Around-Device Devices: My Coffee Mug is a Volume Dial

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ABSTRACT
For many people their phones have become their main everyday tool. While phones can fulfill many different roles they also require users to (1) make do with affordance not specialized for the specific task, and (2) closely engage with the device itself. We propose utilizing the space and objects around the phone to offer better task affordance and to create an opportunity for casual interactions. Such around-device devices are a class of interactors that do not require users to bring special tangibles, but repurpose items already found in the user's surroundings. In a survey study, we determine which places and objects are available to around-device devices. Furthermore, in an elicitation study, we observe what objects users would use for ten interactions.

Author Keywords
spatial interaction; imaginary interface; tangible user interfaces; affordance

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces—*Input devices and strategies, Interaction styles*

INTRODUCTION

For many of us our mobile devices have become our most important everyday tool. Especially our phones, which we focus on here, are with us most of the day, wherever we go. Like a swiss army knife, we use them for a number of tasks in various roles. For example, phones can play the part of the alarm clock, remote control, cook book, level, game controller, or baby monitor. Their computing capabilities and range of sensors, give current phones enough flexibility to handle those scenarios.

While this allows phones to fulfill those roles, they also box the user into a rather restrictive interaction model. Where specialized devices can offer tailored affordances, the phone is usually a small brick-shaped device that requires the user to touch it for almost all interactions. Not only might this not be the best interaction for a given scenario, but this also requires a close engagement with the device. In contrast, interaction with a specialized device can be more casual in nature.

To take advantage of specialized physical affordances, tangibles can be introduced to the interaction. However, such tangibles are not always readily available. Requiring users to bring along tangibles for each desired affordance could encumber them too much for a mobile experience. Even when restricting themselves to a smaller subset of tangibles, the individual tangible could still be unacceptably bulky or heavy.

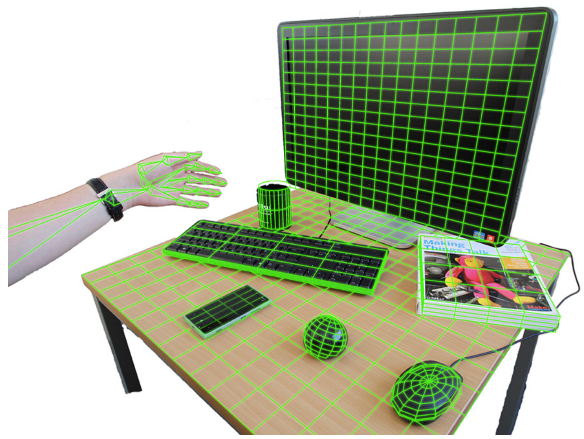

Figure 1. Instead of requiring the user to interact directly with the phone, around-device devices make use of the space and objects in the environment to offer more casual means of interaction. In this conceptual visualization the phone tracks the user's hand and detects objects nearby as geometric primitives, enabling interaction with them.

Instead, we propose repurposing objects and space around the phone for interactions. We notice that many of the objects that are in proximity to our phones over the course of a day offer good affordances for many common interaction tasks. For example, hacky sacks lying around in a room have a natural affordance for usage as push buttons, e.g., to snooze an alarm. Compared to virtual buttons on a phone screen, such physical *ad hoc buttons* allow pressing with less targeting effort (due to increased size) and allows for interactions with more varying force (we can hit the snooze button hard, if we want to).

Around-device devices are not necessarily bound to a physical object though. Instead, such a device can also be imaginary. While we cannot have real input devices floating in the air next to the user, we can have users pretend to interact with such a non-existing device. Such in-the-air input can also be gestures not directly tied to a specific device.

Around-device devices can provide better affordance, appropriateness, and casualness to phone interactions. On the other hand, such interactions around the device will usually not be as precise as direct touch interaction on the phone. Users do retain the choice to pick up their phone for more fine-grained interaction. They can pick the level of control they desire in the *casual interaction continuum* [33].

In this paper, we investigate scenarios where around-device devices could be used. Using collected ground truth data on what kind of objects people have available near their phones, we determine *which* objects and settings should be more closely considered for around-device devices. Based on those results, we furthermore present an investigation of actual behavior exhibited by users when asked to refrain from close interaction and instead tackle a series of tasks with the kind of around-device devices discussed here.

RELATED WORK

Around-device devices primarily build upon previous work in ad hoc interfaces, and around-device and tangible interaction.

Around-Device Interaction

Much around-device interaction works strives to increase the space available for user input. Kratz and Rohs, e.g., use around-device hand gestures for scrolling and selection [26]. The *BeThere* system projects around-device movements from a local space to a remote one [36]. This allows users to collaborate spatially when not collocated.

Yang et al. added an omnidirectional lens to a phone's camera to enable interaction and tracking all around the phone [43]. They use computer vision to (1) identify nearby objects, (2) detect activity, and (3) track users hands. Similar to our concept, users can trigger actions by pointing at nearby objects. However, we also explore using those objects as tangibles.

Tangible Interaction

Tangibles [22] are a way to increase the affordance of an interface, making possible manipulations more apparent [18]. As in our work, Carvey et al. investigated using everyday objects as tangibles, differentiating objects by weight, so that placing an object on an attached scale triggers actions [4]. Corsten et al. used objects with modifiable weight to allow changing of the objects' haptic properties [9].

Portico and *Bonfire* enable tangible interactions around portable devices. Camera-arms are attached to a tablet for *Portico*, where objects on and around the tablet are detected using classifier methods such as template matching [1]. Users can, e.g., roll a physical ball against the tablet to shoot a virtual ball in a game. In *Bonfire* cameras on a laptop detect objects (via color histograms) in two interaction zones to its sides [23]. While *Portico* is input only, *Bonfire* also includes projection output. In contrast to both systems, we investigate tracking that is built directly into a phone and does not require setup, such as *Portico's* extension of the attachment arms.

Ad Hoc Interfaces

Around-device devices repurpose existing objects for interactions. Similarly, Henderson and Feiner used existing features in the environment to add passive haptics to augmented reality controls like sliders and buttons [17]. Buttons, e.g., are placed on existing protrusions and spinning, bending or sliding objects are used for 3D widgets. Cheng et al. in their *iCon* system added markers to everyday objects found on users' desks and enable toggle and consecutive control by moving or touching [6]. While *iCon* looked at desktop systems with tracking above or under the desk, we investigate mobile device scenarios. However, this includes a desk setting similar to *iCon's*. Steins et al. instructed users to use imaginary input controllers and infer the used controller from a user's hand posture [37]. This enables fast device switching between the simulated controller set. *SketchSpace* is a rapid prototyping tool, that allows designers to attach virtual sensors to objects for fast and easy prototyping [19].

Corsten et al. proposed using objects as ad hoc stand-ins for currently unavailable controllers [10]. While our work is similar to theirs, we specifically investigate repurposing objects and space around a mobile device and thus place special emphasis on determining appropriate settings. Instead of focusing on *tracking* and *object association*, we focus more on aspects of *what* can be used and *how* it would be used.

AROUND-DEVICE DEVICES

Many current mobile devices constrain interaction to touch on the device. Around-device devices, on the other hand, strive to *repurpose* surrounding space and objects for interactions.

The idea of making a space *"active"* through the act of placing a device is similar to *PlayAnywhere*, where Wilson proposed a device to be placed on any table in order to enable interactions on it [41]. One could argue that many of the benefits of around-device devices described in this paper could be achieved by installing tracking systems in those locations we investigate, like the office. However, we believe there are intrinsic advantages to an approach that concentrates on sensors built into a device, observing the space around it.

First of all, instrumented rooms require a much larger amount of equipment. This increases costs and costs scale with the number of places in which a user would like to use around-device devices. Furthermore, there are important privacy concerns: would users, e.g., accept offices that constantly track them and would a date be accepting of a bedroom with cameras in the corners? By having the tracking inside their personal device, users can more conveniently customize their tracking (e.g., by defining different gestures) and ensure their setup always comes with them. This also ensures detection can be tailored better to a specific user, whereas room-based systems have to cater to the requirements of a larger number of potential users. Furthermore, containing the system in their personal devices allows users to retain a sense of control. It is clear *when* the system is tracking (the phone is on the table) and tracking can be easily blocked temporarily by turning the phone around, placing a hand over it or putting it away.

Benefits

Looking at the main benefits of around-device devices, they allow users to (1) choose interactors with more suitable affordances, (2) interact more casually when they do not want to grab their phone, and (3) extend their interaction space, no longer restricting them to interaction on the device itself.

Suitable Affordances

Current phones cannot morph into different shapes, and thus cannot adapt to the affordance most appropriate at the moment. Tangibles, on the other hand, are purposely designed

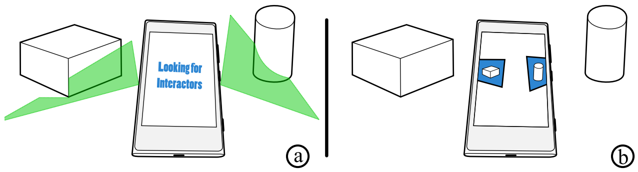

Figure 2. Here we show one way users can define around-device devices. When (a) the phone scans the surrounding space it finds two objects suitable for interaction and (b) uses *Wedge* [13] to inform the user about their type and location. Users can then click on an object to, e.g., associate it with an action in a next step.

to offer specific affordances (e.g., to invite turning in a knob). Unfortunately, users do not always carry such tangibles with them or have them ready at home or at work. For many tasks, we can instead make use of objects already available nearby.

Casual Interactions

Interaction with mobile phones generally requires users to closely engage with them. For physical, social or mental reasons, however, this is not possible or desirable in every situation. Instead of constraining users to a single engagement level, Pohl and Murray-Smith have proposed allowing them to pick their desired level of engagement on the *casual interaction continuum* [33]. They showed, that when given a choice, users naturally adapt their level of engagement (how closely they interact with a device) according to the task difficulty.

Around-device devices can fill an important role in casual interactions. They essentially offer users a more casual interaction possibility for situations when they need less engaging interaction or are ok with relinquishing some control. For example, in situations where close interaction with a mobile phone is frowned upon (e.g., in a meeting), it might still be acceptable to interact with other objects nearby. This could be something as basic as scrolling through a list of upcoming appointments on a *glance screen*[1] by turning a mug. While users might not universally be able to give detailed commands this way, they could still provide coarser input. Some coarse interactions such as slapping, more forceful touching or hitting are only acceptable with objects more resilient than mobile phones. This user-chosen trade-off between interaction fidelity and engagement defines casual interactions.

Extended Interaction Space

While phones have been getting bigger recently, the interaction space is still comparatively limited. Enabling input in the space around the device and with objects around it substantially increases the available space. The space is tied to the sensing in the phone, making it inherently personal. We are less inclined to place our phones next to strangers, thus are also not extending our interaction space towards them.

Challenges

A general problem with any around-device device (and also tangible and gestural interaction in general) is how users inform, e.g., their phone about an around-device device. Ideally, users would not need to retrain such an association every time they intend to reuse an around-device device. However, more ad hoc situations require a fast way to define associations.

When phones track objects around them, those can be offered to the user for associations. In Figure 2 we present an example, with off-screen visualization to show surrounding objects. Avrahami et al. indicate tracked around-device devices in a similar way [1]. This can be reactive—the phone detects an object nearby was pressed and asks the user whether an association should be made. Such a prompt is transient and disappears if the user does not engage further with the device.

In cases a more temporary association is desired, it will often be sufficient to offer the user to grab any object or just use their hands. Figure 3 shows an example of a game that on startup allows the user to either touch the virtual joystick on the screen or place the hands next to the device for an around-device joystick. The association in this case is established in a dedicated specification mode.

Mappings can also be implicit, offering a kind of plausible default mode, based on a state constraint. For example, when music is playing on a phone a user could expect nearby objects to automatically take on a role in the control of the audio. A nearby object with button affordance could, e.g., be assumed to be a play/pause button, a nearby tube to be usable as a volume slider. We can envision similar situations when an alarm is ringing, a call is coming in, or a beep signals an incoming message. For casual interactions it is important that the overall interaction costs are low. Thus, implicit and temporary mappings are more appropriate in that context.

Mobile projection from the phone could be used to indicate the default objects and possible interactors. Thus projection is also possible along the same optical path. Devices would not project on their surrounding space all the time, but would only do so when queried by the user. Projection can also be substituted by off-screen visualizations of the current mappings on the device itself.

Fundamental constraints are imposed through occlusion. If the phone cannot see an object it cannot be tracked for interactions, which may not be clear to a user. While this is a general problem of vision based systems, around-device devices can avoid this limitation to some extent by assuming shape constraints. For example, when the phone sees the front of a bottle it can detect it as a cylindrical shape and *infer* interactions on the back. Thus, occlusion in some situations does not impede interaction. Projection could also demarcate a phone's sensing limits to the user.

AROUND-DEVICE DEVICE TYPES

In this section, we categorize around-device widgets and outline how they can improve interactions.

Around-Device Trigger Controls

Phone applications such as alarm clocks, stopwatches, or call response are centered around simple trigger interactions (e.g., stopping the alarm). With touch control, this requires acquiring targets on the screen and sometimes unlocking the screen to start the interaction. There is no haptic feedback or tactile sensation to pressing those on-screen buttons.

For around-device devices, we propose repurposing objects in the environment as trigger controls. A trigger could be any prominent protrusion [17], but would often ideally be

[1] http://conversations.nokia.com/2013/06/25/a-closer-look-at-glance

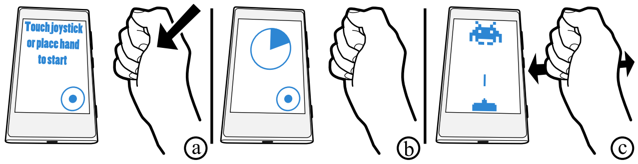

Figure 3. Mobile phones with sideways hand detection can offer players an alternative to on-screen joystick controls. (a) At the start of a game, the player is given the choice on what control to use. (b) When placing her hand next to the phone and holding it still for a short moment, the hand is detected as a joystick replacement. (c) The player can then control her ship's movements by moving the hand next to the phone as if she was holding a physical joystick.

an object inviting pushing. A hacky sack or stress ball, for example, invite slapping and allow users to apply substantially more force to the button than phones would allow (making turning off an alarm that much more satisfying). Apart from tapping or pushing on objects, actions could also be triggered via object arrangements or manipulations (e.g., flipping an object around).

Around-Device Linear Controls

Increasing or decreasing some value is a recurring task in many applications. Most mobile phones, e.g., offer dedicated buttons to control the volume level. Linear control is also required for adjusting the screen brightness, seeking in media, or setting a numeric value with a spinner control. An example of a tangible linear control are *Fillables* by Corsten et al. who, e.g., propose allowing users to scroll through video by moving a glass [9].

Henderson et al. have proposed utilizing edges, pipes, or cords as a base for around-device linear controls, making use of their haptic properties [17]. As we will show later, a number of objects found near mobile phones fit into this category (e.g., pens, candle holders, or cables). Any object that can be moved closer to or further away from the phone could also be used by mapping distance to value.

Around-Device Game Controllers

In contrast to dedicated portable game devices, phones do not offer physical game controls. This constraint has yielded many games specifically designed around touch/gesture control. However, this is not always possible and thus we can find a plethora of on-screen buttons and joysticks. Compared to physical controls, those digital substitutes provide no haptic feedback, making zeroing and not overshooting challenging. Furthermore, large parts of the screen are occluded by the player's hand when using such on-screen controls.

Around-device joysticks or steering wheels could be just tracking the hands themselves (as shown in Figure 3). This has recently been explored by Steins et al. [37]. While this enables fast device switching, those *imaginary devices* do not provide haptic sensations. To get zeroing, plungers could be given to players to grab as around-device joysticks. Any round object (e.g., a plate) would be appropriate to form the base of a steering wheel controller. Thus, children could, e.g., be playing a driving game while waiting for lunch.

Around-Device Input Devices

Researchers have investigated replicating traditional desktop input controllers as imaginary ones. Most prominently, Mistry and Maes built *Mouseless*, where a user's hand is tracked next to a device for an impromptu mouse emulation [30]. Terajima et al. show how fingers could be tracked for in-air typing [39]. Canesta in the past offered a commercial projection keyboard for ad hoc typing capability. In-air typing is also available for the Leap Motion controller through the *DexType*[2] application. Instead of specific shapes for each device, *Visual Panel* tracks a quadrangle and maps user touches to pointing or typing interactions on a desktop [44].

We can envision other input devices being emulated as well. For example, tracking a pen or pen-shaped object around a phone could enable around-device writing or drawing [21]. Simple devices like remote controls can be replaced by gestures [2], but could also map to nearby objects with a more casual interface (i.e., restricting the set of operations, while retaining control of the main task, e.g., changing channels) [33].

Around-Device State Control

Instead of directly interacting with objects, their presence and arrangement itself can encode state. For example, if the phone were to detect several mugs together it could switch to a silent mode as not to disturb a conversation. Arranging common objects on a desk gives a subtle control opportunity, were, e.g., a bottle's proximity to the monitor could affect an application. Users could deliberately reveal or hide arrangements to put their phone in different modes.

Around-Device Storage

While this paper focuses on controls around a device, the objects and space investigated here, could also be used for storing data. For example, Hasan et al. discretized the space in a plane around a device into bins and allowed users to store and browse content there [16]. In addition to such 2D approaches, storing data in 3D space around the user has also been explored [28].

SENSING AROUND-DEVICE INPUT

Current mobile phones do not include the capability for sensing around-device interactions to the extent necessary for around-device devices. However, we think there are no fundamental problems in bringing this kind of sensing to future mobile devices. There has been substantial previous work exploring how this could be done as well as new sensors in mobile form factors from industry. In this section we look at the state of the art for around-device sensing. We believe the approaches described here paint a clear picture that our envisioned around-device devices scenario is grounded in technology that can be expected to be available soon.

Instrumentation

Instrumenting the user, the environment, or objects is one approach to sensing around-device interaction. This could be a worn color glove [40] or markers put on objects. Instead of a glove, *Digits* has users wear a device on the wrist that is able to track hand gestures [25].

[2]http://dextype.com

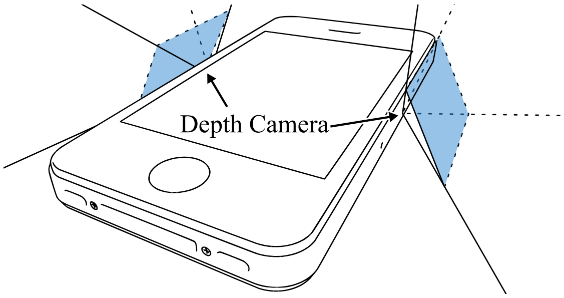

Figure 4. Future mobile devices are likely to include depth cameras with a large field of view in the sides of the device. The field of view shown here is equivalent to the one of a Leap Motion controller. Shading does not indicate sensor range but only highlights the field of view.

Devices incorporating magnetometers, can track fingers wearing magnetic rings [15] or users holding magnets or objects containing magnets [24]. Hwang et al.'s *MagGetz* are physical widgets (e.g., buttons) with embedded magnets that can be placed around mobile devices for customizable around device tangible controls [20]. *EyeRing* is a more sophisticated ring with a built-in camera, that was designed around pointing gesture interaction [32].

Researchers have also looked at using eletromyography to sense muscle activity to, e.g., recognize hand gestures [35]. However, instrumentation restricts interaction to specific rooms or encumbers the user. Thus, we believe a different approach would be more suitable for around-device devices.

Electric Field Sensing

Many touchscreens on mobile devices make use of capacitive sensing. While this technology works well for 2D tracking, it can also be used to track conductive objects (including humans) in 3D. This approach has recently regained interest with researchers looking at tracking users in rooms [8], fine grained hand tracking [11], and tracking for mobile devices [27].

To sense in 3D, electric field sensing requires usage of more than one electrode. Electrode placement has to be such that field lines pass through the desired sensing space. Thus, only having electrodes in a mobile device would most likely not be sufficient for tracking interactions in a larger space. One solution would be to have retractable electrodes that can be pulled out and placed where desired or integrate this technology in earpieces, attached to the phone anyway.

Optical Sensing

Most phones today already include cameras and we believe it would only be a small step from the status quo to integrating depth sensing sensors. In *SideSight* infra-red sensors were embedded along the sides of a mobile device, enabling finger tracking for tasks such as panning on-screen content [3]. Choi et al. arranged the same kind of sensors in a touchpad for *ThickPad*, to enable hover-tracking above the touchpad [7]. Instead of individual infra-red sensors, *Z-Touch* uses infrared laser planes and detects fingers crossing them [38], an approach similar to the one used in *Mouseless* [30].

Depth cameras have also been shrinking and could soon be generally available in mobile form factors. For example, PrimeSense was offering the *Capri* sensor, an embedded design delivering VGA resolution from 0.9 m to 4.0 m before being bought by Apple. Occipital is planning to make the *Structure Sensor*[3], a mobile depth sensor attachment, available in late 2014. Google's *Project Tango*[4] is set to make a prototype phone with a depth sensor embedded in the back available this year.

Other Sensing

More exotic approaches to sense around-device input include *SoundWave*, where the doppler effect is used to detect gestures [12], or using steerable lasers to track fingers in 3D [5].

NOMADIC TANGIBLES FOR MOBILE DEVICES

Around-device devices can be used when the phone is lying around somewhere. While phones are mobile, we posit that most of the time they will, in fact, be placed somewhere. We investigate scenarios where this is the case and what interactions are suitable in those situations. Furthermore, we collected ground truth data on actual device contexts via a crowd sourcing task.

Envisioned Scenarios

We initially brainstormed to collected a set of locations where we think phones would be lying around. In the brainstorming, we identified four such locations:

Office: When brought to the office, people will often place their phone on their desk.

Bedroom: Many people will be using their phones till the end of the day and/or use them as alarms, making placement on the nightstand near the bed a likely option.

Kitchen: During breakfast or dinner, phones might just lay around on the dining table.

Living Room: While relaxing in the evening, phones might be placed on the couch or coffee table.

For each of those locations, we determined what kind of objects we expect to be available for interactions. We do not claim these lists are exhaustive, but they provide a rough bearing of what is characteristic for such places.

Office: staplers, monitors, keyboards, mice, landline phones, mugs, books, pens, office toys (e.g., Newton's cradles).

Bedroom: pillows, books, lamps, glasses cases

Kitchen: cereal boxes, bowls, cups, mugs, glasses, silverware, candle holders

Living Room: remote controls, pillows, books, lamps, bowls, boxes

Depending on the location, different kinds of interactions are appropriate. In an office setting, around-device devices could, e.g., be useful for more casual interactions during a meeting (see earlier scenario) or to support peripheral tasks at the desk. At home, we see the role of around-device devices also primarily as enabler for casual interactions when sitting on a couch or lying in bed. When in the kitchen, users could also benefit from around-device interactions when not willing to interact with their device, e.g., because of dirty hands.

[3] http://structure.io

[4] http://www.google.com/atap/projecttango

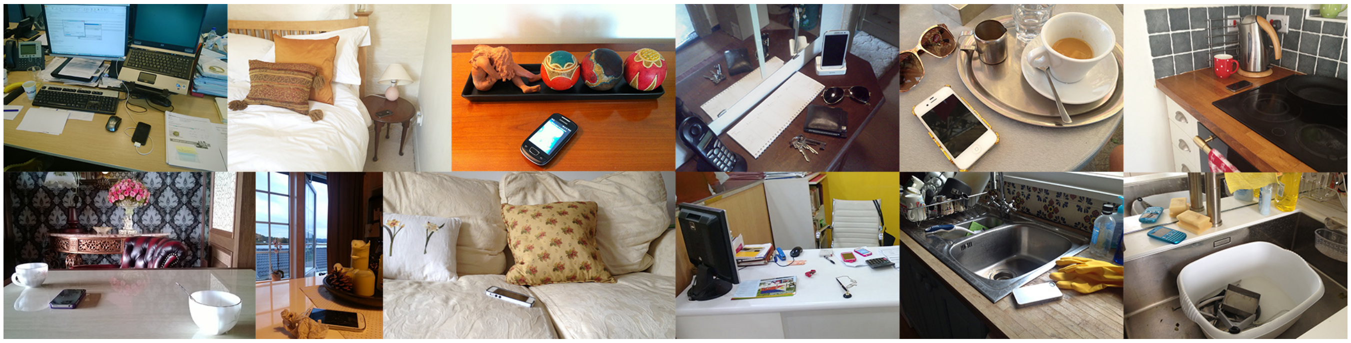

Figure 5. Photos depicting settings where phones are lying around. Overall 510 photos were collected via the Scoopshot crowdsourcing service. Copyright of shown photos (numbered clockwise from top-left corner): Ricardo Alves (3), Jens Bloszyk (4), Sarah Jenkins (2, 6, 9, 11, 12), Petra Larsson (8), Sem Lemmers (1), Brad McDougal (10), Rostislav Sedlacek (5), and Chaichan Srisawat (7).

Phone Context Ground Truth

While we established a rough idea of places and objects for around-device devices with the brainstorming, we felt this does not give a full picture of the space. Previous work gave us additional data on those settings. For example, Harrison and Hudson visited ten participants at home and at work to look at placement locations of their phones [14]. Unfortunately, their list focuses on the materials at those locations and does not include details on the space and the objects available. Another six users were visited by Carvey et al., who looked at nearby objects and interviewed them [4]. This investigation, however, does not focus on phone locations. On the other hand, they made interesting observations on people's object mappings, e.g., how in *transient couplings* users were inclined to repurpose any nearby object for simple and immediate tasks. Finally, Cheng et al. in a field study collected photos of 33 desks and the objects on them [6]. This study also focused on desktop scenarios and the paper unfortunately does not provide detailed object information. However, they did learn that most participants placed phones on their desk.

To get some qualitative validation of our own for our envisioned scenarios, we set out to gather real-world data on the places where people lay down their phones. We used the Scoopshot[5] photo crowdsourcing service to collect photos for this purpose (a subset of the photos can be seen in Figure 5). On Scoopshot, users can create tasks to ask other users for photos, matching the task's description. We created several tasks asking users to send in *"photos of places where people usually have their phones lying around"*, where *"the phone and the context (e.g. objects around the phone) should both be visible in the photo"*. Tasks can be assigned to a geographic region, where users get a notification of the new task on their phone. However, users from elsewhere are able to submit photos as well when seeing the task on the Scoopshot website. We ran the task in several regions with high user density: around Amsterdam, Berlin, Copenhagen, Essen, Frankfurt, and Istanbul.

We collected a total of 510 photos[6] from 249 different users. We were able to collect photos from a wide range of locations, not restricted to only those we advertised the task in (note that not all photos included location information). The majority of submissions still comes from Europe (91.9%, including Turkey), so there might be some cultural bias in the dataset. While the majority of users followed the task description, many sent in photos not in line with our requirements (e.g. no phone visible in the photo). Hence, we removed those contributions, leaving us with 286 valid photos. For each photo, we manually annotated the location of the phone and the nearby objects. We only included objects visible in the photo and did not infer other objects (i.e., no mouse is assumed just because a keyboard and a computer are visible). We also only included objects in the range of the phone, if, e.g., an object is only visible in the far distance (beach, outside, ...) it was not counted. Table 1 shows the most common locations, while Table 2 shows the most common nearby objects.

Location	Count	Location	Count
Table	94	Bathroom	7
Desk	50	Shelf	5
Bed	20	Dresser	5
Kitchen	11	Bag	4
Couch	10	Car	4
Restaurant	8	Nightstand	3
Garden	8	Boat	3

Table 1. Most common phone locations in the photo dataset.

Many participants also left comments in a field reserved for the photo description. While mostly just describing their photo, some left more general comments, e.g.:

- *"my mobile phone must lay beside the bed when i'm sleeping"*
- *"Wherever I am, my phone is too! It even comes with when I'm making food and is usually playing music!"*
- *"If I was cooking. My smartpohne is in the kitchen too."*
- *"Das Smartphone liegt zwischen allem anderen auf dem Schreibtisch, immer griffbereit." (The phone is lying on the desk between all that other stuff, always available.)*
- *"It is always near me"*

Discussion

The locations we got from ground truth roughly match up with the set we expected. Additionally, we saw some that were more surprising to us, such as boats, bathrooms, or window ledges.

[5] http://www.scoopshot.com

[6] Photos for each task available at http://www.scoopshot.com/v2/task/{bdwnmsxpvvhdd | cnqlcbltsgxvr | bxvhlnmpwqcgx | bnnqhlrcbrlzg | lrdljhdppddxm | bxcjxxpvlsbzk} respectively.

Object	Count	Object	Count
Cable	38	Tray	12
Phone	37	Container	12
Glass	35	Can	12
Box	33	Flower	11
Paper	32	Notebook	11
Bottle	30	Candle holder	11
Laptop	28	Lamp	11
Bowl	28	Charger	11
Cup	27	Ashtray	10
Keyboard	24	Saucer	10
Mouse	24	Headphones	10
Pillow	23	Figurine	9
Pen	18	Handle	9
Monitor	16	Spoon	8
Book	15	Fruit	8
Sunglasses	13	Pot	8
Tablet	12	Post-its	8
Mug	12	Vase	8
Plate	12	Keychain	8
Bag	12	Remote	7

Table 2. Most common objects near phones in the photo dataset (corresponding geometric primitives given where applicable)

Objects found near phones also largely overlap with our expectations. Bottles, glasses, bowls, and lamps are rather common, while we did not expect the amount of nearby other phones (which supports collaborative usage scenarios such as [29]). Generalizing the found object set, we can sort the found objects into a set of five categories (also illustrated with proxies in Figure 6):

- Spherical objects, such as balls or some fruits
- Dome-like objects, such as plates, bowls, or cups
- Cylindrical objects, such as bottles, cans, mugs, or candles
- Rectangular cuboids, such as boxes, monitors, books, or other phones
- Complex shapes, such as sunglasses, crumbled paper, or figurines

While each object may have additional semantic cues for how people perceive it to be used, their shape already imbues them with certain affordances. For example, spherical objects invite rolling, while cylindrical objects invite turning around the up-axis.

For many of the observed objects, we can make additional assumptions according to Gestalt law. For example, seeing the front of a glass one can assume that the back is similar. By focusing on interaction with objects corresponding to geometric primitives, we can use those assumptions to, e.g., alleviate occlusion problems somewhat. Just because a part of an object is not seen, does not mean it cannot be tracked or that touch on that part could not be inferred.

USER PREFERENCES IN AROUND-DEVICE DEVICES

The collected images have provided us with a good overview of what objects would be *available* for users to incorporate into their interactions. However, most likely not all those objects would be considered equally by actual users. Thus, we designed an elicitation study to collect additional data on which objects would potentially be *used* for interactions if available. This is similar to a previous study by Wobbrock et al., who asked users to come up with tabletop gestures to achieve a shown effect [42].

Figure 6. Exemplary object arrangement for a desk scenario, including all shape catagories found in the ground truth study.

Participants

We recruited 15 participants (5 female, age 20–46, $\bar{x} = 29.07$, $\sigma = 6.88$) from our institution. The study took approximately 30 minutes and after completion, participants received a small non-monetary gratuity.

Task

We defined a set of ten tasks we felt were an appropriate subset of possible around-device device input scenarios. While covering many phone-specific tasks, we did not include tasks requiring prolonged interaction. Thus, the task list does, e.g., not include a task where participants could be expected to use an object as an ad hoc joystick. However, the used tasks allowed participants to potentially make use of around-device buttons, sliders, or state control.

During the study, participants were asked to find the interaction they deemed most suitable for:

1. Changing the volume of music already playing
2. Rejecting an incoming phone call
3. Dimming the lights
4. Check whether any (email, SMS, IM, ...) new message has arrived
5. Notifying their next appointment they would be a bit late
6. Skipping to the next song
7. Setting an alert/notification for when to leave to catch the next train
8. Querying their sport team's current score (game still running)
9. Querying the status of their ongoing ebay auction
10. Muting their phone

Participants were told that the system has any task-relevant context information available (e.g., calendar with upcoming appointments, information on favorite sport team, or train schedules) and they would not need to relay that information and could limit their interaction to communicating intent.

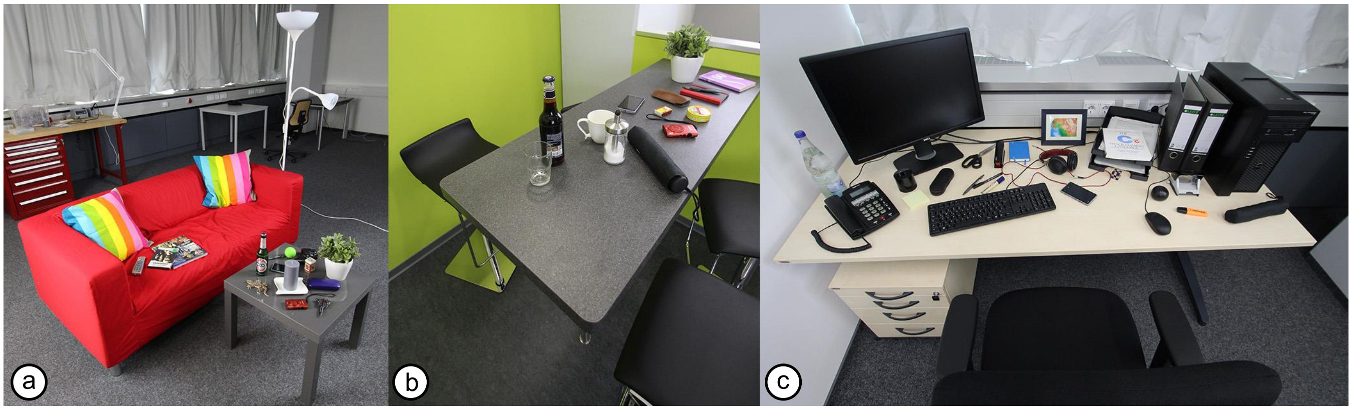

Figure 7. We asked participants how they would perform a series of ten tasks when limited to casual around-device interactions (object movement, object arrangement, gestures, coarse touch, . . .). This was repeated for (a) living room, (b) café, and (c) office scenarios with different objects available.

Procedure

We instructed participants not to consider speech input and close interactions with the phone (such as unlocking and starting an app). As this was an out of the ordinary requirement for many, we used a *priming* technique [31] and pointed out several other approaches they could use with objects instead: (1) moving or rotating, (2) changing arrangement, (3) placing them on top of others, (4) appropriating features or surfaces for touch, (5) performing gestures relative to them, or even (6) performing gestures independent of any object. We did not ask them to restrict themselves to these examples or indicated any preference. As we were only interested in input, we told participants not to worry about output and just assume any feedback would be presented at an appropriate location or provided via audio. Furthermore, we assured participants any answer would be okay including reuse of previously performed interactions. To ensure participants would not concern themselves with recognizability, we told them to assume having previously defined that interaction and that sensing would be capable of picking up any interaction they perform.

In line with the most common settings determined earlier, we choose three different scenes for the study (shown in Figure 7): a living room, a café, and an office. The objects available in each varied, but there was always a mobile phone present in the scene. Other objects present in multiple scenes include: notebooks, bottles, books, umbrellas, pens and markers (see Figure 7 for shots of all present objects). Even though we found multiple phones were often present in the collected dataset, we chose to concentrate on single-user scenarios here were this is not the case. All of the ten tasks were repeated in every scene. We counterbalanced scene order using a reduced latin square design and randomized task order for each scene.

Results

Overall, participants provided a wide range of interaction choices. There was substantial agreement for some tasks, but generally we observed many different approaches.

1. Change Music Volume

Participants almost exclusively followed one of three strategies: (1) turning some object (mostly the phone) on the table, (2) performing a circle gesture on a nearby object (often on the headphones, if available, or on furniture, especially armrests), or (3) using a hand up/down gesture. This behavior was sometimes coupled with an activation step such as clapping three times or pointing at speakers.

2. Reject Phone Call

The most common interaction used by participants was flipping the phone upside down. A close second is performing a "brush aside" gesture over or towards the phone. Some participants also knocked or patted the phone, placed an object on the phone, or performed a "put handset down" gesture.

3. Dim Lights

Here participants used interactions similar to those in task 1. However, they would often point at the lights first before initiating a gesture and use different objects, such as the candle. In the living room scene, several participants used parts of the lamp as base for sliders. Additionally, some participants used hand open/close gestures.

4. Check for New Messages

Most participants here chose to just tap the phone once, stating that any interaction should prompt the phone to display such information. When using gestures, participants would draw question marks on, or circles (like a "refresh" gesture) next to the phone. Many participants associated the notebook with checking for new messages and expected opening the notebook to display the status. Two participant used subtle cues such as glancing at the phone or turning it towards them.

5. Send Delay Message

Generally, participants made three mental connections here: (1) associating the task with leaving and thus, e.g., placing the umbrella or the phone itself ready to go (e.g., at table edge), (2) tapping on their watch or mimicking a clock hand with a pen, stressing the task's association with time, or (3) interacting with the notebook (often described as calendar) because it is associated with the appointment itself.

6. Skip to Next Song

Here participants almost universally waved right, swiped right, or moved objects to the right. They would also tap on the right side of objects (e.g., headphones or chairs) or on the right of two objects (pillows). This was sometimes coupled with claps or pointing to speakers like in the volume changing task.

7. Catch-a-Train Notification
Similarly to task 5, many associations were formed around leaving, the most common one being placing the phone or the umbrella in a "ready to leave"–spot. Many participants also performed a "walking fingers" gesture for the same purpose. Some also placed objects so they would point to the door.

8. Sport Team Status
Most participants here thought of soccer and thus interacted with a ball (or other roundish object if no ball was available) to query the status. One participant arranged three objects in a row to query Formula One rankings. When not referring to a specific sport, participants often just tapped the phone, assuming this would also show game scores (similar to message status in task 4). Some also used notebooks, associating those with a general information lookup action.

9. Auction Status
There was little agreement in this task and participants used a diverse set of interactions. Some made connections to physical auctions, e.g., mimicking use of a gavel. Several times an object (often the camera) was picked and determined to be a stand-in for the auction. Often participants pointed out this task falls under a generic "query status" category and reused tap-on-phone gestures like in task 4.

10. Mute Phone
Almost all participants flipped the phone and placed it screen down for this task. Some also used variations of a shush gesture or placed objects on the phone to cover it.

Discussion
Looking at the interactions picked by participants, we see a strong preference for some (e.g., flipping the phone) and less consensus for others. Overall, we expected participants to make more use of available objects. Instead, participants often used gestures, frequently near or on specific objects, and placed objects in dedicated zones. We speculate this might be due to unfamiliarity with this kind of interaction and *legacy bias* [31]. Correspondingly, phone flipping might have been frequently used because it is already available in some phones for silencing an incoming call. However, we were impressed by the diverse set of associations participants were able to make. Ranging from the very abstract (three paper clips in a row ⇒ Formula One ranking) to the very concrete (writing "ebay" with a finger on the table ⇒ check auction status).

While we told participants to assume context awareness in the system, we still did not expect how much many participants relied on this. For tasks that can be grouped under *check status*, participants very often just looked for trigger interactions and expected the system to show all their desired information. It would be worthwhile to further investigate how we can design systems with more adaptive notification mechanisms that take those expectations into account.

CONCLUSION
In this paper we have looked at around-device devices, a future class of interactors for depth sensing mobiles. We have shown how such devices have beneficial properties with respect to (1) affordance, (2) casual interactions, and (3) interaction space. Furthermore, we conducted a ground truth investigation into what objects would be available for the kind of interaction presented here. We hence gained a quantitative insight into what objects designers could assume to be most likely available. Furthermore, we conducted a study to determine which of those objects users would actually use for a range of tasks and three different settings.

Around-device devices enable users to imbue objects around them with rich interaction capabilities. With many objects sufficiently described by geometric primitives, this also allows for interaction in settings with light occlusion. Mobile phones, our everyday companion device, can be the sensing center for those interactions. This ensures a sense of control and personalization hard to achieve with instrumented rooms.

FUTURE WORK
Small size depth sensing is not yet universally available, however, we expect it to be in the near future. Once available, actual mobile devices with around the device depth sensing can be built. While we investigated which objects are available to these kind of devices, and which ones participants would pick in a lab study, future prototypes with integrated depth sensing will allow in-the field studies of how people actually use such a system under in-the-wild conditions.

We have not investigated the combination of around-device input with around-device output. Especially the combination of mobile depth sensing with mobile projection would enable new interaction possibilities. Around-device devices are also a good fit for experiments in combination with more subtle output possibilities (e.g., ambient indicators in phones [34]).

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