Vinteraction: Vibration-based Information Transfer for Smart Devices

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***Abstract*—According to the spread of smart devices such as smartphones and smart tablets, opportunities to communicate between them will be more increased. Though we usually use WiFi and Bluetooth, it is still burden task for end-users. Many previous techniques to collaborate devices easily has been also proposed, they are not always best solution in some situations. This paper proposes a new interaction method called Vinteracion, which leverages combination of vibrator and accelerometer to send information from smart device to the other smart device. Vinteraction enables users to use touch interaction like Near Field Communication, which provides easy and intuitive way. We present an algorithm and implementation of vibration-based communication that can be adapted to any combination of smart devices. We also present several applications which leverages Vinteraction effectively. Through an evaluation by using popular six products, we confirmed that Vinteraction is easy to use transfer method with current products with reasonable performance.**

I. Introduction

Recent spread of smartphones and smart tablets increases opportunities to communicate various information among them. For example, we often transmit URL information when we want to continue to see a same web page from smartphone with small screen (in outdoor situation) to smart tablets with large screen (after getting home). In this paper, we call smartphones and smart tablets, which has high performance with multi-touch function, accelerometer compared to previous mobile devices, as smart devices. Current most popular way for communication among smart devices is it's information transferring via wireless network such as WiFi and Bluetooth. However, it is still burden tasks for end-users since it requires 4 main steps as following (1) connecting wireless network, (2) identifying a correspondent to communicate, (3) selecting information to be transferred, and (4) actual transferring. On the contrary, though NFC (Near Field Communication) technology can provide very easy interaction mode for information transferring as (1)selecting information to be transferred and (2)transferring the information by just putting, current many smart devices still do not have NFC function.

To provide direct manipulation like NFC without NFC tags and reader, in this paper we present a new information transferring interaction called Vinteraction which leverages combination of accelerometer and vibration equipped in smart devices. Vinteraction achieves information transferring by following steps, encoding information to vibration pattern in a smart device as information sender, vibrating the pattern by the smart device on the other smart device as information receiver, and decoding vibration pattern to information by detecting the vibration via accelerometer of the receiver. Thus, Vinteraction can offer simple interaction to users - just selecting information in a smart device and putting the device on the other smart device. In this paper, we present an algorithm to achieve Vinteraction for any combination of smart devices, and also useful applications with Vinteraction. Through evaluation with popular products, we verify availability and robustness of proposed algorithm. The paper offers following three contributions: 1) presenting a new information transferring method for smart devices called Vinteraction which leverages vibrator and accelerometer, 2) implementing actual applications which cooperates with Vinteraction efficiently, and 3) evaluating performance of Vinteraction with popular products of smart devices.

II. Motivation

With the spread of smart devices, we can access the internet's contents anytime in anywhere. Smart devices can be classified to smartphones such as iPhone, Android Phone or Windows Phone and smart tablets such as iPad, Android Tablets or Windows Tablet in terms of their size. We assume that users will often use both types of smart devices as the situation demands. For example, while users may use smartphones in train or walking, they also prefer to use smart tablets in home or cafe where users can settle into touching the internet contents. We consider that differences between smartphones and smart tablets are not only their size but also the level of private. Since smartphones are small enough for mobile, we consider that they are the most personal devices. Meanwhile, some of cafes or restaurants provide smart tablets as public devices to customers to establish satisfactory progress. These tablets not only provide function to order menus with interactive contents, but also allows users to access the internet contents in some cases. This means that smart tablets are sometimes regarded as public devices. In the near future, more various smart devices will be exist ubiquity as both private and public devices around us. Therefore, there will be more opportunities for interactions between smartphones and smart tablets such as URL transferring for seamless Internet browsing or password transferring with secure functionality.

Currently, people still often use e-mail by transferring information, or just type the information directly. These tasks are still painful for the users. Some of users may concern to use e-mail in smart tablets as public devices. With considering the spread of smart devices in private and public

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environment, the objective of this paper is to provide an easy and intuitive information transfer method between smart devices. We especially offer three main design requirements from above scenarios - (1) without hardware modification, (2) without connecting the same network and (3) with concerning privacy. As the first requirement, it is preferable not to add or change hardware because smartphones have not enough space or ports for adding extra hardware. As the second requirement, it should not be assumed that devices to be communicated are always connected in the same network. As we mentioned in previous section, smart tablets, which are provided as public device, are considered to be connected to original networks in cafe or restaurant. Thus, one of our challenges is to provide intuitive interaction technique between smart devices without connectivity to the same local area network. Third requirement is concerning privacy. This is also related to second requirement, but valuable information such as password should not be transferred through open network immoderately. In the following section, we present that previous research about device collaboration and explain our motivation have not achieved by them.

Many previous research have challenged to provide easy interaction between devices. GesturePen proposed device identifying technique by using infrared(IR) tag [1]. GesturePen facilitates information sharing in mobile computing environments by allowing users to identify devices by simple pointing at them. However, since current smartphones and tablets do not always have infrared sensors, it requires to add hardware to the smart devices. Smart-Its Friends [2] and Synchronous Gestures [3] leverages synchronous actions to connect a pair of devices. In Synchronous Gestures, users can tile together the displays of multiple tablets, which are connected same network, just by physically bumping a tablet into another one. Bumped pair of the devices are identified by monitoring accelerometer of each tablets. ProxNet proposes a method for establishing ad hoc and infrastructure mode wireless network connections based on physical proximity [4]. Shake Well Before Use [5] presented acceleration-based device paring method in securely. In addition, various secure pairing method has been also proposed (i.e., using visual channel [6] [7], audio channel [8], audio-visual combination [9], laser beams [10], button [11] or proximity based on signal strength [12]). Though most of these methods can be adopt to smart devices without their hardware modification, there is a limitation that devices to be communicate must be connected in the same network. Therefore, they are not always the best way for communication among private and public smart devices. NFC (Near Field Communication) is a short range communication based on RFID technology. It can provide easy and intuitive information transferring among devices without assuming for them to connect the same network. Though some of manufactures start to package NFC chips into smartphones, smartphones with NFC are still not widely available. On the other hand, NFC devices still have issues of security and privacy. Short-range communication makes it inherently safer than longer range technologies but there are still security flaws that, if not addressed, can be exploited. The wireless signal generated by data transfers can be picked up by antennas, modified, and dispatched. This makes NFC inherently vulnerable to this kind of attack [13].

III. VINTERACTION

A. Concept

Vinteraction enables users to transfer information among smart devices just by putting one on the another similar to NFC interaction. To provide this interaction with currently available smart devices, we leverage combination of vibrator of information sender and accelerometer of information receiver. In this paper, we especially focus to transfer information from smartphones to smart tablets because such situation is already very popular as described in above scenarios. We surveyed fifty kinds of current products of smart devices, and confirmed that thirty-five of all smartphones have vibrator and fifteen of all smart tablets have accelerometer. Therefore, combination of vibrator and accelerometer is actual and reasonable. Vinteraction transmit information by controlling vibrator of smart devices as information sender according to vibration pattern that encodes information to be transferred. The vibration pattern is decoded by accelerometer of smart devices as receiver. Vibration-based communication was also suggested in [14] and [15]. However, these works requires calibration phase to set a threshold to detect vibration effects to accelerometer values. This is because that vibrator's effects to accelerometer are different for different combination of smart devices. Moreover, even if taking same combination, the effects are also different for place to put a smart device on the other device. On the contrary, since our proposed method provides vibration detecting algorithm that decides adaptive threshold for decoding vibration pattern, it requires no such calibration phase.

Other combinations such as audio speaker and microphone [16] can be short-range communication method for smart devices. However, combination of audio speaker and microphone increases errors in noisy environment. In addition, users must know and care exact places of speaker and microphone. Combination of flashlight and camera (light sensor) can be also a way for short-range communication between smart devices[17]. However, using light has two limitations. Firstly, it is impossible to use in bright environment. Secondly, since flashlight naturally diffuse, range of communication is hard to controlled. Nevertheless, Vinteraction also has limitations. Since it uses accelerometer, it is useless in moving situations such as in a train or a car. Since there are no best way for every situation, we consider that it is important for users to provide various choices of solutions.

B. Vibration Decoding Algorithm

Vibrator and accelerometer are different for different types of smart devices. This means that vibrator's effect to accelerometer is also different. Contact place of two devices and chassis of the devices also causes differences of influence to vibration strength to accelerometer. Figure 1 shows changes in waveform of a tablet's (Sony Tablet S) accelerometer by vibrators of different smartphones (HTC Sensation, Galaxy Nexus and HTC Desire). X-axis represents time and Y-axis represents scalar values of 3D accelerometer with removing gravitational acceleration. In this experiment, each smartphones on the tablet generates vibration pattern of "000 1000101000000100100001100101011011000110111 1100010100000". In the pattern, "0" and "1" means stopping vibrator and generating vibration respectively during 100

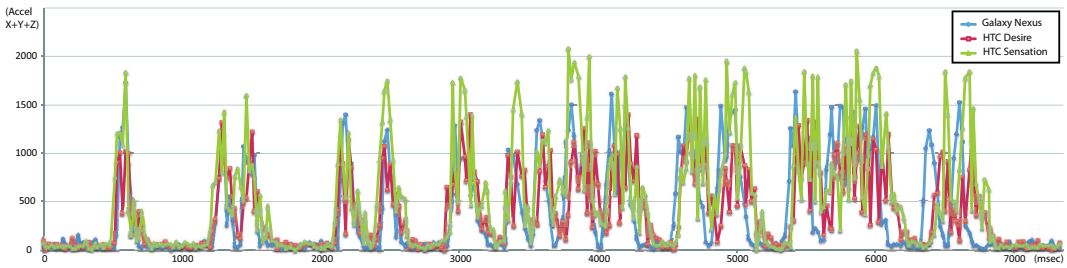

Fig. 1. Differences of accelerometer value affected by vibrator in various smart devices

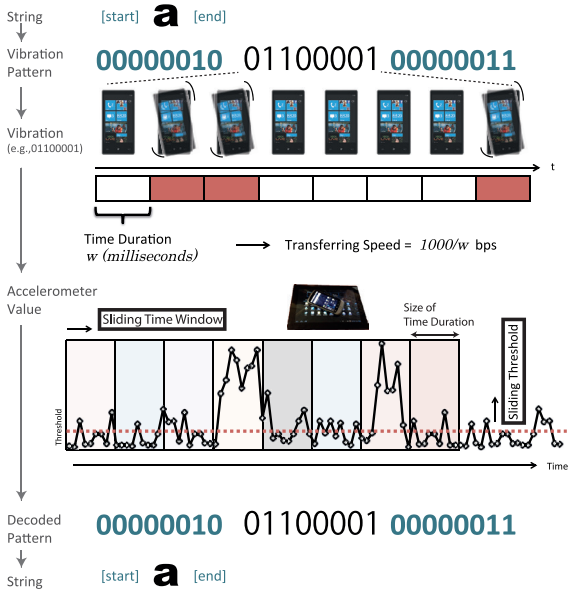

Fig. 2. Process of Vinteraction: Character string to be transmitted is encoded to vibration pattern by using ASCII code. The vibration pattern is decoded to original information by analysing accelerometer of vibration receiver. Vibration analysing leverages two techniques of sliding time window and sliding threshold.

milliseconds. As shown in the graph, changes of accelerometer differs for different types of smartphones. Though straightforward way to detect vibration is to use threshold, it is impossible to set one exact threshold preliminary. To provide vibration-based communication with any combinations of various smart devices, it is necessary to deal differences of vibrator and accelerometer.

To solve the problem, we propose an vibration decoding algorithm for vibration-based communication. Figure 2 shows procedure of information transfer by Vinteraction. Information to be transferred is encoded to binary pattern and it's "0" and "1" means stopping vibration and generating vibration respectively during a certain time. Therefore, the certain time duration decides transfer speed. To detect vibration and decode information from it's pattern, vibration decoding algorithm combines sliding time window and sliding threshold technique. The algorithm works to decide a threshold to detect both start bit pattern (0x02) and end bit pattern (0x03) of information. We chose start and end bit pattern by referring start and end bit pattern of a text in ASCII code's. According to

TABLE I. PSEUDO CODE FOR VIBRATION DECODING ALGORITHM TO DECODE INFORMATION BY ANALYSING ACCELERATION VALUES

```
for i to slidingTimeWindowStepCount do
    dataNum ← 0
    sum ← 0
    baseTime ← accelValueList.get(i).getTime()
    if maxValue < accelValueList.get(i).getValue() then
        maxValue ← accelValueList.get(i).getValue()
        baseThreshold ← maxValue/slidingThresholdStepCount
    end if
    for j = i to accelValueList.size() do
        sum ← sum + accelValueList.get(j).getValue()
        dataNum ++
        if accelValueList.get(j).getTime() − baseTime > timeWindowSize then
            for k = 1 to slidingThresholdStepCount do
                threshold ← baseThreshold * k
                if sum > threshold * dataNum then
                    bitPattern[k] ← bitPattern[k] +'' 1''
                else
                    bitPattern[k] ← bitPattern[k] +'' 0''
                end if
                decodeString(bitPattern[k])
            end for
            baseTime ← baseTime + timeWindowSize
        end if
    end for
end for
```

decided threshold, a bit pattern between start and end bit pattern is extracted and decodes transferred information. In formally, with a set of detected accelerometer's scalar values as $S = \{a_0, a_1, ..., a_n\}$, we define sum of accelerometer in sub set $s_p = \{a_x, a_{x+1}, ..., a_y\}$ in a time window t_p as $\sum_{m=x}^{y} a_m$. If $\sum_{m=x}^{y} a_m$ exceeds a threshold $T \times \mid s_p \mid$, the algorithm recognizes that vibration is generated in t_p. This analysis is continuously executed by sliding both time window t_p and threshold T. Sliding range of T and sliding delta ΔT is dynamically decided according to a maximum value of detected acceleration. In vibration transmission by using vibrator and accelerometer, differences of vibration frequency and strength of vibrator and read frequency and timing of accelerometer affects it's accuracy. Vibration decoding algorithm solves the difference of read frequency and timing of accelerometer by sliding time window, and also solves the difference of vibration frequency and strength of vibrator by sliding threshold.

Pseudo code of vibration decoding algorithm is shown in Table I. In the table, slidingTimeWindowStepCount is dynamically decided as number of accelerometer's read times in a time window, and slidingThresholdStepCount is also decided as number of threshold's sliding times. Notice that this algorithm may decode multiple information. At that time, we currently

Fig. 3. Screenshot of vPasswordManager: it enables users to manage various passwords in their smartphone and transmit the passwords to other smart devices by Vinteraction with AES encryption.

select a most decoded information. If there are more than two information which has same number of decoding time, Vinteraction leaves the final decision on selecting information to the user. Though we can absolutely decide correct information by adding checksum to information to be transferred, this paper focused to evaluate how accuracy is achieved with information as it is by our proposed way.

IV. Implementation

A. Vinteraction Library

We implemented library software for Android platform to use Vinteraction. The reason why we chose Android for prototype implementation is that there are many kinds of products for Android platform. Thus, we can evaluate our proposed method with various combinations of actual products. Vinteraction library has mainly two modules: information sender and receiver. Information sender includes information encoder to vibration pattern, and vibration generator. Information receiver includes vibration detector and information decoder. The library is implemented in light-weight codes that is 312 lines of code as Information sender and 532 lines of code as receiver. By integrating the library, various applications can have Vinteraction function easily.

To generate vibration, we offers two interaction model: (1) just putting a device of vibration sender on a device of receiver, or (2) pushing "vibration" button of sender. Vinteraction library detects a context that the device is put on receiver by monitoring accelerometer. In such a case, Vinteraction library generates vibration when accelerometer values are not significantly changed for 3 seconds. We also provide button interface to generate vibration if users want to generate vibration immediately.

B. Implemented Applications

1) vBrowser: When a user want to browse same web contents from with a smartphone to with wider display such as a smart tablet, vBrowser enables users to transfer URL easily with Vinteraction. To compress binary information of URL, vBrowser also leverages URL compressing service (e.g., bit.ly[1]) and transfer shorten URL via Vibration. When using shorten URL, 6 bytes of character string is transferred through Vinteraction. We also implemented client software in PC which mounts accelerometer (Macbook series which has Hard disk drive with accelerometer).

2) vPasswordManager: It is easy to be stolen passwords when users type them to smart tablets. vPasswordManager enables users to manage passwords in their personal smartphones and transfer it to smart tablets securely. Screenshots of vPasswordManager on smartphone-side are shown in Figure 3. Since vPasswordManager has function to encrypt password by AES (Advanced Encryption Standard), it provides secure information transferring even if someone tries to steal password by recording sounds of vibrating.

V. Evaluation

A. Method

The purposes of evaluation is following two folds: (1) compatibility - evaluating whether Vinteraction can be useful for various combination of devices, and (2) performance - evaluate speed and accuracy of information transfer of Vinteraction. In order to evaluate compatibility of Vinteraction, we tested Vinteraction by using six commercial products of smartphones and tablets. In addition, we also measured performance of Vinteraction by changing information transfer speed with same six products. List of products that we used for evaluation are HTC Desire, HTC Sensation and Galaxy Nexus for smartphones, and REGZA Tablet AT1S0, ICONIA TAB A500 and Sony Tablet S for smart tablets. We executed Vinteraction by putting each smartphones to each smart tablets which are placed on a horizontal desk. We evaluated 9 combination of each smartphones and tablets in total. Additionally, we also executed Vinteraction with 4 different transferring speeds for each combinations - 20 bits/sec (time duration of each vibration is 50 milliseconds), 10 bits/sec (time duration of each vibration is 100 milliseconds), 6.6 bits/sec (time duration of each vibration is 150 milliseconds) and 5 bits/sec (time duration of each vibration is 200 milliseconds). In the each combinations, we tested 5 times of sending a string of "Hello,world!" (96bits) by Vinteraction, and evaluated that all bits are decoded correctly.

B. Result

Figure 4 shows accuracy of decoded bits correctly on each smart tablets by changing information sending rate from 5 bits/sec to 20 bits/sec. In addition, average accuracy of Vinteraction for each smartphone to three kinds of smart tablets is also presented in Figure 5. All the smartphone of HTC Sensation, HTC Desire and Galaxy Nexus achieves almost 100 % of accuracy of information transferring by Vinteraction to all of smart tablets of REGZA Tablet AT1S0, Sony Tablet S, ICONIA TAB A500 at 5 bits/sec (time duration of each vibration is 200 milliseconds) and 6.6 bits/sec (time duration of each vibration is 150 milliseconds). In addition, at 10 bits/sec of transferring speed (time duration of each vibration is 100 milliseconds) , almost of accuracy were more that 95

[1]https://bitly.com

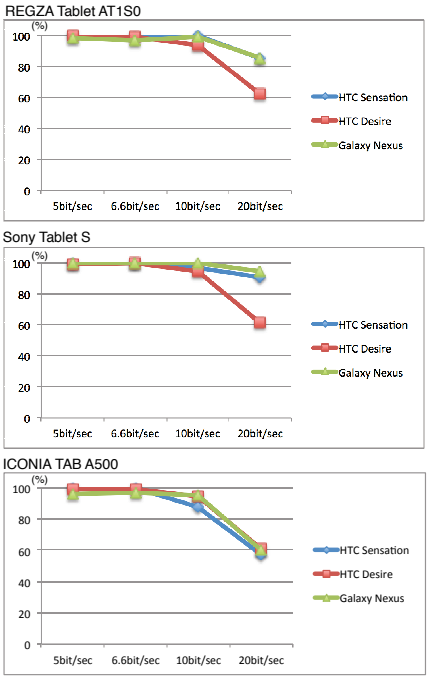

Fig. 4. Accuracy of information transmission from each smartphone to each tablet by Vinteraction

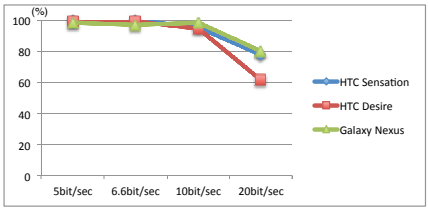

Fig. 5. Average accuracy of information transmission from each smartphone to all of tablets by Vinteraction

%. However, in terms of combination of HTC Sensation and ICONIA TAB A500, accuracy was about 85 % at 10 bits/sec transferring speeds. Additionally, at 20 bits/sec speeds (time duration of each vibration is 50 milliseconds), all of accuracy were decreased. In terms of combination of HTC Sensation / Galaxy Nexus as smartphone and REGZA Tablet AT1S0 / Sony Tablet S as smart tablets, accuracy was around 85 % - 95 % at 20 bits/sec speeds. Moreover, accuracy of Vinteraction from HTC Desire to REGZA Tablet AT1S0 and Sony Tablet S reduced to around 60 %. Moreover, when using ICONIA TAB A500 as vibration receiver, accuracies of Vinteraction from all of smartphones were decreased to 60 %. In total, we recognised that average of accuracies for all smartphone represent similar result that accuracies were decreased at 20 bits/sec speeds, and result of HTC Desire was worse than other smartphones especially at 20 bits/sec speeds. Through the experiment, we learned that current implementation of Vinteraction is interoperable among various combinations of smartphones and tablets with high accuracy under 10 bits/sec speeds. On the contrary, we found that accuracy is decreasing when Vinteraction is executed in higher speed or in specific combination. In the next section, we discuss the reason.

C. Discussion

Through the experiment, we recognised the following three results - (1) accuracy is decreased in higher transferring speeds, (2) when using ICONIA TAB A500, accuracy is worse than with other tablets, and (3) when using HTC Desire, accuracy is worse than with other smartphones. We analyse and discuss these reasons below in order.

1) Reason of low accuracy at higher speed: In terms of all combination of smartphones and tablets, higher transferring speed have a tendency to decrease accuracy. This is caused from limitation of read cycle time of accelerometer in tablets as vibration receiver. According to analysed acceleration data log of the evaluation, all of tablets read accelerometer values about 10 times for 100 milliseconds. When data is transferred in higher speed (i.e., time duration of vibrating is shorten), vibration couldn't be detected correctly as meaningful changes of accelerometer values. In addition, character frequency of vibration motor influences bad accuracy if time duration of vibration is short. To solve this problem, it is important to make read cycle time of accelerometer higher in hardware level and/or software(OS) level. In addition, real-time operation of vibrator is also important to control vibrator precisely.

2) Reason of low accuracy when using ICONIA TAB A500: As compared to other tablets, accuracy was worse with ICONIA TAB A500. This is caused from the character of it's chassis such as size and material of chassis. According to analysed acceleration data log of ICONIA TAB A500, amount of changes of acceleration is much less than those of other tablets. Thus, when vibration is generated in higher frequency, it cannot influence enough changes of acceleration in ICONIA TAB A500. To solve this kind of problem, one approach is providing navigation interface to notice place of accelerometer in tablets to users. If a smartphone is placed near the accelerometer in a tablet, vibrator in smartphone can influence it's vibration to accelerometer in the tablet stronger.

3) Reason of low accuracy when using HTC Desire: As compared to other smartphones, accuracies at 20 bits/sec speed to REGZA Tablet AT1S0 and Sony Tablet S were worse when using HTC Desire as vibration sender. This is caused from influence to accelerometer of HTC Desire is less than it of other smartphones (the difference is also shown in Figure 1). When we conducted experiments, we found that physical contact points of HTC Desire to tablets are less than those of other smartphones since camera module of HTC Desire is a little bit bulging out from it's chassis. Therefore, in the case of higher speeds of transferring, this character of HTC Desire is actualized strongly as low accuracy. One of approach to solve the problem is to place smartphone near by accelerometer in tablets just as described in previous section.

VI. Limitation and Future Work

A. Improvement of accuracy and transmission rate

Main limitation of current Vinteraction is low transmission rate. Since current implementation provide information transmission at only 10 bit/sec with high accuracy, it takes 5 seconds to send 6 characters of shorten URL or 6-7 seconds to send 8 characters of a password. We consider that Vinteraction with current speed is still useful in comparison to using e-mail, QR

code or other way in several situations, but transmission rate should be more improved for enhancing users' satisfaction and also for adapting Vinteraction to various applications. Though current implementation uses ASCII code as vibration pattern for encoding character string, compression of vibration patterns or devisal of character string's encoding can provide higher transmission rate. Accuracy of information transmission also should be improved. In this paper, we reported how much accuracy and transmission rate can be realized with only simple algorithm. However, it is possible to improve accuracy by adapting techniques of error detection and correction such as Reed-Solomon Coding. Other future work is to evaluate Vinteraction with more products. Though smart tablets that we used for evaluation in this paper do not have vibrator, there are some products which has vibrator. Testing of information transmission from smart tablets to smartphones or other combinations can also provide more possibility of applications.

B. Implications for further interaction models

In this paper, we focus to provide one-to-one interaction model between smart devices. However, Vinteraction has possibility to provide further interaction model. For example, one-to-many information transmission may be achieved by placing multiple smartphones on a smart tablet that has a vibrator. We can also adapt Vinteraction to not only smart devices but also sensor nodes because most of sensor nodes have accelerometer. As an example, one-to-many interaction model enables us to configure multiple sensor nodes in one time.

VII. Conclusion

We proposed Vinteraction, an information transmitting method by leveraging combination of accelerometer and vibrator. With spread of smart devices such as smartphones and smart tablets in not only private environment but also public environment , communication method between those devices should be provided in diverse way. We presented the concept of Vinteraction and methodology to realize it for various kinds of smart devices. We also implemented two kinds of application called vBrowser and vPasswordManager which leverages the advantages of Vinteraction. Through an evaluation by using actual 6 products, we confirmed that Vinteraction can transmit information at 10 bits/sec. There still have some limitations in Vinteraction such as low accuracy at higher transmitting speeds, however, we discussed future direction to solve the problems and also provide implications for further interaction model which can be provided by Vinteraction. Smart devices will be more ubiquity around us, and there are various situation to cooperate with the devices. Thus, we consider that Vinteraction can play a important role as additional way of communication between those devices.

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