Chameleon Devices: Investigating More Secure and Discreet Mobile Interactions via Active Camouflaging

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Figure 1. Chameleons are well known for their ability to change the colour of their skin for survival and social signalling [10]. Sometimes this colour change is to indicate aggression towards other animals, or in response to temperature or mood (left); at other times, as in the centre left image shown here, chameleons can match the pattern of their surroundings near perfectly, perhaps to lessen the danger from predators. In this work, we explore how mobile devices might be able to perform the same feat. The centre right image, then, shows a phone placed normally on a table. At right: the same phone blended in to its surroundings, but still able to present social signals to its owner in a subtle manner.

ABSTRACT

Many users value the ability to have quick and frequent sight of their mobiles when in public settings. However, in doing so, they expose themselves to potential risks, ranging from being targets of robbery to the more subtle social losses through being seen to be rude or inattentive to those around them. In nature, some animals can blend into their environments to avoid being eaten or to reduce their impact on the ecosystem around them. Taking inspiration from these evolved systems we investigate the notion of chameleon approaches for mobile interaction design. Our probes were motivated, inspired and refined through extended interactions with people drawn from contexts with differing ranges of security and privacy concerns. Through deployments on users' own devices, our prototypes show the value of the concept. The encouraging results motivate further research in materials and form factors that can provide more effective automatic plain-sight hiding.

Author Keywords

Camouflaging devices; subtle notifications; mobiles.

ACM Classification Keywords

H.5.2 User Interfaces: Interaction Styles; GUIs; Evaluation

INTRODUCTION

In the animal world there are many examples of creatures that are able to camouflage themselves into their environments. Stick insects, for example, have evolved over time to look more like the shrubs they live in, making them less attractive to potential attackers. Other animals, such as certain lizards, toads or owls, have coats imitating the colours of their natural habitat, visually disguising their presence. Some *Chamaeleonidae* species are so adept at this that they are able to replicate the colours and patterns of their surroundings, blending in to almost any background. The ability to hide in plain sight, observed so often in nature, can be an excellent method of security. For many animals, this security is a matter of life-or-death, lessening the likelihood of being devoured by a predator. In the human world, this security is often less critical, but just as effective – see, for example, safes that are disguised as books to keep the most valuable items hidden from burglars, or birdwatching attire intended to minimise scaring wildlife.

In this paper, we explore camouflaging methods for handheld mobile devices that aim to make them more secure and private, and less likely to disrupt social interaction when in public. Like the aforementioned safe disguised as a book, then, the approaches are designed to guard against theft; and, like the leaf-mimicking birdwatching clothes, they aim to avoid interrupting or disturbing those around the user, "in the wild".

The long-term vision for the work is that a user could put down their mobile phone on a surface, on themselves (such as on top of their leg when seated), or on another object, and the device would quickly change colour, pattern or even texture to match the environment. We are aiming, then, for a literal implementation of Weiser's famous ubicomp principle that computing should "vanish into the background" [49], disappearing into the woodwork (and other surfaces). Once dissolved into the surroundings, the device should still be able to provide some services of value to the user (such as providing notifications of events or messages). Figure 1 shows both real chameleons and an artist's impression of the Chameleon Phone concept.

To explore the opportunities for such a device, we carried out several studies and participatory design workshops over a year-long period focusing on two types of location. Firstly, we worked with people who live in contexts where security and safety are daily concerns and where people make a conscious effort to limit device visibility in public places [50]. Their intense understanding of the need to protect their mobiles while out and about led us to consider the opportunities around radically hiding a device in plain sight, in the same way the chameleon is able to. Secondly, we considered places where daily security concerns were much lower. Here we saw strong evidence that mobile devices are routinely visible in public while not being actively used by their owners, presenting clear opportunities to design for subtler, discreet interactions.

In this paper we present the findings of these studies and the Chameleon Phone probe that we have built. To understand how to address the spectrum of needs relating to security, privacy and social disruption, we conducted a longitudinal deployment of this probe with groups of users in three locations where security concerns are high; and, one location where such concerns are much lower. We discuss the contrasts between the needs for security, privacy and social interruption in the four sites as well as examining the design's potential use across the regions. The probe was deployed as an app on each user's own phone; our aim here, though, is also to encourage innovation in terms of materials and device form factors. To conclude the paper, then, we discuss possible ways that future devices might address the opportunities identified during our studies.

BACKGROUND

Invisibility and blending in

The ability to make things invisible or 'blend in' to the background has always been highly sought after. Whether in science fiction or nature, there are a wide variety of techniques for reducing the perceived visibility of an object or creature.

Some animals (such as certain jellyfish or frog species) and materials (such as glass or perspex) allow light to pass through them, making them appear transparent and therefore more difficult to see. Turning to digital technology, there is plentiful research that suggests that semitransparent displays are beneficial for users to be able to simultaneously see on-screen content as well as the background behind the display (e.g., [23, 34–36]). Selective transparency has also been used to make a user's hands and tools appear partially transparent to aid in manual tasks [3]. Similarly, related research has employed virtual transparentising to alter the appearance of the top layer of a document stack to reveal the documents beneath [24].

The technique of optical camouflaging [21] creates the illusion of invisibility by projecting the scene directly behind an object (from a precisely-placed camera) on to the object itself. This type of 'invisibility' has also been used for safety purposes in vehicles. Yoshida et al. [51], for example, proposed cars with 'see-through' doors and dashboards in order to reveal objects that would otherwise be out of view for a driver. Similarly, Samsung has trialled trucks with large displays that broadcast the view from the front of the vehicle to following drivers, allowing them to 'see-through' the truck and pass safely [44].

A wide variety of physical approaches have been used to achieve varied levels of cloaking. For example Choi and Howell [7] demonstrate the use of lenses to steer light around an object. However, due to the nature of the method, the invisibility effect is only achieved when viewed from direct angles. Cloaking has also been achieved using optical metamaterials (e.g., [12, 43]) or light redirection (e.g., [5, 18, 20, 53]. More detail on these types of technology can be found at the end of this paper where we discuss future directions for the research.

Blending-in research has also been conducted in the area of fashion HCI. Kashanipour [30] for instance, also took the chameleon as inspiration, styling mobiles to match (rather than blend into) a user's clothes by setting the phone's wallpaper to a photograph of part of the owner's outfit. Related research into the use of mobile devices as fashion accessories (e.g., [27]) has also explored phone cover designs [25] or organic interfaces [28] in order to better fit fashion-conscious users. In this work, we focus on visual camouflaging in a similar manner to the optical hiding of [21], or large-scale 3D projections.[1] However, our design also employs subtle changes to the camouflaged surface in order to provide discreet notifications and updates, while endeavouring to remain hidden.

Subtle notifications

As we will explore in subsequent sections, the chameleon probes described in this paper combine camouflaging with discreet signalling. One of the benefits of this approach is its ability to provide subtle notification cues to users to give a sense of privacy and minimise social disruption. It is well known that frequent push notifications can cause social disruption [16, 17, 22], particularly when it is estimated that the average phone user receives around 63 notifications per day [39]. Many push notifications are both audible and visual, and often tactile in nature, aiming to ensure as far as possible that they capture the attention of the phone user.

Hansson et al. [14] suggest that audio-based cues are often intrusive and disrupt social interaction, whereas tactile cues are so private and subtle that they can lead to awkwardness if collocated users cannot understand the actions that a notification gives rise to. Similar suggestions about candid interactions have been made by Ens et al. [11] from the perspective of wearables. With this in mind, we opted to use subtle visual colour cues in our design to provide notifications. As a result, cues will be discreet, but more importantly abstract, ensuring the privacy of the user is maintained. Similar abstract cues have also been investigated on low-resolution displays – see, for example [4], which used just three pixels on a wearable, so that only the wearer was able to interpret meaning.

[1] See: emftechnology.co.uk/outdoor-building-projection.

Bartram et al. [2] have studied the use of moving icons (Moticons) on-screen in terms of distraction and effectiveness at conveying information. Their results showed that motion is significantly better than colour or shape changes for attracting attention, particularly when seen in peripheral vision. In our probes, we subtly mimic the use of motion by using a 'glowing' effect that aims to subtly attract the attention of the user when a notification is received.

The use of subtle cues to provide unobtrusive notifications to users is not a new concept. Many smartphones have notification LEDs that can be used for this purpose; others use the camera flash in a similar way. There is also a significant amount of research in this area. Anderson et al. [1], for example, present several examples around deception and illusion, drawing on principles of magic to increase the subtlety of interfaces, including devices that can disguise numerical data in audio alerts. There is also work around wearable devices and visual displays. Costanza et al. [8], for example, use LEDs embedded in eye glasses to provide discreet cues to users in their peripheral vision. Lucero and Vetek [37] also made use of eyewear to display notifications opting to display virtual butterflies and text-based notifications on the glass. Other wearable devices—such as the reminder bracelet [13]—use simple LED cues on a wristband to convey reminders from an accompanying device. Similarly, Thomas [47] uses coloured LEDs embedded into clothing to provide subtle notifications, and Pearson et al. [38] discuss the possibility seeing alerts on other people's wearables. Each of these examples make use of additional, often wearable accessories, however, whereas our approach aims to use the device itself to provide the cues to the user, in addition to blending in to its background.

Other work into subtle notifications includes that of Harper and Taylor [15], who designed a system that allows phone users to subtly glance at the person they are calling via their phone's camera to check availability before calling. The use of tactile feedback has also been a popular modality to provide personal, subtle feedback. Lee and Starner [33] for instance, make use of a wrist-worn device that uses three vibration sensors to provide alerts to users without the need for a visual display. Subtle vibration cues have also been used as a method of unobtrusive casual navigation [41].

MOTIVATION

The motivation for this work originated during a series of participatory future design workshops we conducted with emergent users.[2] The aim of these sessions was to learn about daily life as lived by participants, but also to spur thoughts, inspiration and ideas for innovative future mobile designs. We invited 54 emergent mobile users from Bangalore, India, eight from Langa, a township in Cape Town, South Africa, and nine from areas around Nairobi, Kenya. The workshops involved asking participants to create designs for future devices and services using sketching [29] and "magic thing" [19] techniques. At the end of the workshops we collected participants sketches, and combined these with notes, videos and photos from the events.

[2]In this context we refer to emergent users as people living in communities where resource constraints (for example, economic, educational or infrastructural) or other barriers are prominent [9].

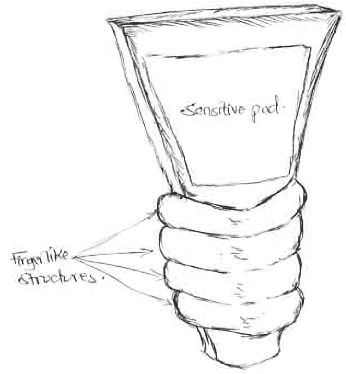

Figure 2. One Nairobi participant's sketch of a phone designed with security in mind.

Even when the user is not actually carrying or holding the phone, its display and visually finger-like design would give the illusion that it is still being held, providing extra physical theft protection for the device.

Three researchers independently reflected on these materials to identify themes, then came together to discuss and generate design concepts based on participants' insights and ideas.

One universal theme we encountered during the workshops was of issues surrounding security. Many emergent users are very aware of the dangers they face on a daily basis [50]. Understandably, then, participants were particularly protective and cautious about valuables such as mobile phones that are a tempting target for thieves – they would never use their phone in public view. This type of lifestyle has given participants a unique viewpoint, both in terms of how best to avoid undesirable scenarios with current technology, but also how they might innovate an ideal solution given the opportunity – and these were reflected in their designs. Figure 2, for instance, illustrates one participant's contributions – their design motivation (not shown) reads: *"the finger like structures [are] for security purposes – suppose you drop the phone on the table, it would give the illusion of someone's finger still holding it."* This sketch and other similar designs involving hidden or hideable mobiles inspired our first Chameleon Phone thoughts.

During the workshops, participants also spoke of their desire to be able to receive discreet notifications and to keep in touch with friends and family in lightweight ways. So, for example, in a group of female domestic workers in Bangalore, the need to hide their use of their mobiles was motivated by the fact that their employers might become angry if they saw the women using their devices. Some solutions to this issue (as suggested by these participants) included: wearable mobiles in the form of rings; necklace-shaped mobiles that could be subtly hidden in the folds of a sari; and, earpieces that automatically answered calls or provided spoken content without others being aware of the interaction. One lady even suggested hiding a mobile in a hairbrush: she explained that as she brushed her hair, she could listen to a call from her husband as well as talk to him via the brush.

DESIGN AND INITIAL PROBE

The future mobile design workshops, then, surfaced a wide range of designs and user needs. Building on these, we created an initial version of a Chameleon Phone which we tested in-situ with participants in South Africa and India.

Chameleon Phone (version 1)

We imagined a device with behaviour analogous to a chameleon – that is, a mobile that can change colour to blend

Figure 3. Optically camouflaged mobiles: hiding in plain sight on everyday objects.

Left: the Chameleon Phone probe "camouflaged" on a patterned surface. While the outer fascia of the phone is still visible, the screen displays an exact replica of the object underneath.

Right: subtle visual alerts are provided by changing the colours in the image. In this example the dark blue background glows lighter to indicate that a notification has been received. The colour that glows indicates the type of notification. In this case, dark blue corresponds to WhatsApp: a new message has just arrived.

into its surroundings, while also providing subtle glowing cues for notifications that not only respect its users' privacy, but also minimise social interruption. This extended functionality provides the device with a dynamic, environment-dependent appearance that protects against theft by making itself hard to see, but at the same time allows discreet interactions. As we will explain in later sections, our overall goal in this work is to create a fully camouflaged device that can truly blend-in to its surroundings. We believe this can be achieved via a variety of techniques, ranging from bimetallic nanodot arrays [48] to polarising beam-splitters [20].

Before embarking upon such an undertaking, though, we first built a technology probe to better understand the needs and desires of the contexts in which the device will be used. Our initial Chameleon Phone prototype, then, was an Android app that takes a photograph of the surface on which the phone is to be placed, and then allows the user to zoom and pan the image to match the underlying pattern (see Fig. 3 left). When a notification is received, a colour in the image 'glows' for several seconds to discreetly alert the user (see Fig. 3 right), before returning to its initial state. Users can assign colours within the image to three different notification types in order to distinguish between the types of cues they might receive. For example, in Fig. 3, the background might be assigned to WhatsApp, the red parts of the logo to SMS messages and the white text to Facebook. When part of the image glows, the user can see at a glance which type of alert they have received. The accompanying video figure shows interaction with this and the deployed prototype described later in the paper. As this version of the prototype was to be used only as a probe, the cue for the image glow was simulated in a Wizard-of-Oz manner. That is, we made the appropriate colours glow manually by sending a cue to the probe during each of the studies described below.

Evaluations

Six months after the future mobile design workshops, we carried out two further workshops with participants in Langa (Cape Town) and Dharavi (an informal settlement in Mumbai) to focus specifically on chameleon-like opportunities. We recruited 16 participants in each location (32 people in total – 15F, 17M, aged 18–50) to take part. Participants lived in communities the same as (in the case of Langa) or similar to (Dharavi) participants in the first workshops. None of the participants had taken part in the previous studies.

Figure 4. The initial Chameleon Phone probe in use by participants in the studies in Dharavi (left and top right) and Langa (bottom right).

Each study was performed in groups of four participants, and took the same general format across both sites (with the addition of a rating exercise in Langa – see below). After an IRB-approved informed consent procedure, we began each session by gathering demographics and asking participants about their phone usage, including where and how they leave them when not in use. Following this we showed each group three low-fidelity prototypes of chameleon-type designs. To simulate a device that could turn completely clear, these prototypes were simply a series of clear plastic 7×12 cm rectangles of different thicknesses (12 mm perspex, 3 mm perspex, 0.1 mm acetate), used to gauge how participants felt about a potentially "best-case scenario" chameleon device. In Langa, for each prototype we also asked participants to rate their level of concern about using or putting it down in full view of others in several different environments, on a scale of 1 (not at all worried) to 10 (very worried).

After the discussion around these versions, we proceeded to show each group the Chameleon Phone probe. We gave participants time to experiment with the functionality of our initial prototype until they were familiar with and understood its use (see Fig. 4 for an example), then concluded with a short interview probing their thoughts on the general concept. Each group session took around 1 hour, and we gave participants an incentive of R150 (Langa) and ₹200 (Dharavi) per person.

Current phone	12 mm perspex	3 mm perspex	0.1 mm acetate	Chameleon Phone
8.4	4.0	4.8	5.1	5.9

Table 1. Average scores from the Langa group (n=16) for how comfortable participants would feel if they had to put their phone down in a public place, in comparison to each of the four separate chameleon prototypes, on a scale from 1 (not at all worried) to 10 (very worried).

Results: Langa

All but three of the participants in the Langa study had a basic level of literacy in English, with all except four having the same in their native isiXhosa. The majority of the participants in this cohort were students (10 people), and the remainder were either unemployed (1) or held a part-time job (5). All but one of the participants owned a mobile phone, including: Samsung touch screen (6 people), old-style Blackberry (5), iPhone 4 (2) and Nokia feature phone (2).

It was clear that the safety and security of participants and their possessions was a real issue. This theme was inherent throughout our questioning about where they kept their phone while not in use. When at home, the majority of participants were happy to leave their phone unattended (13 people), while a further two would hold the phone without hiding it. In contrast, the majority (15 of 16) said that they would hide their devices away while in public. Participants rated their willingness to use their phone in public as 8.4 out of 10 (see Table 1).

Clearly, then, participants in this study were very worried about the physical security of their devices. But this concern seems to go beyond simply worrying that someone will take their possessions if they are left unattended. Participants were also very aware that if they are seen using a phone, it becomes a target for thieves. Comments such as *"it attracts danger in public," "I don't want people seeing me with [my phone],"* and *"it's very risky to use a phone in a public place – that's why I don't have a phone now"* further echoed these concerns.

Although the primary reason for keeping phones hidden was security, other factors such as social interruption and privacy were also mentioned by several of the participants. One, for example, often hid her phone away while she was at home with her friends because she did not want to come across as rude: *"when I'm with others I don't want my friends to say I'm addicted to my phone,"* while several others commented that they would leave their phone face down if others were around because they did not want their private messages being seen.

Ratings for the level of comfort participants would feel about using the transparent plastic devices indicate that any type of camouflage of their device would lessen their worries about security (see Table 1). Of the three options, participants felt most comfortable with thicker perspex, followed by thin perspex and then thin acetate. The reasoning behind this preference centred solely around the thinner devices being so invisible that the user could lose or forget the devices themselves.

After demonstrating the Chameleon Phone prototype it was clear that participants saw value in the approach for both security and privacy. Participants' willingness to leave the device in public was greater than for their current phone (see Table 1), though less than the fully transparent examples. The comments and discussion also highlighted benefits of the approach: *"people wouldn't know it's a phone, so it's more secure,"* though also pointed out that the lowered visibility of the phone might make it easier to misplace the device themselves. Others focused on aspects of the notification glow: *"[it is] really cool – much more private"*, *"it's very discreet, only you know what it's doing – your friends don't"* and *"if the phone flashes I can smile about it because only I know I have a message"*.

When asked about the drawbacks of such a system, participants' main concerns were about battery use, or the possibility of lit screens in dark environments making the device stand out. There was also useful feedback around showing the source or repeating the notification, suggestions for how alerts could be displayed on plain, single-colour backgrounds, and finding mislaid devices – for example: *"maybe if I lost my phone if I wave my hand it flashes"* and *"to find it, [. . .] it could use voice recognition and call out for it"*. Finally, other suggestions for improvements to the system included automatic zooming of the photograph and the use of different pre-set colours for different situations (such as emergencies).

Results: Dharavi

All of the 16 participants from Dharavi had a basic level of textual literacy in their native language (Hindi, Tamil, Telugu, Kannada or Marathi) and 11 also had a very basic level of English. Six of the participants were in work, five were housewives and the remainder were either unemployed (3) or still in school (2). Participants in this cohort had far less technology experience than those in South Africa. While all owned a mobile phone, only four owned a touch-screen (all low-end Android). The remainder either owned a basic handset such as the Nokia 1100 (8 people) or a low-end feature-phone (4). Of the 12 participants who did not own a smartphone, seven had never used a touch-screen before.

When we asked the participants in this group if there were any places outside of their home where they would put their phones down (even if they were able to keep an eye on the device), the responses resonated strongly with those from Langa – that is, participants were very wary of leaving their possessions in view of others around them when they are in a public place. The majority of the participants stated that they would never put their phone out on a table in public, with comments such as: *"it's not safe"*, or *"I fear someone will take it from me"*. In addition to security, these groups were also more concerned with forgetting their devices than Langa participants, and many were worried about their phones getting damaged if they were left out on a table or chair and knocked onto the floor.

Responses to the transparent 'blending in' examples were mixed, with some participants suggesting that it was hard to imagine this capability ever being possible, but all groups pointed out that the risk of the device being stolen would be lower. The problem of forgetting the device was reiterated by groups in this study, with several participants feeling that if their phone blended-in too well they would end up leaving it behind inadvertently. Participants also pointed out that the potential for accidental damage of the device was increased by the transparency aspect if people could not see the phone.

Figure 5. Opportunities for a camouflaging mobile device. Left: a phone laid on a checkered picnic rug. Right: a phone on a cluttered restaurant table. Both photos were captured in situ during our observational study.

Turning to the Chameleon Phone's subtle notification cues, in general, participants saw the potential for subtle but informative messages. Several groups also suggested options for what the flashing colours could mean: *"I would mostly use the yellow colour for incoming SMS messages. I could set different colours for different close friends"*. Similarly, one participant wanted to always associate the same colour with a particular person, whereas another wanted a specific action to happen when a service provider was calling so they could avoid answering unwanted calls. Participants also liked the glowing feature in particular, prompting comments such as, *"eyes are fast – in the corner of my eye I can see something glowing"*.

Discussion and implications for design

Participants in Langa were relatively technology-savvy, on low to medium incomes, whereas those from Dharavi were mostly on very low incomes and far less accustomed to high-end devices. Discussion in both locations, however, highlighted issues of security, to the extent that simply using a phone in public made participants a target for robbery, strengthening their desire for socially discreet devices and interactions. The Chameleon Phone approach was well received, though participants cautioned about the possibility of losing devices if they were too well hidden. Other suggestions included using colour cues to show the message source, placing the image automatically to match the background, and ideas for how to repeat missed notifications. We used this feedback in creating a refined prototype, a deployment of which is described later.

THE POTENTIAL OF CHAMELEON DEVICES FOR DISCREET, SUBTLE INTERACTIONS

Our participants from Cape Town, Bangalore, Mumbai and Nairobi made it very clear that they were extremely wary about leaving their phones out in public. In this section we report on an observational study (in the UK and other locations in Europe) and interviews with UK-based participants. In contrast to our earlier studies, results from these less "resource constrained" communities showed that practices and concerns were markedly different. Here we saw many opportunities for mobiles to blend in when on display in public, affording subtler, more private interactions in social settings.

Observations

We conducted an observational study to determine how and where people leave their phone when in the company of others in public (and not actively using their phone), basing our method on that of [38]. The study was conducted over a period of 15 weeks in seven countries, all of which were in non emergent contexts. Using a simple logging app, we recorded the location, phone type, visibility and placement (as shown in Table 2) of devices we saw. We also gathered images of where phones were placed, noting the surfaces and other objects that they were on or near; and, observed people's 'passive' interactions with their devices. Clearly, this public observation-based method does not capture any instances where devices are hidden from view, but it did provide us with a useful indication of opportunities for the chameleon concept in these contexts.

	On table	In hand	On lap	On chair	On floor	Other position
% Obs.	51	34	4	2	1	8

Table 2. Percentages of the 224 observations recorded in each placement.

Results

Over the 15-week study period we observed a total of 224 phones. The most common locations were public spaces (126 observations) and third places (88), with 10 phone placements observed in workplaces. The majority of devices were smartphones (218), with five featurephones and one basic phone.

Table 2 shows the number of observations of each phone placement. The most common position was on a table (51 %), followed by in-hand (34 %). The vast majority of the devices we observed tended to be placed or held face-up, with their screens fully- (63 %) or semi-visible (25 %) to their owner. Only 12 % of devices we saw would not be immediately visible (in most cases these were placed face-down on a surface).

Figure 5 shows two exemplar images collected during the study. In each there are ways the mobiles could be blended into the surroundings, from mimicking the pattern of the predominant surface (e.g., becoming checkered on the picnic rug) to taking on visual elements of nearby objects (e.g., the mobile being placed on any of the objects on the cluttered restaurant table). These, and our other images, point to the rich range of textures, patterns and objects under or around phones placed out in public that could be used in the camouflaging process.

Views from a UK perspective

We recruited 10 participants (4M, 6F) aged 21—52 to take part in a UK deployment of our Chameleon Phone prototype (see full discussion in the next section). All 10 were employed, educated to degree level, and owned a high-end smartphone. In individual interviews, it was clear that UK participants were far less concerned with safety and security than those from other regions. Although several participants mentioned that they would be worried about leaving their phone unattended, none expressed concerns about using their phone while in public. In fact, all participants said they were either likely (50 %) or very likely (50 %) to leave their phone in full view of others in this situation. Turning to discreetness and privacy, six participants tried to be discreet with phone interactions mainly because of social or work disruption and being perceived by others as 'rude' The remaining four participants stated that they did not need to worry about seeing notifications subtly.

Discussion

In contrast to our earlier studies with emergent users, in these studies, both the device placements we observed and the responses from participants demonstrated far less concern about physical device security. Even in busy public areas, people clearly felt safe leaving their device in full view of others. There were, however, more worries about social interruption or appearing to be rude. In these situations, then, the benefits of a chameleon-like device would be in subtlety and unobtrusive interaction, rather than physical device security.

Our observations and photo data demonstrated clear opportunities for mobiles to be blended into their surroundings. As a result, we developed a refined version of the Chameleon Phone probe in order to study its usage over an extended period.

THE SECOND CHAMELEON PHONE PROTOTYPE

In order to explore usage of camouflaged mobile devices and subtle notifications 'in the wild,' we created a deployment-ready version of the Chameleon Phone prototype that responds to actual phone notifications. In the same way as our original probe, the application allows users to take a photo, zoom and pan to match the underlying surface, and then assign colours to three notification-producing apps. When notifications are received, areas of colour in the image corresponding to the notification source glow, as shown previously in Fig. 3.

In this version, we also aimed to accommodate the comments and suggestions made by participants in our lab-based evaluations. First, in response to worries about not noticing a notification 'glow,' we added a discreet interaction that reanimates any recent notifications: users simply wave their hand over the phone to repeat any unseen alerts (detected via the device's front camera). Our aim here was that this method might allow the action to be done as part of a conversation or other common action, such as reaching over a table. Another comment made by participants was that the glow alone did not give any further context about the notification (such as its sender or type, etc.) beyond knowing which app it originated from. To improve this aspect, we added a simple pop-up summary of an app's most recent notifications, accessed by tapping its assigned colour on the screen. Touching again on the pop-up opens the relevant app. Finally, in response to suggestions for improving the app's setup when placed on a new surface, we added automatic colour detection and initial zoom level estimation to speed up this process. After taking a photo of the surface, users need only make minor adjustments to the image's scale and alignment, and can choose to accept the automatically-detected colours, or assign their own and change the screen's brightness if they wish.

DEPLOYMENT STUDIES

To further evaluate the chameleon notion, we wanted to explore how the concept resonated with users in a more natural environment, providing further use-case scenarios and improvements to the updated prototype design. With this in mind, we deployed the second version of the Chameleon Phone prototype over a period of five-weeks in each of four locations. Three of these regions were where we knew safety and security was an issue for local residents; that is, people drawn from communities in Langa, South Africa; Nairobi, Kenya; and, Mumbai, India. In addition, we also deployed it to the 10 UK participants described in the previous section.

Figure 6. Interaction with the deployed Chameleon Phone prototype. After taking a photo of a surface, the app automatically zooms the image as the user sets down the phone (the user can then pan or zoom the display for perfect alignment). The app automatically assigns the three main colours found in the image to Facebook, SMS and WhatsApp notifications. If desired, the user can select their own choices via a colour loupe (the popup shown in the centre of the screen), or adjust the brightness of the image to more closely match the surrounding surface (slider at bottom). When a notification is received from one of the three linked apps, the corresponding colour in the image will glow, as shown in Fig. 3.

The purpose of performing this evaluation in the UK as well as in regions where we know security to be an issue was to provide a different perspective. While we recruited from various social, educational and technological backgrounds in Kenya, South Africa and India, participants across all three sites remained cautious about security – particularly around using their phone in a public place for fear of it being a target for theft. In the UK, as we have seen, there was far less concern about this issue. We recruited a total of 48 participants over the four sites (12 in Langa, 11 in Nairobi, 15 in Mumbai, 10 in the UK) to take part in the five-week longitudinal evaluation.

In order to be eligible to take part in the study, participants had to own their own Android phone (to enable them to install the app). Each of these deployments followed the same pattern: an initial interview, followed by two interim interviews (at weeks one and three), and finally an exit interview at week five.

Procedure

After an IRB-approved informed consent procedure, the initial session began with a short interview gathering participant demographics and general phone use. This interview also probed participants' thoughts on security and privacy, with a focus on their likelihood of using their phone in a public place.

We demonstrated the Chameleon Phone app to each participant, showing all aspects of its functionality, and allowing them to practice until they felt comfortable with its use. Participants then installed the app on their own phones (via Google Play to allow for minor bugs to be addressed if required). We asked participants to use the app at least three times a week for the duration of the deployment.[3] They were asked to use the probe as they wished, but in a variety of different contexts and locations. We gave potential locations in the briefing (e.g., cafes, libraries, transport, friends' homes, clubs, etc.), but also made it clear that while the aim of the app was to disguise the phone, participants should not use their phone anywhere they felt it was not safe to do so. We emphasised that throughout

[3] Logs showed average use as almost double this.

	Normal phone		Chameleon phone	
	Home	Public	Home	Public
South Africa	3.0	1.8	4.5	4.5
Kenya	2.9	1.7	4.3	2.2
India	4.9	1.7	2.8	3.2
UK	5.0	4.5	3.5	2.2

Table 3. Ratings from deployments in South Africa, Kenya, India and UK for participants' likelihood of leaving their phone or the Chameleon Phone prototype in full view of others at home or in a public place (from 1: very unlikely to 5: very likely).

the study we wanted participants to think about the broader concept of chameleon-like devices (i.e., not just this prototype's particular method of hiding). We gave incentives of R200 (South Africa), KES1000 (Kenya), ₹500 (India) and £10 (UK) to each participant for each interview session attended.

We conducted three follow-up interviews with participants during the deployment at one week, three weeks and five weeks after the initial session. The interview sessions were semi-structured, with opening questions about the previous period of usage, followed by discussion about good and bad aspects of the app, and then exploration of other factors such as reactions of passersby, and the effectiveness of the glowing notifications. The purpose of the two interim interviews (weeks one and three) was to gauge how effective participants were finding with the prototype, determine if there were any minor problems that could be fixed in an update without affecting the study, and gather preliminary results from its use. In the final interview session we aimed to gather more in-depth feedback, and also asked scalar questions about the app's effectiveness, and whether participants' attitude towards leaving their phone out had changed. The first interview was 1.5 hours in duration, while each of the others were between 30–45 minutes. Interviews were carried out by researchers who could speak the languages of participants (English, isiXhosa, Swahili, Hindi, Tamil, Telugu, Kannada and Marathi). Interviews were audio recorded and notes taken, and English transcripts made. The researchers who conducted the interviews, and others, reviewed this data independently to identify themes in each location. Two of these researchers then reviewed the full data set across locations. Standard thematic analysis and reflection techniques were used as in other field work of this nature (e.g., [50])

Results: emergent users in Langa, Nairobi and Mumbai

The Langa deployment consisted of 12 participants (6M, 6F aged 19–40) with at least an average level of literacy in English and isiXhosa. Eight participants were in full time work, three were unemployed and one was a student. As with the Langa-based group who participated in our earlier study, participants in this area were particularly worried about the physical security of their devices. Again, this was very apparent when we asked about where they kept their phone when not in use. Eleven participants said they would leave their phone unattended when at home; however, this attitude was completely reversed when in public. All participants said that they would not feel safe using their phone in public places, and that they kept their devices hidden in a pocket or a bag at all times. This overarching concern over device safety is reflected in the ratings given by participants (see Table 3) again confirming that visibly using mobiles in public is a major concern. In terms of notifications, 10 of 12 participants wanted to be able to discreetly see alerts, with privacy being the primary reason.

The Nairobi deployment consisted of 11 participants (4F, 7M, aged 19–27) with at least a good level of literacy in both English and Swahili, and all were either in full time work (8 people), students (2) or unemployed (1) Security concerns were again dominant: all would leave their phone in view when at home, but 9 would keep it hidden (or even left at home) when in public. Discreetness was also seen as important, with privacy and rudeness given as the primary reasons for this.

The Mumbai deployment consisted of 15 participants (13F, 2M, aged 19–40), primarily with a low level of textual literacy in English and a good level in Marathi. Two participants were unemployed, six in full time work, three were students and four were housewives. Over half had less than a year's experience with touchscreens. Mumbai participants were similarly cautious about using their phones publicly – while they would happily leave their devices in full view at home, all 15 would keep their phones in a bag or pocket when in public. They were far less concerned with discreet notifications, however. Only five participants stated that they had ever wanted to see notifications discreetly, each stating privacy as the reason.

Reflections on safety and security

Overall, when considering the Chameleon Phone prototype in terms of safety and security, participants felt that the design did give a certain level of device protection, but their phone would need to be fully hidden in order for them to feel completely safe leaving it out in public. For example, the majority of the Nairobi participants were positive (e.g., *"I feel more secure leaving it on a surface than before when the application is on"*), with over half stating that they would feel safer leaving their phone in full view. The remainder, however, saw a need for camouflage of the whole device rather than just the screen – they felt that the technology was not yet at a stage at which they would feel safe having their phone visible in public: *"I still don't feel leaving my phone out is secure – with the app it's more private now, but my neighbourhood doesn't have good security"*. This was made particularly evident in Langa, where six participants withdrew from the study. While half of these were uncontactable or had needed the space on their phone that the app was using, three participants no-longer had their phone due to theft (not while using the app). As one Langa participant reflected: *"I'm still not 100 % on trusting the app and the people around me when I have my phone"*.

By the end of the Mumbai deployment, over half of the participants felt safer about leaving their phone in full view of others. The rest of the group felt that while the app made the phone less visible (*"to some extent it is hidden"*), they would still only leave it out while at home or a trusted location, and several of these participants said they had not felt comfortable enough to try the app in public. Overall, it was clear that when thinking about future chameleon-like devices, participants in all three areas saw benefits of blending-in devices, but that the technology in its current form was not yet advanced enough.

Reflections on emergent user privacy and subtlety

Participants particularly appreciated the privacy and subtlety aspects of the design. Discussing their thoughts about leaving phones in view of others, those in Langa explained the privacy benefits of the prototype: *"I feel good, not worried, as they cannot see as my notifications are silent,"* and *"my privacy is protected"*. Typically, these participants used the app when they were in groups, but all said no one around them had noticed the app in action – a positive result for the blending-in aspect. This subtlety did not seem to hinder notification usage – all participants reported seeing the image 'glow' while using the app. Participants also felt that the app helped them to discreetly see alerts when others were around: *"I can leave my phone on the table knowing that someone else won't be able to know which message came through"* and *"I like that my friends cannot see when I'm receiving a message"*.

Similar responses were gathered in Nairobi and Mumbai. All Nairobi respondents said they noticed the notification glows and found them useful – for example: *"I've generally been using it to hide my notifications from other people,"* and *"I hate the noisy notifications, so I just glance at my phone and see if it's [glowing]"*. Participants in Mumbai had all noticed notifications, and saw the discreetness benefits of the system: *"no one knows when notifications are coming in,"* and *"it's easier for me to look at messages because it's more private"*. In terms of behavioural change, participants reported that they were more likely to leave their phone visible: *"I'm more confident leaving my phone out: it's very private, which I like,"* and *"I'm more open to leaving my phone out because people won't have access to my messages"*. Finally, there were also comments around social benefits of the approach: *"I won't annoy people around me,"* and *"it can help people improve from being anti-social during gatherings"*.

Improvements to the prototype

While participants clearly felt that future devices able to fully blend in would be the best solution to meet their needs, they also identified areas for improvement in the current probe. These included lowering use of resources (e.g., storage space and battery), streamlining the setup process by saving colour choices, and ways of notifying when using the app on single-coloured surfaces (*"I don't always go to places with colourful things to camouflage"*). Participants also suggested other notification types that the colour-based alerts could be used for, including phone calls and a range of instant-messaging apps.

Results: UK participants

The 10 UK participants (demographics as described previously) were from comparatively more affluent backgrounds to those in Langa, Nairobi and Mumbai, and were less concerned with the safety and security of their phones, despite owning more expensive, higher-end devices. Instead, it was evident that participants saw particular value in the chameleon approach for providing discreet notifications. In contrast to many of the reactions we have already seen, however, UK participants were far more concerned with conversation disruption, or being portrayed as 'rude'. One, for example, found it useful for teamwork: *"[it's] definitely useful if you are working with someone else and you don't want to interrupt the work,"* while others saw benefits in social situations: *"its selling point is that I can decide when I get the notifications easily with my hand so there's no social interruption or being rude"*.

Participants did not see a great benefit of the camouflaging aspect in terms of security. In some cases this was attributed to the fact that the often large and bulky protective cases or battery packs phones gave the devices a larger than usual outline. Others noted that the camouflaging effect was greater on textured or colourful surfaces, and less so on the surfaces they often used (such as desks). One participant felt that her device security had changed for the worse, referring not to potential theft, but the lack of a normal lock screen while the app was operating.

Several of the UK participants stated that they found themselves making more use of their phones than they did previously, due to the subtle notification aspect of the app. One, for instance, noted that she is more aware of her notifications at busy times of the day: *"I'm consciously leaving it out now – I won't acknowledge the messages, but I know now that I have them if I'm in a meeting"*. Others reported changes in behaviour relating to the privacy aspects: *"I feel that before I tended to put the telephone upside down but I don't now because I don't need to,"* and *"I leave it out a bit more in work at least – I like the subtle messages"*.

Improvements to the prototype

In the UK study, we encountered an issue as a direct result of participants owning more recent smartphones, which had an effect on some users' perception of the prototype's notifications. In the first interim session one participant reported that in addition to the colour glow, their phone was also briefly showing the standard notification popup. We discovered that this was a non-rectifiable problem caused by the recent release of an Android platform update—coinciding with the study—that intentionally prevents notification suppression. None of the participants in the three other locations experienced this issue, but the number of UK participants affected rose to five (50 %) by the end of the study period. These participants tried to overlook this problem and respond objectively given their overall experience with the prototype – encouragingly, they still saw the value in the general approach (e.g., *"it would be very handy if it worked correctly because it's not very obvious and useful to stop social interruption"*). However, this example shows how difficult it can be to create innovations using modern mobile devices without the direct backing of device and operating system manufacturers.

DISCUSSION AND FUTURE WORK

Implications for safe, secure and subtle design

There has been much previous interest in providing subtle, ambient notifications (e.g., [8, 13, 33]). Our studies show that in contexts where there are very real safety concerns, prior techniques that require the phone to be visible (e.g., [4]) will not be effective. If the approaches are based on a device or notification that is made less visible – either through camouflaging as we demonstrate, or more directly by their physical design, then their value may be higher. For emergent users, the use of additional devices (e.g., [42]) may be less attractive due to cost and power issues. Similarly, the availability of objects to embed devices within may be lower than for traditional users envisaged in prior work [1].

Turning to the Chameleon Phone prototype, there is clearly much work to do to provide true invisibility. Our work to date has focused on interaction techniques, as well as the concept design and reception from a diverse audience, demonstrating that it is worth the effort of pursuing a more camouflaged solution. In the next section, therefore, we consider a range of state-of-the art technical developments that could provide more effective implementations of the ideas presented here.

In terms of our current approach, however, there are several immediate improvements that could be made. For instance, better automatic image capture and alignment would reduce the set-up cost of using the technique, and a 'chameleon mode' for a user's common surfaces (such as their work desk) would ensure a quicker and more elegant interaction. Another issue with the current method of camouflaging is battery life: if the concept is to be made appropriate for mainstream users—particularly those in emerging markets—it must be far less resource hungry and reduce battery use as much as possible (for example by minimising use of the handwave feature). Finally, as many participants noted, using the image glow technique on single-coloured or plain surfaces reduces its effectiveness. This can be addressed by creating additional types of notification cue for these surfaces (e.g., a water ripple effect over the screen, or highlighting specific words in text).

As we have described, our exploration of chameleon-like devices was driven through a range of engagements with emergent users from resource constrained communities. While most prior work with such users has focussed on adapting and appropriating current technologies to meet needs, our work illustrates the value of working with such groups to envision and investigate more radical devices and services that can inspire design globally [26]. A critical part of this work, we found, was to emphasise in both the workshops and throughout the deployments that the props and prototypes we were using were thinking tools with regard to security and privacy rather than final devices or apps. In addition, deploying the prototype on users' own devices overcomes the problem of participants being fixated on the phones that are lent during the studies.

New materials and technologies to platform invisibility

The deployments described in this paper were conducted using standard smartphones that are commercially available worldwide. As we have seen from participants' comments, device borders or cases can lessen our prototype's ability to truly blend in to its surroundings. Screens are taking up an increasing amount of handsets' front fascias in recent years, however, and even in mainstream devices the desired 'borderless' phone is becoming a reality. Several manufacturers have demonstrated edge-to-edge displays, and it is not outrageous to consider the prospect of a truly bezel-less device as within the realms of possibility in the not-so-distant future. In addition, coloured eInk is also on the horizon,[4] making it sensible to consider the possibility of a non-backlit screen that can blend in easily while using almost no battery. Finally, transparent OLED lighting panels[5] could also be a useful direction for future prototypes if contrast and brightness can be improved.

We now turn to more research-focused techniques which could provide the materials required for devices to blend more convincingly into their environment. Chameleons reflect and absorb specific wavelengths of visible light in order to change colour. This is achieved by changing the spacing between the guanine nanocrystals in their skin [46], as well as combining with light reflected from underlying pigments. To mimic this, a number of artificial materials have been developed for active camouflage that selectively reflect and absorb light of different wavelengths. For example, the bimetallic nano-dot arrays in [48] can be transparent or show different colours by using a camera to capture the background scene. Yu et al. [52] combine light sensors and thermochromic dye to adapt backgrounds. In nature, light sensing molecules are found in colour-changing cephalopod skin [31, 40]. Cephalopods have also evolved special pupils [45] to sense the colour and pattern of their background. Specialised low-cost, bio-inspired light sensors could be developed for camouflage and could be activated and actuated by the background light. Flexible polymer image sensors have also been suggested for this purpose [32].

Optical 'carpet' cloaks that work in visible light are able to hide bumps on their surfaces. Such approaches would allow the concealment of devices in specialised cases that would appear visually as a flat sheet. Chen et al. [6], for example, present an invisibility cloak of visible light that can hide macroscopic objects in the centimetre range, but only works in specific polarised light conditions. Other approaches include that of Schittny et al. [43], where a macroscopic object is cloaked, including its shadow, in a diffusive light condition, and Gharghi et al. [12], who demonstrate a carpet cloak effective for all visible wavelengths.

CONCLUSION

In this paper we have presented a set of probes to investigate the notion of chameleon-like devices. We have explored the value of the concept with participants from a variety of contexts, as well as in longitudinal deployments across three continents. This work has shown that for some users the ability to hide in plain sight will address safety and security concerns, whereas others will see benefits from the privacy enhancing and social disruption-reducing features of the concept. The chameleon approach, with its hideability and subtle signalling, then, is flexible enough to provide discreet solutions to a range of user needs. In addition, our studies provided evidence that it is worth pursuing the more complex, state-of-the art methods and techniques we describe at the end of this paper in order to create a more effective and automatic Chameleon Device.

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[4]See: goo.gl/BZ6Lj5; [5]See: goo.gl/ixof8I.

REFERENCES

1. Fraser Anderson, Tovi Grossman, Daniel Wigdor and George Fitzmaurice. 2015. Supporting subtlety with deceptive devices and illusory interactions. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15). ACM, New York, NY, USA, 1489–1498. DOI: 10.1145/2702123.2702336.

2. Lyn Bartram, Colin Ware and Tom Calvert. 2003. Moticons: detection, distraction and task. *Int. J. Hum.-Comput. Stud.* 58, 5, 515–545. DOI: 10.1016/S1071-5819(03)00021-1.

3. Volkert Buchmann, Trond Nilsen and Mark Billinghurst. 2005. Interaction with partially transparent hands and objects. In *Proceedings of the Sixth Australasian Conference on User Interface - Volume 40* (AUIC '05). Australian Computer Society, Inc., Darlinghurst, Australia, Australia, 17–20. http://dl.acm.org/citation.cfm?id=1082243.1082246.

4. Christopher S. Campbell and Peter Tarasewich. 2004. What can you say with only three pixels? In *Mobile Human-Computer Interaction - Mobile HCI 2004, 6th International Symposium, Glasgow, UK, September 13-16, 2004, Proceedings*, 1–12. DOI: 10.1007/978-3-540-28637-0_1.

5. Hongsheng Chen, Bin Zheng, Lian Shen, Huaping Wang, Xianmin Zhang, Nikolay I Zheludev and Baile Zhang. 2013. Ray-optics cloaking devices for large objects in incoherent natural light. *Nature communications* 4.

6. Xianzhong Chen, Yu Luo, Jingjing Zhang, Kyle Jiang, John B Pendry and Shuang Zhang. 2011. Macroscopic invisibility cloaking of visible light. *Nature Communications* 2, 176.

7. Joseph S. Choi and John C. Howell. 2014. Paraxial ray optics cloaking. *Opt. Express* 22, 24, 29465–29478. DOI: 10.1364/OE.22.029465.

8. Enrico Costanza, Samuel A. Inverso, Elan Pavlov, Rebecca Allen and Pattie Maes. 2006. Eye-q: eyeglass peripheral display for subtle intimate notifications. In *Proceedings of the 8th Conference on Human-computer Interaction with Mobile Devices and Services* (MobileHCI '06). ACM, New York, NY, USA, 211–218. DOI: 10.1145/1152215.1152261.

9. Devanuj and Anirudha Joshi. 2013. Technology adoption by 'emergent' users: the user-usage model. In *Proceedings of the 11th Asia Pacific Conference on Computer Human Interaction* (APCHI '13). ACM, New York, NY, USA, 28–38. DOI: 10.1145/2525194.2525209.

10. Patricia Edmonds. 2015. The Colorful Language of Chameleons. http://ngm.nationalgeographic.com/2015/09/chameleons/edmonds-text.

11. Barrett Ens, Tovi Grossman, Fraser Anderson, Justin Matejka and George Fitzmaurice. 2015. Candid interaction: revealing hidden mobile and wearable computing activities. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology* (UIST '15). ACM, New York, NY, USA, 467–476. DOI: 10.1145/2807442.2807449.

12. Majid Gharghi, Christopher Gladden, Thomas Zentgraf, Yongmin Liu, Xiaobo Yin, Jason Valentine and Xiang Zhang. 2011. A carpet cloak for visible light. *Nano Letters* 11, 7, 2825–2828. DOI: 10.1021/nl201189z.

13. Rebecca Hansson and Peter Ljungstrand. 2000. The reminder bracelet: subtle notification cues for mobile devices. In *CHI '00 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '00). ACM, New York, NY, USA, 323–324. DOI: 10.1145/633292.633488.

14. Rebecca Hansson, Peter Ljungstrand and Johan Redström. 2001. Subtle and public notification cues for mobile devices. In *Proceedings of the 3rd International Conference on Ubiquitous Computing* (UbiComp '01). Springer-Verlag, London, UK, UK, 240–246. DOI: 10.1007/3-540-45427-6_20.

15. Richard Harper and Stuart Taylor. 2009. Glancephone: an exploration of human expression. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '09). ACM, New York, NY, USA, 24:1–24:10. DOI: 10.1145/1613858.1613890.

16. Joyce Ho and Stephen S. Intille. 2005. Using context-aware computing to reduce the perceived burden of interruptions from mobile devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '05). ACM, New York, NY, USA, 909–918. DOI: 10.1145/1054972.1055100.

17. Eric Horvitz, Johnson Apacible and Muru Subramani. 2005. Balancing awareness and interruption: investigation of notification deferral policies. In *Proceedings of the 10th International Conference on User Modeling* (UM'05). Springer-Verlag, Berlin, Heidelberg, 433–437. DOI: 10.1007/11527886_59.

18. John C Howell and J Benjamin Howell. 2013. Simple, broadband, optical spatial cloaking of very large objects. Tech. rep. arXiv:1306.0863. https://cds.cern.ch/record/1553460.

19. Giulio Iacucci, Kari Kuutti and Mervi Ranta. 2000. On the move with a magic thing: role playing in concept design of mobile services and devices. In *Proceedings of the 3rd Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques* (DIS '00). ACM, New York, NY, USA, 193–202. DOI: 10.1145/347642.347715.

20. H Ichikawa, M Oura and T Taoda. 2013. Invisibility cloaking based on geometrical optics for visible light. *Journal of the European Optical Society-Rapid publications* 8.

21. Masahiko Inami, Naoki Kawakami and Susumu Tachi. 2003. Optical camouflage using retro-reflective projection technology. In *Proceedings of the 2Nd IEEE/ACM International Symposium on Mixed and Augmented Reality* (ISMAR '03). IEEE Computer Society, Washington, DC, USA, 348–. http://dl.acm.org/citation.cfm?id=946248.946825.

22. Shamsi T. Iqbal and Eric Horvitz. 2010. Notifications and awareness: a field study of alert usage and preferences. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work* (CSCW '10). ACM, New York, NY, USA, 27–30. DOI: 10.1145/1718918.1718926.

23. Hiroshi Ishii and Minoru Kobayashi. 1992. Clearboard: a seamless medium for shared drawing and conversation with eye contact. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '92). ACM, New York, NY, USA, 525–532. DOI: 10.1145/142750.142977.

24. Daisuke Iwai and Kosuke Sato. 2006. Limpid desk: see-through access to disorderly desktop in projection-based mixed reality. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology* (VRST '06). ACM, New York, NY, USA, 112–115. DOI: 10.1145/1180495.1180519.

25. Mattias Jacobsson, Ylva Fernaeus and Stina Nylander. 2012. Mobile actdresses: programming mobile devices by accessorizing. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '12). ACM, New York, NY, USA, 1071–1074. DOI: 10.1145/2212776.2212388.

26. Matt Jones, Simon Robinson, Jennifer Pearson, Manjiri Joshi, Dani Raju, Charity Chao Mbogo, Sharon Wangari, Anirudha Joshi, Edward Cutrell and Richard Harper. 2016. Beyond "yesterday's tomorrow": future-focused mobile interaction design by and for emergent users. *Personal and Ubiquitous Computing*, 1–15. DOI: 10.1007/s00779-016-0982-0.

27. Oskar Juhlin and Yanqing Zhang. 2011. Unpacking social interaction that make us adore: on the aesthetics of mobile phones as fashion items. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services* (MobileHCI '11). ACM, New York, NY, USA, 241–250. DOI: 10.1145/2037373.2037410.

28. Oskar Juhlin, Yanqing Zhang, Cristine Sundbom and Ylva Fernaeus. 2013. Fashionable shape switching: explorations in outfit-centric design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13). ACM, New York, NY, USA, 1353–1362. DOI: 10.1145/2470654.2466178.

29. Younghee Jung and Jan Chipchase. 2007. Nokia Open Studio: Engaging Communities. Tech. rep. Nokia Research. http://younghee.com/wp-content/uploads/2008/10/nokiaopenstudio_final_20081030.pdf.

30. Morvarid Kashanipour. 2011. "Mobile Fashion" Application. MA thesis. Stockholm University, Stockholm, Sweden: KTH, Royal Institute of Technology. http://www.diva-portal.se/smash/get/diva2:571546/FULLTEXT01.pdf.

31. Alexandra CN Kingston, Alan M Kuzirian, Roger T Hanlon and Thomas W Cronin. 2015. Visual phototransduction components in cephalopod chromatophores suggest dermal photoreception. *Journal of Experimental Biology* 218, 10, 1596–1602.

32. Alexander Koppelhuber and Oliver Bimber. 2013. Towards a transparent, flexible, scalable and disposable image sensor using thin-film luminescent concentrators. *Optics express* 21, 4, 4796–4810.

33. Seungyon "Claire" Lee and Thad Starner. 2010. Buzzwear: alert perception in wearable tactile displays on the wrist. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '10). ACM, New York, NY, USA, 433–442. DOI: 10.1145/1753326.1753392.

34. Jiannan Li, Saul Greenberg, Ehud Sharlin and Joaquim Jorge. 2014. Interactive two-sided transparent displays: designing for collaboration. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (DIS '14). ACM, New York, NY, USA, 395–404. DOI: 10.1145/2598510.2598518.

35. David Lindlbauer, Toru Aoki, Robert Walter, Yuji Uema, Anita Höchtl, Michael Haller, Masahiko Inami and Jörg Müller. 2014. Tracs: transparency-control for see-through displays. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology* (UIST '14). ACM, New York, NY, USA, 657–661. DOI: 10.1145/2642918.2647350.

36. David Lindlbauer, Klemen Lilija, Robert Walter and Jörg Müller. 2016. Influence of display transparency on background awareness and task performance. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 1705–1716. DOI: 10.1145/2858036.2858453.

37. Andrés Lucero and Akos Vetek. 2014. Notifeye: using interactive glasses to deal with notifications while walking in public. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology* (ACE '14). ACM, New York, NY, USA, 17:1–17:10. DOI: 10.1145/2663806.2663824.

38. Jennifer Pearson, Simon Robinson and Matt Jones. 2015. It's about time: smartwatches as public displays. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15). ACM, New York, NY, USA, 1257–1266. DOI: 10.1145/2702123.2702247.

39. Martin Pielot, Karen Church and Rodrigo de Oliveira. 2014. An in-situ study of mobile phone notifications. In *Proceedings of the 16th International Conference on Human-computer Interaction with Mobile Devices & Services* (MobileHCI ’14). ACM, New York, NY, USA, 233–242. DOI: 10.1145/2628363.2628364.

40. M Desmond Ramirez and Todd H Oakley. 2015. Eye-independent, light-activated chromatophore expansion (lace) and expression of phototransduction genes in the skin of octopus bimaculoides. *Journal of Experimental Biology* 218, 10, 1513–1520.

41. Simon Robinson, Matt Jones, Parisa Eslambolchilar, Roderick Murray-Smith and Mads Lindborg. 2010. "i did it my way": moving away from the tyranny of turn-by-turn pedestrian navigation. In *Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services* (MobileHCI ’10). ACM, New York, NY, USA, 341–344. DOI: 10.1145/1851600.1851660.

42. Thijs Roumen, Simon T. Perrault and Shengdong Zhao. 2015. Notiring: a comparative study of notification channels for wearable interactive rings. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI ’15). ACM, New York, NY, USA, 2497–2500. DOI: 10.1145/2702123.2702350.

43. Robert Schittny, Muamer Kadic, Tiemo Bückmann and Martin Wegener. 2014. Invisibility cloaking in a diffusive light scattering medium. *Science*. DOI: 10.1126/science.1254524.

44. Christina Medici Scolaro. 23 June 2015. Samsung tests trucks that you can see through. Found at: http://www.cnbc.com/2015/06/23/samsung-tests-trucks-that-you-can-see-through.html.

45. Alexander L. Stubbs and Christopher W. Stubbs. 2016. Spectral discrimination in color blind animals via chromatic aberration and pupil shape. *Proceedings of the National Academy of Sciences* 113, 29, 8206–8211. DOI: 10.1073/pnas.1524578113.

46. Jérémie Teyssier, Suzanne V Saenko, Dirk Van Der Marel and Michel C Milinkovitch. 2015. Photonic crystals cause active colour change in chameleons. *Nature communications* 6.

47. B. H. Thomas. 2002. Minimal social weight user interactions for wearable computers in business suits. In *Proceedings of the 6th IEEE International Symposium on Wearable Computers* (ISWC ’02). IEEE Computer Society, Washington, DC, USA, 57–. http://dl.acm.org/citation.cfm?id=862896.881088.

48. Guoping Wang, Xuechen Chen, Sheng Liu, Chingping Wong and Sheng Chu. 2016. Mechanical chameleon through dynamic real-time plasmonic tuning. *ACS Nano* 10, 2, 1788–1794. DOI: 10.1021/acsnano.5b07472.

49. Mark Weiser. 1991. The computer for the 21st century. *Scientific american* 265, 3, 94–104.

50. Susan P. Wyche, Thomas N. Smyth, Marshini Chetty, Paul M. Aoki and Rebecca E. Grinter. 2010. Deliberate interactions: characterizing technology use in Nairobi, Kenya. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI ’10). ACM, New York, NY, USA, 2593–2602. DOI: 10.1145/1753326.1753719.

51. Takumi Yoshida, Kensei Jo, Kouta Minamizawa, Hideaki Nii, Naoki Kawakami and Susumu Tachi. 2007. Transparent cockpit. In *ACM SIGGRAPH 2007 Emerging Technologies* (SIGGRAPH ’07). ACM, New York, NY, USA. DOI: 10.1145/1278280.1278303.

52. Cunjiang Yu, Yuhang Li, Xun Zhang, Xian Huang, Viktor Malyarchuk, Shuodao Wang, Yan Shi, Li Gao, Yewang Su, Yihui Zhang, Hangxun Xu, Roger T. Hanlon, Yonggang Huang and John A. Rogers. 2014. Adaptive optoelectronic camouflage systems with designs inspired by cephalopod skins. *Proceedings of the National Academy of Sciences of the United States of America* 111, 36, 12998–13003. DOI: 10.1073/pnas.1410494111.

53. Bin Zheng, Lian Shen, Zuozhu Liu, Huaping Wang, Xian-Min Zhang and Hongsheng Chen. 2014. A simple unidirectional optical invisibility cloak made of water. *Progress In Electromagnetics Research* 146, 1–5.