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# USING THE PUBLIC PERCEPTION OF DRONES TO DESIGN FOR EXPLICABILITY

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Drones are increasingly used for civil and commercial purposes, and the general public is therefore increasingly exposed to this technology. To make drones acceptable to citizens, their perception of drones must be understood, and their input used to improve drone design. In this paper, early indications of the Danish public's perception of drones for use in public healthcare are presented. Quantitative and qualitative empirical data on visual and aural perception of drones were gathered from 110 citizens through a range of successive studies conducted in 2018-2019. The results indicate that citizens have a moderate preference for fixed wing, airplane-like drones, but that the drone's color is more suitable than its configuration for indicating the drone's purpose. Informative text on the drone indicating its purpose is considered a must-have attribute, and informative symbols an attractive attribute. The inclusion of a visible camera leads to reduced satisfaction. Low-pitched sound profiles are preferred, and the "natural" sound of the drone is favored over one with add-on sounds – even sounds specially designed to be less annoying. Danish citizens want to know when and why drones are nearby through visual and aural means, but not be annoyed or have their privacy violated. These results hint at a general approach to "design for explicability", and five design questions are presented to aid in this process. This work contributes by indicating how explicability can make drones that are more acceptable to citizens - in Denmark, and perhaps beyond.

## 1. Introduction

Drones are used worldwide for a range of civil and commercial operations [1]. This is also the trend in Europe [2], although legislation in many countries limits drone operations due to safety or legal issues [3, 4]. Much attention is focused on safety, and this is codified in EU legislation, such as the requirement for extensive operational risk assessments [5]. However, although drones that are acceptable to the general public is also a prerequisite for a future relaxation of the legislation, less attention has so far been given to European citizens' perception of drones.

Experiments carried out in Denmark show that it is difficult for those standing on the ground to decipher the purpose of a drone in the sky, as its design offers few indicators, and when a drone is spotted, people will react by looking around for the operator to be able to hold him or her accountable [6]. This expectation of human control is currently supported by EU legislation requiring that the operator has ultimate responsibility over the drone [4], although he or she may be out of visual range of it. Currently, neither identification of the operator nor the purpose of the drone flight is required to be made visible, although such transparency will be an important factor in developing drones that are acceptable to members of the general public [6]. These considerations bring to light the importance of *design for explicability*.

Most of the time, drones will be flying at a significant distance from those on the ground, which limits the perception to the visual and auditory senses. Designing for visible or audible conveying of information from a long distance is not straightforward, and it remains unclear exactly which information should be conveyed and in what manner. A comparative study shows that drone noise is perceived to have an overall higher level of annoyance than road noise [7]. This indicates that drone operations may not be acceptable to the public simply because they are no louder than conventional means of transportation – other factors come into play.

Carefully designing the visual and audible profile of drones may be key to making them acceptable to citizens. This paper sheds light on the Danish public's perception of healthcare drones regarding visibility and audibility and use these insights to present potential ways of designing drones for explicability – specifically, for the human values of accountability and intelligibility [16] – by conveying information to the general public at a distance.

## 2. Literature review

Drones, also known as unmanned aerial vehicles, are either controlled at a distance by a remote operator or fly semi- or fully autonomously [8]. They are used for a variety of civil and commercial missions [2]. For example, fixed wing drones that resemble small airplanes are used for aerial mapping, and multirotor drones that can take-off vertically and hover are used for video inspection [9]. Hence, drones vary in shape, size, and capability depending on the missions they perform, but a camera or other types of sensors are often standard payloads for civil and commercial operations [10].

In Europe, drones are used especially in an agricultural context [3]. However, they are not yet part of everyday life since, in many countries, legislation based on safety or legal considerations [4] currently limits civil and commercial operations [3]. To consider a potential relaxation of the legislation, civil aviation authorities must await technological progress on e.g. fail-safe solutions and at the same time seek public reactions to civil and commercial drones [11]. Boucher [12] stressed not to aim at public acceptance of drones (technology push), but rather on developing drones that are acceptable to citizens. Moreover, "citizens make nuanced decisions about the acceptability … depending upon the purpose of the [drone] flight and the actors involved" [12: 1391]. A study assessing random passersby's acceptability of leashed companion drones for blind travelers in public spaces [13] identified both support and concerns. The passersby found that a companion drone would be acceptable if they were well informed about its purpose, functioning, and benefits, but they expressed concerns regarding the safety of the general public as well as the users with visual impairments and questioned whether the drone would actually perform a better job than e.g. a guide dog. These nuances emphasize the need for understanding the underlying values and actual perceptions among the general public regarding drones to be able to increase the explicability of this emerging technology.

### *2.1. Explicability of drones*

The ethical principle of explicability has recently come into focus in the design of artificial intelligence systems [14]. The purpose of focusing on explicability in the design process is to ensure technological transparency and thereby the ease at which systems can be understood. Design for explicability is likewise relevant in the drone domain, as people on the ground discovering a drone in the sky try to make sense of it [6].

Unleashing drones into society will affect different stakeholders. Users of the technology, e.g. citizens who ordered a drone delivery, might be prepared for the drone's arrival. However, the general public will also be overflown and potentially impacted by the drone. They become spectators and listeners and shape their perception of the flying drone by registering e.g. color, size, noise [15], and altitude [6]. Hence, they will see and/or hear the drone and may seek to understand what is flying above them. In that connection, two human values especially relevant to transparency must be addressed to ensure that critical information is available to the general public: 1) *accountability*, i.e. who is responsible for the drone in the sky, and 2) *intelligibility*, i.e. what is the purpose of the drone and how does it work [16].

The fact that drone operations are by their very nature remote and the pilot may be positioned far away from where the drone is flying puts demands on the accountability of the system. This is especially the case where cameras are involved which can create power asymmetries whereby the operator – by means of a camera mounted on the drone – can see those who are overflown, but they cannot readily see who is behind the drone [16]. Currently, EU legislation requires that one pilot has ultimate responsibility over a drone [4]. This makes it possible to satisfy a "tracing" requirement, as identified in the literature on meaningful human control of autonomous systems [17], where ultimate responsibility of the flight can be traced back to a specific person. Experiments conducted in Denmark [6] show that if those being overflown by a drone find out that it is used by a professional, e.g. in connection with firefighting, they trust that it is flown safely, and they are more accepting of being overflown. Hence, if drones are perceived as legitimate, they will be acceptable to the general public. This means that the purpose, and preferably also how the drone works, must be understood from its design. However, as a drone mostly flies at high altitudes and is often quite small, it becomes challenging to design it in a way so that the message gets through to those trying to make sense of it from the ground.

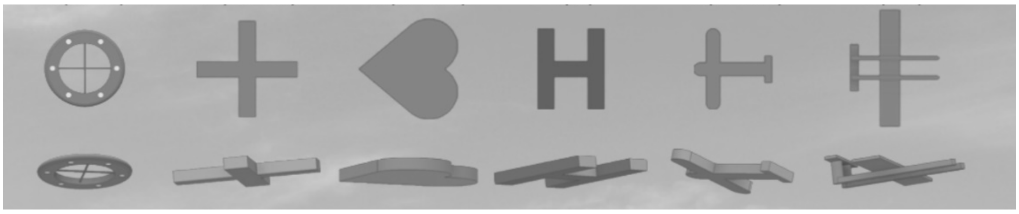
## 3. Methods

Primary data were gathered from 110 participants in total during 2018 and 2019 to gain insights into the Danish public's perception of drones. Rather than being exhaustive, the aim was to give some early indications of their views of drones in a healthcare context with a focus on the drone's visual and acoustic design, so that these inputs could be applied to the design of future drones. A mixed-methods approach was employed including exploratory and semi-structured interviews, quantitative and qualitative surveys, and an in-dept focus group.

Drones are still new in a Danish context, so the in-depth **focus group** used an anticipatory methodology [18] to gather initial impressions. This method puts emphasis on context-setting to understand how participants relate to technologies that they are familiar with, which then leads to how they might frame new technologies – in this case, drones. Two males and four females participated in the two hours' long session. The time was spent on contextualizing technology, discussing drones in general, and then a specific healthcare application – blood sample transportation. Towards the end of the session, stimulus materials were presented to gather specific feedback about currently available drone designs. The materials consisted of pictures of four commercially available drones with very different shapes: a DJI S800 EVO multirotor [19], a Sky-Watch Cumulus fixed wing [20], a STRIX Nano Goblin flying wing [21], and a Wingcopter 178 hybrid multirotor/fixed wing [22].

Several studies were conducted to investigate **visual aspects of drones**. *First*, to investigate if a drone is even visible in the sky, 12 participants were overflown at four altitudes between 30-100 meters by the white Sky-Watch Cumulus fixed wing drone with a wingspan of 165 cm and the black DJI S800 EVO multirotor drone with a wingspan of 80 cm. *Second*, 20 participants were interviewed to gather feedback about six different simplified drone shapes (as shown in Figure 1) and completed a survey where they were asked to preference rank the shapes. The same 20 participants were then asked about their preferences on four visual aspects of a Danish healthcare drone: lights, informative text, informative symbols, and the visible presence of a camera. A Kano model [23] was applied to the data to identify "must-have", "performance",

Figure 1: Six drone shapes were preference-ranked by 20 participants (from left to right) 1. UFO 2. Plus 3. Heart 4. H-shape 5. Airplane, and 6. Twin-fuselage airplane. Image used with permission.



“attractive”, “indifferent”, and “reverse” attributes. *Third*, 12 participants were presented with four illustrations of fixed wing drones with three contextually informed colors and markings: two drones in bright yellow and dark green based on that of a Danish ambulance (one with and one without lights), one with traditional hospital colors of white and red, and one in high-visibility orange. The participants were told that the drone would be for Danish healthcare and asked to preference-rank the four designs. *Fourth*, the preferred configuration and color were further studied through a quantitative survey with 19 participants. A rating-based conjoint analysis was employed to assess the relative importance of configuration and color. A full factorial, 3x3 experimental design was used to reduce the number of participants required to study the large number of possible combinations. The configurations representing a hybrid fixed wing/multirotor drone, a fixed wing drone, and a flying wing drone (Figure 2) were variants of the traditional airplane shape (shape 5 in Figure 1), as the earlier study identified this as the preferred shape (see Results section). Three color combinations were tested in conjunction with the three shapes: plain white, Danish ambulance colors (bright yellow and dark green) and traditional hospital colors (white and red).

Three studies were conducted to gain insights into **acoustic aspects of drones**. *First*, it was investigated how loud a Sky-Watch Cumulus drone was in a quiet location in the countryside. The drone was hand-launched, and then flown at cruise speed overhead at pre-determined altitudes. A hand-held sound pressure level (SPL) meter was used to determine the noise level in decibels (dB) and compared with a large multirotor drone – a DJI S1000 octocopter. *Second*, the perception of the volume, frequency, and identifiability of the drone’s propeller sounds, as well as specially developed add-on sounds, were explored. A sound recording of the Cumulus was played back as a stimulus material when interviewing 15 participants who live near the hospital in Odense, Denmark. The interviews also included a 5-point JAR (just about right) questionnaire. A similar study was made with 26 participants living near the hospital in Svendborg, Denmark. Here, the stimulus material, i.e. the sound of the Cumulus was: 1. unaltered, 2. modified to have a higher pitch, 3. modified to have a lower pitch, and 4. unaltered but with an additional warning sound. *Third*, a small qualitative study was conducted with three participants in Svendborg. Perceptions were gathered on two specially developed add-on sounds identified as being less annoying but still able to attract attention. These included: 1. a low-pitched harmonic (23,69 Hz) [24] and 2. a broadband white noise or “static” sound [25].

Figure 2: Stimulus material for shape and color investigation for a Danish healthcare drone. Image used with permission.

## 4. Results

The results indicate that Danish citizens want to know when a drone is near them, its origins, and purpose, but they do not want to be annoyed by its presence or have their privacy violated.

**The focus group** established the need for explicability in drone design. The participants underlined that, although maybe hard to see and hear, drones should be recognizable and the person and organization behind the drone should be known as, "Actually, it is a bit spooky, the thing with not knowing who is on the other end [of the drone]." The participants were critical of the drone making too much noise, and one stated that a drone with the sound of an ambulance "would probably be annoying". Despite self-identifying as technology optimists, the participants mentioned many concerns about drones; the most oft-reported concern was that of privacy violations and was mentioned by all participants.

**The investigation of visual aspects** showed that both the fixed wing and the multirotor drone were visible at all altitudes – up to and including 100 meters – despite the Cumulus drone's white color, which could blend in with the clouds, and despite the multirotor drone's smaller size. The respondents noted that the Cumulus had a familiar profile like that of a bird or airplane. The preference ranking of the six drone shapes in Figure 1 showed that 25% of the respondents preferred number 5, the Airplane configuration, but not by a substantial margin compared to the other shapes: 1. UFO-shape = 17%, 2. Plus-shape = 14%, 3. Heart-shape = 14%, 4. H-shape = 16%, 6. Twin-fuselage airplane = 14%. They stated for example that the Airplane shape "seems safe" and is "something you are used to seeing in the sky", whereas for example the Plus-shape (simulating a red cross for healthcare associations) was perceived as "a familiar shape" but also "melancholic" and "a bit creepy". The Kano model analysis showed that informative text was a must-have attribute, and informative symbols an attractive attribute. Participants were by and large indifferent to the inclusion of lights on the drone, yet they found the inclusion of a camera to be a reverse attribute, i.e. including a camera leads to reduced satisfaction. The contextually-informed colors and markings survey showed that, given the Danish healthcare context, there was a slight preference for the bright yellow and dark green colors of a Danish ambulance (33%) compared to the white and red colors traditionally associated with a hospital (29%). The factorial shape and color survey showed that respondents overwhelmingly found color (90%) a more important attribute than shape (10%) with respect to explicability. They found the Danish ambulance colors most preferable, with traditional hospital colors rated negatively, and plain white rated most negatively. Both the hybrid fixed wing/multirotor drone and the fixed wing drone shapes from Figure 2 were rated moderately positively, while the flying wing shape was rated negatively.

**The investigation of acoustics** showed that the Cumulus was easy to hear during launch, but that it quickly became more difficult to detect as it gained altitude (Table 1). Above 75 meters the drone was indistinguishable from the low ambient noise in the countryside (37 dB). For comparison, the large DJI S1000 octocopter was distinguishable from the background noise generating an SPL of 50 dB at 100 meters altitude.

Table 1: Sound pressure level of the Cumulus drone during hand-launch and cruise at different altitudes.

| Altitude (meters) | Sound Pressure Level (dB) | Audible? (Yes/No) |
|---|---|---|
| Launch (~2 meters) | 76 | Yes |
| 35 | 53 | Yes |
| 50 | 40 | Yes |
| 75 | 37 | No (ambient noise level = 37 decibels) |
| 100 | 37 | No (ambient noise level = 37 decibels) |

The further studies investigating acoustics gave several important insights. The drone can make some noise so that citizens are aware of its presence, but it should not be too loud or annoying. Lower frequency sounds are preferred, with high frequencies being considered shrill. The volume of the Cumulus drone is considered just about right, but the frequency is too high pitched. The drone should have a unique or identifiable sound profile (the sound of a multirotor drone is currently most familiar), but 100% of the respondents did not want any add-on sound – even the purportedly less-annoying low-pitched harmonic or “white noise” alarm. The only time a loud drone would be accepted was if there was an emergency.

## 5. Design for explicability

The results of these perception studies hint at design approaches to enhance explicability. Design for explicability requires consideration of questions such as those in Table 2.

Table 2: Questions to consider in design for explicability.

| |
|---|
| How can the drone be designed to convey the organization and person responsible for it? |
| How can the purpose of the drone (e.g. healthcare) be easily identified from a distance? |
| How can the drone be made visible, despite its size and altitude, but not overly distracting? |
| How can the drone be made audible without being annoying? |
| How can the drone visually or audibly display that it does (or does not) carry a camera? |

Overall, the design should be context-appropriate – a healthcare drone should resemble a healthcare vehicle. The drone’s configuration is important, and fixed wing drones are moderately more accepted than multirotors, but color is more important, and white may be a poor “default” color. Color can be difficult to see in flight as the underside of the drone is usually in shadow, so illuminating it could be beneficial. Colored streamers could be used as a low-cost way to increase visibility and indicate the drone’s purpose if standardized colors are used. For example, in Denmark a yellow streamer could indicate healthcare, red firefighting, blue for police, white for commercial, and black for hobbyists. Text that identifies the drone’s purpose is highly valued and easily accomplished. A standardized way to signal the presence of a camera should be established and could become law. For example, a flashing red light could signal a camera on board, while a solid green light could indicate no camera.

A smartphone app has the potential to increase explicability by overcoming visibility challenges. But designers should not depend completely on an app – citizens have the right to know about the presence and purpose of drones near them without an additional piece of technology. Avoiding flying over people in the first place eliminates many excitability challenges, and approaches such as privacy-aware route planning make good sense here [27].

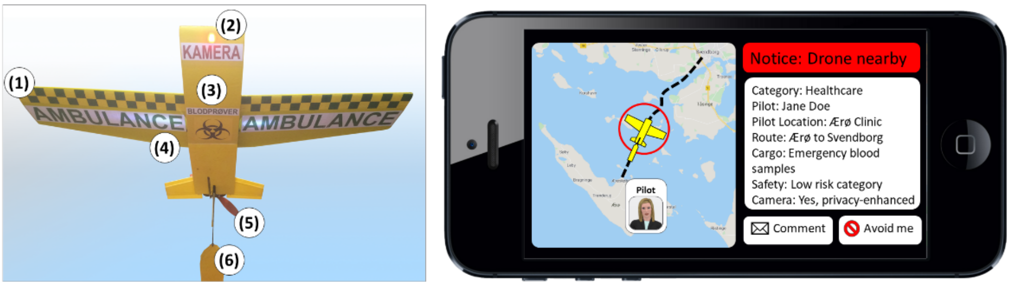
Larger, slower-turning propellers – either geared-down or with lower-speed, higher torque motors – would reduce the pitch and annoyance of the drone’s noise. A less conventional approach would be using single-bladed propellers or flapping wings to reduce sound frequency.

### *5.1. Design for explicability in a Danish healthcare drone*

The early data gathered in these studies have been used to inform the conceptual design of a Danish blood sample transportation drone and accompanying smartphone app [27]. Since then, a prototype drone has been built and the smartphone app concept refined as shown in Figure 3. The drone is a fixed-wing configuration and bright yellow and dark green like a Danish ambulance (1). It has a flashing red light in the nose (2) as it carries a camera that allows the pilot to navigate and land. It displays symbols and text (in Danish) indicating its medical payload (3) and lights that illuminate text on the underside of the wings (4) that are in shadow. The drone’s electric motor is inside the body to reduce noise and is geared 4.4:1 which lowers the propeller speed and noise frequency from 10,000 RPM/Hz to a less-annoying 4,000 RPM/Hz (5). It tows a yellow streamer to increase visibility and show that it is a healthcare drone (6).

The explicability-enhancing smartphone app uses push or pull notifications to show when a drone is near the user. The app displays the location and identity of the pilot enhancing accountability, and the purpose, payload, and route of the drone increasing transparency.

Figure 3: A prototype Danish blood sample transportation drone has been built that incorporates design for explicability based on the data in these studies (left) and a refined concept developed for the accompanying explicability-enhancing smartphone app (right). Images by the authors.




## 6. Discussion

This paper provided hints at the Danish general public's perception of drones. However, the "general public" is a highly non-homogeneous group so results should be interpreted as indicative rather than definitive. That said, some will be more impacted by drones than others, hence this work focused on citizens near hospitals where drone operations are in development. While the general public is an important and sometimes neglected stakeholder, they are not the only group impacted by drones and it is not *only* their input that matters in design. Robust design practice involves engaging multiple stakeholders throughout the design process [29], and design for explicability can be a useful tool but should not be the only design consideration. The public perception of drones can change rapidly, as exemplified by the shift from the "Predator Era" (2003-present) i.e. large military drones to the "Phantom Era" (2013-present) i.e. small hobby drones [1]. As citizens become more aware of drone technology through the media or first-hand experience, their perceptions will change, making drone design in general, and design for explicability in particular, a "moving target". Robust design practice will require continual input from citizens, re-assessment, and re-design to maintain or enhance explicability.

In this work, visual and audible aspects were often artificially separated, but there is an inter-relationship between these design elements that could be explored. This work focused on individual drones, but soon drone swarms may become legal and prevalent. This will increase the responsibility placed upon the drone pilot and could alter the public's perception of drones and accountability. Continued consideration of the public perception of drones and design for explicability will help create drones that are acceptable to citizens, now and in the future.

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