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Drone-based Privacy Interfaces: Opportunities and Challenges

Florian Schaub
School of Computer Science
Carnegie Mellon University
Pittsburgh, PA, USA
fschaub@cs.cmu.edu

Pascal Knierim
Institute for Visualization & Interactive Systems
University of Stuttgart
Stuttgart, Germany
pascal.knierim@vis.uni-stuttgart.de

ABSTRACT

Providing users with awareness and control about privacy-sensitive information flows is a major challenge in Internet of Things scenarios, because of constrained input and output capabilities of the involved sensors and devices. We propose the use of autonomous personal drones, specifically nanocopters, as device-independent drone-based privacy interfaces. Nanocopters have the potential to indicate privacy risks, visualize information flows, and provide tangible privacy controls within a smart environment without being tethered to specific IoT devices. We provide an overview of recent advancements in human-drone interaction and describe our vision of leveraging personal drones as privacy indicators and controls, including a discussion of opportunities and associated challenges.

1. INTRODUCTION

Personal drones have gained in popularity in recent years. Commercially available personal drones are commonly intended for outdoor use. They are equipped with several sensors and often with a camera for monitoring or aerial photography. Typically, drones are remote-controlled by the user or a certain application. Drones with major payload have numerous applications in search and rescue, covering finding victims, delivering a defibrillator in emergency situations or delivery of human organs for transplant. Logistics companies put great research effort towards the use of drones for parcel delivery [1]. Current drones for the consumer market are equipped with high resolution cameras for aerial photography and cinematography. Sensors and algorithms enable semi-autonomous flight, following a specified object or the user, and avoiding collisions. Yet, direct interaction with such drones is discouraged and can even be hazardous due to their speed and exposed rotor blades.

However, recent research efforts have proposed miniaturizing drones and making them safe for direct human-drone interaction [4, 10]. Nano-scale drones can be equipped with LEDs, small screens and touchscreens and thus act as free-floating displays indoors. One advantage of drones is that they can move relatively precisely in three dimensional space as well as levitate in place, which almost gives them proporties of "programmable matter" [4] and facilitates tangible interaction [6]. While current drones are still the size of a soccer ball, current miniaturization efforts suggest that future drones may be the size of a human fist or even smaller. Such nano-scale drones, or more precise nanocopters, hold the potential for novel visualizations, interaction techniques, and interactive applications.

In this paper, we propose the use of nanocopters for the creation of novel privacy interfaces in smart environments and Internet of Things (IoT) scenarios. Communicating privacy information and providing privacy controls to users is a major challenge in IoT scenarios, because most IoT devices and sensors have no or limited output and input capabilities. Nanocopters hold the potential of providing device-independent privacy indicators and controls *within* the smart environment. We discuss opportunities for leveraging nanocopters as privacy interfaces and the research challenges associated with making such drone-based privacy interfaces practical.

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2. HUMAN-DRONE INTERACTION

Over the last years more and more sensors and advanced algorithms have been integrated into drones and quadcopters. Hence, rich user interaction has become possible in many domains. Visual object tracking and GPS support enable drones to accompany a runner and act as a jogging companion that motivates during exercise [5], helps runners maintain their pace [9], or films the run for later training analysis.

Schnegass et al. proposed a free floating midair display [16], facilitated by a display attached to an autonomous drone. Such a floating display makes it possible to show users information in situations in which ordinary fixed or wearable displays are cumbersome to use. For instance, during exercise or to support crowd control in emergency situations. Scheible et al.'s *DisplayDrone* [15] is a projector-augmented drone that can project short messages on close-by surfaces and walls. Nozaki extended this idea [11] by equipping a second drone with a light-weight white board, which serves as a levitating projection surface.

Neither jogging companion drones nor display drones allow direct tangible interaction due to their size and exposed rotors. Cauchard et al. [2] explored natural spatial interaction metaphors for interacting with drones. Their ideas were pursued in *BitDrones* [4]. Gomes et al. [4] developed small nanocopters encased in a light mesh cube to create an interactive, gravity-defying tangible display for direct manipulation. Small drones equipped with LEDs or displays provide information output, while the user can directly interact with the floating cubes via manipulations such as touching, grabbing and movement. The proposed system is currently limited to 12 simultaneously flying *BitDrones*.

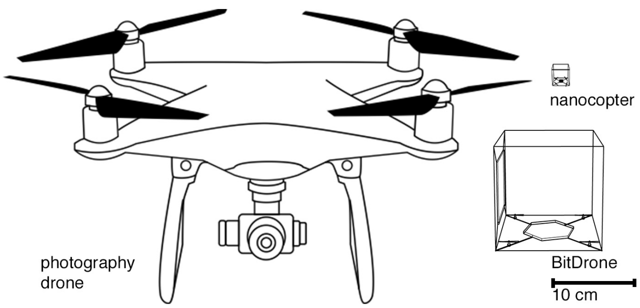

Figure 1: Size comparison of an aerial photography drone, a *BitDrone* and an envisioned nanocopter.

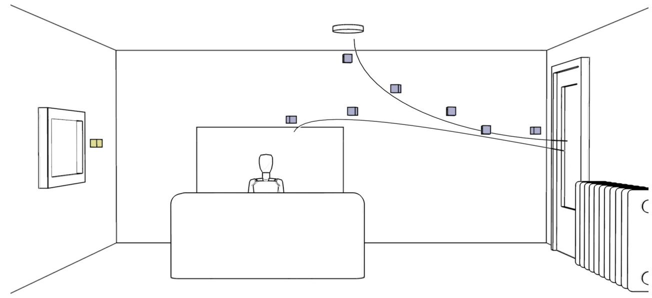

Figure 2: Drone-based privacy interfaces in a smart home: information flow visualization caused by a motion sensor (*ceiling*) and depth camera (*TV*). Drone-based permission request to access image cloud storage next to a digital image frame (*left*).

However, Kushleyev et al. [7] showed that autonomously flying swarms of drones are possible, including collision-free trajectory planning and collaborative task solving [12]. We expect that the current miniaturization trend for drones will continue, possibly yielding “flying pixels” – small, flying cubes organized in autonomous swarms that can dynamically form multi-dimensional displays and diverse tangible interfaces. Figure 1 provides a size comparison of different drone generations. Similar to BitDrones, we envision that smaller nancopters can be equipped with touchscreen displays on all sides to facilitate natural interaction with indvidual drones as well as a swarm of drones.

3. DRONE-BASED PRIVACY INTERFACES

While current drones are still comparatively large, further miniaturization of drones seems feasible. We envision the combination of nanocopters, autonomous swarm algorithms, and spatial interaction concepts to create interactive drone-based privacy interfaces for IoT scenarios and smart environments. Drone-based privacy interfaces can visualize information flows, provide tangible privacy controls, and manage user consent *within* a smart environments, rather than *about* the smart environment.

Instead of just showing privacy-related information and privacy settings on a display, in a drone-based privacy interface individual nanocopters can represent different privacy-related concepts and offer different interaction opportunities. Nanocopters can operate independently of specific devices or sensors which makes it possible to leverage them as floating privacy representations of a certain device or sensor in the smart environment; a specific kind of information being collected or transmitted by sensors and devices; or a specific recipient or consumer of information. Furthermore, nanocopters cannot only act as privacy indicators but also be directly used as privacy controls.

Next, we describe three potential scenarios that demonstrate how we envision drone-based privacy interfaces in smart environments. Note that these are mere examples; we expect that creative uses and interaction techniques for drone-based privacy interfaces will emerge, evolve, and mature over time.

3.1 Information Flow Visualization

Multiple nanocopters can act in concert to visualize information flows in a smart environment. In this scenario, individual nanocopters represent certain information that is being collected and transmitted. They fly from one device or sensor to the next to indicate where in the smart environment this information is collected, to which other devices it is transmitted, and how information from multiple sensors is combined to infer knowledge. Figure 2 shows an example of a smart home in which a motion sensor detects how many people are present. The entertainment system’s depth camera analyzes facial features to identify individuals and determine who is ‘home.’ Both sensor streams are consumed by a smart thermostat that sends information about who is present to its manufacturer’s server, which returns heating or cooling instructions optimized to the ‘heat preferences’ of the present persons.

To visualize these information flows, nanocopters would navigate to the motion sensor and depth camera with all their displays off. Near the sensor, the displays are activated to indicate what kind of information is being collected by the sensors, e.g., with different colors, icons, or the actual information. For instance, when individuals are identified by the depth camera their photo can be shown on a nanocopter’s display. Nanocopters fly in two streams to the smart thermostat – marking the two sensors streams with different colors. To indicate that the two sensor streams are combined by the thermostat, the nanocopters combine the information on their displays and continue flying towards the wifi router, or better, towards another nanocopter levitating near the front door, representing the thermostat manufacturer by showing the manufacturer’s logo on its display. Multiple nanocopters would fly in a loop to indicate the continuous stream of collected information.

By grabbing a nanocopter mid-flight, the user can inspect in detail what specific information is being transferred – similar to deep packet inspection at the network level. Once the nanocopter senses that it is being touched it can levitate in place and its displays can provide further information. Privacy controls could be offered on the display or via more natural interaction, for instance, by blocking the path of a nanocopter or pushing it out of its flight path.

3.2 Ambient Exposure Display

Information flow visualization and control, as outlined above, require user attention and interest to actively engage with privacy interfaces. However, nanocopters can also form ambient displays of data exposure. Instead of actively zooming through the environment, nanocopters can indicate the amount of information a certain device or sensor has accumulated. Exposure can be indicated by concentrations of nanocopters, how high they levitate above a device, or by “stacking” nanocopters – either in mid-air or by landing them on top of each other on or near an IoT device.

Ambient exposure displays are not limited to data practices by devices or sensors in the user's environment, but could also represent the accumulation of information about the user by online services, e.g., a social network site, a retailer, or a data broker. Instead of anchoring the ambient display on a physical device, another nanocopter can represent the respective service provider.

Such ambient exposure displays have the advantage that users do not need to pay attention to the display but have the opportunity to notice egregious or unexpected data practices that are otherwise invisible. Picking up one of the nanocopters can provide access to privacy controls and settings for the respective sensor, device, or service.

3.3 Permission and Consent Requests

Nanocopters further provide the opportunity for IoT devices and systems to ask for consent or request permissions in situ. Rather than having to rely on a companion app on a smartphone, tablet or voice assistant, a nanocopter can be used to indicate the need for the user to make a privacy decision and facilitate in-situ privacy decision making, i.e., in the context of the system and data practice. A nanocopter can either fly directly to the user (which should be reserved for urgent interventions) or levitate in a location related to the permission or consent request. For instance, the nanocopter could hover in front of a digital picture frame requesting the permission to access the user's cloud image storage, as depicted on the left in Figure 2. Information about the requested permission or consent can be provided on the nanocopter's displays or by leveraging information flow visualization as described above. Users can indicate consent either by interacting with the nanocopter's display or by moving it to a certain location. Swatting the nanocopter away or placing it back in its resting (and charging) dock can indicate denying the request.

4. RESEARCH CHALLENGES

Drone-based privacy interfaces provide a novel paradigm for interacting with privacy indicators and controls in future smart environments. While current nanocopters already facilitate the realization of certain aspects of the outlined scenarios, making drone-based privacy interfaces a practical reality poses multiple research challenges.

Drone miniaturization

The availability of very small, autonomous flying nanocopters is a crucial prerequisite for our vision. Reducing the size of a drone is closely related to a drone's potential payload. Thus, miniaturization would likely require reducing the amount of sensors, as well as output and input modalities available on a drone – or making such components lighter. Battery power is also a concern. The design and development of suitable nanocopters will remain a challenging endeavor in the foreseeable future. We encourage researchers to investigate the optimal size, payload and sensor set to facilitate autonomous flying and sufficient output modalities for rich interaction at minimal sizes.

Due to weight constraints, battery life of current off-the-shelf nanocopters is about 8 minutes. To tackle this issue, we propose wireless charging docks. Nanocopters could land on a charging dock to recharge their batteries while not in use. Furthermore, nanocopters with depleted batteries could be dynamically replaced by charged ones during long lasting interaction periods.

As a result of the potentially large number of nanocopters involved in our scenarios, the audible noise of each nanocopter should be minimal. However, mechanical instability and fast spinning electrical engines in current drones cause high frequency noise. Developing nanocopters with low noise signatures is an import challenge to address in order to make human-drone interaction pleasant and engaging.

Drone and user tracking

Seamless human-drone interaction requires robust and reliable drone and user tracking in three dimensions. Accurate indoor localization and tracking of drones and users is an active research area. In addition, locations of IoT devices and sensors in the smart environment have to be known to realize meaningful information flow visualisation. Furthermore, the proposed interface requires a framework that enables the mapping of data flows and privacy practices to devices and sensors in the physical environment.

Collision-free controlling of a swarm of nanocopters seems feasible. Nonetheless, direct user interaction and manipulation of a swarm of drones is an under-explored challenge and requires further investigation, especially with regard to scalability and user safety.

Drone regulation

User and airspace safety are likely to continue to be important considerations in regulation and public policy regarding drones. For instance, in the United States drones that weigh more than 0.55 lbs (250 g) currently have to be registered with the Federal Aviation Administration (FAA) [3] before they can be operated outdoors. The weight of our envisioned nanocopters may eventually be below this threshold. Yet, autonomous swarms of nanocopters could still constitute potential hazards for aviation and people.

Thus, in addition to weight requirements, future regulation may introduce height restrictions for small-scale drones, as well as requirements for technological safe guards to facilitate safe interaction with drones and nanocopters. The research community can help inform the respective public policy debate by developing drone-based safety features.

Privacy infrastructure

Assuming that technical challenges related to drones and localization can be addressed eventually, drone-based privacy interfaces need to be provided with information about data practices and information flows in the smart environment. Privacy systems and infrastructure are required to detect and model information flows between sensors and devices.

A potential approach is the specification of data practices in machine-readable privacy policies and their distribution in the smart environment, which would not only enable drone-based privacy interfaces, but device-independent privacy awareness and control tools in general [8, 13]. While much focus has been placed on expressing data practices in machine-readable formats, exposing control APIs, user choices, and privacy settings to other systems is an equally important challenge [14].

Creating infrastructures that can collect and exchange privacy-relevant information about devices in a smart environment or an individual's vicinity would enable the aggregation of privacy settings and privacy management functionality for multiple devices in a consistent interface, which may be drone based, but could also be provided on a tablet, mobile device, wall display or computer. Such aggregation of privacy information and settings would facilitate contextualized privacy decision making support and has the potential to reduce user-burden by providing users with personalized recommendations and automating certain privacy decisions and settings configurations for the user [13].

Human-drone interaction design

Related work has started to investigate natural metaphors for the interaction with drones [2, 4]. Yet, further research is needed to develop and study paradigms and metaphors for human-drone interaction. A challenge that deserves particular attention is how drones can be integrated into smart environments and existing interaction paradigms, without being obtrusive or even threatening.

Our described scenarios provide a first indication of how drones could enable privacy interfaces in smart environments. A major challenge in human-drone interaction design for privacy is mapping data practices, which are often abstract and involve multiple stakeholders, to the physical environment. A further challenge is the communication of choice and consent options. Addressed these aspects requires investigation of natural and intuitive metaphors, which is also part of the broader challenge of communicating privacy information and choices in a concise, yet meaningful fashion.

Furthermore, drone-based privacy interfaces require control systems and interfaces that determine when the nanocopters should become active, what they should represent, and how they engage with users.

5. CONCLUSION

In this paper, we proposed drone-based privacy interfaces for smart environments and Internet of Things scenarios. Nanocopters are self-actuated and can autonomously move and levitate in three dimensional space and enable direct human-drone interaction. Future nanocopters will be small enough to interact in swarms indoors. This provides novel opportunities to create device-independent privacy interfaces, indicators and controls that can arrange themselves in relation to specific devices and sensors as needed. We outlined multiple scenarios for drone-based privacy interfaces. Small swarms of nanocopters could visualize otherwise opaque data flows in the environment, indicate exposure and data leakage, and act as tangible privacy controls to re-configure privacy settings. In contrast to privacy interfaces on mobile or desktop devices, drones have the potential to provide a direct mapping between data practices and the physical environment. Nanocopters further provide the opportunity to augment IoT devices and sensors with rich interaction capabilities, which can be leveraged for privacy control.

We outline multiple challenges – with respect to drones and privacy technology – that need to be addressed in future research to realize our vision of drone-based privacy interfaces and turn it into a practical approach. We expect that further ideas and concepts will develop and evolve around this new paradigm of tangible interaction with privacy aspects of technology in the future.

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