EnhancedTouchX: Smart Bracelets for Augmenting Interpersonal Touch Interactions

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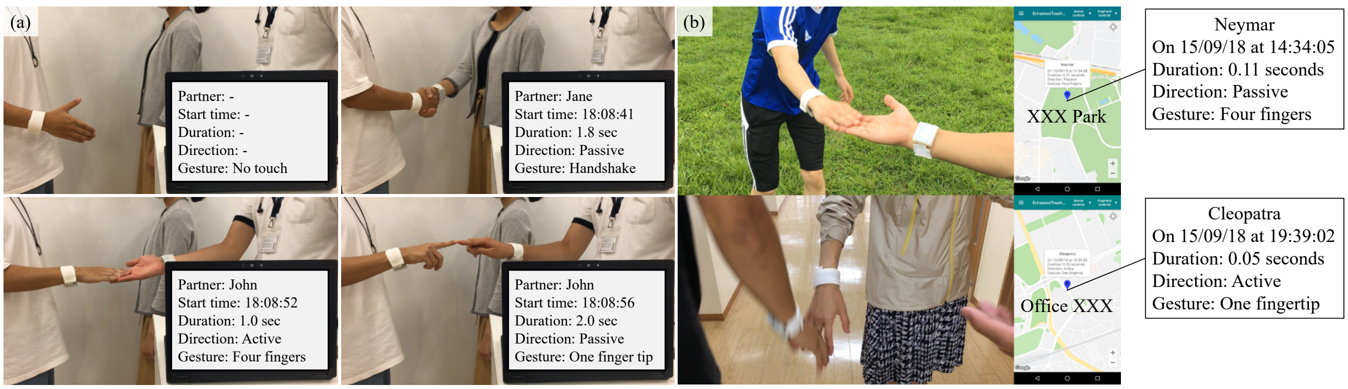

Figure 1: EnhancedTouchX: (a) Identifying a partner, a direction (from one initiating the touch (active touch) to the one being touched (passive touch)), and gestures of interpersonal touch of the left user; (b) Interpersonal touch logging system using a smartphone (EnhancedTouchLog).

ABSTRACT

EnhancedTouchX, a bracelet-type interpersonal body area network device, not only detects but also quantifies interpersonal hand-to-hand touch interactions. Without any wired connection, it can identify the direction and gestures of a touch. The developed device can connect to an external device via Bluetooth Low Energy for monitoring and logging where, when, how long, who, and how the touch interactions occurred. These daily augmented touch interactions provided by such contextual information would offer a variety of applications to facilitate social interactions. Our experiment, conducted with several pairs of participants, demonstrates that the devices can identify the direction of a touch (from one initiating the touch (active touch) to the one being touched (passive touch)) with 95% accuracy. In addition, the devices are also capable of identifying four types of touch gestures with 85% accuracy using a simple threshold classifier.

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CCS CONCEPTS

• **Human-centered computing** → *Haptic devices*; *Gestural input*; *Ubiquitous computing*;

KEYWORDS

EnhancedTouch, interpersonal body area network, interpersonal touch

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1 INTRODUCTION

Interpersonal touch is one of the most influential nonverbal communications for human social behavior. One well-known phenomenon, called the Midas touch effect, has been demonstrated by Crusco and Wetzel [7], where servers in a restaurant were instructed either to touch or not to touch customers while returning their change. The researchers observed that the tipping rate was significantly higher in the with-touch condition than in the without-touch condition. A similar effect of touch on economically generous behavior has also been observed in another situation [17, 30, 35]. In addition, touch also modulates the tendency to comply with a request [18, 21, 31], and help/collaborate with someone [19, 20, 36]. While there have been a variety of discussions over the effect of awareness of touch on behavior, Joule and Guéguen demonstrated that participants who had noticed touch tended to comply with a request more than those who had not noticed [32]. In addition to the social behavior modulation effect, touch offers various benefits and positive effects regarding nursing [5, 28, 56], development of children [8, 11, 54], etc (see [12, 14, 50] for an overview of interpersonal touch).

We are interested in quantitatively measuring interpersonal touch interactions in daily life to analyze and facilitate the effect on social interactions. Our challenge is not only to detect physical contact between two people but to also analyze contextual information from touches, such as when, where, who, and how a human touches.

Similar to the rapidly advancing smart wristbands that are capable of logging the users' personal activities such as the number of steps taken, we design the device to be Bluetooth-connectable to increase its applications flexibility. This allows human-human interaction designers such as social psychologists, social game developers, or therapists to monitor, log, analyze, and augment interpersonal touch interactions in daily life.

This paper presents EnhancedTouchX (ETX), a bracelet-type interpersonal body area network (interpersonal BAN—more specifically, interpersonal hand area network) device that is capable of identifying the direction and gestures of an interpersonal touch (Fig. 1). Here, we define the direction of a touch as one hand actively touching another that is passively being touched. Although we expect the direction and gestures to serve as key conditions in the research field of interpersonal touch interaction, it is out of the scope of this paper to study how these two modalities affect social interaction.

Contributions

The contributions of this study are as follows.

(1) Methodology for identifying the direction and gestures of an interpersonal touch using interpersonal BAN and sensor fusion technology.
(2) Design and implementation of the wireless wearable device used to identify the direction and gestures of an interpersonal touch.
(3) Evaluation of the identification of the direction of an interpersonal touch.
(4) Evaluation of identifying gestures of an interpersonal touch.
(5) Introduction of possible applications of ETX.

The remainder of this paper is organized as follows. In section 2, we review the existing literature on touch sensing technology and the technology of EnhancedTouch [49] that is the primary technology for our ETX device. In section 3, we describe the implementation of ETX. In section 4, we describe the two evaluations used to demonstrate the unique capabilities of ETX. In section 5, we introduce the four applications of ETX. In section 6, we conclude the paper.

2 RELATED WORK

Touch Sensing

In the field of human-computer interaction research, researchers have developed techniques to measure bare skin to bare skin contact using sound/vibration processing techniques [27, 37, 58], computer-vision/photo sensor techniques [26, 38, 57], and capacitive sensing techniques [46, 59, 60]. These techniques are primarily used to identify the mode of the touch within a user (not with another person) to enrich inputs into a computer.

Conversely, we are aware of relatively few studies regarding the measurement of interpersonal touch interactions and their applications. There are systems that detect handshake when observing the similar oscillating profiles of acceleration values obtained from a pair of a user's smart wristsbands [25, 55]. While the method is promising to detect a handshake, it is difficult to measure another mode of touch because it does not directly detect skin-to-skin contact.

Another method is to actively apply electric voltage to a human body [3, 34, 40]. Canat et al., for example, applied a swept frequency capacitive sensing method that is a capacitive sensing technique for detecting different types of touch patterns [46] to facilitate interpersonal touches between two players in designing a collaborative video game [3]. These sensing techniques are promising for measuring bare skin-to-skin touches and in demonstrating the positive effects of interpersonal touches on social interactions. However, the systems require a wired-connection either to a large size of ground planes or to the earth for stable measurements, which would be a problem for certain wearable applications.

Zimmerman proposed the concept of BAN (also known as the personal area network, intrabody network, body channel communication, etc.) that uses a human body as a communication channel to expand the freedom of designing devices attached to the human body [61, 62]. In BAN, a modulated signal propagates between a transmitter and a receiver through the human body. The communication is only established when the human body comes in contact with or in proximity of both the transmitter and the receiver. This can be used for touch/proximity sensing and for communication between the devices. BAN technology can be categorized into two types [47]: capacitive coupling (electric field) type [2, 45, 61] and galvanic coupling (electric current) type [24, 33, 53]. The former does not require the user to directly attach the device (electrode) on the skin, because the electric field induced around the surface of the human body is used as a communication channel. Conversely, the latter performs communication via electric currents in the human body, and the user has to attach the device/electrode on the skin.

BAN applications have been explored in the field of human-computer interactions involving user identification and localization. DiamondTouch is an interactive tabletop surface, where the touch location is determined independently for each user [9]. A set of transmitters is embedded in the tabletop and generates a location-dependent signal while a receiver installed in a chair receives the signal propagated through a user's body. Grosse-Puppendahl et al. demonstrated ubiquitous interaction facilitated by BAN technology [15]. In addition to a device ID, the acceleration values, for example, are sent, which expands the freedom of interaction design.

BAN technologies are also implemented into the bracelet device. Touching a peripheral device or a touch screen, a user is authenticated by a computer [29, 41]. Varga et al. developed TouchCom, a BAN platform, and explored the interactive infrastructure including bracelet devices [51, 52]. However, it can also detect proximity and should be difficult to discern contact and proximity because TouchCom employs capacitive coupling type BAN. In addition, it is a significant challenge to implement stable communication in wearable devices owing to the lack of common ground. One solution is to enlarge the size of the ground plane although it also enlarges the size of the device to enhance capacitive coupling between the device ground and the earth. Another solution is to use a sensor with exceedingly high input impedance to detect small displacement currents, although it requires a special component, such as [13, 48]. For an overview of capacitive sensing and the importance of ground connections, refer to Grosse-Puppendahl et al.'s review paper [16].

Considering the measurement of interpersonal touch interactions, we employ galvanic coupling BAN technology because a channel is established only when two users touch each another.

EnhancedTouch

EnhancedTouch is a bracelet-type device that is capable of measuring and representing interpersonal touches between humans using galvanic coupling type interpersonal BAN technology [49]. Because we implemented the ETX device

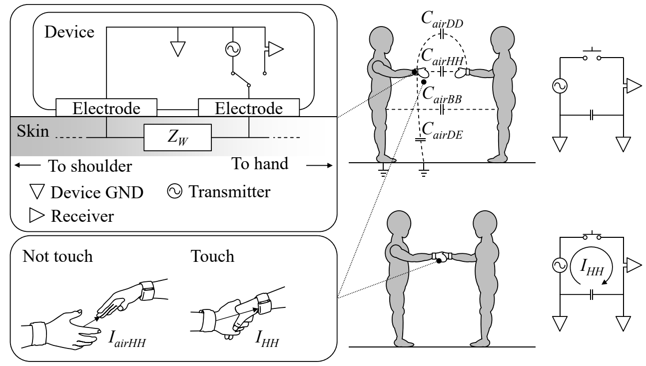

Figure 2: Principle of touch measurement of Enhanced-Touch [49]

based on the EnhancedTouch device, this section reviews the principle of EnhancedTouch.

Figure 2 shows a model of the touch measurement system with a pair of EnhancedTouch devices. While the device is categorized as an active transmit + receive mode (intrabody coupling), according to the taxonomy of [16], the device does not measure the displacement current I_{airHH} flowing through the capacitive coupling C_{airHH} between the hands similar to capacitive coupling type BAN, but measures the electric current I_{HH} flowing through the hands similar to galvanic coupling type.

Creating a ground path is crucial for wearable applications [16]. Transmitting a signal via electrical current requires two paths, i.e., a signal path and a ground path, whereas the human body is generally regarded as a single conductive wire consisting of resistors and capacitors. If the human body was used as the signal path by attaching a signal electrode to the wrist, the ground path would be established only by the capacitive coupling, C_{airDD} in the air between the ground of the devices and C_{airDE} in the air between the ground of the device and the earth. However, both the couplings are exceedingly weak for the device to transmit or receive the current even while a pair is touching each other.

To improve connectivity, the EnhancedTouch device employs the method developed by Doi and Nishimura [10], where a ground electrode is also attached to the wrist as well as the signal electrode. The body is divided into signal and ground paths by the electric impedance, Z_W of the skin between the two electrodes. As a result, a large area of the body, such as the torso, works as a ground electrode (gray area of the body in Fig. 2 and Fig. 3a), achieving a significantly stronger capacitive coupling, C_{airBB} with the body of another user than C_{airDD} and C_{airDE}. Thus, the still weak (less than 3 mA) but stable measurable current, I_{HH} flows between the devices only while the pair is touching each other. According to the ICNIRP guidelines [1], to avoid side effects such as nervous system interference, whole-body heat stress, and excessive localized tissue heating when using a 10-MHz signal, the maximum contact current should be lower than 20 mA. The pair of devices communicates with each other by modulating the current. The device exchanges its device ID, allowing identification by the partner. In addition, the device measures the start time and duration of an interpersonal touch interaction using a timer in the microcontroller.

3 ENHANCEDTOUCHX

This section describes the implementation of the ETX device. In addition to time, duration, and partner identity that EnhancedTouch is able to measure [49], the ETX device is also able to identify the direction and gestures of an interpersonal touch. We define four design requirements for the device to measure touch interactions in daily life and to demonstrate the potential of the device.

First, the device should be capable of measuring the direction and gestures of interpersonal touches and the identity of the partner. Although the device could measure a time and location if the device employed a timer and a global positioning system (GPS) device, we do not implement them. Instead, the external terminal, such as a smartphone, measures them.

Second, the device should be connectable to an external terminal, such as a smartphone, with wireless communication and possess the capability to work offline. This is expected to increase the degree of freedom of designing applications.

Third, it should be possible to use more than two devices simultaneously. This is necessary if the devices are used by several people. Because it is difficult to predetermine the master and slave devices, the devices need to dynamically communicate with each other (ad-hoc network) to measure interpersonal touch interactions.

Finally, the device should be easy to wear and remove. While this condition was also referred to by the design requirements of EnhancedTouch [49] to support children with autism and their therapists, it is equally important for daily use.

Principle

Identification of Direction. We employ the acceleration sensor for identifying the direction of a touch. First, a device measures the acceleration of a user's hand before a touch occurs. Next, when a pair of the users, A and B, touches each other, Device A sends the acceleration to Device B through interpersonal BAN at the moment of contact. Device B then compares the received acceleration to its own acceleration. If the received acceleration is greater, Device B identifies its user's touch as a passive touch and informs Device A that "your user's touch is an active touch" through interpersonal BAN, and vice versa. This can be regarded as a sensor fusion, i.e., combination of a touch detection sensor afforded by interpersonal BAN technology and an acceleration sensor.

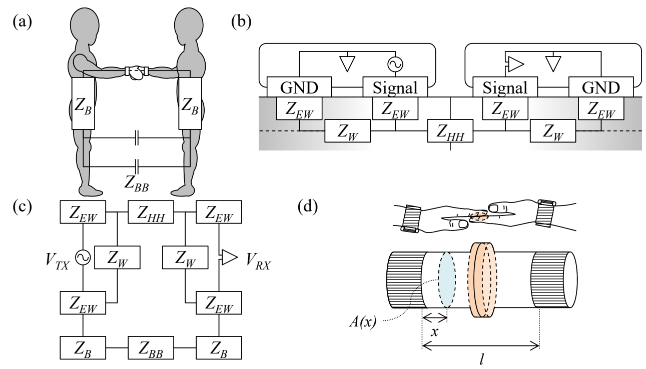

Figure 3: Impedance model of the transmission path: (a) A pair of the bodies, except a hand with the device, working as ground electrodes and achieving capacitive coupling; (b) Transmission path; (c) An equivalent circuit; and (d) Resistor model of the hands.

Identification of Gestures. To identify gestures of a touch, the device measures the received signal intensity indication (RSSI). Figure 3a shows that a pair of bodies works as ground electrodes with impedance, Z_B and achieves capacitive coupling with impedance, Z_{BB}. Figure 3b shows that the transmission path between the hands consists of an impedance between an electrode and the skin, Z_{EW}, impedance between the electrodes, Z_W, and impedance between the hands, Z_{HH}. Figure 3c shows an equivalent circuit with transmitted voltage, V_{TX} and received voltage, V_{RX}. According to the figure, V_{RX} is expressed by the following equation:

$$V_{RX} = \frac{Z_{RX}}{Z_{EW} + Z_{RX}} \cdot \frac{Z_\alpha}{Z_\beta} \cdot V_{TX} \tag{1}$$

where,

$$Z_\alpha = \frac{1}{\frac{1}{Z_W} + \frac{1}{Z_{RW}+Z_{EW}}}, \tag{2}$$

$$Z_\beta = Z_\alpha + 3Z_{EW} + 2Z_B + Z_{BB} + Z_{HH}, \tag{3}$$

and Z_{RX} is the impedance of a receiver.

In our preliminary observation, Z_{HH} is a variable that depends on the gesture of the hands and primarily affects the V_{RX}. Figure 3d shows the resistor model of the hands. For the sake of simplicity, we consider the hands as a resistor with constant electrical resistivity, ρ. The Z_{HH} is expressed by the following equation:

$$Z_{HH} = \int_0^l \frac{\rho}{A(x)} dx \tag{4}$$

where l is the distance between the devices, and $A(x)$ is the cross-sectional area at a distance x from one device. Z_{HH}

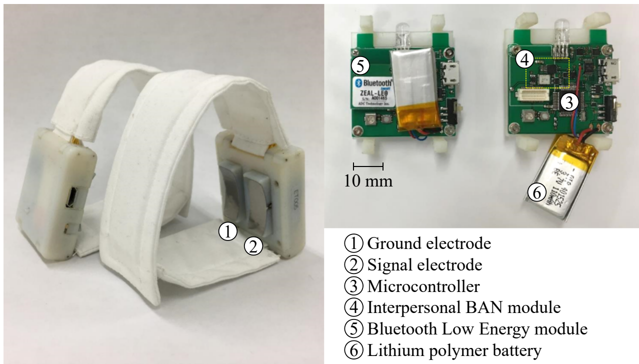

Figure 4: The EnhancedTouchX device

becomes smaller when either l becomes shorter or contact area (red area in Fig. 3d) becomes larger, resulting in higher V_{RX}. Thus, measuring V_{RX} allows for estimating the contact area. Based on this principle, we attempt to identify the predetermined four gestures of an interpersonal touch.

According to our informal RSSI measurement tests, we do not consider the impedance of C_{airDD} and C_{airDE} because their effects (size of the device's ground plane and height of users) were negligible compared to C_{airBB}. Further, Z_{EW} and Z_W are primarily affected by the contact condition of the electrodes and skin and individual differences in the electrical characteristics of the human body, respectively, which results in relatively large variance of V_{RX}.

Hardware

Figure 4 shows the developed ETX device. It consists of two electrodes, a printed circuited board (PCB, 35 × 35 mm), a lithium polymer (3.7 V, 110 mAh), a Bluetooth Low Energy (BLE) module (ZEAL-LE0, ADC Technology), a 3D-printed plastic housing, and cloth belts with Velcro.

A three-axis digital acceleration sensor (MMA8653FC, Freescale Semiconductor) is installed on the PCB. A microcontroller (LPC1549, NXP Semiconductors) acquires values of the sensor at a 10-Hz sampling rate through an inter-integrated circuit (I^2C) protocol with a 400-kHz clock. The acquired values are used for the identification of the direction of a touch.

As shown in Fig. 2, one electrode (signal electrode) connects with either a transmitter or a receiver in the interpersonal BAN module on the PCB through an analog switch while the other (ground electrode) connects with the ground of the PCB. While the device can be worn with the housing on both palm and backside of the wrist, users in this paper wore it on the palm side of the wrist. This is because hairs on the backside prevent the electrodes from making stable contact with the skin.

We developed an interpersonal BAN module comprising a transmitter, a receiver, and an analog switch (TS5A63157, Texas Instruments). The transmitter modulates a 9600-bps universal asynchronous receiver transmitter (UART) signal from the microcontroller using on-off keying with a 10.7-MHz sinusoidal carrier wave. The peak-to-peak amplitude of the signal is 3.3 V.

The receiver demodulates the signal by passing it through a band-pass filter (SFECF10M7FA00-R0, Murata Manufacturing), an intermediate frequency amplifier (NJM2549, New Japan Radio), and a comparator. The demodulated signal is received by the microcontroller. The intermediate frequency amplifier outputs an RSSI whose voltage value is linear to the input level (in dBV) of the received voltage, V_{RX}. The RSSI output pin connects with an analog-digital converter built into the microcontroller and with the comparator. The converted value is used to identify the gestures of a touch.

In summary, ETX uses the 10.7-MHz sinusoidal wave and the 10.7-MHz band-pass filter with ±280-kHz bandwidth while EnhancedTouch [49] uses the 10-MHz square wave and the 10.7-MHz band-pass filter with ±500-kHz bandwidth. In addition, an analog-digital converter is implemented in ETX to obtain continuous values of RSSI. This careful bandwidth selection improves signal-noise ratio and enables stable RSSI measurement.

In addition, the device has a visual and vibration feedback function. Although this paper does not cover the details of the function, it is available even when the device is offline and is especially useful for real-time feedback to the wearer to facilitate social interactions [23, 49]. While the ETX device has more functions with the stable BAN module, it has almost the same size as EnhancedTouch [49].

Software

To achieve the first and third requirements, i.e., ad-hoc network capability and identifications of a direction and gestures, we implemented automatic synchronization technique revised from [49].

Figure 5 shows an example of the half-duplex communication procedure between Device A and Device B. A packet consists of a 2-byte header, 1- to 3-byte data, and 2-byte cyclic redundancy check (CRC). The header consists of a command byte, i.e., synchronization request (SYN), request acknowledgement (ACK), master request (MST), and slave acknowledgement (SLV), and a data size byte (Size). The data includes a device ID (ID), acceleration (ACC), the direction of touch (DIR), and an RSSI. While these are example packets, the device can send higher resolution data and add different types of data, such as temperature and a request to synchronize the visual and vibration feedback.

In phase (a), the pair of users does not have touch contact with each other. Each device attempts to synchronize with

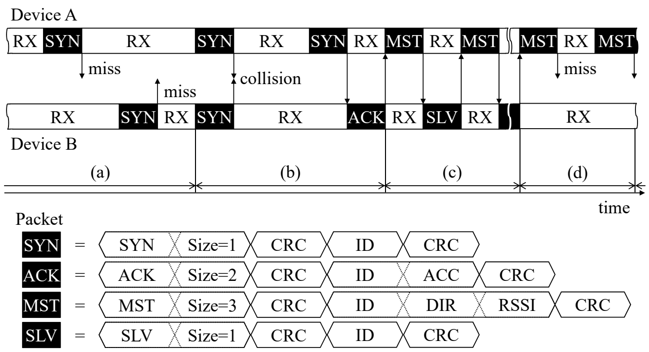

Figure 5: Example procedure of communication between two devices: packet contains a header, data (e.g., device ID), CRC; (a) Prior to synchronization, the devices transmit at random intervals; (b) The transmission channel is established, but synchronization initially fails because of a collision between transmissions; (c) Synchronization succeeds and the two devices can communicate smoothly; and (d) Communication was disconnected and the devices go back to (a).

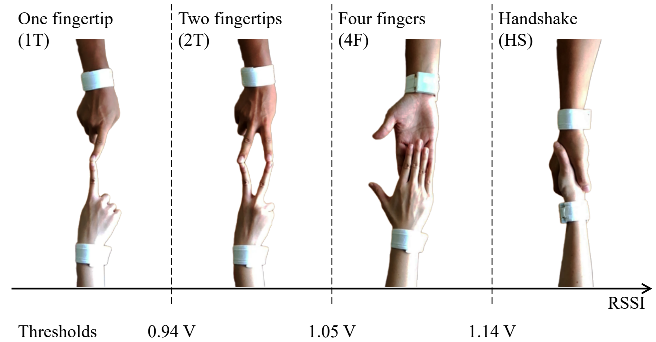

Figure 6: Four gestures to be identified with the device

other devices by transmitting an SYN packet at intervals selected randomly from five alternatives (1, 2, 3, 4, and 5 ms). Using the random intervals helps avoid collisions between multiple transmitted signals. When the device is not transmitting, it waits to receive signals from other devices. In this phase, the states of both devices are "standby." During "standby", the device calculates the difference between the root mean square (RMS) of current acceleration and the RMS of prior acceleration. In addition, the device calculates the average of the ten recent differences used for the ACC data. In addition, the device measures RSSI while waiting for the packet from the partner.

In phase (b), the pair of users is in touch contact with each other. However, first, synchronization initially fails because of a collision between the transmissions while the transmission path is being established. Subsequently, Device A succeeds in transmitting an SYN packet to Device B. Device B immediately responds with an ACK packet, including the ACC data. Furthermore, Device B quits the ACC and RSSI measurement.

In phase (c), Device A receives the ACK packet from Device B. First, Device A compares its own ACC to the received ACC. If its ACC is greater, the state of Device A transitions from "standby" to "active" and if it is less, the state transitions to "passive." Device A then responds to Device B with an MST packet, including DIR and RSSI data. When Device B receives the MST packet, it transitions from "standby" to either "passive" or "active" according to the received DIR data. In addition, Device B updates its RSSI data according to the received RSSI data (MST packet). Device B responds to Device A with an SLV packet. After that, the pair can communicate smoothly and repeat the exchange of the MST and SLV packets to share the updated status and confirm the connection.

In phase (d), the pair of users stops the touch contact. Device A attempts to transmit an MST packets several times while it does not receive an SLV packet. After a certain period of time, the state of Device A transitions to "standby" and returns to phase (a). Conversely, Device B also transitions to the "standby" state and returns to phase (a) after a period without receiving an MST packet.

The device identifies gestures of a touch according to the RSSI data. As mentioned, it is possible to estimate the contact area of a touch. As shown in 6, a pair of the device attempts to identify the four gestures: 1) one-fingertip touch (1T); 2) two-fingertip touch (2T); 3) four-finger touch (4F); and 4) handshake (HS). Note that we picked up the gestures with various contact areas for demonstration and we observed it to be difficult to discern gestures with similar contact areas. The classification is performed based on a simple threshold algorithm that does not require much computational power and is compatible with offline wearable applications. We defined the three thresholds of RSSI value based on the result of our preliminary test, as shown in Fig. 6.

The ETX device can connect with an external terminal device, such as a smartphone or a tablet PC, through BLE. After receiving a request from the terminal device, the ETX device sends data, containing partner ID, direction, RSSI, and identified gesture at the moment where at least one of them is changed. In addition, the device sends data periodically to confirm the connection with the terminal.

4 EVALUATION

This section describes two evaluations in the laboratory to demonstrate the identification performance of the developed device.

Identification of Direction

The objective of this experiment is to evaluate the identification of direction of a touch.

Setup. The experiment was conducted using a pair of participants (Participant A and Participant B). The experimental setup consisted of a pair of the developed ETX devices and a laptop computer on a desk. The device worn by Participant A was connected to the computer via BLE. Seven pairs (eight males and six females, in their 20's to 40's) of participants took part in the experiment.

Procedure. First, an experimenter obtained informed consent after explaining the purpose and procedure of the experiment to a participating pair. The pair sat in front of the table and wore the device on their right wrists.

Next, the computer monitor displayed a figure of a handshake, instructing either that Participant A grasps the hand of Participant B while Participant B keeps her/his hand still or vice-versa. When the pair were ready to perform a handshake, keeping about 10-cm gap from each other's hands, Participant A pressed the 4 key on the computer's numeric keyboard and the pair performed the handshake. Then, the pair released their hands and Participant A pressed the 6 key, as instructed on the monitor. The pair repeated the procedure 30 times (2 directions × 15 repetitions).

After 30 trials, the pair switched roles and performed 30 more trials. The computer randomly presented either direction and recorded the direction identified by the device.

Result. Table 1 shows a confusion matrix of all the data. As shown in Fig. 7, the accuracy of the identification is 94.8%. The experimenter sometimes observed that participants moved her/his hand to make fine adjustment or cushion the impact even when she/he was instructed to allow only touch by the partner. While this would also be observed in a realistic situation, the device correctly identified the direction. In addition, a touch without a direction (both people try to actively touch each other) happens in daily life. Because we did not consider it in this experiment, modifying the algorithm would enable the device to identify this neutral touch.

Table 1: An overall confusion matrix of a direction identification

	Identified active	Identified passive
Performed active	203	7
Performed passive	15	195

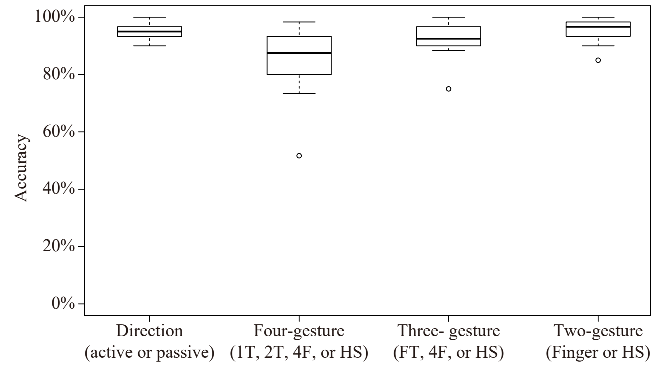

Figure 7: Accuracy of a direction identification and gesture identifications: the overall accuracy of direction, four-gesture, three-gesture, and two-gesture are 95%, 85%, 93%, and 96%, respectively.

Identification of Gestures

The objective of this experiment is to evaluate the identification of gestures of touch.

Setup. We used the same setup with the same pairs of participants as the previous experiment. Although the device can perform offline four-gesture identification in real time, we also recorded the RSSI measured by the device to assess performance dimensions that were not available in the real-time identification.

Procedure. First, an experimenter obtained informed consent after explaining the purpose and procedure of the experiment to the pair. The pair sat in front of the table and wore the device on their right wrists.

Next, the computer monitor displayed a figure of one gesture among the four shown in Fig. 6. After the pair performs the gesture, Participant A pressed the 4 key on the numeric keyboard and the pair kept the gesture for about one second while the computer recorded 100 samples of RSSI sent by the device. The pair then released their hands and Participant A pressed the 6 key, as instructed on the monitor. The pair repeated the procedure 60 times (4 gestures × 15 repetitions).

After 60 trials, the pair switched roles and performed 60 more trials. The computer randomly presented one gesture of the four and recorded the gesture identified by the device and 100 samples of the RSSI.

Result. Table 2 shows a confusion matrix of the data. As shown in Fig. 7, while the accuracy of offline four-gesture identification is 85.0%, considerable variation is found. In particular, the accuracy for one participant is 51.5%. As shown in table 3, the identified gesture tends to shift from the performed gesture to the right side. This implies that the device overestimated the contact area. We consider that the impedance of the participant's hand was small because the hand had a lot of moisture that resulted in a small ρ.

Table 2: An overall confusion matrix of four-gesture identification: The four gestures are shown in Fig. 6.

	Identified			
	1T	2T	4F	HS
Performed 1T	161	48	1	0
Performed 2T	17	171	22	0
Performed 4F	0	1	175	34
Performed HS	0	1	2	207

Table 3: A confusion matrix of four-gesture identification from a participant with the worst accuracy (51.7%)

	Identified			
	1T	2T	4F	HS
Performed 1T	0	14	1	0
Performed 2T	0	10	5	0
Performed 4F	0	0	6	9
Performed HS	0	0	0	15

We simulated three- and two-gesture identifications using measured RSSI. A pair of the gestures found to have the lowest accuracy is combined. In the three-gesture identification, 1T is combined with 2T to create fingertip(s) touch (FT). In the two-gesture identification, FT is combined with 4F to create finger touch (Finger). The accuracy of the simulated three- and two-gesture identifications are 92.7% and 95.6%, respectively.

5 APPLICATIONS

In this section, we introduce three applications of the ETX. The "X" in EnhancedTouchX implies variable and unknown. In addition to a partner and duration that the previous EnhancedTouch device can measure [49], ETX can identify direction and gesture of interpersonal touch interactions. Furthermore, connecting the device with a smartphone through BLE, for example, enables measurement of a location and a time.

EnhancedTouchLog

EnhancedTouchLog (ETL) is a chronicle of a user's interpersonal touch interactions. Unlike most existing lifelog systems, it logs a user's social interactions rather than her/his individual activities. While several wearable devices have been developed to log interpersonal proximity interactions [4, 6, 22, 42–44], ETL records the closest interpersonal interactions, i.e., touch. Figure 1b shows a user reviewing today's interpersonal touch interactions.

While studying interactions between mother-child, children with developmental disorders, and children with/without special needs, we observed that there are several styles of touch interactions, such as short/long time, active/passive, and small/large contact area touches. We observed several situations where such a style gives different meanings, i.e., contexts. To describe the styles of the touch interactions in daily life in an objective manner, ETL would be useful, especially for social psychologists who analyze a context and deepen their understanding of interpersonal touch effect on social interactions, such as the Midas touch effect introduced in section 1.

EnhancedTouchGo

EnchancedTouchGo (ETG) is an augmented reality game such as Niantic's Pokémon Go, where the players physically travel around the real world with a smartphone or tablet PC to enjoy the contents in the virtual world. In Pokémon Go, for example, Raid Battles consists of a group of players that cooperate majorly to capture a rare creature. Because Raid Battles occur at a certain time and place, numerous players gather at the same time and place. However, the players seldom have physical interactions while they interact with each other in the virtual world.

ETG requires that players not only physically travel to a certain place but also have physical touch to enjoy the contents. The player, for example, has to travel to the ET-Stop that is similar to a Raid Battles spot in Pokémon Go, and touch another player to obtain an item and points, as shown in Fig. 9. In addition, it would be interesting to set rare items and more points that are available for players who exhibit success in a complex touch interaction, such as a secret/special handshake and a touch at a cable-suspended bridge. Such a challenge level adjustment is facilitated by the new contextual information sensed by ETX. We expect ETG to allow players to raise their faces from smartphones, look at the partner's face, have a conversation, smile, and perform a handshake because they need physical collaboration.

EnhancedTouchPlay

EnhancedTouchPlay (ETP) is a social playware that utilizes interpersonal touch interactions. Playware refers to intelligent hardware and software for developing leisure activities (play) among users, of which computer games are a subgenre [39]. In addition to capability for measuring interpersonal touch interactions, another characteristic capability of the device is real-time visual and vibration feedback. Suzuki et al. demonstrated that visual feedback facilitated touch interactions among children with autism spectrum disorders

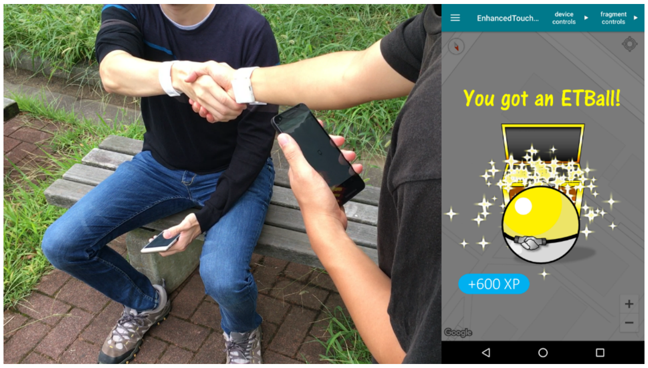

Figure 8: EnhancedTouchGo: An augmented reality game to facilitate interpersonal touch interactions.

Figure 9: EnhancedTouchPlay: A playware utilizing interpersonal touch interactions using real-time visual and vibration feedback according to the measured mode of touch.

(ASD), who often exhibit particular communication patterns, such as lack of physical touch [49]. Hachisu and Suzuki developed a novel haptic feedback technique where a vibrotactile apparent motion is induced between individuals [23].

ETP provides real-time visual and vibration feedback according to identified style of touch that would offer a variety of augmented interpersonal touch interactions. Combining the technique of direction identification with the technique of vibrotactile apparent motion [23], for example, would represent a direction of touch. Such a sensing-feedback loop helps users be aware of a contingency of interpersonal touch interactions, such as active/passive touch.

We believe that one of the most important application fields of ETP is a school, especially for children with special needs, such as ASD and intellectual disabilities, because touch offers various benefits and positive effects for the development of children, as mentioned in section 1. While introducing the details is out of the scope of this paper, thus far, the devices have been worn by dozens of children with developmental disorders as well as typically developed children, as shown in Fig. 9. The children have exhibited positive behavior, such as expressions of amazement and smiles, especially when they discovered the interaction rule designed by teachers, therapists, etc. The more sensing and feedback technique the device has, the more the freedom of interaction design would expand.

EnhancedTouchCare

EnhancedToucCare (ETC) is primarily used in hospitals and assisted living residences. As mentioned in section 1, touch offers various benefits and positive effects for nursing. ETC automatically quantifies and logs touch interactions between caregivers and patients that is used to visualize the social interactions in such facilities, similar to ETL.

In addition, ETC allows for easy data transmission between caregivers and patients utilizing a natural gesture, i.e., handshake. While the present device only stores its device ID to identify its user, the device can store any other information. At a hospital reception, for example, a patient can wear the device to allow a receptionist to register the patient's information, such as medical history and the procedure for today's visit. If the patient loses her/his way, she/he would ask a nurse nearby who also wears the device. The patient's data is sent to the nurse via a handshake to allow the nurse to guide the patient. While this can be achieved using another technology, such as scanning a bar code on the patient's nametag, ETC utilizes a natural gesture that is especially friendly to people with limited media literacy.

6 DISCUSSION AND CONCLUSION

In this paper, we introduced the development of EnhancedTouchX, a bracelet-type interpersonal BAN device for analyzing contextual information of interpersonal touch interactions, i.e., when, where, who, and how, a user touches. As a wearable interpersonal touch sensor, in particular, a novel capability is to measure "how" users touch each other, i.e., to identify a direction and gestures of touch. The two laboratory experiments demonstrated that the accuracy of direction identification was 95% while the accuracy of four-, three-, and two-gesture identifications were 85%, 93%, and 96%, respectively. We designed the device to be compatible with activities in daily life such as existing wearable gears: easy to wear and remove; Bluetooth-connectable; and ability to work offline. We expect this design to increase the application flexibility, as we introduced.

The present study has certain limitations. One is that the device cannot stably measure short-duration touches. While increasing data-transfer rates of the interpersonal BAN would improve temporal resolution, it would deteriorate the accuracy of the identifications.

Another limitation is that the device cannot measure touch events involving body parts other than the hand on which the device is worn or when the electrodes are not in contact with the skin. A possible solution is to employ capacitive coupling type BAN technology, where the electric field induced around the surface of the human body is used as a communication channel and the electrodes do not need to be attached to the skin [51, 52]. However, in this case, accurately differentiating the touch and proximity is a challenging task.

In addition, it is noteworthy that the result is obtained in a laboratory experiment. Regarding direction identification, we require studying the extent to which the identification is robust in the considerably realistic condition where both hands may move although one moved and the other was fixed during the experiment. Regarding gesture identification, the accuracy would be affected by the contact condition of the electrodes and skin and individual differences in the electrical characteristics of the human body as mentioned in section 3. Although we need to study the types of factors that affect the result to evaluate the external validity and explore better identification algorithms, the result is promising because even a simple comparison- and threshold-based algorithm could identify the direction and gestures of an interpersonal touch.

We predict two future directions of this work. The first is improving the accuracy of the measurement, wearability, and the battery life. The degrees of these requirements depend on the type of applications, while some of them have trade-off relationships. For example, the contact condition between the electrode and the skin affects the accuracy of the measurement. However, firm fixation would deteriorate the wearability. Thus, we attempt to construct the design guidelines by studying the trade-off relationships in a quantitative manner. The second is to describe more styles of interpersonal touch interactions. The present device measures the acceleration and RSSI values to estimate the direction and gestures of a touch. We plan to employ temperature and mechanical impedance of the hands that would be useful to describe the haptic sensations of touch.

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