Eyecam: Revealing Relations between Humans and Sensing Devices through an Anthropomorphic Webcam

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Figure 1: a) *Eyecam* is an alternative anthropomorphic design of conventional webcams, b) which draws inspiration from the human eye morphology to c) exaggerate the sensing capacities of webcams like face detection, and d) foster affective relationships.

ABSTRACT

We are surrounded by sensing devices. We are accustomed to them, appreciate their benefits, and even create affective bonds and might neglect the implications they might have for our daily life. By presenting *Eyecam*, an anthropomorphic webcam mimicking a human eye, we challenge conventional relationships with ubiquitous sensing devices and call to re-think how sensing devices might appear and behave. Inspired by critical design, *Eyecam* is an exaggeration of a familiar sensing device which allows for critical reflections on its perceived functionalities and its impact on human-human and human-device relations. We identify 5 different roles *Eyecam* can take: *Mediator*, *Observer*, *Mirror*, *Presence*, and *Agent*. Contributing design fictions and thinking prompts, we allow for articulation on *privacy awareness and intrusion*, *affect in mediated communication*, *agency* and *self-perception* along with speculation on potential futures. We envision this work to contribute to a bold and responsible design of ubiquitous sensing devices.

CHI'21, May 08–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-XXXX-X/18/06.
https://doi.org/10.1145/1122445.1122456

CCS CONCEPTS

• **Human-centered computing** → **Interaction design theory, concepts and paradigms**; **Interaction devices**; • **Applied computing** → *Media arts.*

KEYWORDS

Critical Design, Anthropomorphism, Webcam, Ubiquitous computing, Sensing Devices

ACM Reference Format:
Marc Teyssier, Marion Koelle, Paul Strohmeier, Bruno Fruchard, and Jürgen Steimle. 2021. Eyecam: Revealing Relations between Humans and Sensing Devices through an Anthropomorphic Webcam. In *CHI'21: ACM Conference on Human Factors in Computing Systems, May 08–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/1122445.1122456

1 INTRODUCTION

Today's interfaces have long transcended the traditional desktop setup and learned to sense and comprehend their environments. We are surrounding ourselves with an ever increasing number of sensing devices, ranging from cameras to smart speakers and motion sensing radar chips. They allow for object detection and recognition [55], natural interactions using speech [83], hand or body gestures [103], and for creating interactive rooms [40, 108], surfaces [100, 107] to furniture [92] and garments [34]. We encounter these sensing devices everywhere: in public, at our workplace, and inside our homes and living spaces. They have become ubiquitous.

Simultaneously, ubiquitous sensing devices are becoming invisible and morph into our daily lives, up to a point where we are unaware of their presence and stop questioning how they look, sense, and act. This is alarming, because the way ubiquitous sensing devices are designed can have implications on

- how aware we are of what our surroundings,
- how we communicate with others,
- how we behave and how we perceive our selves,
- how comfortable and safe we feel in public and private surroundings, and
- how we interact with sensing devices and vice versa.

As a result, it is important to challenge conventional design assumptions and strategies to evaluate what other options of designing technology can be pursued to positively engage with everyday individual and societal life. In light of this, it is timely to rethink and reconceptualize the relationship between humans and sensing devices through novel design alternatives. To this end, we decided to single out one specific sensing device – the webcam. Everyone is *highly familiar* with this device, and it is widely-used, making it *highly relatable*. Hence, everybody can participate in a discussion about it and contribute with their personal experiences, thereby facilitating an inclusive discussion on the design of human-technology relations.

In addition, webcams, as image sensing devices, are interesting to study because of their ambiguity: they are both essential to (video) communication over a distance [63], as well as a potential cause of disturbance [86] and a privacy hazard [80]. We sought to re-think the conventional design of webcams (Figure 1-a) to emphasize the potential implications sensing has on its user and other people. For this purpose, we leveraged the similarity of its basic function with the human eye: seeing and observing.

Taking inspiration from critical design [5, 22] and anthropomorphic interfaces [93, 95], we create *Eyecam* as a physical instantiation of the implications an exemplary sensing device can have for a human. To this end, *Eyecam* exaggerates concealed functionalities using anthropomorphic metaphors (e.g., field of view, capturing turned on). Modeled on the human eye morphology (Figure 1 - b), *Eyecam* comprises an actuated eyeball with a pupil replaced with a camera, actuated eyelids and actuated eyebrows whose combined movements enable human-like behaviors. By making it *physical*, *Eyecam* makes abstract concepts more tangible and illustrative. The *exaggeration* of its appearance captures attention and triggers spontaneous reactions and critical reflections.

Our rationale behind designing *Eyecam* in this way was two-fold. Firstly, to create a contrast to the current trend of increasingly unobtrusive sensing devices, we aimed to learn from the opposite, a clearly "seeing" device. We achieve this by presenting a speculative, anthropomorphic instantiation based on the the human eye, thereby leverage the tacit knowledge we have of the human act of seeing. Secondly, *Eyecam* continues and joins prior research themes of the individual authors, including antropomorphism [93–95], (self-)expression and perception [91] and privacy awareness [48, 90]. Originating from these diverse perspectives, this work broaches critical (social) issues around the ubiquity of sensing devices *in breadth* and by providing *novel overview perspective* that is contextualized, compared, and contrasted with prior work. As a result, *Eyecam* does not directly explore the impact of anthropomorphic design, but proposes to use anthropomorphism as a new (uncanny) tool for speculation.

Our work falls in line with research efforts in HCI transcending mere usability of devices to encompass emotions, values and affects, and the increasing interest in ethical [77], social [46, 47], and privacy [2, 74, 80] issues with ubiquitous sensing devices. Yet, in contrast to prior work, we use anthropomorphic design to take a speculative turn, challenging the reader to imagine themselves interacting with *Eyecam*, actively contribute to the debate, and speculate and iterate on potential futures. To this end, we contribute *Eyecam* as a plug-and-play physical prototype that can be re-used, re-built, or re-purposed. We further contribute five provocative design fictions which explore different types of behavior of our prototype. These open up a debate on plausible and implausible ways future sensing devices might be designed.

Through these fictions, we identify five different roles of *Eyecam*'s design: *Eyecam* as an *Observer*, a *Mediator* in remote communications, a *Mirror* of the self, an Ambient *Presence* acting as Genius Loci, and an autonomous *Agent*. Through design scenarios revolving around the provocative design of *Eyecam*, we discuss the relevance of *privacy awareness and intrusion*, *affect in mediated communication*, *self-perception*, and *agency* beyond the realm of desktop working environments and video capturing systems, and sketch potential futures relating to ubiquitous sensing devices.

With this work we intend to broaden the discourse on sensing technologies to include affective aspects, allow to further articulate social and ethical challenges, and spark speculations on artifact aestheticism and function. Finally, we envision this work to contribute to both a bold and responsible design of cameras and other ubiquitous sensing devices.

2 BACKGROUND

While multiple relevant arguments presented by prior work are woven in with our design fictions, we opt to highlight the essential areas of contact here, in a dedicated background section. We outline relevant background information on webcams and other sensing devices in HCI, systems utilizing eye gaze for interaction, anthropomorphic interfaces as well as methods using artifact design for reflection.

2.1 Cameras and other Sensing Devices

The proliferation of sensing devices into diverse areas of daily life relates to research in HCI on sensing methods that enable novel ways of interacting [53, 100, 103, 107, 108]. In particular, cameras have a long history of being employed in interactive systems. For instance, they are used to realize visual tracking [43], object or face detection [101]. Camera-based assistance in everyday use cases, early-on envisioned and implemented by Mann as 'Sixth Sense' [60], is nowadays ubiquitously available, e.g., as part of Google Lens [37] or Microsoft's Seeing AI [39]. In addition, interactive systems often employ cameras that exceed the visual range of the human eye. For instance, RGB-D cameras such as the Kinect (c.f., Jones et al. [40]) operate in the human perceptible and the near infrared spectrum, thermal cameras [82] in the far infrared spectrum, invisible to the human eye. As a result, the line between cameras as human-operated, picture-taking device, and as a powerful sensor that actually 'sees' its environment, become increasingly blurred. We elaborate on this theme using *Eyecam* as example.

As a second major area of interest, HCI has researched the effects ubiquitous sensing has on humans. Here, prior work looked into the use of wearable sensor devices, e.g., smart glasses in public spaces [18, 46, 86], lifelogging [45, 80], and ubiquitous sensing in smart home applications [66, 77, 88, 105]. Most related to our paper, a string of research by Pierce et al. [73–77] sought to investigate "network anxieties" caused by always-on sensing in domestic environments using speculative design scenarios. His playful camera prototypes [73, 77] explore reassuring metaphors preventing information leaks, including curtains, cages and caps, as well as unpredictable autonomous sensing devices, e.g., a camera riding a Roomba [75]. These prototypes all have a clean, minimal and industrial aesthetic. By employing exaggeration and anthropomorphic design, *Eyecam* complements and extends this prior design research.

2.2 Privacy and Security Issues with Webcams

Webcams pose a potential privacy hazard as they might capture activities that their user (or other depicted persons) would not want to be recorded [16]. Their surreptitious and ubiquitous nature facilitates misuse including the secretive observation of others in the home, e.g., intimate partners or other family members [13, 51], as well as attacks on other internet service users, so-called webcam trolling [49]. These issues intensify, as effective locators or feedback mechanisms (as demanded by Song et. al. [88]) are sparse and image masking techniques (e.g., blur filtration) fail to provide sufficient protection [64]. The webcam status LED, build-in with commodity notebooks, is the most common status indicator. Yet, it has been shown to be spoofable [11], and insufficiently noticeable and understandable [79]. In response to this danger of being surreptitiously watched, users have been observed to block their webcam's view with stickers or sliding covers [57, 58]. A guidebook of such "countermeasures" also extending to other, non-visual sensors has been proposed by Angus [59] who illustrates how to deceive a magnetometer and how to disable a smart phone's microphone using a manipulated audio jack. Similarly, the use of perceptually intuitive physical solutions using eye-lid or curtain metaphors has been proposed to improve understandability [15, 48, 77, 90]. *Eyecam* takes up these insights and implements the eye metaphor as design, following the Tangible Privacy [2] principles.

2.3 Eye Gaze for Interaction

The human eye gaze is crucial to convey non-verbal social cues. The temporal dynamics of gaze can improve communication, for instance by modulating social cognition and behaviour [14], influencing attention and engagement [84] and desire to communicate [24, 33]. Moreover, in combination with facial features such as eyebrow movements, eye gaze can convey pro-social emotions [56]. The importance of gaze has also been explored extensively in robotics [1] and with virtual agents [26]. The aesthetic and tangibility of the eyes are an important trait for anthropomorphism [21] and are beneficial for embodiment and familiarity. While social gaze communicates social engagement, a deictic gaze communicates task-related referential information [106] and can be used to guide the user's actions.

While human gaze was largely explored in the context of human-robot interactions, to the best of our knowledge, it was never explored in the context of ubiquitous sensing devices. With *Eyecam* we demonstrate how one can leverage the human gaze to better communicate the interaction design of ubiquitous sensors, and foster affective communication with them.

2.4 Anthropomorphic Interfaces

Anthropomorphism in HCI relates to the attribution of human characteristics to inanimate objects with the goal to help us rationalise their actions [21]. Persson [70] considers anthropomorphism as being a multi-layered phenomenon, and highlight the fact that the aliveness perception of the interface is conveyed mainly through *actuation* and *movement*, *look-and feel* and through a perceived inner *behaviour* of the device. While using anthropomorphism is common for the design of social robots and can benefit interaction [12, 41, 52], explorations of anthropomorphic cues for the design of conventional everyday devices are less common.

In the HCI literature such examples are often encountered in the area of shape changing interfaces. Here, traditional objects are designed to communicate a sense of agency through movement [9, 96]. Research has shown that traditional non-verbal behaviour can be mimicked through simple actuation, such as communicating attention or aversion through body-posture inspired movements [31], convey aliveness through life-like signals such as breathing rhythms [30, 69] or present emotions through shape and shape dynamics [91]. Recent work proposed re-thinking or extending the form factor of usual interactive devices to produce an anthropomorphic look-and-feel. For instance, Teyssier et al. proposed to augment touch devices with artificial realistic human skin [95] or augment phones with realistic finger-shaped attachment [93], while Park et al. proposed to augment mobile devices with animal-like antennas [68]. These approaches leverage knowledge of human behavior to convey intuitive interactions. Similar to this approach, we argue that morphological cues are a key component for conveying and exacerbating interaction capabilities. In this paper, we use the term Anthropomorphic Affordances to refer to the tacit knowledge of the interaction cues and capabilities that are conveyed through a human-like appearance [25].

2.5 Artifact Design to Reflect on our Relationships with Sensing Devices

Historically, CHI has a tradition of using prototype design to perform empirical studies of firsthand use. However, there is a growing interest of using new artifacts to reflect on our relation with technology itself. While this perspective was traditionally deployed through the lens of philosophy [99], this practice can now thrive through design fiction, [10, 109] and critical and speculative design [22]. We opt for a different approach than speculative fictions through imaginary devices [10] by fabricating a proof-of-concept tangible and functional prototype. Creating a physical artifact allows researchers and users to experience the device and discuss their experience with others to generate discussions [19]. With this approach, previous work demonstrated for instance the benefits of designing counter-functional interfaces [76], or even uncomfortable interactions [8].

Similar to the critique of Ubiquitous Computing through science fictions scenarios by Dourish and Bell [20], *Eyecam* aims to point out societal issues of the current challenges of technology, challenge the established convention [5], while questioning implicit themes in sensor design research.

3 *EYECAM*, ANTHROPOMORPHIC WEBCAM

The physical design is central in our work. The artifact design and look and feel result from the coupling between functional and aesthetic considerations as well as technological constraints. In this section, we discuss our design considerations, and the physiological and behavioral design of *Eyecam*. We also provide insight on the iterative design process.

3.1 Design Considerations

We had the following three primary goals for the implementation of *Eyecam*: 1) fabricate a fully functional proof-of-concept tangible device to experience it, 2) preserve conventional webcam functionalities, 3) support anthropomorphic affordances through appearance and motions.

1. Tangible Proof-of-concept Artifact. Creating a physical prototype is not mandatory to reflect on the usage of a device, yet it is seen as a commitment to the idea [72]. The physical presence of an anthropomorphic agent has more impact on our behavior [52], hence a tangible prototype allowed us to experience it and concretely experiment with the look-and-feel of this device to foster discussion. *Eyecam* is not only a fully functional prototype, but all information for others to replicate it is freely available, making *Eyecam* an open platform for experimentation. We encourage designers and researchers to replicate our device, create novel interactions with it, and reflect on the relations they have with such a device to shape new experiences[1].

2. Preserve Conventional Webcam Functionalities. In the last decades, the form factors of USB Tethered webcams have marginally evolved. These devices are familiar to us, and we understand their roles in our computing space as well as their functionalities. To emphasize their role in our lives without radically changing it, the design of *Eyecam* crosses the traditional form-factor of a webcam with a human eye. Like traditional webcams, *Eyecam* can be placed on a computer, facing the user, or *Eyecam* could be used in a living room to enable remote social communications with relatives, integrating larger social circles. Either way, *Eyecam* behaves as expected of a commodity device. It plugs into a computer via USB and is recognized as a camera.

3. Provide Anthropomorphic Cues. To promote social interaction through human-likeness and to foster familiarity, we chose to reproduce the human eye. The eyes serve as social emotional display, hence are a critical trait for anthropomorphism [21]. We particularly want to emphasize on reactive human gaze dynamics and expressive eyebrow movements. An important consideration for anthropomorphism is the level of realism. Designers usually intend to avoid falling into the Uncanny Valley. In contrast, we embrace the uncanny valley by intentionally provoking it through an out-of-body and out-of-context body part, to shine a spotlight on critical issues hidden in ubiquitous sensing.

[1]We provide our code and implementation materials at https://marcteys.github.io/eyecam/

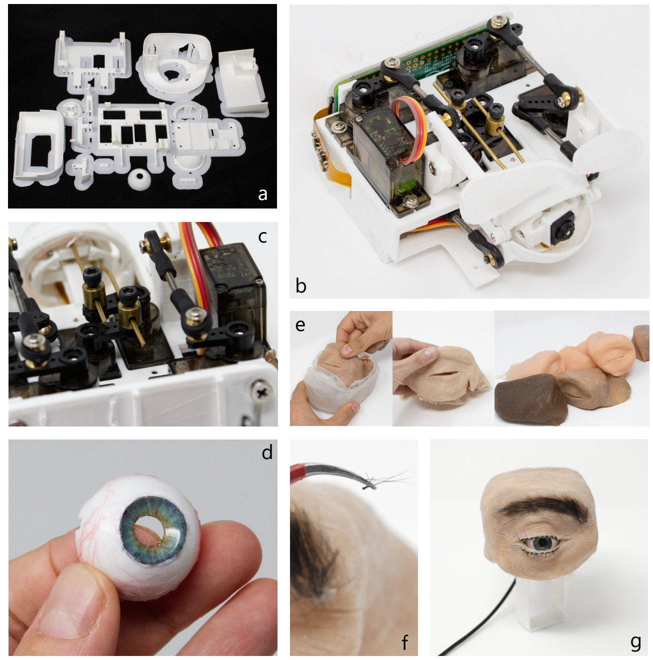

Figure 2: We manufactured *Eyecam* from a 3D-printed body (a), which we equipped with six servo motors for actuation (b). The servo motors are mechanically connected to the eyebrows and the eyeball (c). We created a realistic eyeball and iris encompassing the camera (d). The skin layer was molded in pigmented silicone (e), and augmented with hair implants (f) to generate a human-like impression (g). More details on the prototype hardware and material for replication can be found online[1] .

The implementation of *Eyecam* follows high-level principles derived from the field of social robotics [21] and commonly used for anthropomorphic and human-like technologies. It comprises *physiological* and *behavioral* aspects.

3.2 Physiological Design: Fabricating a Human Eye

While anthropomorphic affordances can be present even in abstract representations [91], creating an artifact with high levels of realism removes levels of abstraction, fostering both a direct interpretation of anthropomorphic cues and a visceral response [70]. Consequently the physiological design of *Eyecam* replicates human characteristics and capabilities as realistically as possible, including the look-and-feel of the interface, the way it is actuated and the way it senses.

Human-like Appearance. *Eyecam*'s form factor is inspired by a real-size human eye's anatomy (Figure 2g). It is composed of three main parts: the skin layer, the musculoskeletal system and the eyeball. The skin layer is made with skin-pigmented silicone (*Ecoflex00-30*), reproduced after a manually sculpted human eye shape (Figure 2e). To enhance the realism, human hair is implanted in the silicone for the eyebrows and eyelashes (Figure 2f). This skin layer fits on a 3D printed eye skeleton with embedded servo motors for actuation (Figure 2a and 2b). Finally, a sphere with 24mm diameter – based on typical measures of the human eye – is 3D printed to form the eyeball (Figure 2d), and a miniature camera is inserted where the pupil would be (Figure 2b). Unlike the human eye, the iris and pupil radius have a fixed diameter (respectively *12mm* and *6mm*) defined by the enclosure of the underlying camera sensor. Unlike traditional robot building processes, we first sculpted a mock-up of the eye in *Plastiline*, motivated by aestheticism only. This initial step helped us define the artistic direction as well as the proportions. The base was designed to clamp on top of computer screens (similar to a webcam), the lateral limits were defined by the human eye to nose bridge dimensions and the top by the eyebrow.

Actuation. To make *Eyecam*'s movements feel believable and natural, we mimic the eye's muscle structure in positioning the actuation mechanisms: *Eyecam* is composed of six servo motors (*HiTech MG90s*), selected for their fidelity to perform smooth and rapid movements (Figure 2b). For the eyeball, we mimic four muscles. One motor replicates the lateral motion of the *lateral* and *medial rectus* while another replicates the vertical movements of the *superior* and *inferior rectus*. For the eyelids, we mimic the *superior* and *inferior levator palpebrae* using one motor for each. For the eyebrows, we replicate the effects of the *corrugator supercilii* muscles using one motor for each muscle. We use an *Arduino Nano* to drive all the motors simultaneously. Initial actuation experiments using on muscle-like contractions of shape memory alloys (SMAs) indicated that these were too weak for prolonged use and that controlling them was not sufficiently reliable. Micro servo motors (such as the *PZ-15320*) were also tested, but proved insufficiently powerful to mechanically move the silicone. As a result of these considerations, we packed the motors and electronics as tightly as possible to maintain the proportions. To this end, the motors are positioned behind the eyeball, affecting the depth of *Eyecam*.

See and sense. To capture the eye vision, we place a small camera (*Zero Spy Camera*) in place of the iris, sensing a high resolution image (*720p60*). We attach this camera to a Raspberry Pi Zero using the CSI Interface. The Raspberry is used to emulate a webcam. This allows *Eyecam* to act as a conventional plug-and-play webcam which can be connected via USB port to allow computers. Users can setup, configure and use *Eyecam* with any program or environment which supports video input. We use *OpenCV* to process the image flux for implementing various behaviours. Adding a webcam in a human-sized eyeball impacts the inner mechanical structure of the eyeball. It should accommodate the camera while allowing a two-axis rotation, hence preventing the inclusion of the traditional ball joint mechanism in the center of the eyeball.

3.3 Behavioral Design: Actuating a Human Eye

The design of *Eyecam* highlights both the functional and representational properties of an eye. To assign human characteristics to *Eyecam*, it is essential to maintain a familiar feeling and unconsciously induce personality traits through movements [70]. The implementation of the behavioral aspect reproduces two major aspects of the human behavior. *Physiological unconscious behavior*, and *conscious behavior*. In both cases, we rely on underlying software developed in Unity3D, that implements a simple behaviour model and controls the movement of each individual motor.

Physiological Unconscious Behavior. The reproduction of human-like unconscious movements must match what users expect of life-like behavior. In our prototype, this principle is reflected through three actions. First, *Eyecam* is always *blinking*. T The blinking is performed at a rate similar to the human blinking rate (varying in a range from 1 to 2 second). The *eyelids dynamically adapt* to movements of the eyeball: when *Eyecam* looks up, the top eyelid opens widely while the lower one closes completely. Finally, we reproduce the *eye saccades*, by doing quick and subtle eyeball movements while fixing a target. Blinking alone is often used with anthropomorphic robots [50], yet the other two behaviour are equally important.

Conscious Behavior. Eyecam can adopt autonomous behavior and reactive behavior to simulate aliveness. The *autonomous behaviour* consists of imitating lifelike behavior independently of what is required of the specific interactive scenario [102]. For instance, the motors are parametrically controlled to follow a series of movements, such as looking about or reaching predefined poses while waiting for interaction. The device can also *react* to external stimuli, such as the presence of users in front of it. This is performed on background software processing, which interprets the image and detects relevant features. This reactive behavior is often used in robotics, and helps matching social norms, for example, by supporting conversation through appropriate gaze behavior [14]. The choice of *Eyecam*'s behavior depends on interaction context and the scenario implemented by the designer.

In addition to the low-level physiological unconscious behavior, we implemented a control interface for programming high-level conscious behavior. This control interface is optimized for prototyping and explore patterns of high level-level behavior, while *Eyecam* maintains its low-level unconscious behavior characteristics.

Each design scenario presented in the following section implements one or several of those behavioral conditions. One advantage of having high-level behaviors independent from the physiological unconscious ones is to favors serendipity: making errors while programming conscious behaviors can lead to unexpected interactions with its low-level behaviors, creating new and unexpected interaction scenarios.

4 DESIGNING ALTERNATIVE WEBCAM USES

To disrupt our perception of webcams – as an example of ubiquitous sensor – and to reflect on the corresponding human-artifact relations, we used a design process inspired by speculative and critical design [5, 17] and design fiction [10]. As common with critical design, we did not follow a formal methodology [6], but rather adopted a thinking-by-doing approach, where our insights emerged from conversations within the research team and externals, from reflective physical prototyping [27] and experimentation with the prototypes as well as collected reactions to the videos. Design fiction allowed us to ideate on plausible as well as implausible scenarios of use. In turn, by producing concrete interactive artifacts we approached design as a thinking-by-doing activity and gained insights from the "conversation with materials" [27]. Our initial interest was stirred by the human eye's affective expressivity and how humans (visually) perceive and interpret the world. As our intuition was that hands-on creation would allow us to immerse ourselves in interaction with the prototype and help gaining a deeper understanding, we developed the design fictions iteratively through regular discussions amongst the authors alongside developing *Eyecam*. While our conceptual starting points were loosely focused around Ihde's theoretical framework of Human-Technology Relations [99], engaging with the design of *Eyecam* and the finished implementation broadened our focus to also reflect on social (human-human) issues, aspects of privacy in ubiquitous sensing [7], and agency [17]. Throughout these reflections, our exploration of various stages of the prototype (or videos) was tightly interwoven with the physical formation of *Eyecam*, which put different key aspects in focus: the mechanics of the eyelids (Fig. 2b) pointed us to awareness of sensing, while speculation around the creation of human-device-bonds and self-representations arose from skin shading (Fig. 2e); we experienced the prototype sitting in our lab - as an ambient presence. These key aspects ultimately led us to identify five roles, which we subsequently present as a non-exhaustive list: Mediator, Observer, Mirror, Presence, and Agent.

The variety of roles presented here are representative of our intricate relation towards devices and our perception of the capabilities of these tools. The roles are not mutually exclusive and we acknowledge that the device can potentially, in turn, perform several of these roles.

We structure the following sections as follows. The **Imagine** sections represent design scenarios using *Eyecam*. They address the reader as user of technology. They are not based on rigorous empirical experiments but are critically informed from the authors' analysis of the device operating and their experience with it. We recommend readers watch the Video Figure beforehand as a complement to the written scenarios.

The **Think about** sections represent thinking prompts. They address the reader as HCI researcher, developer or designer, and call the reader to reflect on their practice and the implications when designing a new sensing system. Acknowledging that we do not have all answers ready, we include ourselves in this thinking exercise asking *"How might we..."*, a common way to capture and phrase open design challenges [38].

4.1 Observer: *Eyecam* revealing (un)awareness

> ***Imagine*** *your computer had eyes; imagine Eyecam replacing your notebook's webcam by being mounted on top of its display. When active, Eyecam's eyelids are open with occasional blinks; otherwise closed. When you are standing in the periphery, Eyecam might move its eyeball to adjust its field of view to better take you in. You might take a step farther to avoid its gaze. You can see if the camera is unexpectedly on. How does it feel when Eyecam leers at you? Would you lend it to your kids?*

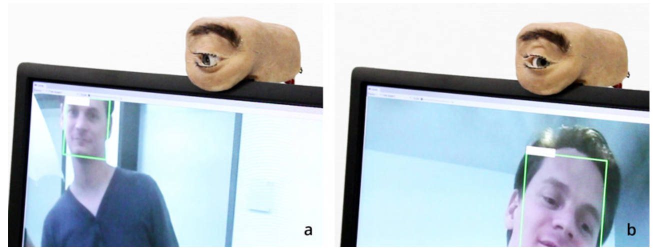

Figure 3: *Eyecam*'s gaze adapts to follow the users around.

Webcams, as 'seeing' devices, are a potential privacy hazard. Yet, in contrast to the human visual system, which indicates whether a person is watching (open or closed eyelids) and where they are looking (gaze direction), the actual risk of 'being seen' is hard to gauge. Cameras do not explicitly convey their internals: their status (i.e., turned on or off) is often unclear, as Status LEDs have been shown to be only insufficiently noticeable and understandable [2, 48, 79], and their field of view is not easily discernible. All this information, however, would be essential to realize appropriate feedback and control [7]. To reassure themselves of not being observed, many webcam users thus resort to blocking their webcam's view with stickers or sliding covers [57, 58], a strategy that has been taken up in the HCI literature and extended into solutions using eye-lid or curtain metaphors in interactive systems [15, 48, 77, 90].

Here, *Eyecam* illustrates a trait that most sensor devices are (so far) missing: its blink reflex signals activity, movement shows attention and conveys directionality (Figure 3). *Eyecam* can't 'see' when its eyelids are closed, but can when they are opened. Yet, by embodying an exaggerated version of the perceptually intuitive 'eye-lid' metaphor, *Eyecam* takes an admittedly 'easy' path which is inaccessible to most other sensing devices. While the issue of potential (un)awareness of sensing is not unique to webcams, the trajectory sketched by the increasing miniaturization and disappearance of sensors highlights the issue's breadth and impact, as well as its challenge. We might speculate on potential futures, where HCI and design research succeeds in surfacing such metaphors, and in providing sensor awareness to users and bystanders; or we might envision a more dystopian version of it, where the availability and diversity of sensing devices outgrows our ability to come up with comprehensible indicators, and everybody is 'seen' all the time, everywhere.

Think about implications of indiscernible sensing.

Standing in the middle of a room we might find no indicators of – for instance – a camera, or where it is placed, its direction and field of vision. Often, it is not even discernible whether and how a digital object at hand, e.g. smart speakers with built-in microphones, can sense [2]. *How might we make perceptible if and what it is sensing?* For other types of sensors this might even be a greater challenge. For instance, motion sensing radar chips such as Google's Soli [53, 103], are not (yet) linked to a perceptually intuitive metaphor. *How might we use existing metaphors that communicate what it is doing*? For other sensing techniques, e.g., contact-based object recognition on interactive fabrics [104], the convenient form factor might support unobtrusiveness rather than awareness. *How might we make use of form, materiality, or aesthetics to foster privacy awareness?*

4.2 Mediator: *Eyecam* augmenting communication

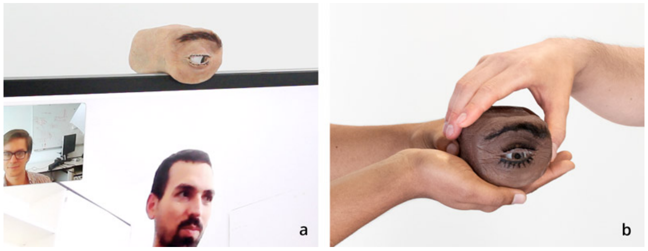

Figure 4: a) *Eyecam* incarnates a remote user and reproduce their eye gaze and eyebrow expressions. b) A user lend its *Eyecam* doppelganger to his significant other.

> ***Imagine*** *Eyecam reproducing the gaze of the person you are communicating with over a distance. Through Eyecam you could know where the person is looking, Eyecam might also reproduce their facial expression if the video stream quality drops. While this feature would fill the gap between co-located and mediated communication, would it be too invasive? We could go a step further, where the appearance of Eyecam would match the appearance of the callers, making Eyecam an external and remote extension of their bodies. Would we really perceive Eyecam as an extension of a person’s body? Would you give an eye that looks like yours to someone else?*

The benefits of eye gaze for communication are known for a long time, yet rarely used in traditional computing and sensing devices. This can be explained easily, as it requires a tangible eye [12]. In the context of remote communication, however, the benefits of eye gaze are attenuated if not completely hampered. For instance, it is complicated to know where a person is looking at through a webcam, or the poor quality of the video stream can prevent us from recognizing facial expressions and might impair the human-human communication.

Using *Eyecam*, the eye gaze and eyebrows’ expression of the remote partner can be detected and reproduced through the artifact (Figure 4a). This feature could reproduce facial emotions to foster mediated communication. It could also facilitate turn taking in a multi-person call [33], reveal when a person is embarrassed by the topic discussed [24], or enable the audience to see the speaker looking at the background rather than focusing on you. It can also bring back the lost interaction of the mutual look in the eye. *Eyecam* becomes a physical extension of the remote users’ body which enables users to “see through the eye”. Users could even appropriate that to fabricate doppelgangers and share them with relatives or friends (Figure 4b).

A perfect webcam would be one which vanishes from attention, allowing the user to focus only on the person they are communicating with (see also [99]). Here, however, in an inversion of embodied mediation, *Eyecam* inserts itself between the communicators, drawing attention away from the remote user and to itself. The eye might even act as shield, removing workload from the user, by feigning interest in a boring meeting.

Think about what increases presence and creates empathy.

The ability to accurately infer a conversational partner’s thoughts or feelings (so-called empathic accuracy) as well as one’s reaction to them impacts how a relationship develops, whether we build trust or mistrust: both in the physical world and online [23]. Yet, many important social cues are missing online. *How might we bridge the gap between co-located and remote communication through behavioral devices?* The transmission of more information (e.g. non-verbal cues such as gaze direction, heart beat, breath) that might otherwise pass unseen is an obvious solution, but comes with strings attached. Sharing physiological signals with a (remote) conversational partner can generate closeness and spark empathy, but might also create an image different of what the user might want to communicate about their state of mind [28]. It remains an open question how much sensing is needed to create empathy and what is “too much”. *How might we strike a balance between communicative and intrusive?*

4.3 Mirror: *Eyecam* as self reflection

Figure 5: The user is falling asleep (a) and *Eyecam* is mimicking him (b) to emphasize his physical behavior.

> ***Imagine*** *you are working late at night in front of a bright screen in a dim room. With a quick glance at the top of your display, you see Eyecam on the verge of closing its eyelids, overwhelmed by fatigue. Would you not feel compassion for it? You then realize it is mirroring your facial expression – it is time to call it a day. Now, what if Eyecam would look angry because you just had one of those everlasting meetings and felt like wasting time. Would you deny your emotion and remove the device from your display, or rather accept it and reflect on your emotional state?*

We are not always aware of our emotions or bodily experiences, yet they influence the way we communicate, behave and effect our overall well-being. Following somaesthetic design principles [35], *Eyecam* can serve as a behavioral mirror to emphasize the users’ body state. This enables a constant visual and tangible feedback of their bodily experiences. This role is the direct opposite of *Eyecam* as a *mediator*; it highlights the *self* rather than the *other*.

In contrast with ad-hoc methods for reflection like the *affective diary* [89], *Eyecam* enables in-situ and timely feedback (see Figure 5) building on devices like the *breathing lamp* [35]. *Eyecam* constantly staring at the user, without blinking, may nudge the user into changing their blink behaviour. We take advantage of anthropomorphism to create a direct one-to-one mapping. By mimicking parts of the user's facial expression, behaviors of the user and the device are coupled hence *Eyecam* embodies the mental state of the user. At the same time, *Eyecam* acts in the *background* to avoid disrupting the user's attention, however still providing subtle cues.

Think about what reflects our self and external images.

Just like mirror, sensing devices can reflect what they are sensing at the moment, or what they have been sensing moments, days, or even years ago. Sensed data might lead us to adjust ourselves, e.g., to "sound more mature" or "look professional", but can also promote awareness of ourselves and others, affirmation and connection [36] and foster (self-)reflection [81]. *How might we anticipate changes in behavior or perception caused by sensing devices?* Some changes of behavior or perception might resonate positively, some negatively; others might even be ethically questionable. To this end, there are different design options available for how information is sensed, processed, maybe abstracted or coded, and then feed back to the user. *How might we balance accuracy and abstraction in sensed data?* How a system approaches the different notions of opacity, transparency, and anonymity (as e.g., discussed by Howell et al. [36]) can influence what the user makes of this data and how it affects them. *How might we inform the user about what the system learned about them?*

4.4 Presence: *Eyecam* as a Genius loci

Figure 6: *Eyecam* in a public space staring at passers-by.

Imagine *Eyecam is present while you work, eat or sleep. Like a cat sitting in the corner of your (home-) office, it is just there; dozing off, silently taking in (or ignoring) your actions, waiting for you to interact with it, and from time to time acknowledging your existence with a blink. Would you feel observed? Would you get used to it? Or would you rather adjust your behavior – maybe to move more smoothly to not wake it?*

Devices with ambient presence can "be there" to offer interactions without catching attention or causing disturbance, e.g., act as peripheral displays [4, 29], and become a Genius loci in their environment, an incarnation of the "spirit of the place". Some of them might move into the background and wait for the user to initiate an interaction. For instance, a user might walk up to *Eyecam* raising their hand in front of the webcam (as suggested in [62]) to signal the sensing device to deactivate itself, i.e., to close its eyelids. Awaiting commands, ambient sensor devices are passive most of the time, but still listening and waiting for a command to be triggered (Figure 6). This watchful passiveness and unobtrusive integration with the environment can cause disembodiment and dissociation [7]: over time, people simply tend to forget about sensing devices in their vicinity, which is a door-opener for misuse such as unexpected and unsolicited dissemination of imagery [74] or audio files [88]. Simultaneously, the sheer plausibility of an ambient (camera) presence can cause the feeling of being observed. Here, locators [88], i.e., feedback mechanisms that cause sensing devices to be discoverable, become necessary to not have to be always on guard and to provide a sense of comfort.

This so-called surveillance-pressure, i.e. a negative state of mind caused by the potentiality of being observed, is made more experienceable by *Eyecam*. Through exaggeration and personification, *Eyecam* can even increase it to an extent where it might become uncomfortable. This way, it can act as a constant reminder to mind potential long-term consequences: continued anticipation of being watched can have severe and unexpected social consequences [32]; ever-observing "eyes" and "ears" might – alike the watchful-eyes effect – elicit negative emotions, such as annoyance, anxiety, rage, disgust or shame [66, 67]. This is important because sensing artifacts that remain in the background shape the context of our experience in a way that is not consciously experienced [99], and thus not necessarily considered throughout system design.

Think about ubiquitous sensing interwoven with day-to-day social life.

Vigilant devices can have an impact on people in their vicinity, for instance causing anxiety [66]. When we build, use, or deploy sensing devices we should consider why and when it needs to be on. *How might we re-design the effect its presence has on people sharing its space?* Ubiquitous sensing devices might be required to take on different roles, from watchful in one moment, to respectfully minding a users privacy in another. *How might we tell it to go to sleep?* We might even borrow interactions from human customs and social norms. Waving a good bye [78] or whispering "good night" to a smart speaker might seem more natural than covering it with a shielding cardboard box. Nevertheless, there might be situations where users would not want to bother with telling a sensor what to do, but would rather expect it to be courteous [44]: the sensing device would need to infer on its own when it is unwelcome. *How might we combine different ways of sensing to create respectful behavior?*

4.5 Agent: *Eyecam* as Anthropomorphic Incarnation

Imagine *Eyecam having a personality. It might learn to recognize objects you showed it, look sad when you leave, and look happy when you come back. At some point, it will have learned enough to start to making its own decisions. It might gain the agency to decide for itself when it would want to be observant, or when to be sleepy. Would you let it? Would you expect Eyecam to be polite or show discretion? How much would you teach it? And how would you engage in interactions with it?*

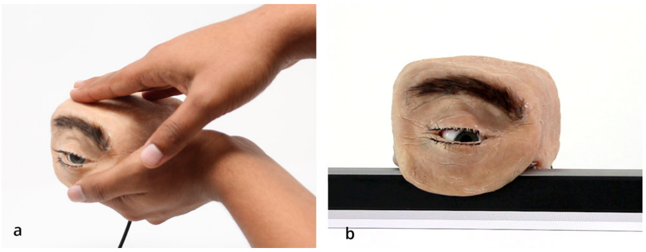

Figure 7: a) Users can develop a personal bond with *Eyecam*. b) *Eyecam* disappointed that its owner is late.

Advances in artificial intelligence enable sensing devices to gain more and more agency, i.e., the ability to act and elicit an intended effect (c.f., Cila et al. [17]). As a result, sensing devices morph from passive command-takers to more and more autonomous agents. As such, they gain the ability to pro-actively adapt to their surroundings and connect with people. For instance, *Eyecam* might observe its user's body posture and facial expression, and algorithmically decide to show compassion. In return, the user might anthropomorphize *Eyecam* and bond with it (Figure 7a) – or perceive it as a rather intimidating presence that they can't fully control. Elaborating potential avenues, *Eyecam* could be perceived as an autonomous agent, or the incarnation of the attached device's soul [61, 97].

Anthropomorphism is a powerful design metaphor to highlight the agency of sensing devices: *Eyecam* acts autonomously using human-like behaviors (Figure 7b), reacts to the user's actions mimicking self consciousness, and attracts the user's attention to engage in a conversation. *Eyecam*'s human-like appearance also helps to articulate concerns about human boundaries being invaded by impolite or overbearing sensing devices. It illustrates how, alike young humans, smart sensing devices would need to learn "the art of social grace and diplomacy" [17]. Such implicit anthropomorphizing of *Eyecam* and similar devices leads to additional design responsibilities. For instance, problematic social implications can arise when sensing devices acting as submissive virtual assistants are depicted female, "young and beautiful" or "toned down" to meet perceived or apparent role expectations [87].

Think about sensing devices possessing agency.

If we want sensing devices to become more proactive and autonomous, we would need to make design decisions about how much agency they should be granted. *How might we let them decide on their own what and when to sense? Or should we?* Sensing devices sharing our space would need to consider cultural social norms [42], including both verbal and non verbal communication cues [54]. For instance, a smart speaker would ideally not interrupt human conversations; for an eye it would be polite to maintain eye contact. Users might start to rationalize its personality, affectionately bond with it or project existing prejudices. *How might we avoid to embody stereotypes?* With more agency, complexity increases. Hence, the definition of rule sets becomes both necessary and challenging (as greatly illustrated by Asimov's Robot series "I, Robot" [3]). *How might we teach sensing devices to respect boundaries?*

5 DISCUSSION

With this work, we set out to investigate implications of ubiquitous sensing devices on human-device and human-human relations. In the following, we take a step back and reflect on our choice of methods, its limitations and generalizability, as well as implications for future work.

'Seeing' everything around it, *Eyecam* is well-suited to challenge the on-looker. Yet, this approach also comes with some inherent limitations. In particular, we chose a sensing device that is familiar and easy to relate to, but also very specific. As a result, while many conceptual considerations visualized by *Eyecam* (e.g., awareness) extend to other sensing devices (e.g., motion sensing radar chips [53]), some aspects of form factor, usage context, or modality might not fully generalize. In consequence, we ask the reader (or on-looker) to view *Eyecam* from a level of abstraction of their choice, and then re-apply their reflections to the sensing device they build, use or deploy (c.f., **Think about** sections). Not all of the design fictions we implement will apply to all sensing devices, and some sensing devices might require roles or scenarios beyond what we present here. For these reasons, this paper also includes *Eyecam*'s implementation details that allow other researchers to build upon our contributions.

Exaggerating human features, *Eyecam* uses an anthropomorphic design to physically illustrate scenarios. Hereby, it fosters critical reflection on the perceived functionality of a familiar sensing device, the webcam. While we believe that the core idea behind our work – employing a physical artifact to re-think common assumptions – is highly potent in surfacing design challenges, anthropomorphism is not the only design approach to achieve this. In fact, as demonstrated by prior work [48, 75, 77], the essence of making abstract concepts more physical generalizes to a wide range of high- and low-fidelity artifacts. In addition, it is reasonable to question the aestheticism of anthropomorphic design, which is neither minimal nor clean. One might also note that *Eyecam* is not entirely human-like: rather than assembling *Eyecam* from pre-used human parts (c.f. Shelley [85]), we opted for electro-mechanical actuators and silicone; the integrated servo motors create a slightly squeaking or squawking noise. With the sounds in sync with the eyeball's movements, this not-fully-human appeal contributes to a slight creepiness, which do not distract from the uncanny and anthropomorphic effects but rather enhances it. Nevertheless, we believe that the choice of anthropomorphic design, and *Eyecam*'s uncanny appearance, is particularly well suited for questions around perceived comfort and privacy. For instance, *Eyecam*'s exaggeration renders the so-called privacy paradox [65] visible: when prompted, most people would self-report higher levels of privacy concern than indicated by their behavior, culminating in the statement *"It's Creepy, But It Doesn't Bother Me"* [71].

This work touches upon a variety of themes around ubiquitous sensing devices. In writing this paper we deliberately decided for breadth instead of depth, which results in some aspects to be omitted or only brushed. While many of these themes are covered individually and in detail in prior work, we also fully acknowledge that there is much left to be said, debated and speculated about. By contributing our reasoning behind *Eyecam*'s design process and the resulting speculative overview perspectives, we hope to provide new incentives and starting points for reflections beyond what is covered in this work. While not originally intended, some aspects of *Eyecam* might also fall in line with debates in and around post-human design, for instance the way how so-called "smart" or "intelligent" objects (like *Eyecam*) are designed and conceived [98].

Through our explorations and reflections on *Eyecam* we identified five roles a sensing device can assume with regard to a person: *Observer*, *Mediator*, *Mirror*, *Presence*, and *Agent*. They allow to articulate design fictions (**Imagine**'s), and distill a number of concrete prompts for the design of sensing devices (**Think about**'s). In particular, they (un)cover the challenges of (1) employing sensing in a way that is not opaque to the user; (2) finding a balance between mediation and intrusion; (3) anticipating behavior change in response to feeling 'watched' (4) creating smart sensing devices to be present where needed, but respectfully absent when not; and (5) granting the 'right' amount of agency to smart sensing devices. Using *Eyecam* to articulate these challenges, we hope to spark attention, awareness *and a bit of joy*, amongst designers and developers beyond the group of researchers looking already into ethical, social and privacy issues with sensing devices.

6 CONCLUSION

With this work we sought to re-think and re-conceptualize the potential implications of ubiquitous sensing devices on individuals and on societal life. To foster critical reflection, we presented *Eyecam* an anthropomorphic webcam resembling a human eye and speculate on potential roles it can take. Through exaggeration, *Eyecam* surfaced design challenges that might be generalized to other types of sensing devices, and calls for responsible, but bold design decisions. At last, we contribute *Eyecam* as functional prototype to be re-produced and re-appropriated by researchers, designers, or makers who wish to experience it, explore it, and extend to create provoking, novel or uncanny sensing devices.

7 ACKNOWLEDGEMENTS

This project received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement 714797 ERC Stg InteractiveSkin).

REFERENCES

[1] Henny Admoni and Brian Scassellati. 2017. Social Eye Gaze in Human-Robot Interaction: A Review. *J. Hum.-Robot Interact.* 6, 1 (May 2017), 25–63. https://doi.org/10.5898/JHRI.6.1.Admoni

[2] Imtiaz Ahmad, Rosta Farzan, Apu Kapadia, and Adam J. Lee. 2020. Tangible Privacy: Towards User-Centric Sensor Designs for Bystander Privacy. *Proc. ACM Hum.-Comput. Interact.* 4, CSCW2, Article 116 (Oct. 2020), 28 pages. https://doi.org/10.1145/3415187

[3] Isaac Asimov. 1950. I, Robot, Robot series.

[4] Saskia Bakker, Doris Hausen, and Ted Selker. 2016. Introduction: Framing Peripheral Interaction. 1–10. https://doi.org/10.1007/978-3-319-29523-7_1

[5] Jeffrey Bardzell. 2011. Interaction criticism: An introduction to the practice. *Interacting with computers* 23, 6 (2011), 604–621.

[6] Shaowen Bardzell, Jeffrey Bardzell, Jodi Forlizzi, John Zimmerman, and John Antanitis. 2012. Critical design and critical theory: the challenge of designing for provocation. In *Proceedings of the Designing Interactive Systems Conference.* 288–297.

[7] Victoria Bellotti and Abigail Sellen. 1993. Design for privacy in ubiquitous computing environments. In *Proceedings of the Third European Conference on Computer-Supported Cooperative Work 13–17 September 1993, Milan, Italy ECSCW'93.* Springer, 77–92.

[8] Steve Benford, Chris Greenhalgh, Gabriella Giannachi, Brendan Walker, Joe Marshall, and Tom Rodden. 2012. Uncomfortable interactions. In *Proceedings of the sigchi conference on human factors in computing systems.* 2005–2014.

[9] Samuel Bianchini, Florent Levillain, Armando Menicacci, Emanuele Quinz, and Elisabetta Zibetti. 2016. Towards behavioral objects: A twofold approach for a system of notation to design and implement behaviors in non-anthropomorphic robotic artifacts. In *Dance Notations and Robot Motion.* Springer, 1–24.

[10] Mark Blythe. 2014. Research through design fiction: narrative in real and imaginary abstracts. In *Proceedings of the SIGCHI conference on human factors in computing systems.* 703–712.

[11] Matthew Brocker and Stephen Checkoway. 2014. iSeeYou: Disabling the MacBook Webcam Indicator {LED}. In *23rd {USENIX} Security Symposium ({USENIX} Security 14).* 337–352.

[12] A. Bruce, I. Nourbakhsh, and R. Simmons. 2002. The role of expressiveness and attention in human-robot interaction. In *Proceedings 2002 IEEE International Conference on Robotics and Automation (Cat. No.02CH37292)*, Vol. 4. 4138–4142 vol.4.

[13] Sloane C. Burke, Michele Wallen, Karen Vail-Smith, and David Knox. 2011. Using technology to control intimate partners: An exploratory study of college undergraduates. *Computers in Human Behavior* 27, 3 (2011), 1162 – 1167. https://doi.org/10.1016/j.chb.2010.12.010 Group Awareness in CSCL Environments.

[14] Roser Cañigueral and Antonia F. de C. Hamilton. 2019. The Role of Eye Gaze During Natural Social Interactions in Typical and Autistic People. *Frontiers in Psychology* 10 (2019), 560. https://doi.org/10.3389/fpsyg.2019.00560

[15] Yu-Ting Cheng, Mathias Funk, Wenn-Chieh Tsai, and Lin-Lin Chen. 2019. Peekaboo Cam: Designing an Observational Camera for Home Ecologies Concerning Privacy. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19).* Association for Computing Machinery, New York, NY, USA, 823–836. https://doi.org/10.1145/3322276.3323699

[16] Eun Kyoung Choe, Sunny Consolvo, Jaeyeon Jung, Beverly Harrison, and Julie A. Kientz. 2011. Living in a Glass House: A Survey of Private Moments in the Home. In *Proceedings of the 13th International Conference on Ubiquitous Computing* (Beijing, China) *(UbiComp '11).* Association for Computing Machinery, New York, NY, USA, 41–44. https://doi.org/10.1145/2030112.2030118

[17] Nazli Cila, Iskander Smit, Elisa Giaccardi, and Ben Kröse. 2017. Products as Agents: Metaphors for Designing the Products of the IoT Age. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17).* Association for Computing Machinery, New York, NY, USA, 448–459. https://doi.org/10.1145/3025453.3025797

[18] Tamara Denning, Zakariya Dehlawi, and Tadayoshi Kohno. 2014. In Situ with Bystanders of Augmented Reality Glasses: Perspectives on Recording and Privacy-mediating Technologies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14) (CHI'14).* ACM, New York, NY, 2377–2386. https://doi.org/10.1145/2556288.2557352

[19] Tom Djajadiningrat, Stephan Wensveen, Joep Frens, and Kees Overbeeke. 2004. Tangible products: redressing the balance between appearance and action. *Personal and Ubiquitous Computing* 8, 5 (2004), 294–309.

[20] Paul Dourish and Genevieve Bell. 2014. "Resistance is futile": reading science fiction alongside ubiquitous computing. *Personal and Ubiquitous Computing* 18, 4 (2014), 769–778.

[21] Brian R Duffy. 2003. Anthropomorphism and the social robot. *Robotics and autonomous systems* 42, 3-4 (2003), 177–190.

[22] Anthony Dunne and Fiona Raby. 2013. *Speculative everything: design, fiction, and social dreaming.* MIT press.

[23] Jinjuan Feng, Jonathan Lazar, and Jenny Preece. 2004. Empathy and online interpersonal trust: A fragile relationship. *Behaviour & Information Technology* 23, 2 (2004), 97–106. https://doi.org/10.1080/01449290310001659240 arXiv:https://doi.org/10.1080/01449290310001659240

[24] Tom Foulsham, Esther Walker, and Alan Kingstone. 2011. The where, what and when of gaze allocation in the lab and the natural environment. *Vision Research* 51, 17 (2011), 1920 – 1931. https://doi.org/10.1016/j.visres.2011.07.002

[25] Thomas Fuchs. 2001. The tacit dimension. *Philosophy, Psychiatry, & Psychology* 8, 4 (2001), 323–326.

[26] Maia Garau, Mel Slater, Vinoba Vinayagamoorthy, Andrea Brogni, Anthony Steed, and M Angela Sasse. 2003. The impact of avatar realism and eye gaze control on perceived quality of communication in a shared immersive virtual environment. In *Proceedings of the SIGCHI conference on Human factors in computing systems.* 529–536.

[27] Björn Hartmann, Scott R Klemmer, Michael Bernstein, Leith Abdulla, Brandon Burr, Avi Robinson-Mosher, and Jennifer Gee. 2006. Reflective physical prototyping through integrated design, test, and analysis. In *Proceedings of the 19th annual ACM symposium on User interface software and technology.* 299–308.

[28] Mariam Hassib, Daniel Buschek, Paweł W. Wozniak, and Florian Alt. 2017. HeartChat: Heart Rate Augmented Mobile Chat to Support Empathy and Awareness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17).* Association for Computing Machinery, New York, NY, USA, 2239–2251. https://doi.org/10.1145/3025453.3025758

[29] Doris Hausen, Hendrik Richter, Adalie Hemme, and Andreas Butz. 2013. Comparing input modalities for peripheral interaction: A case study on peripheral music control. In *IFIP Conference on Human-Computer Interaction*. Springer, 162–179.

[30] Fabian Hemmert. 2008. Ambient Life: Permanent Tactile Life-like Actuation as a Status Display in Mobile Phones. In *UIST'08: Adjunct Proceedings of the 21st annual ACM symposium on User Interface Software and Technology (Monterey, California, USA, October 20-22, 2008)*.

[31] Fabian Hemmert, Matthias Löwe, Anne Wohlauf, and Gesche Joost. 2013. Animate Mobiles: Proxemically Reactive Posture Actuation as a Means of Relational Interaction with Mobile Phones. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction* (Barcelona, Spain) *(TEI '13)*. Association for Computing Machinery, New York, NY, USA, 267–270. https://doi.org/10.1145/2460625.2460669

[32] Alison Hirst and Christina Schwabenland. 2018. Doing gender in the 'new office'. *Gender, Work & Organization* 25, 2 (2018), 159–176.

[33] Simon Ho, Tom Foulsham, and Alan Kingstone. 2015. Speaking and Listening with the Eyes: Gaze Signaling during Dyadic Interactions. *PLOS ONE* 10, 8 (08 2015), 1–18. https://doi.org/10.1371/journal.pone.0136905

[34] Cedric Honnet, Hannah Perner-Wilson, Marc Teyssier, Bruno Fruchard, Juergen Steimle, Ana C Baptista, and Paul Strohmeier. 2020. PolySense: Augmenting Textiles with Electrical Functionality using In-Situ Polymerization. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[35] Kristina Höök, Martin P. Jonsson, Anna Ståhl, and Johanna Mercurio. 2016. Somaesthetic Appreciation Design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 3131–3142. https://doi.org/10.1145/2858036.2858583

[36] Noura Howell, Greg Niemeyer, and Kimiko Ryokai. 2019. Life-Affirming Biosensing in Public: Sounding Heartbeats on a Red Bench. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3290605.3300910

[37] Google Inc. 2020. Google Lens - Search What You See. https://lens.google.com/. [Online; accessed 17-Sept-2020].

[38] IDEO Inc. 2021. How Might We, IDEO Methods Kit. https://www.designkit.org/methods/3. [Online; accessed 08-jan-2021].

[39] Microsoft Inc. 2020. Seeing AI App from Microsoft. https://www.microsoft.com/en-us/ai/seeing-ai. [Online; accessed 17-Sept-2020].

[40] Brett R. Jones, Hrvoje Benko, Eyal Ofek, and Andrew D. Wilson. 2013. IllumiRoom: Peripheral Projected Illusions for Interactive Experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 869–878. https://doi.org/10.1145/2470654.2466112

[41] James Kennedy, Paul Baxter, and Tony Belpaeme. 2015. Comparing robot embodiments in a guided discovery learning interaction with children. *International Journal of Social Robotics* 7, 2 (2015), 293–308.

[42] Sara Kiesler, Jane Siegel, and Timothy W McGuire. 1984. Social psychological aspects of computer-mediated communication. *American psychologist* 39, 10 (1984), 1123.

[43] Georg Klein and David Murray. 2009. Parallel tracking and mapping on a camera phone. In *2009 8th IEEE International Symposium on Mixed and Augmented Reality*. IEEE, 83–86.

[44] Marion Koelle, Swamy Ananthanarayan, Simon Czupalla, Wilko Heuten, and Susanne Boll. 2018. Your Smart Glasses' Camera Bothers Me!: Exploring Opt-in and Opt-out Gestures for Privacy Mediation. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI'18)*. ACM, New York, NY, USA, 473–481. https://doi.org/10.1145/3240167.3240174

[45] Marion Koelle, Wilko Heuten, and Susanne Boll. 2017. Are You Hiding It? Usage Habits of Lifelogging Camera Wearers. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Vienna, Austria) *(MobileHCI '17)*. Association for Computing Machinery, New York, NY, USA, Article 80, 8 pages. https://doi.org/10.1145/3098279.3122123

[46] Marion Koelle, Matthias Kranz, and Andreas Möller. 2015. Don't Look at Me That Way! Understanding User Attitudes Towards Data Glasses Usage. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Copenhagen, Denmark) *(MobileHCI '15)*. Association for Computing Machinery, New York, NY, USA, 362–372. https://doi.org/10.1145/2785830.2785842

[47] Marion Koelle, Torben Wallbaum, Wilko Heuten, and Susanne Boll. 2019. Evaluating a Wearable Camera's Social Acceptability In-the-Wild. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3290607.3312837

[48] Marion Koelle, Katrin Wolf, and Susanne Boll. 2018. Beyond LED Status Lights - Design Requirements of Privacy Notices for Body-Worn Cameras. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (Stockholm, Sweden) *(TEI '18)*. Association for Computing Machinery, New York, NY, USA, 177–187. https://doi.org/10.1145/3173225.3173234

[49] Kamil Kopecký. 2016. Misuse of web cameras to manipulate children within the so-called webcam trolling. *Telematics and Informatics* 33, 1 (2016), 1 – 7. https://doi.org/10.1016/j.tele.2015.06.005

[50] Hagen Lehmann, Alessandro Roncone, Ugo Pattacini, and Giorgio Metta. 2016. Physiologically inspired blinking behavior for a humanoid robot. In *International Conference on Social Robotics*. Springer, 83–93.

[51] Roxanne Leitão. 2019. Anticipating Smart Home Security and Privacy Threats with Survivors of Intimate Partner Abuse. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19)*. Association for Computing Machinery, New York, NY, USA, 527–539. https://doi.org/10.1145/3322276.3322366

[52] Daniel Leyzberg, Samuel Spaulding, Mariya Toneva, and Brian Scassellati. 2012. The physical presence of a robot tutor increases cognitive learning gains. In *Proceedings of the annual meeting of the cognitive science society*, Vol. 34.

[53] Jaime Lien, Nicholas Gillian, M. Emre Karagozler, Patrick Amihood, Carsten Schwesig, Erik Olson, Hakim Raja, and Ivan Poupyrev. 2016. Soli: Ubiquitous Gesture Sensing with Millimeter Wave Radar. *ACM Trans. Graph.* 35, 4, Article 142 (July 2016), 19 pages. https://doi.org/10.1145/2897824.2925953

[54] Shao-Kang Lo. 2008. The nonverbal communication functions of emoticons in computer-mediated communication. *CyberPsychology & Behavior* 11, 5 (2008), 595–597.

[55] Josh Lovejoy. 2018. The UX of AI: Using Google Clips to Understand How a Human-Centered Design Process Elevates Artificial Intelligence. In *Proceedings of the AAAI Spring Symposium Series*. https://aaai.org/ocs/index.php/SSS/SSS18/paper/viewPDFInterstitial/17565/15461

[56] Daniel Lundqvist, Francisco Esteves, and Arne Ohman. 1999. The face of wrath: Critical features for conveying facial threat. *Cognition & Emotion* 13, 6 (1999), 691–711.

[57] Dominique Machuletz, Stefan Laube, and Rainer Böhme. 2018. Webcam Covering as Planned Behavior. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3173754

[58] Dominique Machuletz, Henrik Sendt, Stefan Laube, and Rainer Böhme. 2016. Users Protect Their Privacy If They Can: Determinants of Webcam Covering Behavior. In *Proceedings of the European Workshop on Usable Security at the Privacy Enhaning Technologies Symposium (EuroSEC'16) (EuroUSEC'16)*. Internet Society, Reston, VA. https://doi.org/10.14722/eurousec.2016.23014

[59] Angus Main. 2019. Countermeasures: Learning to Lie to Objects. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3290607.3310420

[60] S. Mann. 2000. Telepointer: Hands-free completely self-contained wearable visual augmented reality without headwear and without any infrastructural reliance. In *Proceedings of the International Symposium on Wearable Computers (ISWC'00)*. IEEE Computer Society, 177–178. https://doi.org/10.1109/ISWC.2000.888489

[61] Betti Marenko. 2014. Neo-Animism and Design. *Design and Culture* 6, 2 (2014), 219–241. https://doi.org/10.2752/175470814X14031924627185 arXiv:https://doi.org/10.2752/175470814X14031924627185

[62] Carman Neustaedter and Saul Greenberg. 2003. The design of a context-aware home media space for balancing privacy and awareness. In *International Conference on Ubiquitous Computing*. Springer, 297–314.

[63] Carman Neustaedter and Saul Greenberg. 2012. Intimacy in Long-distance Relationships over Video Chat. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12) (CHI'12)*. ACM, New York, NY, 753. https://doi.org/10.1145/2207676.2207785

[64] Carman Neustaedter, Saul Greenberg, and Michael Boyle. 2006. Blur Filtration Fails to Preserve Privacy for Home-Based Video Conferencing. *ACM Trans. Comput.-Hum. Interact.* 13, 1 (March 2006), 1–36. https://doi.org/10.1145/1143518.1143519

[65] Patricia A Norberg, Daniel R Horne, and David A Horne. 2007. The privacy paradox: Personal information disclosure intentions versus behaviors. *Journal of consumer affairs* 41, 1 (2007), 100–126.

[66] Antti Oulasvirta, Aurora Pihlajamaa, Jukka Perkiö, Debarshi Ray, Taneli Vähäkangas, Tero Hasu, Niklas Vainio, and Petri Myllymäki. 2012. Long-Term Effects of Ubiquitous Surveillance in the Home. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing* (Pittsburgh, Pennsylvania) *(UbiComp '12)*. Association for Computing Machinery, New York, NY, USA, 41–50. https://doi.org/10.1145/2370216.2370224

[67] Costas Panagopoulos and Sander van der Linden. 2017. The feeling of being watched: Do eye cues elicit negative affect? *North American Journal of Psychology* 19, 1 (2017).

[68] Joohee Park, Young-Woo Park, and Tek-Jin Nam. 2014. Wrigglo: shape-changing peripheral for interpersonal mobile communication. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 3973–3976.

[69] Esben W Pedersen, Sriram Subramanian, and Kasper Hornbæk. 2014. Is my phone alive? A large-scale study of shape change in handheld devices using videos. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2579–2588.

[70] Per Persson, Jarmo Laaksolahti, and Peter Lönnqvist. 2000. Anthropomorphism–A multi-layered phenomenon. *Proc. Socially Intelligent Agents–The Human in the Loop, AAAI Press, Technical report FS-00-04* (2000), 131–135.

[71] Chanda Phelan, Cliff Lampe, and Paul Resnick. 2016. It's Creepy, But It Doesn't Bother Me. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5240–5251. https://doi.org/10.1145/2858036.2858381

[72] James Pierce. 2014. On the presentation and production of design research artifacts in HCI. In *Proceedings of the 2014 conference on Designing interactive systems*. 735–744.

[73] James Pierce. 2019. Lamps, Curtains, Robots: 3 Scenarios for the Future of the Smart Home. In *Proceedings of the 2019 on Creativity and Cognition* (San Diego, CA, USA) *(Camp;C '19)*. Association for Computing Machinery, New York, NY, USA, 423–424. https://doi.org/10.1145/3325480.3329181

[74] James Pierce. 2019. Smart Home Security Cameras and Shifting Lines of Creepiness: A Design-Led Inquiry. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300275

[75] James Pierce. 2020. Roomba+Clips Cam: Exploring Unpredictable Autonomy in Everyday Smart Systems. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (Eindhoven, Netherlands) *(DIS' 20 Companion)*. Association for Computing Machinery, New York, NY, USA, 317–320. https://doi.org/10.1145/3393914.3395816

[76] James Pierce and Eric Paulos. 2015. Making multiple uses of the obscura 1C digital camera: reflecting on the design, production, packaging and distribution of a counterfunctional device. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 2103–2112.

[77] James Pierce, Richmond Y. Wong, and Nick Merrill. 2020. Sensor Illumination: Exploring Design Qualities and Ethical Implications of Smart Cameras and Image/Video Analytics. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–19. https://doi.org/10.1145/3313831.3376347

[78] Patryk Pomykalski, Mikołaj P. Woundefinedniak, Paweł W. Woundefinedniak, Krzysztof Grudzień, Shengdong Zhao, and Andrzej Romanowski. 2020. Considering Wake Gestures for Smart Assistant Use. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3334480.3383089

[79] Rebecca S. Portnoff, Linda N. Lee, Serge Egelman, Pratyush Mishra, Derek Leung, and David Wagner. 2015. Somebody's Watching Me? Assessing the Effectiveness of Webcam Indicator Lights. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1649–1658. https://doi.org/10.1145/2702123.2702164

[80] Blaine A. Price, Avelie Stuart, Gul Calikli, Ciaran Mccormick, Vikram Mehta, Luke Hutton, Arosha K. Bandara, Mark Levine, and Bashar Nuseibeh. 2017. Logging You, Logging Me: A Replicable Study of Privacy and Sharing Behaviour in Groups of Visual Lifeloggers. *PROC ACM IMWUT* 1, 2 (2017), 22:1–22:18. https://doi.org/10.1145/3090087

[81] Kimiko Ryokai, Julia Park, and Wesley Deng. 2020. Personal Laughter Archives: Reflection through Visualization and Interaction. In *Adjunct Proceedings of the 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2020 ACM International Symposium on Wearable Computers* (Virtual Event, Mexico) *(UbiComp-ISWC '20)*. Association for Computing Machinery, New York, NY, USA, 115–118. https://doi.org/10.1145/3410530.3414419

[82] Alireza Sahami Shirazi, Yomna Abdelrahman, Niels Henze, Stefan Schneegass, Mohammadreza Khalilbeigi, and Albrecht Schmidt. 2014. Exploiting Thermal Reflection for Interactive Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 3483–3492. https://doi.org/10.1145/2556288.2557208

[83] Alex Sciuto, Arnita Saini, Jodi Forlizzi, and Jason I. Hong. 2018. "Hey Alexa, What's Up?": A Mixed-Methods Studies of In-Home Conversational Agent Usage. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18)*. Association for Computing Machinery, New York, NY, USA, 857–868. https://doi.org/10.1145/3196709.3196772

[84] Atsushi Senju and Toshikazu Hasegawa. 2005. Direct gaze captures visuospatial attention. *Visual Cognition* 12, 1 (2005), 127–144. https://doi.org/10.1080/13506280444000157 arXiv:https://doi.org/10.1080/13506280444000157

[85] Mary Wollstonecraft Shelley. 1818. *Frankenstein; or, The Modern Prometheus*. Lackington, London.

[86] Samarth Singhal, Carman Neustaedter, Thecla Schiphorst, Anthony Tang, Abhisekh Patra, and Rui Pan. 2016. You are Being Watched: Bystanders' Perspective on the Use of Camera Devices in Public Spaces. In *Proceedings of the SIGCHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI'16 EA)*. ACM Press, New York, New York, USA, 3197–3203. https://doi.org/10.1145/2851581.2892522

[87] Marie Louise Juul Søndergaard and Lone Koefoed Hansen. 2018. Intimate Futures: Staying with the Trouble of Digital Personal Assistants through Design Fiction. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18)*. Association for Computing Machinery, New York, NY, USA, 869–880. https://doi.org/10.1145/3196709.3196766

[88] Yunpeng Song, Yun Huang, Zhongmin Cai, and Jason I. Hong. 2020. I'm All Eyes and Ears: Exploring Effective Locators for Privacy Awareness in IoT Scenarios. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376585

[89] Anna Ståhl, Kristina Höök, Martin Svensson, Alex S Taylor, and Marco Combetto. 2009. Experiencing the affective diary. *Personal and Ubiquitous Computing* 13, 5 (2009), 365–378.

[90] Julian Steil, Marion Koelle, Wilko Heuten, Susanne Boll, and Andreas Bulling. 2019. PrivacEye: Privacy-Preserving Head-Mounted Eye Tracking Using Egocentric Scene Image and Eye Movement Features. In *Proceedings of the 11th ACM Symposium on Eye Tracking Research amp; Applications* (Denver, Colorado) *(ETRA '19)*. Association for Computing Machinery, New York, NY, USA, Article 26, 10 pages. https://doi.org/10.1145/3314111.3319913

[91] Paul Strohmeier, Juan Pablo Carrascal, Bernard Cheng, Margaret Meban, and Roel Vertegaal. 2016. An evaluation of shape changes for conveying emotions. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 3781–3792.

[92] Shan-Yuan Teng, Da-Yuan Huang, Chi Wang, Jun Gong, Teddy Seyed, Xing-Dong Yang, and Bing-Yu Chen. 2019. Aarnio: Passive Kinesthetic Force Output for Foreground Interactions on an Interactive Chair *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300902

[93] Marc Teyssier, Gilles Bailly, Catherine Pelachaud, and Eric Lecolinet. 2018. MobiLimb: Augmenting Mobile Devices with a Robotic Limb. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (Berlin, Germany) *(UIST '18)*. Association for Computing Machinery, New York, NY, USA, 53–63. https://doi.org/10.1145/3242587.3242626

[94] Marc Teyssier, Gilles Bailly, Catherine Pelachaud, and Eric Lecolinet. 2020. Conveying Emotions Through Device-Initiated Touch. *IEEE Transactions on Affective Computing* (2020).

[95] Marc Teyssier, Gilles Bailly, Catherine Pelachaud, Eric Lecolinet, Andrew Conn, and Anne Roudaut. 2019. Skin-On Interfaces: A Bio-Driven Approach for Artificial Skin Design to Cover Interactive Devices. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 307–322. https://doi.org/10.1145/3332165.3347943

[96] Jonas Togler, Fabian Hemmert, and Reto Wettach. 2009. Living interfaces: the thrifty faucet. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*. 43–44.

[97] Philip van Allen, Joshua McVeigh-Schultz, Brooklyn Brown, Hye Mi Kim, and Daniel Lara. 2013. AniThings: Animism and Heterogeneous Multiplicity. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (Paris, France) *(CHI EA '13)*. Association for Computing Machinery, New York, NY, USA, 2247–2256. https://doi.org/10.1145/2468356.2468746

[98] Jelle van Dijk. 2020. Post-Human Interaction Design, Yes, but Cautiously. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (Eindhoven, Netherlands) *(DIS' 20 Companion)*. Association for Computing Machinery, New York, NY, USA, 257–261. https://doi.org/10.1145/3393914.3395886

[99] Peter-Paul Verbeek. 2005. *What things do: Philosophical reflections on technology, agency, and design.* Penn State Press.

[100] Nicolas Villar, Daniel Cletheroe, Greg Saul, Christian Holz, Tim Regan, Oscar Salandin, Misha Sra, Hui-Shyong Yeo, William Field, and Haiyan Zhang. 2018. Project Zanzibar: A Portable and Flexible Tangible Interaction Platform. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3174089

[101] Paul Viola and Michael Jones. 2001. Rapid object detection using a boosted cascade of simple features. In *Proceedings of the 2001 IEEE computer society conference on computer vision and pattern recognition. CVPR 2001*, Vol. 1. IEEE, I–I.

[102] Kazuyoshi Wada and Takanori Shibata. 2007. Living with seal robots—its sociopsychological and physiological influences on the elderly at a care house. *IEEE transactions on robotics* 23, 5 (2007), 972–980.

[103] Saiwen Wang, Jie Song, Jaime Lien, Ivan Poupyrev, and Otmar Hilliges. 2016. Interacting with Soli: Exploring Fine-Grained Dynamic Gesture Recognition in

the Radio-Frequency Spectrum. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (Tokyo, Japan) *(UIST '16)*. Association for Computing Machinery, New York, NY, USA, 851–860. https://doi.org/10.1145/2984511.2984565

[104] Te-Yen Wu, Lu Tan, Yuji Zhang, Teddy Seyed, and Xing-Dong Yang. 2020. Capacitivo: Contact-Based Object Recognition on Interactive Fabrics Using Capacitive Sensing. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) *(UIST '20)*. Association for Computing Machinery, New York, NY, USA, 649–661. https://doi.org/10.1145/3379337.3415829

[105] Yaxing Yao, Justin Reed Basdeo, Oriana Rosata Mcdonough, and Yang Wang. 2019. Privacy Perceptions and Designs of Bystanders in Smart Homes. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW, Article 59 (Nov. 2019), 24 pages. https://doi.org/10.1145/3359161

[106] Cristina Zaga, Roelof A.J. de Vries, Jamy Li, Khiet P. Truong, and Vanessa Evers. 2017. A Simple Nod of the Head: The Effect of Minimal Robot Movements on Children's Perception of a Low-Anthropomorphic Robot. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 336–341. https://doi.org/10.1145/3025453.3025995

[107] Dingtian Zhang, Jung Wook Park, Yang Zhang, Yuhui Zhao, Yiyang Wang, Yunzhi Li, Tanvi Bhagwat, Wen-Fang Chou, Xiaojia Jia, Bernard Kippelen, Canek Fuentes-Hernandez, Thad Starner, and Gregory D. Abowd. 2020. OptoSense: Towards Ubiquitous Self-Powered Ambient Light Sensing Surfaces. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 4, 3, Article 103 (Sept. 2020), 27 pages. https://doi.org/10.1145/3411826

[108] Yang Zhang, Chouchang (Jack) Yang, Scott E. Hudson, Chris Harrison, and Alanson Sample. 2018. Wall++: Room-Scale Interactive and Context-Aware Sensing. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3173574.3173847

[109] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 493–502.