3 axes. Only if the maximum difference among the latest intervals in each axis is smaller than T_2 [second], it judges that the circle operation is still continued. Otherwise, it determines that the circle operation is over. If there is no peak in axes more than two during the past T_3 [second], it also judges that the circle operation is finished. We set parameters T_1, T_2 and T_3 as 1, 0.5 and 1.5, respectively, through a basic experiment.

3.5 Entire Procedure of User and Neighborhood Devices

We explain the entire procedure of user and neighborhood devices, using **Fig. 5**. First, the user performs the circle operation (Section 3.1) (Fig. 5 (1)), and the user device then detects the start of circle operation through its accelerometer (Section 3.4) (Fig. 5 (2)). Second, it performs two procedures concurrently. It broadcasts the notification of its device address and acoustic wave information to neighborhood devices via wireless communication (Fig. 5 (3-1)), such as Bluetooth, Wi-Fi, or acoustic wave communication. At the same time, it starts transmitting acoustic waves (Fig. 5 (4-1)). After it finishes transmitting acoustic waves, it notifies the user of the end of the transmission via its vibrator or alarm sound. After that, the user finishes the circle operation. When neighborhood devices A and B receive the noti-

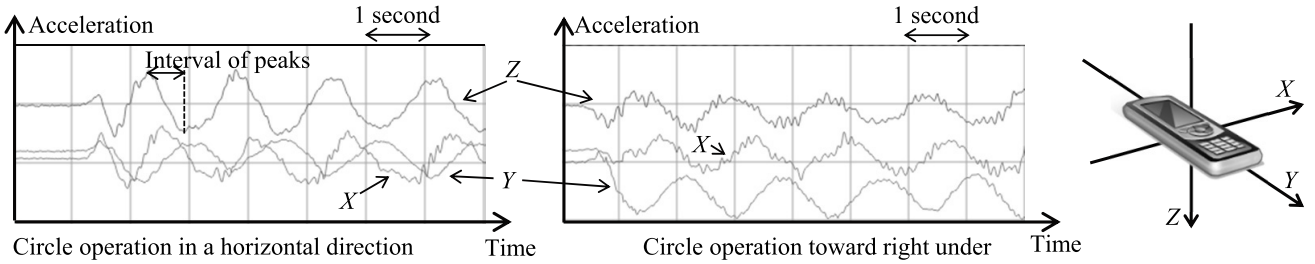


Fig. 4 Examples of the acceleration of the circle operation.

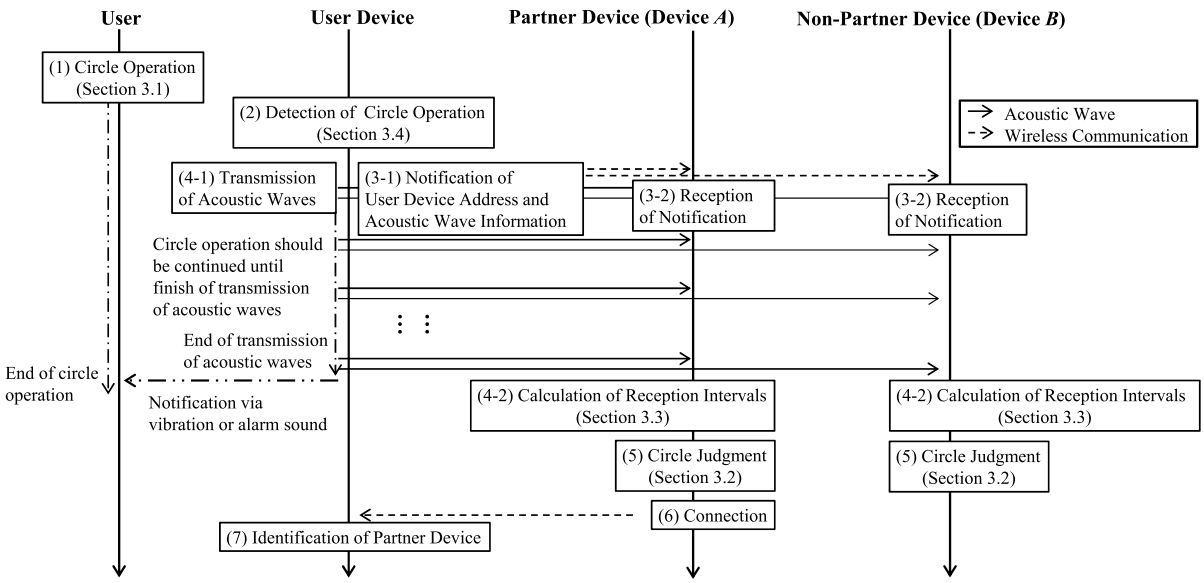


Fig. 5 Entire procedure of the user and the neighborhood devices.

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fication, they obtain the user device address and acoustic wave information (Fig. 5 (3-2)). They also receive acoustic waves and calculate the reception intervals (Section 3.3) (Fig. 5 (4-2)). After that, they undertake the circle judgment (Section 3.2) (Fig. 5 (5)). If neighborhood device A judges that it has been circled, it tries to connect to the user device (Fig. 5 (6)), using the notified device address. Finally, the user device obtains the partner device address and identifies it with the partner device (Fig. 5 (7)).

We will also explain the procedure, if multiple users perform the circle operation concurrently. In this case, neighboring devices receive multiple notifications. Each notification includes the acoustic waves information, e.g., frequency of acoustic waves. After that, the neighboring devices perform the circle judgment, regarding all the acoustic waves from multiple user devices, independently. If the neighboring device passes the circle judgment regarding the acoustic waves of a frequency, it tries to connect to the user device which transmitted the acoustic waves of the frequency. Like this, the proposed method works even in the case of multiple user devices.

4. Analysis of Resolution

We analyze the resolution of the proposed method, which indicates the performance in distinguishing between a partner and a non-partner device. Since the result of the circle judgment depends on the relative position between the user and neighborhood devices, we first calculate the relative position of a neighborhood device that satisfies Eq. (4). We then analyze the resolution of the proposed method. In addition, we analyze the relationship between the resolution and parameter TH.

The supposed condition for the analysis of the resolution is shown in **Fig. 6**. In the rectangular coordinate system of three-dimensional space, a partner and a non-partner device are located on the X-Y plane. The partner device is located on the Y-axis, while the coordinates of the non-partner device are denoted by $(x, y, 0)$. In addition, θ denotes the angle that is formed by the line connecting the origin and the partner device and that connecting the origin and the non-partner device. The radius of the circle operation is denoted by R. The center of the circle operation is assumed as the origin, and the user device moves in a Z-X plane during the circle operation.

Under this condition, the approaching and the withdrawing semicircles of Device B are those from points P to Q and Q to P, respectively. Hence, the maximum accumulated change in distance DA_B and DW_B is that accumulated from points P to Q and Q to P, respectively. Equation (4) is calculated as follows:

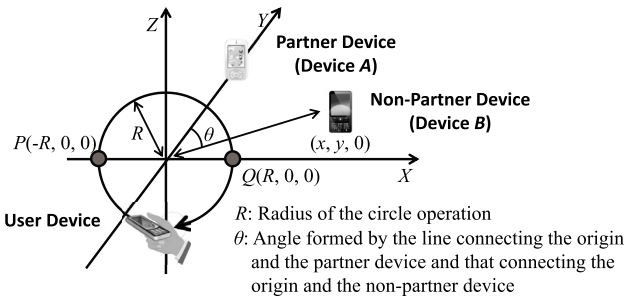


Fig. 6 Supposed condition for analysis of the resolution.

$$\sqrt{(x+R)^2+y^2} - \sqrt{(x-R)^2+y^2} \le TH. \quad (5)$$

Equation (5) shows the area where the neighborhood device judges that it is circled (hereafter referred to as a specification area). Now, the locus satisfying the equality condition is a hyperbola, the focal points of which are P and Q. The hyperbola and its asymptote are relatively calculated as follows:

$$x^2/(TH/2)^2 - y^2/(R^2 - TH^2/4) = 1. \quad (6)$$

$$y = \pm\sqrt{(2R/TH)^2 - 1} * x. \quad (7)$$

Therefore, the resolution of the proposed method, φ [degrees], is approximately calculated from the slope of the asymptote as follows:

$$\varphi = 90 - \mathrm{Arctan}(\sqrt{(2R/TH)^2 - 1}) \quad (8)$$

Equation (8) shows that the larger radius R is, the smaller (better) resolution φ becomes, and vice versa. This is because a larger radius R generates a larger change in distance between devices. It also shows that resolution φ does not depend on the distance between devices.

The specification area is surrounded by two asymptotes, as illustrated in **Fig. 7**. In the analysis so far, the locations of neighborhood devices are assumed to be on the X-Y plane. Even if neighborhood devices are located within three-dimensional space, the specification area is similarly calculated. The area is the interior of a circular cone that is generated by turning the asymptote 360 degrees.

Next, we analyze the relationship between resolution φ and parameter TH, using Eq. (8). If parameter $TH = 2 * R$, resolution φ becomes 90 degrees, which implies that distinguishing between a partner and a non-partner device is impossible, like Toneconnect [1]. Accordingly, parameter TH should be lower than $2 * R$. For example, in the case of parameter $TH = R/2$, resolution φ becomes around 14.5 degrees. Here, there is a problem of how we set parameter TH. If radius R and resolution φ are known in advance, we can determine parameter TH. In fact, resolution φ can be obtained by the requirement of an application, but radius R cannot be determined because it would differ each time according to the user.

One way to determine parameter TH is to use the assumption of a realistic range of radius R. Based on the length of the human arm and burden on the user, radius R would range from 0.1 to 0.3 meters. So, an averaged radius R of 0.2 meters is used. Another way is to estimate actual radius R each time. Since there are some works [10], [11] for estimating the tracking of a device

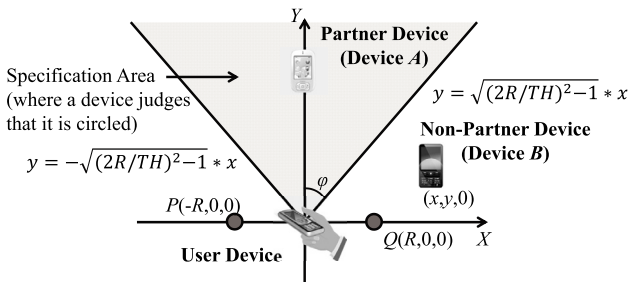


Fig. 7 Area where the neighborhood device judges that it is circled.

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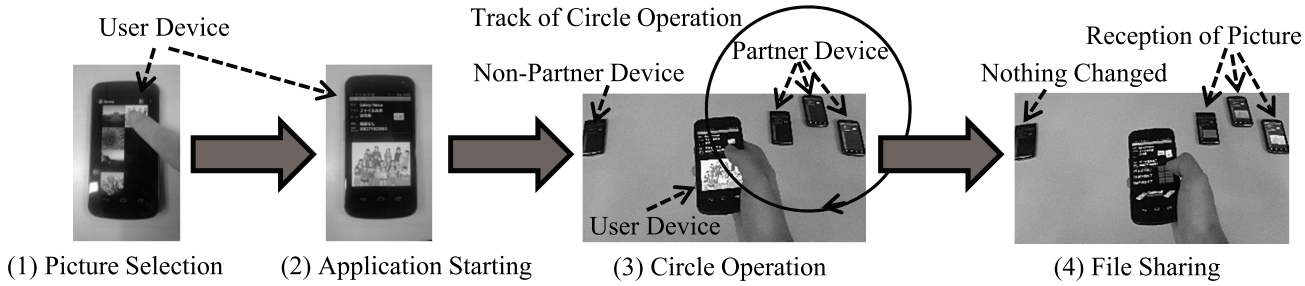


Fig. 8 Usage of the implemented application.

via its accelerometer, radius R would be estimated by combining such works and the proposed method.

The analysis result that the larger radius R results in a smaller resolution may contradict the intuition of some users. For example, when specifying many partner devices simultaneously, some users would draw a large circle so as to enclose all the devices. This makes the resolution φ small and several partner devices may become out of range. On the other hand, we assume that users hardly change the radius of circle operation R, regardless of the number of partner devices. In order to realize this assumption, we have two solutions: feedback and instruction of the circle operation. Regarding the feedback, after the circle operation, the user receives feedback of the actual radius of circle operation R. If the actual one is larger than that required for the proposed method, the user is asked to draw a smaller circle, and vice versa. The actual radius of circle operation R can be estimated, by using related works [10], [11]. Regarding the instruction, the user is asked to draw a circle with the radius of about 0.2 meters. We will measure the change of radius R of the circle operation, in both the cases of specifying one and several partner devices in Section 6.2.6.

5. Implementation

We implement the proposed method as an application for smartphones (Android 2.3.3 or later) in order to evaluate it. We show the usage of the application and an outline of the implementation in turn.

Figure 8 depicts the usage of the implemented application, where there are three partner devices. In this application, BDA is used as the device address. First, the user selects the picture on the user device (Fig. 8 (1)). Second, the user starts the application by tapping the sharing button provided by Android, which calls the Android function to start a required application (Fig. 8 (2)). Third, the user performs the circle operation (Fig. 8 (3)). Subsequently, three Bluetooth channels are automatically connected between the user device and each partner device, without the input of the device address by the user. After that, the user device identifies the connected devices with the partner device. Finally, the picture is shared among them via Bluetooth (Fig. 8 (4)).

Accordingly, the proposed method can specify multiple partner devices simultaneously. Furthermore, as the non-partner device is not specified, the proposed method is able to distinguish between the partner and the non-partner device. Here, although it may be difficult for a beginner to perform the circle operation, we believe that instruction or feedback helps him/her. We discuss instruction and feedback of the circle operation in Section 7.

We provide an outline of the implementation as follows.

- Some commercially available devices, such as Xperia Arc (Sony Ericsson), Photon (Motorola), and Galaxy Nexus (Samsung) are used for implementation.
- A normal microphone and a speaker with which the device is equipped are used to transmit and receive acoustic waves.
- Acoustic wave communication is used to notify the user device address, wave pattern, and transmission interval (Fig. 5 (3-1)). We use FSK (Frequency Shift Keying) as a modulation method.
- A chirp signal is selected as an acoustic wave, because it has a sharp peak of the cross-correlation function. The sampling rate of acoustic waves is set to 44.1 kHz.
- Parameters regarding acoustic waves, e.g., the frequency, the signal length, the transmission intervals and the number of acoustic waves n, are configurable from the setting menu of the implemented application. Decision of these parameters depends on the type of application and the characteristic of acoustic waves. We decide these parameters in Section 6.1.3.
- Bluetooth is used for the connection between the user and partner devices (Fig. 5 (6)). We use automatic pairing of Bluetooth, for the realization of use of this application without any presetting, e.g., Bluetooth pairing setting.
- An accelerometer sensor of a device is used to detect the circle operation.

Thus, the proposed method uses the sensors and the actuator with which the generic device is equipped and does not require any pre-planned infrastructure. Here, competition of sensors and actuators with other applications is a concern, because multiple applications usually work on a smartphone at the same time. We discuss the competition of those in Section 7.

6. Experiment and Evaluation

For evaluation of the proposed method, we measure its performance, using the implemented application. First, we evaluate the distance between devices within which the proposed method works sufficiently for practical use. When file sharing is performed in restaurants, cafés, and shops, noise due to people, music and so forth, may affect the performance. In addition, the difference of the circle operation, e.g., the radius of the circle operation, affects the performance. Therefore, we evaluate the influence of noise and the radius of the circle operation on the performance of the proposed method. Finally, we evaluate the number of partner devices that the proposed method can specify simultaneously.

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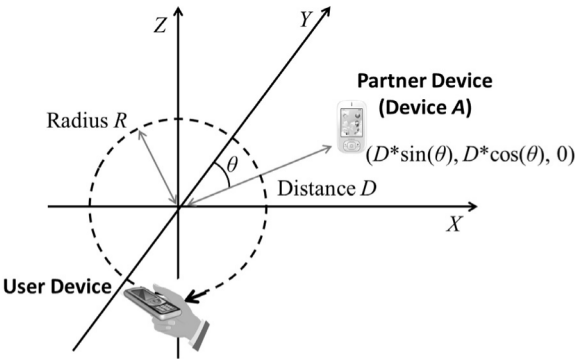


Fig. 9 Relative positions between the devices in the experiment.

Table 2 Experimental conditions.

Experimental Content	Distance D [meters]	Angle θ [degrees]	Radius R [meters]	Noise	Number of Partner Devices
1. The number of acoustic waves n	3	0, 15, 30, 45	0.2	None	1
2. Distance D	1, 3, 5	0, 15, 30, 45	0.2	None	1
3. Noise	3	0, 15, 30, 45	0.2	None, Music, White noise	1
4. Radius R	3	0, 15, 30, 45	0.1, 0.2, 0.4	None	1
5. Number of partner devices	3	-15, -10, 5, 0, 5, 10, 15,	0.2	None	7
6. Difference by users	3	0, 15, 30, 45	0.2	None	1

6.1 Experimental Method

6.1.1 Metric for Evaluation

We use a proportion of the number of times of success in device specification to the number of times of trials of device specification, as a metric for the evaluation. The number of times of success in device specification denotes the number of times that the device judges that it was circled. The larger proportion means that the proposed method specifies the partner device more certainly and vice versa.

6.1.2 Experimental Setting

We use three models of smartphones (Xperia Arc (Sony Ericsson), Photon (Motorola), and Galaxy Nexus (Samsung)) in the experiments.

Figure 9 shows the relative position between the user device and the partner device in the experiment. The center of the circle operation is assumed to be the origin and the user device moves in a Z-X plane during the circle operation. The radius of the circle operation is R, while the distance between the origin and the partner device is denoted by D. The angle that is formed by the Y-axis and the line connecting the origin and the partner device is θ. The coordinates of the partner device can be shown as $(D*\sin(\theta),\ D*\cos(\theta),\ 0)$. We use some values of each distance D and angle θ as well as radius R to evaluate the proposed method under various conditions as follows.

We conduct six experiments as depicted in **Table 2**. In the first experiment, the influence of the time for which the circle operation is continued is measured, by changing the number of acoustic waves n transmitted from the user device. The number of acoustic waves n used after this experiment is determined via the first experiment. In the second experiment, the distance D is set to 1, 3, and 5 meters. For measurement of the influence of noise, the third experiment is performed while playing music or white noise on a PC. The loudness level near the partner device due to the noise is about 80 dB, which assumes a noisy urban city in daytime [12]. The frequency of the music file is 7 kHz or less, which is frequency range similar to noise generated by people, cars, and so forth. The frequency of the white noise ranges from 0 to 22.05 kHz. In the fourth experiment, the influence of difference of the circle operation is imitatively measured, by setting radius R to 0.1, 0.2, and 0.4 meters. In the fifth experiment, we measure the number of partner devices that the proposed method can specify simultaneously. In the sixth experiment, 4 users perform the circle operation to check the robustness of the proposed method for difference by users. User A is one of the authors, while Users B, C and D have neither known the proposed method nor the implemented application. Before the experiments, Users B, C and D watched the demo movie of the implemented application for 10 seconds and were asked to draw the circle with the radius R of 0.2 meters for 5 seconds. In addition to that, we measure the change in radius R of the circle operation, when specifying one or multiple partner devices. This is because some users may draw a larger circle when specifying multiple partner devices, due to acting intuitively, as described in the last part of the Section 4.

In the first, second, third, fourth and sixth experiments, we set the number of partner devices to 1 and angle θ to 0, 15, 30, and 45 degrees. In contrast, in the fifth experiment, we place 7 partner devices at intervals of 5 degrees. This placement enables us to estimate the number of partner devices that the proposed method can specify simultaneously. Common to all experiments, the number of times of trials of device specification is 30 to measure the proportion. Three models of smartphones are used for each experiment 10 times, respectively.

The experiment is conducted in a room that is of approximately 5 meters × 5 meters. Parameter TH is set to 0.1 meters, which implies that resolution φ is calculated to be about 14.5 degrees in the case of a radius of 0.2 meters by Eq. (8).

6.1.3 Parameter Setting of Acoustic Waves

We set parameters regarding acoustic waves, e.g., the frequency, the signal length, the transmission interval and the number of acoustic waves n, as shown in **Table 3**.

Table 3 Parameters regarding acoustic waves.

Frequency [kHz]	Signal Length [milliseconds]	Transmission Interval [milliseconds]	The number of Acoustic Waves n
18-19	50	250	Determined via first Experiment

We use the frequency of acoustic waves of 18–19 kHz, due to their robustness to environmental noise and almost inaudible characteristic for humans. Available frequency ranges from 1 kHz to 20 kHz, because the smartphones that we use, e.g., Xperia Arc (Sony Ericsson), Photon (Motorola), and Galaxy Nexus (Samsung), have the capability to transmit and receive acoustic waves of that range. However, environmental noise of frequency under 10 kHz is relatively strong, due to human voice, music and musical instruments. Thus, a high frequency is suitable for robustness to environmental noise. Moreover, a frequency higher than 18 kHz is almost inaudible to humans. Since we believe that inaudible acoustic waves may be suitable for file sharing, we use 18–19 kHz in this experiment.

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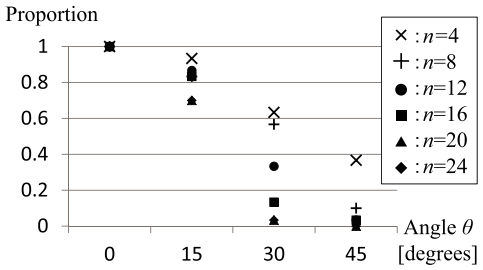


Fig. 10 Results when the number of acoustic waves n is 4, 8, 12, 16, 20 and 24.

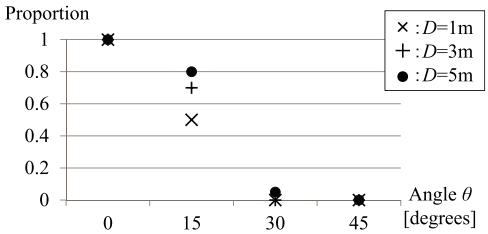


Fig. 11 Results when distance D between devices is 1, 3, and 5 meters.

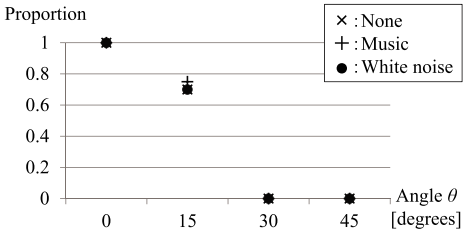


Fig. 12 Results under noise influence.

We set the signal length of acoustic waves to 50 milliseconds, which strikes a good compromise between multipath effects suppressing and robustness to environmental noise [3].

We select the transmission interval of acoustic waves to be 250 milliseconds, in order to avoid overlapping between acoustic wave A_i and A_{i+1} in the time domain, while collecting sufficient information for the circle judgment. In general, an acoustic wave attenuates based on propagation distance, and stays for a while near the point of transmission (the location of the user device), by repeating reflection from a wall or a ceiling, especially indoors. For this reason, if the transmission interval of acoustic waves is too small, the reflected acoustic wave A_i and acoustic wave A_{i+1} may be overlapped. As a result, the calculation of the reception time of acoustic waves may include some errors. The transmission interval of 250 milliseconds is sufficient for avoidance of the overlapping, since an acoustic wave almost disappears due to propagation in long distances of about 85 meters during 250 milliseconds. In contrast, a rather small transmission interval is required for the circle judgment, because the circle judgment uses the change in distance during the circle operation. Theoretically, the user device must transmit at least 3 acoustic waves, while it describes one circle. When only 2 acoustic waves are transmitted during one circle, the device located on the perpendicular bisector of the line connecting between two points of transmission passes the circle judgment, even if it is not circled. If we suppose an angular velocity of 360 degrees, the transmission interval of 250 milliseconds is sufficiently small, because 4 acoustic waves are transmitted during one circle.

The number of acoustic waves n is determined via the first experiment. The larger number of acoustic waves n probably shows better performance. However, the larger number of acoustic waves n requires the user to perform the circle operation for a long time.

6.2 Experimental Results

6.2.1 The First Experiment Regarding the Number of Acoustic Waves *n*

The experimental results of the number of acoustic waves n are shown in **Fig. 10**. The vertical and horizontal axes imply the proportion and angle θ, respectively. Common to all the number of acoustic waves n, the proportions become 1 in the case of angle $\theta = 0$, which implies that the proposed method successfully identifies the partner device. When the angle $\theta = 15$, 30 and 45, the larger the number of acoustic waves n is, the smaller the proportion becomes. In particular, when the number of acoustic waves n is larger than 20, the proportions with angle $\theta = 30$ and 45 are kept near 0. On the other hand, the resolution in Eq. (8) is calculated to be about 14.5 degrees in the case of radius $R = 0.2$ meters and $TH = 0.1$. This implies that the proportion of angle $\theta = 30$ and 45 should be kept 0. Therefore, the number of acoustic waves n should be at least 20. This is because the maximum accumulated change in distance in Eqs. (2) and (3) becomes smaller than the actual value when the small number of acoustic waves n. So, we use the number of acoustic waves n of 20 in the following experiments. In this case, the circle operation would be continued for 5 seconds, until the transmission of acoustic waves is finished.

6.2.2 The Second Experiment Regarding Distance *D* between Devices

We illustrate the results when the distance D is 1, 3, and 5 meters in **Fig. 11**. Common to all distances D, the proportions become 1 in the case of angle $\theta = 0$. The proportions when angle $\theta = 30$ and 45 are kept near 0. This implies that a device located in the direction of 30 degrees or more is not specified. These results show that the resolution is independent of the distance D, when angle $\theta = 0$, 30, and 45 degrees. In contrast, the proportions when angle $\theta = 15$ are different, as they range from 0.5 to 0.8. Here, the resolution in Eq. (8) is calculated to be about 14.5 degrees in the case of radius $R = 0.2$ meters and $TH = 0.1$. When the partner device is located in the near direction to 14.5 degrees, errors including the radius R of the circle operation or the calculation of acoustic waves have a large influence on the circle judgment by Eq. (4). This is because the magnitude relation in Eq. (4) often changes due to errors. This causes the difference of the proportions.

6.2.3 The Third Experiment Regarding Noise

The experimental results of noise are shown in **Fig. 12**. There are few differences in proportions from the type of noise. Regarding music, the main reason is that the frequency of acoustic waves (18–19 kHz) is different from that of music (under 7 kHz). In terms of the white noise, although each frequency is overlapped, the waveform is different. Due to this, the procedure to calculate the reception time of acoustic waves based on cross-correlation function works well.

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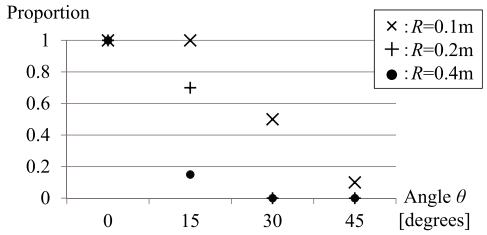


Fig. 13 Results in the case of the radius R of 0.1, 0.2, and 0.4 meters.

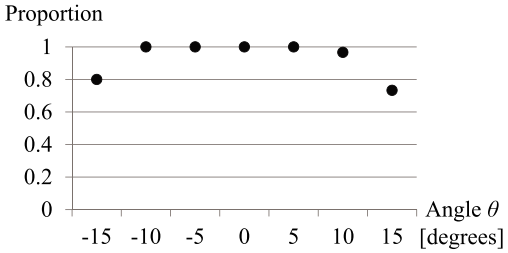


Fig. 14 Results where the number of partner devices is 7.

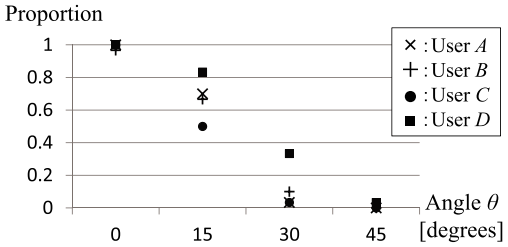


Fig. 15 Results where 4 users perform the circle operation.

6.2.4 The Fourth Experiment Regarding Radius *R*

The experimental results in the case of radius R = 0.1, 0.2, and 0.4 meters are illustrated in **Fig. 13**. All proportions when angle $\theta = 0$ are 1, independent of radius R. In contrast, where angle θ = 15, 30, and 45 degrees, the larger radius R is, the smaller the proportion becomes. These results show that the resolution of the proposed method is improved with a larger radius R, following Eq. (8). For example, the resolution with radius R = 0.1 meters is about 15 degrees, since the proportions with smaller radius R than 15 degrees are 1. Conversely, the resolution with radius R = 0.2 and 0.4 meters is smaller than 15 degrees.

6.2.5 The Fifth Experiment Regarding Multiple Devices Specification

The experimental results in the case of the number of partner devices of 7 are illustrated in **Fig. 14**. Each plot shows the proportion of each 7 partner device. The larger the absolute value of the angle is, the smaller the proportion becomes. When the absolute value of the angle is lower than 10 degrees, the proportion becomes almost 1. This implies that the resolution with radius R = 0.2 meters is 10 degrees. In addition, these results show that the proposed method can specify all devices that are located in a direction smaller than 10 degrees. The maximum number of partner devices to be specified simultaneously is determined by the physical limitation of the maximum number of devices that can be placed in a direction smaller than 10 degrees.

6.2.6 The Sixth Experiment Regarding Difference by Users

The experiment results where 4 users perform the circle operation is shown in **Fig. 15**. All proportions when angle $\theta = 0$ are 1 and angle θ = 45 are kept near 0, independent of the user's skill. This implies that every user can specify the partner device and distinguish a non-partner device located in the direction of 45 degrees. We can see the difference by users, when angle θ = 15 and 30. Since the cause of this difference is estimated as the difference in radius R, we measured the actual radius R of the users. The actual radiuses R of Users A, B, C and D were 0.21, 0.18, 0.3 and 0.12 meters, respectively. These radiuses explain the difference of the proportions, since the proportions of User C whose radius R is larger get smaller among 4 users. In addition to that, the proportions of User D whose radius R is smaller become larger.

In addition to that, the change in radius R of the circle operation is measured, when specifying one or multiple partner devices. The experiment results show that there is little difference. This implies that at least 4 users in the experiment do not change the radius R of the circle operation, regardless of the number of partner devices.

6.3 Evaluation

6.3.1 Resolution for Specification of Partner Device

We evaluate the proposed method by using the experimental results, comparing them to the existing method. In the use case of picture sharing with multiple partner devices in the meeting place of the social gathering or restaurant, Toneconnect [1] enables simultaneous specification of them. Here, in such places, the distance to the next tables ranges from 1 to several meters. Therefore, if a non-partner device is located at the next table, the user device cannot distinguish between a partner and non-partner devices. As a result, it accidentally specifies and shares files with a non-partner device.

Regarding the proposed method, the experimental results show that it enables the concurrent specification of multiple devices located in a direction smaller than 10 degrees. In addition, it can distinguish between a partner and a non-partner device that are located in a direction larger than 45 degrees, when a radius R of the circle operation is 0.2 meters. After putting partner devices on a table, the user performs the circle operation by drawing a circle over their devices. In this case, the distance between the user device and the partner devices would range from 0.1 to 1 meter. If the non-partner device is located at the next table 1 meter away, angle θ exceeds 45 degrees. Thus, since the proposed method can distinguish between a partner and a non-partner device and specify multiple partner devices simultaneously, the proposed method is practical for the above use case. In addition, since the proposed method does not need a server on the Internet unlike Toneconnect [1], file sharing is possible via the proposed method even in the environment where the Internet cannot be used.

Regarding the difference by users, 4 users could specify the partner device by using the implemented application, after they watched the demo video and were asked to draw the circle with radius R of 0.2 meters for 5 seconds. Though there were some differences in the radius R, they could specify the partner device and distinguish a non-partner device located in the direction of 45 degrees or more. However, it may be insufficient for other users only by watching the demo video. It is also desirable that

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users who do not watch the demo video can use the implemented application. We will discuss the instruction or the feedback of circle operation in Section 7.4, which may be the solution.

6.3.2 Time of Circle Operation

The number of acoustic waves n that is used for the experiments is 20. This implies that the circle operation should be continued for 5 seconds. We have examined 3 users' impressions (Users B, C and D) in two cases that they rotate their arm for 5 seconds and that they see someone rotating arm, respectively.

Regarding the first case, a user said that the user can rotate arm for 5 seconds without minding surrounding people. On the other hand, other two users may mind the surrounding people. They also said that they can rotate their arm, if the time of the circle operation is shorter than 5 seconds.

Regarding the second case, they said that they may be surprised or that they minded when seeing someone rotating their arm. There is a comment that people may not mind the circle operation, after the implemented application becomes popular.

After the examination, we feel the necessity of shortening the time of the circle operation, for popularizing the implemented application. In order to achieve this, more acoustic waves must be transmitted and received in a short time. As stated in Section 6.1.2, the transmission interval of 250 milliseconds should not simply be shorten, because the reflected acoustic wave in the past and the direct acoustic wave may be overlapped. In this case, the performance of the proposed method would reduce due to the difficulty of distinguishing between both waves. One solution is to transmit various acoustic waves, such as acoustic waves of different frequencies in turns and shorten the transmission interval. In the case of the overlapping of reflected and direct acoustic waves, they can be distinguished. This is our future work.

7. Discussion

There are some points to be discussed, when providing applications that use the proposed method, such as the implemented application shown in Fig. 8. In this section, we discuss incorrect specification, concurrent use of plural users, conflict of a speaker and a microphone with other applications as well as instruction and feedback of the circle operation to users.

7.1 Incorrect Specification

It is necessary to avoid the incorrect specification of a non-partner device that starts the implemented application and is listening to acoustic waves. An incorrect specification may sometimes result in file sharing with the device of a stranger. We explain two typical cases of incorrect specification and solutions for these cases.

The first case is an incorrect specification of a non-partner device located nearby. In particular, the incorrect specification of the non-partner device located in the same direction as the partner device from the user device can occur. This is because the specification area where a device judges that it is circled is a circular cone, as analyzed in Section 4.

One solution for this incorrect specification is the addition of a procedure for confirmation. After connection (Fig. 5 (6)), the user device selects a number or picture, and then shares it with the connected device via the connection. Next, the user device and the connected device show the shared number or picture on their display. The user device also shows the confirmation and decline buttons. If the user sees that numbers or pictures shown on displays of the user device and the partner device are the same, the user pushes the confirm button and the device specification is completed. Conversely, when different numbers or pictures are shown, the user pushes the decline button, in order not to specify the non-partner device. In the case where multiple neighborhood devices pass the circle judgment, the user device shows multiple confirmation buttons for each device.

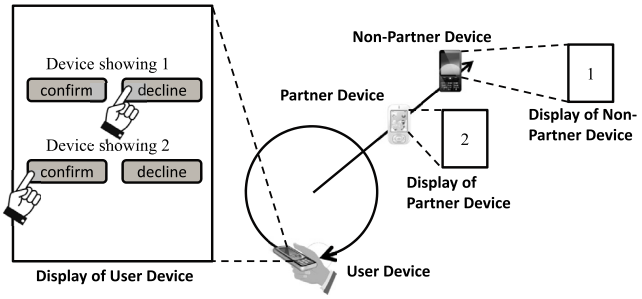


Fig. 16 Example of confirmation for incorrect specification.

Figure 16 shows the example of confirmation for an incorrect specification. The non-partner device is located in the same direction as the partner device from the user device. So, both the partner and non-partner devices connect to the user device. The user device shares the number 1 with the non-partner device and the number 2 with the partner-device, respectively. These numbers are shown on their displays, as shown in Fig. 16. The user sees that the partner device shows the number 2, and then, pushes the confirm button of the device showing the number 2. In addition to that, the user pushed the decline button of the device showing the number 1, since the user does not see that there is no partner device showing the number 1.

In general, usability and security have a trade-off relationship. In this solution, the security level can be increased at the sacrifice of some usability.

The second case is an incorrect specification of a malicious device. A malicious device is one of the non-partner devices that ties to be specified, even if it is not circled. Now, in the proposed method, the circle judgment is dispersively performed by each neighborhood device. For this reason, if a malicious device performs a false judgment, the user device may incorrectly specify the malicious device.

To solve this incorrect specification, we can use concentrated circle judgment by the user device. In concrete terms, the neighborhood device calculates the reception intervals of acoustic waves and notifies the user device of the calculated reception intervals. After that, the user device performs the circle judgment for each neighbor device, by using the transmission and reception intervals. If the transmission intervals are selected randomly for each trial, the neighborhood device including a malicious device never knows the reception intervals that satisfy the circle judgment. Therefore, the incorrect specification of a malicious device can be avoided. For the same purpose, the proposed method can use a server, like [1], [5]. The server collects transmission and re-

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ception intervals from the user device and neighborhood devices, respectively, and then, it performs the circle judgment.

On the other hand, the circle judgment is performed by the neighboring devices in the implemented application. The reason is to reduce the number of concurrent connections of Bluetooth, since the number of concurrent connections of Bluetooth is limited to 7. If the circle judgment is done in the user device, all neighborhood devices that receive acoustic waves try to connect to the user device via Bluetooth. The number of the concurrent connections is more likely to exceed the limitation. Conversely, if the circle judgment is done in the neighborhood devices, only the neighborhood devices that pass the judgment try to connect to the user device. So, the number of the concurrent connections is less likely to exceed the limitation. When realizing applications like the implemented application, we have to decide which device or server should perform the circle judgment, based on the requirements, such as security level, what wireless communication is used or the availability of a server.

7.2 Concurrent Use of Plural Users

There is a possibility that plural users try device specification concurrently at the same place. The possibility is very low, because the transmission of acoustic waves lasts for only 5 seconds in the experimental setting and the transmission range of acoustic waves is at most 20 meters. However, even in this case, the proposed method should work well. If plural user devices use acoustic waves of the same frequency, acoustic waves from them interfere with each other. This interference may result in the failure of device specification or incorrect device specification.

One solution to avoid the interference is the use of acoustic waves of different frequency. We can use several frequencies, since the smartphones that we use have the capability to transmit and receive acoustic waves from 1 kHz to 20 kHz. One way for each user device to decide the frequency is random selection from available frequencies. Another way is to decide the frequency that is not used at that time. The user device is able to know an unused frequency, by scanning the transmitted acoustic waves nearby. These methods reduce the probability that plural user devices concurrently use the same frequency at the same place.

7.3 Conflict of Microphone and Speaker

There are some applications that use a microphone and/or a speaker, such as a telephone (standard telephone or Skype), music player, and voice recorder. For this reason, the conflict of a microphone and a speaker with other applications may occur. In the case of smartphones with Android 2.3.3 or later, a speaker can be used by multiple applications at the same time. Conversely, since a microphone can be used by only one application at the same time, the conflict of a microphone may have a bad influence on the behavior of applications. If we suppose the use case of file sharing, the concurrent use of file sharing and existing applications, e.g., telephone, music player, and voice recorder, has been rare so far. Thus, it may be said that there are few cases where this becomes a problem in practice. However, there will be new applications that always work and use a microphone, e.g., those that estimate user context from the sound around the user.

One way to soften this conflict is the estimation and report of the application that occupies a microphone. In concrete terms, when the implemented application cannot use a microphone, it estimates the application that occupies a microphone by monitoring log information of other applications. It then reports the name of the application to the user. After that, when a user expects the use of the implemented application, the user stops the application occupying a microphone.

7.4 Instruction and Feedback of the Circle Operation to Users

Instruction of the circle operation to a beginner is very important. One way is using a movie of instruction on a smartphone, like many existing applications. This is because graphical information is often easy to understand. In concrete terms, after the application is started, it plays a movie that shows how the circle operation should be performed. Feedback of the circle operation is also important. For example, the circle operation must be continued for 5 seconds on the setting of the experiments. If the duration of the circle operation was shorter than 5 seconds, the application shows feedback to ask a user to continue it for 5 seconds. Duration of the circle operation can be estimated via an accelerometer sensor of the user device.

8. Conclusion

In the case of file sharing among multiple devices on the spot (e.g., a meeting picture of a social gathering or an alumni association), user operation to specify a partner device is required. The general operation, e.g., specification of a device address, is sometimes irritating to users and may cause an operation error. Some device specification methods without a user having to be aware of the device address have been provided. In particular, a method that uses acoustic waves enables a user to specify multiple partner devices simultaneously. However, it cannot distinguish between a partner device and a non-partner device with which the user does not require file sharing. Therefore, if the non-partner device is located within the transmission range of acoustic waves, it accidentally identifies and shares files with the non-partner device. We newly proposed a device specification method by describing a circle to surround the partner device. The proposed method has features that are able to distinguish between a partner and a non-partner device. In the proposed method, the Doppler Effect is generated by the operation to circle the partner devices with the user device. Subsequently, by the estimation of change in the relative position between devices based on the Doppler Effect, the user device identifies the device that has been circled with the partner devices. We implemented the proposed method as a smartphone application and evaluated its performance. The experimental results show that the resolution of the proposed method is about 10 degrees, implying that the proposed method is practical for file sharing.

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