PickRing: Seamless Interaction through Pick-Up Detection

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ABSTRACT
We are frequently switching between devices, and currently we have to unlock most of them. Ideally such devices should be seamlessly accessible and not require an unlock action. We introduce *PickRing*, a wearable sensor that allows seamless interaction with devices through predicting the intention to interact with them through the device's pick-up detection. A cross-correlation between the ring and the device's motion is used as basis for identifying the intention of device usage. In an experiment, we found that the pick-up detection using *PickRing* cost neither additional effort nor time when comparing it with the pure pick-up action, while it has more hedonic qualities and is rated to be more attractive than a standard smartphone technique. Thus, *PickRing* can reduce the overhead in using device through seamlessly activating mobile and ubiquitous computers.

Author Keywords
Ubiquitous; wearable; seamless; activation; pick-up.

ACM Classification Keywords
H.5.2. User Interfaces: Input Devices and Strategies.

INTRODUCTION
The world is filled by an increasing number of electronic devices in distinct smart environments; and to move towards ubiquitous computing [33] requires to easily switch between these devices. In the manner of "Implicit Human-Computer Interaction" (iHCI) [28], researchers [17, 27] proposed to interpret natural behavior of users as intended commands. That potentially is the case if a user picks up a device, as grasp recognition is proposed as more natural method of seamlessly associating devices with users [30]. Thus, one solution to support seamless interaction with devices surrounding us (e.g. phones and cameras) would be to have automatic accessibility in the moment that they are taken into the hand.

One major research question of ubiquitous computing, which defines the environment as a "world of fully connected devices, with cheap wireless networks" [33], is how to seamlessly access ubiquitous computers. Fukumoto and Suenaga [12] suggest that input devices should be invented that allow immediate input to mobile devices, because the "Setup time" of activating a mobile device in order to use it takes too long. Brewster *et al.* [5] also suggest separating input and output devices to improve the usability in the mobile context. Wolf *et al.* [36] propose finger-mounted sensors as an input device for controlling mobile devices separately with motion-based finger gestures.

If one input device is able to control more than one output device the transition between two output devices should be seamless for the user. Thus, the input and output device should not need an explicit connection and disconnection mechanism, instead they should know when they need to couple through the context. *EyeRing* [23] leverages the pointing gesture of a user's index finger as an "implied dialog" for selecting the device that is desired to control. The ubiquitous device should always be available [10]; and the activation of these devices would ideally be realized implicitly [28] without requiring user's attention (e.g. no explicit connection through a settings menu). Implicit device pairing is a promising technique for enabling seamless interaction. Interaction is seamless when the user is not required to activate the device by an effort-costing trigger nor required to change an input interface when changing a device. Also the access to a device through an interface ought to be immediate [12]. According to Ballagas *et al.* [4] the connection between an in- and an output device should be automatic, fast and easy, because users want to concentrate on the interaction with a system rather than spending time on connecting input and output devices. The connection between in- and output device is more comfortable when it is done wirelessly (e.g. in [19, 24]). Finally, in order to allow for seamless interaction, the process of switching from one device to another should also be implicit, thereby saving time and effort, which allows for continuous and non-interrupted task-solving, as recommended by Suh *et al.* [29].

This paper contributes to reducing the overhead in switching between devices through introducing *PickRing* - a wearable device that enables coupling with ubiquitous devices through a cross-correlation between the wearable and picked-up devices, which are automatically connected to a wireless network.

RELATED WORK
We identified two research domains that are related to this work, namely *seamless device connection* and *wearable input devices*.

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Seamless connection of input and output device

Beyond devices that enable grasp recognition using capacitive sensors [35] and RFID reader in combination with accelerometer [2]; work has been carried out for associate an object with its user [12, 13], for device-to-device authentication through movements pattern that were triggered by shaking devices together [22] as well as for one-to-one seamless pairing of separate in- and output devices [16, 23, 31, 36]. Fujinami, K. and Pirttikangas, S. [11] associated an object (e.g. hand bad, door knob or bottle) with its user within 4-5 seconds of usage using accelerometer data. Hinckley [16] uses synchronous gestures as the trigger for pairing two tablets as a 1:1 connection: When bumped against each other the acceleration data of the two tablets is inversely equal. Lester et al. [21] used accelerometer sensing to couple two devices by calculating the Euclidean distance. *Ubi-Finger* [31] makes it possible to connect almost seamlessly to devices by pointing an infrared sensor that is attached to a user's finger to a unique infrared light source of the devices it can control. The system then knows which device is selected and the user can control the device remotely with mid-air gestures. *Ubi-Finger* uses an indirect 1:1 connection from the input- to the output-device. *Tickle* [36] has de-coupled input and output units for controlling a hand-held tablet and uses a 1:1 Bluetooth connection between both hardware components. The *EyeRing* interface [23] has a 1:1 relation to the objects it can detect through its camera. The camera images are sent to a smartphone via Bluetooth for the detection of objects.

Wearable input devices for fingers, wrist, and arm

Many others [12, 13, 19, 20, 24, 25, 31, 36] have investigated tracking finger and hand motions with wearable sensors for gesture-based interaction. *GestureWrist* [25] recognizes hand-gestures by measuring through capacitive sensors that are embedded in a wristband. *Ubi-Finger* [31] and *Tickle* [36] detect finger motions of accelerometer and gyroscope sensor data for gesture classification. Passive RFID/NFC tags (attached to nails [32] or mounted on fingers [3]) were used to capture gestures, useful, for example, when interacting with a wearable display or other mobile computing environment where a keyboard is not appropriate.

Other sensors that enable finger and hand gestures to be detected include optical sensors [18], sensing muscle activities [26] or using magnetometers [1, 14]. *Digits* [18] is also wrist-worn, it uses an IMU sensor to detect the hand direction and an infrared depth-camera to detect the hand pose. Saponas [26] uses an armband that measures the EMG signal in a user's arm to extract movements and gestures of a user's finger. Moreover, magnetic sensors were used [1, 14] that track the position of a magnetic ring worn on the user's finger, while *FingerPad* [7] detected gestures drawn on the fingertips using magnets. To avoid wired between finger-worn sensors and a wrist-worn microcontroller, the *Body Coupled FingerRing* [13] uses a method called "Direct Coupling" that uses the human body as an electric wire.

Summary

We identified a research gap in uniting the fields of wearable input devices and seamlessly pairing separate in- and multiple output devices, which contributes to the area of seamless interaction through the following three contributions: (1) Introducing a ubiquitous wearable input device (*PickRing*) that enables seamless device activation. (2) Developing a one-to-many network between one ubiquitous input device and many close-by (mobile) devices. This allows an immediate coupling of the input device (*PickRing*) with the desired output device. (3) Enabling to activate a desired device based on the interpretation of implicit natural behavior (taking the device up) as intention to interact with the device.

PICKRING

The advantage of using a ring interface for ubiquitous computing is that a ring is a transparent device [8] as people are used to wear rings on their fingers as jewelry [9]. RFID/NFC tags have been mounted on fingers [3] or embedded in jewelry [32] to detect if fingers are close to smart objects. However, ring devices with embedded NFC tags are available[1], for our purpose (detection the intention of device usage) closeness would provide too few information and could not be interpreted as implicit interaction [27]. Thus, we use the motion when a device is taken up to assume that a user is willing to use an object.

Like others [16, 22, 36], we propose to use motion instead of optical sensors for detecting hand motions, as optical solutions tend to work well in laboratory environments [6, 18] but frequently suffer from occlusion if users act naturally and if they take objects in their hands. Motion sensors need much less energy than a video camera with image analysis while not suffering from occlusion. Moreover motion sensors are tiny and can easily be embedded in jewelry such as a ring or wrist- and arm-bands, which increases the usability of such a technology. The benefit to have the sensors at the finger is to have less motion noise than if the sensors would be worn at the wrist or arm. The wrist joint has 2 DOF.

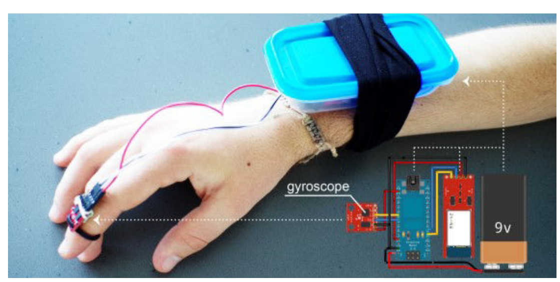

Figure 1. *PickRing* mounted on index finger and wrist.

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[1] NFC Ring Lock: https://play.google.com/store/apps/details?id=co.mclear.nfcringunlockpro&hl=en.

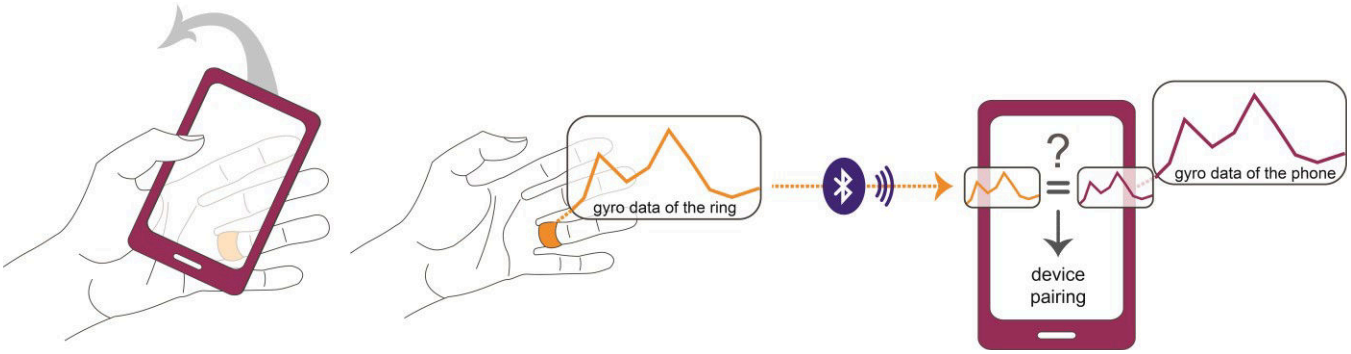

Figure 2: After *PickRing* is connected to nearby devices via Bluetooth, it automatically activates a device through interpreting that action as activation gesture. The gesture is recognized device and hand motion's cross-correlation.

Thus, the motion of the grasped device and the sensor unit would be less similar using wrist- and arm-bands than if using a finger ring. However, the current prototype stores the microcontroller and the battery in a wristband, we assume that the size of batteries and hardware will shrink within the next years and therefore, we propose a ring interface, as shown in Figure 1.

PickRing is a finger-worn controller with embedded gyroscope to detect natural hand movements when taking up a device as intention to use the device. Thus, the ring is immediately paired to the device and ready to receive further (e.g. gesture) commands. The whole seamless interaction system consists of a finger- mounted interface and multiple mobile devices. *PickRing* interprets the "take up" of an output device as a pairing trigger to couple *PickRing* to the taken output device (see Figure 2).

To do so *PickRing* tracks a user's finger movement using its gyroscope sensor and sends the sensor data through a Bluetooth Piconet network simultaneously to all output devices connected to the network. An ad-hoc Bluetooth network is created that suits to the mobility requirements of ubiquitous computing because it is capable of connecting to output devices in non-smart and non-prepared environments. This allows for switching an output device from a standby to an active mode when it is taken into the hand.

PickRing Hardware

The hardware for the wearable interface consists of a gyroscope sensor attached to a finger and a microcontroller and a Bluetooth modem, which are worn on the wrist. The attachment of *PickRing* and its electronic schematic can be seen in Figure 2. The gyroscope (ITG3200) has 3 degrees of freedom and can be attached to any finger of the user. The sensor data is sampled with 5Hz by an "Arduino Nano V3.0" microcontroller that is connected via I2C to the sensors. The whole ring system is operated by a 9V battery. That allows for about 15 hours working time. However, 15 hours battery life time is enough for an experiment; this could be improved (for research in the wild or a more product-like prototype) by several magnitudes using a lipo battery and Bluetooth Low Energy.

PickRing Software

The software consists of two parts: The firmware on the Arduino that samples and sends the sensor data and the application on the devices that receives and evaluates it. This application is also capable of relaying the ring's sensor data to the other devices if the device is setup as the host of the Piconet.

PickRing sender software

Initially the ring connects automatically to all Bluetooth-capable Android phones and tablets that are close to the user in about a reach of 10 meters (limited by the Bluetooth Class 2 signal strength) via a Bluetooth Piconet. After a successful connection the microcontroller of *PickRing* samples the sensor data of the gyroscope and sends it to all devices every 200ms in raw format.

Device receiver software

First of all, the ring application connects to the host device of the Bluetooth Piconet that connects all devices that can be controlled via their receiver software. Therefore, a star network topology was implemented in which the host device connects to all other Bluetooth devices around it. The host Android device then relays the ring's sensor data to all other Android devices. The receiver software on all devices in the network receives and analyzes the gyroscope data in order to determine if it should activate the device. Thus, the ring's and all Android devices' local gyroscope sensor data are compared to identify the device that is taken up.

The application of the mobile device receives the remote ring sensor data every 200ms and samples its own gyroscope data. The sum of yaw, pitch and roll of both devices' gyroscope data are calculated with the formula of the Euclidean distance: $\sqrt{yaw^2 + pitch^2 + roll^2}$ (while Lester et al. [21] had calculated the Euclidean distance from accelerometer data). With the Euclidean distance it is guaranteed that the direction of the movement is not an error source because ring and device could sense inverse movements depending on their position to each other. A mobile device is activated when a rotation threshold of 16 degrees is passed 5 times in a row for the ring and a device at the same time. The device is deactivated when the thresh-

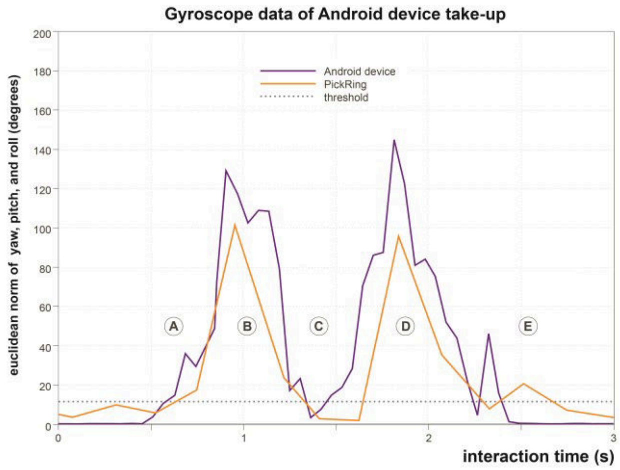

Figure 3. Gyroscope data of *PickRing* and of picked-up device: (A) device motion passes the threshold (B) picking up the device (C) holding the device in hand (D) putting the device down (E) device motion comes below the threshold.

old is passed 5 times in a row by the ring while the local gyroscope data was below that value. The threshold of 16 degrees has been set by iteratively testing false positive and false negative login attempts. Below 16 degrees devices got activated even if they were just touched, above 16 degrees the login mechanism was sometimes not triggered. Figure 3 shows the gyroscope data of the ring and a device that is lying on a table with the screen turned downwards. The user grabs the device, holds it and lays it down again. Sending the ring's data via Bluetooth causes a delay of the sensor data of about 100ms, which can be seen in the horizontal offset between both graphs.

The *PickRing* device enables to actuate a broad range a devices, smart objects, and smart environments, as soon they have an embedded gyroscope, a Bluetooth connection, and are running Android. We demonstrated in three exemplary applications: (A) smartphone actuation (B) smart device actuation (C) smart room activation that *PickRing* works in the according scenarios, shown in Figure 4. Moreover, we exemplarily evaluated the first scenario as described in the following section.

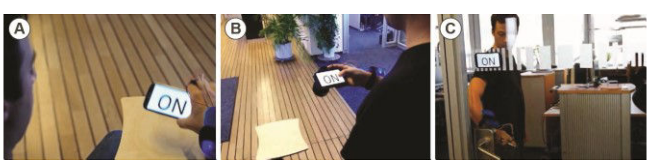

Figure 4. Exemplary application scenarios for *PickRing*: (A) smartphone actuation (B) smart device actuation (C) smart room activation.

EXPERIMENT

A user study was carried out in order to evaluate if the proposed *PickRing* interface supports the previously (in the Related Work section) identified requirement for enable for seamless interaction using the example of phone actuation:

- Enable immediate device pairing of *PickRing* to all devices that potentially shall be controlled via an ad-hoc Bluetooth Piconet, which will be displayed through activating the paired device
- Detect natural taking-up events of devices and use them as implicit activation command

PickRing will be compared against two different types of device activations regarding their usability and performance: one state-of-the-art technique as well as one idealized technique, that by default offers immediate access.

Design

Our study had a within-subject design for comparing the device activation techniques regarding seamless interaction appropriateness. The activation techniques were:

(I) Ready-to-hand. When taken into the hand, a device is automatically activated without explicit interaction.

(II) State-of-the-art. This is a common login mechanism of today's smartphones: Users have to press a button and swipe over the touchscreen to activate the device.

(III) PickRing. Users had to put the ring on a finger. When smartphone and ring move at the same time the device is activated.

The appropriateness of the individual techniques was measured through comparing as dependent variables performance (interaction time), perceived effort, and usability (perceived usability, subjective opinions) of different device activation techniques. The independent variable was the activation technique (e.g. I, II or III). Our baseline was the *ready-to-hand* technique (I) as this technique suits the vision of ubiquitous computing by being seamless. The *state-of-the-art* technique (II) represents common mobile device activation techniques because mobile devices are used as placeholder for ubiquitous devices in our experiment. The activation technique with the *PickRing* (III) is the proposed seamless activation technique. The interaction time for each trial was recorded in log-files during the experiment. A trial of a participant started by taking up a device from a table in front of her/him and was finished when the device was put back at the table. Perceived effort was measured using the SMEQ scale. The usability of each device activation technique was recorded using the AttrakDiff mini-questionnaire.

Task

We tested the proposed *PickRing* (technique III) against two other systems: a visionary (technique I) and one that represents the state-of-the-art (technique II).

The scenario of our experiment refers to taking up a ubiquitous device with the intention to immediately use it. For identifying if a user is cognitively ready to use the device, we included a cognitive low-effort task. This task was reading a letter-digit combination. To avoid that participants could read the text before the device was taken up; the devices were lying on a table with the screen faced down. We used mobile devices as prototype because they have embedded sensors and all technology we needed for our study. Please note that these devices were used only as an example for ubiquitous devices that are desired to be used seamlessly when taken into the hand.

The procedure of activating a device and reading the text on the screen was simulated in our experimental task through displaying random letter-digit combinations, which the participants were asked to read aloud. Reading the message required them to take up a device from the table as all three test devices were laying upside down on the table. After actuating the device, the participants were able to read the displayed message and put the device back on the table when the message had been read. The displayed letter-digit message was displayed directly for the *state-of-the-art* (II) as well as for the *PickRing* (III) techniques after the participants successfully activated the device. The (randomly changing) message was constantly displayed for the *ready-to-hand technique* (I). Users had to deactivate the device by pressing a button on the side of the device when they used the state-of-the-art technique. With the other two techniques this was done implicitly by laying down the device.

Apparatus

The apparatus consists of:

- 3 Android phones (2 Samsung Galaxy S3, 1 Samsung Galaxy S2) that shall be activated by the user
- 1 Android tablet (Asus TF101) to configure the Android phones during the experiment, e.g. to display a new message on their screen
- Just for the *PickRing* technique: a wearable device as described in the previous section.

An application was running on the 3 Android phones that implemented the activation techniques I-III. After a successful login it showed a dynamically changing letter-number combination which the users had to read out aloud. An experiment-control application was running on the tablet that allowed us to change the combination on all test devices wirelessly between the trials of condition I. Besides creating log-files for each trial the control application also showed all current messages on the devices to verify that users read aloud the correct combinations.

Procedure

19 participants (18 right-handed and 1 ambidextrous, 11 males, 8 female, aged 25.7 years in average, ranging from 16 to 54 years, SD=7.4) were asked to activate three devices in one sequence and 10 sequences per activation technique (*ready-to-hand, state-of-the-art*, and *PickRing*). The techniques were applied by the participants in counter-balanced order. For each technique, three devices were placed at three distinct positions on a table in front of the participant with the screen pointing downwards at the table. The participants were asked to take one device after the other in their hand, activate the device according to the current activation technique and then read aloud the message that appeared. The messages changed after putting the devices back at the table. Before testing each technique, we had a training trial, which was completed as soon as the participants felt comfortable with the technique and task. Each time after completing the task with an activation technique, the participants were asked to fill in the AttrakDiff and the SMEQ questionnaires. After all tasks were completed, the participants answered open questions about their general opinion and in particular about the acceptability of *PickRing*. Finally, participants filled in demographic questionnaires.

RESULTS

During the user test, we had collected objective and subjective *performance* data, as well as perceived *usability.*

Performance

The task completion time and the perceived task effort are objective and subjective indicators for the performances of technique I-III that are presented here.

Task completion time

The mean interaction times per pick-up technique was 1.9s for the *ready-to-hand* technique (SD=0.2). Picking up a device while *PickRing* was worn took 2.2s (SD=0.2); and applying the *state-of-the-art* technique lasted 2.3s (SD=0.2). An ANOVA yielded no significant difference for the variable *interaction time* ($F_{2,125}$=1.9, p=.369)*,* as shown in Figure 5.

Perceived task effort

A repeated measure ANOVA showed a significant different effort for *technique* ($F_{2,42}$=34.8, p<.001). Sidak-corrected pairwise comparison (see Figure 6) showed that the button & swipe-activation method *state-of-the-art* was perceived as being significantly more difficult than the *ready-to-hand* (p<.001) and the *PickRing* (p<.001) techniques. Our proposed *PickRing* technique was not perceived as requiring more effort than the *ready-to-hand* technique (p=.981). The median for rating the perceived effort for the *state-of-the-art* technique was "fairly hard to do", whereas

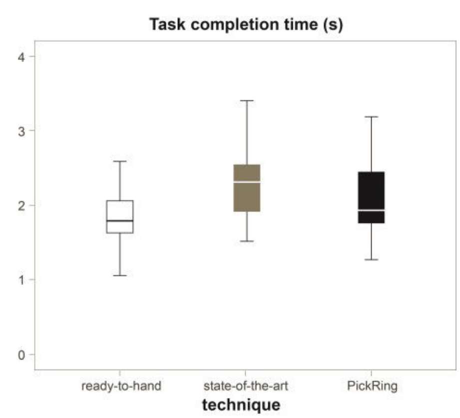

Figure 5. Time to take up the devices from table, read the message and put the device back, applying each of the 3 tested activation techniques.

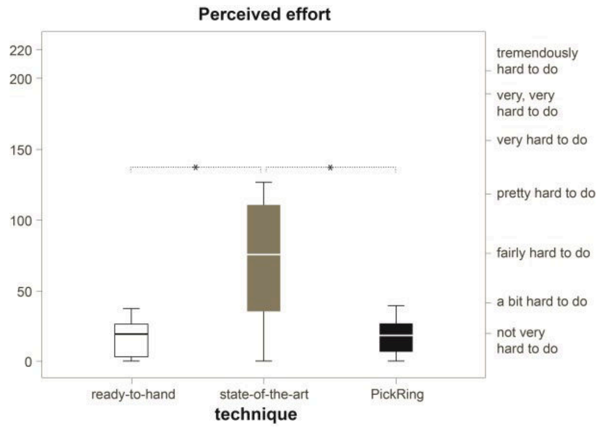

Figure 6. Perceived effort to activate a device per tested technique for reading a test message.

the median rating for reading a message that is presented *ready-to-hand* as well as seamlessly displayed when a device is picked up while wearing the *PickRing* was close to "not very hard to do".

Usability

The indicators for the usability of techniques I-III were measured with the perceived attractiveness, pragmatic quality and the hedonic qualities of the AttrakDiff mini questionnaire.

Perceived attractiveness, hedonic & pragmatic quality

ANOVA yielded for each AttrakDiff sub-scale significantly different ratings per technique (global attractiveness: $F_{2,40}$=4.9, p=.012, pragmatic quality: $F_{2,45}$=26.9, p<.001, hedonic quality (stimulation): $F_{2,40}$=15.1, p<.001, hedonic quality (identification): $F_{2,39}$=8.1, p=.001), see Figure 7.

Sidak-corrected comparison indicated that the state-of-the-art activation was found to be significantly less attractive than the *ready-to-hand* (p=.030) and *PickRing* (p=.036) activation method. Attractiveness of *ready-to-hand* and *PickRing* activation had no significant difference.

Unsurprisingly, similarities can be found between interaction time, perceived effort and the pragmatic quality rating: *ready-to-hand* and *PickRing* activation were rated higher than the traditional login (*ready-to-hand*: p<.001, *PickRing*: p<.001). The perceived pragmatic quality of *ready-to-hand* and *PickRing* activation was not rated significantly different. Thus, no practical difference was perceived for the seamless device activation in comparison to just grabbing an object whose functionality is *ready-to-hand*.

Hedonic qualities

Regarding the hedonic quality stimulation, the *PickRing* activation method was rated highest with significant difference to ready-to-hand (p<.001) and *state-of-the-art* (p<.001). Still, *state-of-the-art* had significantly less hedonic quality to the users than ready-to-hand (p<.001).

For the hedonic quality identification, users could identify higher with the *PickRing* activation than with the *state-of-the-art* technique (p=.001). No difference was found between *ready-to-hand* and *PickRing* and also between *ready-to-hand* and *state-of-the-art*.

DISCUSSION

In the following we will discuss how *PickRing* succeeded in seamless device activation in regard to *perceived effort* and *usability*, while the performance was equally good for all tested conditions.

Perceived effort

The explanation for the high perceived effort of the *state-of-the-art* technique is that using this method, the unlocking task is much more complex in comparison to the techniques *ready-to-hand* and *PickRing* (even though it took the same time). To unlock the phone with this technique, users had to spend a higher effort than when just grabbing the phone and reading the message without a perceived unlocking mechanism. Thus, ready-to-hand and *PickRing* activation may have been rated to be much easier.

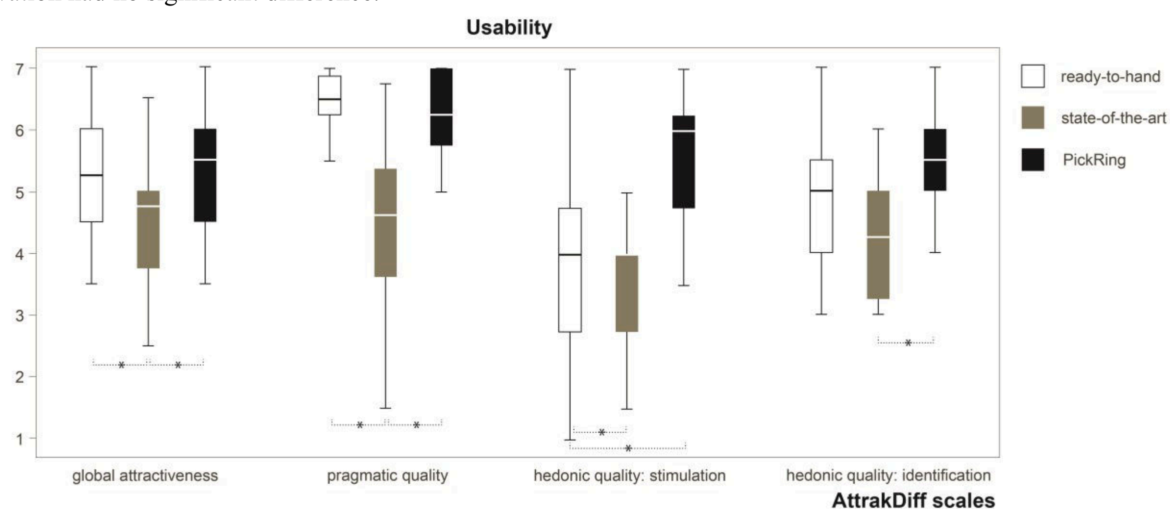

Figure 7: Usability scales: global attractiveness, pragmatic quality, hedonic quality stimulation, hedonic quality identification to rate the three activation techniques ready-to-hand, state-of-the-art and *PickRing* from 1=low rating to 7=high rating.

Low perceived effort is a strong argument for convincing people to use a certain technology. *PickRing* requires wearing additional technology and convincing people to spend money on an extra device and to carry that around in daily life has also to be convincing in regard to usability aspects.

Usability

Usability aspects cover pragmatic as well as hedonic (stimulation and identification) qualities that both influence the overall attractiveness of interaction techniques and technology.

Pragmatic quality

The pragmatic quality of the *state-of-the-art* technique was rated worse than *ready-to-hand* and *PickRing*, which goes in line with the effort measurements and improves these. Having a device accessible in a *ready-to-hand* manner was rated to be as pragmatically good as using *PickRing.* Thus, we assume that the users did not perceive *PickRing* as an obstacle while accessing the device. Otherwise the pragmatic quality rating of *PickRing* might have been lower.

Hedonic qualities

High *stimulation* ratings indicate that *PickRing* offers "novel, interesting and stimulating functions" [15]. This stimulation quality may motivate people to wear an additional device, such as *PickRing,* which is a precondition for establishing a separated input device that allow for seamlessly control generic devices in a ubiquitously connected world. In contrast to the good rating of *PickRing,* the *state-of-the-art* method was not perceived stimulating which may be because it interrupts the flow between the desire of using a device and its actual accessibility.

The high *identification* ratings of *PickRing* may indicate that users might wish to have such a device and value it as "status symbol" as it is the case with technology from some companies (e.g. Apple) rather than from others. That would support the distribution of such a ubiquitous remote controller and also ensure the needed social acceptance of wearing such a device.

Overall Attractiveness

The attractiveness of the three tested techniques is in line with the other usability results that are an improvement of the previously described findings as attractiveness combines pragmatic and hedonic qualities.

Limitation // other usage scenarios

While the idea behind *PickRing* (enabling seamless interaction with ubiquitous devices when these are taken up) is generic, our experiment design (taking up a phone those screen is facing a table) is limited. We are aware that there are infinite ways to pick up objects, even though they may have same form factors, as shown by Wimmer [34]. The grasp type in our user study was rather chosen to capture the moment when the user is ready to start the interaction than to represent a main grasp behavior. Thus, this controlled experiment set-up does not limit the contribution of this paper. This paper is proposing a conceptual solution to enable for seamless interaction. Scenarios that are not covered by our set-up, such as taking up devices without any rotational motion, would not be detected by our *PickRing* prototype. Considering multiple sensors as well as preventing against accidently device pairings leave many open research questions that should be addressed in future works.We also only evaluated the phone actuation scenario while further scenarios (see Figure 4) also seem very promising to be enriched through the PickRing device as well, which may be in future works.

CONCLUSION

We propose to split in- and output interface to allow for seamless interaction with any grasped device and switch dynamically in between those by interpreting the natural movement of taking up a device as intention to interact with. This would allow for activating a ubiquitous device when taken into the hand. We implemented a prototype of a ubiquitous controller, called *PickRing*; and we used a phone to represent ubiquitous devices. We evaluated *PickRing* by comparing its performance, effort, and usability against an established phone activation technique as well as against an idealized ready-to-hand method. In a user study, we showed that our proposed interface contributes successfully to the idea of ubiquitous computing through three aspects: (1) *PickRing* enables control of multiple devices seamlessly. (2) The immediate pairing between the ubiquitous controller and a ubiquitous device could be realized seamlessly through providing an ad-hoc Bluetooth Piconet. (3) In a user study, we show that the natural hand motion when taking-up a device can serve as implicit activation command. Thus, our findings show that the proposed *PickRing* fulfills the requirements of seamless interaction, which we outlined at the beginning of this paper. Furthermore, we show that the acceptance of using such a device is shown through its attractiveness and its ease of use while no increase of effort is perceived.

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REFERENCES

1. Ashbrook, D., Baudisch, P., and White, S. Nenya: subtle and eyes-free mobile input with a magnetically-tracked finger ring. In *Proc. CHI '11,* 2043–2046.
2. Berlin, E., Liu, J., van Laerhoven, K., and Schiele, B. Coming to grips with the objects we grasp: detecting interactions with efficient wrist-worn sensors. In *Proc. TEI'10*, 57-64.
3. Bainbridge, R. and Paradiso, J. Wireless Hand Gesture Capture through Wearable Passive Tag Sensing. In *Proc. BSN'11,* 200-204.

4. Ballagas, R., Borchers, J., Rohs, M., and Sheridan, J. G. The smart phone: A ubiquitous input device. In *Pervasive Comp. 5*, 2006, 70–77.
5. Brewster, S., Lumsden, J., Bell, M., Hall, M., and Tasker, S. Multimodal 'eyes-free' interaction techniques for wearable devices. In *Proc. CHI'03*, 473–480.
6. Brockmann, C. and Müller, H. Remote vision-based multi-type gesture interaction. *Gesture-Based Communication in HCI 2004*, 198–209.
7. Chan, L., Liang, R., Tsai, M., Cheng, K., Su, C., Chen, M., Cheng, W., and Chen, B.. 2013. FingerPad: private and subtle interaction using fingertips. In *Proc. UIST'13*, 255-260.
8. Dey, A. K., Ljungstrand, P., and Schmidt, A. Distributed and disappearing user interfaces in ubiquitous computing. In *Proc. CHI '01*, 487–488.
9. Drossos, N., Mavrommati, I., and Kameas, A. Towards ubiquitous computing applications composed from functionally autonomous hybrid artifacts. *The Disappearing Computer* (2007), 161–181.
10. Fishkin, K. P, Moran, T. P., and Harisson, B. L. Embodied user interfaces: Towards invisible user interfaces. In *Proc. Working Conference on Engineering for HCI,* 1-18.
11. Fujinami, K. and Pirttikangas, S. A study on a correlation coefficient to associate an object with its user. In *Proc. Intelligent Environments'07*, 288-295.
12. Fukumoto, M., and Suenaga, Y. "FingeRing": a full-time wearable interface. In *Proc. CHI '94*, 81–82.
13. Fukumoto, M., and Tonomura, Y. "Body coupled FingerRing": wireless wearable keyboard. In *Proc. CHI '97,* 147–154.
14. Harrison, C., and Hudson, S. E. Abracadabra: wireless, high-precision, and unpowered finger input for very small mobile devices. In *Proc. UIST '09,* 121–124.
15. Hassenzahl, M. and Monk, A. The Inference of Perceived Usability From Beauty. *Human-Computer Interaction 25*, 3 (2010), 235–260.
16. Hinckley, K. Synchronous gestures for multiple persons and computers. In *Proc. UIST '03*, 149–158.
17. Hinckley, K., Pierce, J., Sinclair, M., and Horvitz, E. Sensing techniques for mobile interaction. In *Proc. UIST '00,* 91–100.
18. Kim, D., Hilliges, O., Izadi, S., Butler, A. D., Chen, J., Oikonomidis, I., and Olivier, P. Digits: freehand 3d interactions anywhere using a wrist-worn gloveless sensor. In *Proc. UIST '12*, 167–176.
19. Kim, Y. S., Soh, B. S., and Lee, S.-G. A new wearable input device: Scurry. *Industrial Electronics, IEEE Transactions on* (2005), 1490–1499.
20. Lee, J., Lim, S.-H., Yoo, J.-W., Park, K.-W., Choi, H.-J., and Park, K.-H. A ubiquitous fashionable computer with an i-throw device on a location-based service environment. In *Proc. AINAW 2007*, 59–65.
21. Lester, J, Hannaford, B, and Borriello, G. "Are You with Me?" – Using Accelerometers to Determine If Two Devices Are Carried by the Same Person, *Pervasive Computing*, *Volume 3001, 2004*, 33-50.
22. Mayrhofer, R. and Gellersen, H. Shake well before use: authentication based on accelerometer data. In *Proc. PERVASIVE'07*, 144-161.
23. Nanayakkara, S., Shilkrot, R., Yeo, K. P., and Maes, P. Eyering: a finger-worn input device for seamless interactions with our surroundings. In *Proc. AH '13*, 13–20.
24. Perng, J. K., Fisher, B., Hollar, S., and Pister, K. S. J. Acceleration Sensing Glove. In *Proc. ISWC'99*, 178–180.
25. Rekimoto, J. Gesturewrist and gesturepad: Unobtrusive wearable interaction devices. In *Proc. ISWC'01*, 21-27.
26. Saponas, T. S. Enabling always-available input: through on-body interfaces. *CHI EA'09,* 3117–3120.
27. Schmidt, A. Implicit human computer interaction through context. *Personal Technologies 4*, 2-3 (2000), 191–199.
28. Schmidt, A., Kranz, M., and Holleis, P. Interacting with the ubiquitous computer: towards embedding interaction. In *sOc-EUSAI 2005*, 147–152.
29. Suh, S.-B., Hwang, J.-Y., Shim, J.-Y., Ryu, J., Heo, S., Park, C., Kim, C., Lee, J.-R., Park, I., and Lee, H. Computing state migration between mobile platforms for seamless computing environments. In *Proc. CCNC 2008*, 1216 –1217.
30. Taylor, B. T., and Bove, Jr., V. M. Graspables: grasp-recognition as a user interface. *Proc. CHI '09,* 917–926.
31. Tsukada, A., and Yasumura, M. Ubi-finger: Gesture input device for mobile use. In *Proc. Ubicomp 2001*, 388–400.
32. Vega, K. and Fuks, H. Beauty Tech Nails: Interactive Technology at your Fingertips. *Proc. TEI '14*, 61-64.
33. Weiser, M. The computer for the 21st century. *Scientific American* (1991), 94–104.
34. Wimmer, R. Grasp sensing for human-computer interaction. In *Proc. TEI '11*, 221-228.
35. Wimmer, R.and Boring. S. HandSense: discriminating different ways of grasping and holding a tangible user interface. In *Proc. TEI'09*, 359-362.
36. Wolf, K., Schleicher, R., Kratz, S., and Rohs, M. Tickle: a surface-independent interaction technique for grasp interfaces. In *Proc. TEI '13,* 185-192.