Domestic Drones: Context of Use in Research Literature

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ABSTRACT

Domestic robotic entities are on the rise, out of which, domestic drones are taking place in our society as one of the upcoming interactive technologies that we will see in our daily lives. In this paper, we scope for research literature that addresses the use of domestic drones within our environments to understand the current usage as well as identifying future research directions. After performing a search based collection of relevant papers in the ACM digital library (N=61 papers), we analysed the drone's application areas, their interaction modalities, the target users, and the level of autonomy of the proposed systems. The results show interesting trends in the modalities of interaction (visual projection combined with hand/foot gestures) as well as important research gaps such as child-drone interaction, and the use of drones for healthcare or education, given that currently most use cases for domestic drones are generic in nature.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Interaction design**; **Empirical studies in HCI**.

KEYWORDS

Domestic Drones; Social Drones; Human-Drone Interaction; Drone Applications

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1 INTRODUCTION

Traditionally, the field of Human-Agent Interaction (HAI) encompasses a wide range of interfacing mediums or "agents" that humans interact with across numerous scenarios [57]. These include embodied agents such as social robots, humanoids, virtual agents. Additionally, flying robotic agents (drones) is emerging as a state of the art research area in the field of HAI, cutting across an extended range of applications such as security, surveillance, navigation, way-finding and more. More recently, we are seeing efforts directed in the topical area of social drones or domestic drones. Such drones are typically deployed within a user's localised environment (such as home, office, park, etc.), employing a range of social cues to interact with the user. This has led to the conceptualisation of research into the areas of Human-Drone Interaction (HDI) [16]. In this field, in addition to the focus on technical aspects and algorithmic development, we have seen extensive emphasis on the design of interaction modalities between humans and drones in a range of different application areas. Typically, such investigations extend to usability or user experience of the interactions as well as improving the accuracy or efficiency of the communication between humans and machines [66]. We anticipate an increase in research interest in the topic of HDI, particularly in the area of domestic drones. In this context, Baytas et al. [11] referred to such a drone as a "Social Drone", where they defined it as

> [...] an autonomous embodied agent in an inhabited space can be similarly described as social.

Therefore, we believe this is an opportune moment to establish an understanding or an overview of current research being conducted using (social) domestic drones, to identify the gaps, challenges, and future opportunities.

Therefore this paper aims to unearth the application areas where such domestic drones are being deployed as well as delineate the interaction modalities between drone and user.

We found a handful of survey or review articles focusing on or related to drones, and none specifically in the field of HAI. Some review articles focus on the technical aspects of drones [5] or their engineering applications [15, 65]. Others have looked at understanding user perception [9] or design aspects related to drones [10]. Further review articles have looked at Unmanned Aerial Vehicles (UAV) in a non-domestic context [54], emphasising the technical instead of interaction aspects. However, to the best of our knowledge none of the prior review articles touch upon HDI in domestic settings nor do they investigate their applications and context of use. Thus, in this paper we contribute to the HAI research community the following:

- A review of domestic drone applications and their context of use.
- A collated set of papers that represent several application areas on domestic drones.
- Future directions that can build the base of HAI research on domestic drones.

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2 METHOD

Our approach to collate a list of relevant literature on domestic drones was based on a literature scoping approach. This is a common methodology that has been used in several other Human-Agent Interaction, Human-Computer Interaction and Human-Robot Interaction (HRI) literature to provide a review or a survey of emerging technologies. For example, Mubin et al. [58] used an identical approach to investigate Sci-Fi robotics in HRI literature. Baytas et al. [11] used a similar approach to review literature on the design of social drones but without looking into the details of the applications and context of use of the drones. We also notice scoping reviews in the field of robots for healthcare [25]. For a topic that is in its infancy (case in point Human-Drone Interaction), we understand a scoping review is the preferred methodology [67]. In the following two sections we described the details of the process of consolidating a set of relevant publications for further analysis.

2.1 Term Search

We started by conducing a term search using the ACM Digital Library (ACM DL). The ACM DL is the one of the prominent repositories for Computing literature and gives us sufficient confidence in its breadth. A number of other researchers have used the ACM DL in their review research such as the work presented by Baytas et al. [11].

To start, we aimed to scope for broad range of HDI literature, thus we selected several generalised search terms that can span across HDI research. However, to retrieve relevant publications, we made sure that the search terms had a focus on the human aspects, such as social and domestic interactions. At the end, our search terms included: "human-drone interaction", "human drone interaction", "social drones", "domestic drone", or "domestic drones". The final search was conducted in early June 2020.

The initial search retrieved 69 publications. Thereafter, we scanned the cited references in the most recent review article on designing social drones by Baytas et al. [11] to seek for further relevant HDI articles, which resulted in an additional 20 publications.

Overall, we had a total set of 89 publications that we thoroughly processed to make sure that each publication matched the following inclusion criteria; otherwise, the paper was excluded.

- A research publication must belong to one of the following tracks: full papers, posters, demos/videos, work in progress, and workshop papers. We excluded workshop proposals, keynote briefs, and publications that are unrelated to the field (i.e. did not do research on drones, but only had a mention as an example of the domain area).
- The publication is not significantly similar to another publication in the collated list, such as publications from the same research group. In this case, for example, a full paper that extends the work of a poster or a workshop will be selected as it is the most elaborate publication.
- The paper must explicitly mention the use or design of a drone, so for example review or survey papers were excluded.

In total, we excluded 28 publications that did not match the inclusion criteria and, finally, we had a set of 61 publications to investigate further for the purpose of the presented review.

2.2 Coding

We used a deductive categorisation approach to derive the annotation categories based on the authors' experience in the HAI/HRI fields. Firstly, the three authors started with an iterative process to define and discuss each of the presented categories. Thereafter, the coding procedure was commenced by three coders. The coders started with four publications each and then discussed their annotations of the four publications thoroughly and resolved any misunderstandings; this was to minimize any ambiguity in the annotation categories. Then, each coder was given a set of publications to annotate. Such a layered approach to multi-rater qualitative coding is commonly used in HRI research [49].

The annotation scheme consisted of six categories that include the following: (1) year of publication, (2) application area (which included a wide range of applications of agents, which were derived from seminal works and surveys on social robots and agents such as [29, 32]), (3) primary user or participant group (such as adults or children), (4) setup type (fully autonomous, Wizard of Oz (such that the user perceived the drone to be autonomous), or teleoperated (i.e. operated by the user themselves or a researcher)), (5) interaction mode between the user and drone (hand, body, expressive, proxemics, visual, controller, auditory, haptic, tangible, gaze, program-code, or text based interactions) and (6) the location of the setup (indoor or outdoor). The results of the annotated coding of the categories are presented in the next section.

3 RESULTS AND ANALYSIS

The annotations of the 61 collated publications revealed several findings. In particular, we found that the application domains associated with the 61 publications to span over 14 different areas, generic (or not addressing a specific application area) being the most popular with 28 hits. Table 1 shows the different application areas and the collated literature associated with it. A figure is also presented as a cross-section of application areas and the year of publication (see Figure 1). Wizard of Oz was the most popular mode of operation with 20 hits, followed by autonomous (16) and teleoperation (14). Eight papers did not mention a mode of operation and 3 used a mixed strategy. Adults were the dominant targeted user group with a frequency of 52. There were 5 papers that did not mention a user group and only 1 paper mentioned children as the primary user. There were 3 papers that focused on either public audiences or mixed user groups. In the following sections we take a detailed look into the context of use of the different application areas of domestic drones.

3.1 Applications

Inspired from the contextual usage of social agents, we identified a number of areas that categories our papers on domestic drones.

3.1.1 Generic. Because the research field of domestic drone is still in its infancy, a lot of research papers do not focus on a specific application area but instead investigate novel human-drone interaction methods or technological advancements. We termed this as the generic category. Of the 28 papers in the generic category, only 8 papers reported the use of an autonomous drone in their study, 11

Table 1: The corpus of research literature collated and their associated application areas.

Application Area	Associated References
Generic Approach	Obaid et al. [64], Kunde and Duncan [50], Hoppe et al. [35], Khan et al. [43], Yamada et al. [79], Duan et al. [26], Zhang et al. [83], Braley et al. [13], Jensen et al. [37], Knierim et al. [47], Lee et al. [53], Han and Bae [33], Khamis et al. [42], Walker et al. [77], Yeh et al. [82], Abtahi et al. [2], E et al. [27], Obaid et al. [62], Matrosov et al. [56], Gomes et al. [31], Hieida et al. [34], Scheible and Funk [70], Yamaguchi et al. [81], Cauchard et al. [17], Szafir et al. [74], Arroyo et al. [6], Szafir et al. [73], Scheible et al. [71]
Navigation	Cauchard et al. [18], Brock et al. [14], Knierim et al. [48], Colley et al. [23], Kim et al. [44], Matrosov et al. [56], Schneegass et al. [72]
Wellbeing	La Delfa et al. [51], La Delfa et al. [52], Romanowski et al. [68], Al Zayer et al. [4], Zwaan and Barakova [84], Mueller and Muirhead [59], Schneegass et al. [72]
Companionship	Watanabe et al. [78], Karjalainen et al. [41], Cauchard et al. [19], Kim et al. [44], Ng and Sharlin [60]
Accessibility	Garcia et al. [30], Avila Soto et al. [8], Avila et al. [7], Al Zayer et al. [4]
Entertainment	Rubens et al. [69], Matrosov et al. [56], Kljun et al. [46]
Art/Performance	Eriksson et al. [28], Kim and Landay [45], Agor et al. [3]
Video(Photo)graphy	Chen et al. [22], Chen et al. [21]
Shopping/Advertisement	Abtahi et al. [1], Yamada et al. [80]
Security	Chang et al. [20]
Video Conferencing	Jones et al. [39]
Delivery	Tan et al. [75]
Education	Huggard and Mc Goldrick [36]
Environment	Obaid et al. [63]

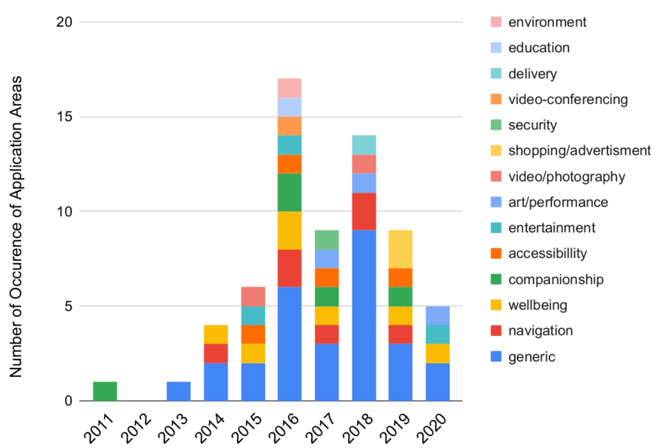

Figure 1: Frequencies of the different application areas that are represented in 61 publications on domestic drones research per year.

had a Wizard of Oz approach, while the other papers were teleoperated or did not operate a drone) . Most of the studies investigated proxemics [37, 82], body motion, or hand gestures [27, 62] as new modalities of interaction with drones. We also noticed an interesting trend; several papers reported the use of a visual display, often content projected on the floor, combined with hand or foot gestures [18, 70]. This trend seems to mimic touch screens and aims to use drones as a way to provide experience of a pervasive touch display. The fact that these studies were mainly using a Wizard of Oz approach, may demonstrate the limitations of the current drones in terms of tracking and human sensing. Among these generic papers, none involved children participants and very few with a public audience (one count of public audience as users). Finally, most of these studies, often investigating new modalities of HDI, are occurring indoors (18 papers) in lab environments and feature a technical setup (i.e. external cameras, Wizard of Oz system).

3.1.2 Navigation. A prominent research application for domestic drones is navigation, such that the user and drone guide or direct along a route with the assistance of either or both. Within our pool of papers we saw examples of drones being used to guide users in a touristic area [72], a museum [18, 56], or outdoors [14, 23, 44, 48]. In this guiding role, the drone indicates the path usually outdoors (5 papers out of the 7 in the navigation category). In terms of a communication channel, we see that predominantly researchers have proposed systems to extend the drones capabilities with a visual display. The visual display can take several forms: projector [14, 18, 48], attached screen on the drone [72], or using a smartwatch [44]. Another trend of research in navigation scenarios is to investigate motion as a medium of communication with the drone, using hand and body gestures (foot tracking) [14, 18]; and for the drone with the design of novel drone behaviours to indicate the way [23]. None of the papers reviewed in this category have involved children participants.

3.1.3 Well-being. Another relevant application area that we observed was using drones as a sport companion, a sport coach or a logging system. These applications take advantage of the abilities of the drones to move swiftly with six degree of freedom. Interestingly there is a trend in the interaction mode being to use either proxemics - for jogging and running applications [4, 59, 68], hand gestures [84] or wearable controllers [51, 52]. In this category, papers reported studies with adults participants only. There is only one paper that proposes a teleoperated robot [68], in which supporters use the robot to cheer up a race runner. The other studies employed autonomous drones or a Wizard of Oz equally.

3.1.4 Companionship. Companion robots are designed for personal use in domestic environments, and are expected to communicate in a natural and social way with humans [24]. Some researchers have explored the use of drones as companions, with studies mainly investigating how drones could feature and incorporate pet-like or companion-like behaviours. These studies report on the design of non-verbal drone behaviours that could for instance be related to personality or emotion [19].

3.1.5 Accessibility. The HAI/HRI research fields have addressed the area of accessible and inclusive assistive robotics in different prospective including robotic forms, intended tasks and user groups, such as the work presented in [40, 55, 76].

In the context of domestic drones, our dataset revealed only four publications that have tackled research that address accessibility related application areas. Three of which include a domestic drone to support visually impaired individuals in different situations, such as navigating and running scenarios [4, 7, 8], while the other publication focused on designing a controller to support drone pilots with disabilities [30]. It appears that three of the publications associated with accessibility applications have demonstrated to use auditory interactions and proxemic interactions, while all of the experimental setups were conducted in indoor environments.

3.1.6 Other Applications. The five popular application areas mentioned above have included several publications (four or more) that allow us to scope for a better understanding on their context of use and then elaborate on possible future directions. On the other hand, our results show that there are nine other application areas that have a low number of research publications associated with them. For example, applications in entertainment and art where apparent in three research publications each; despite the popularity in commercial entertainment and art installation use. Similarly, video(photo)graphy applications and shopping/advertisement applications had only two mentions each in the collated list. Finally, the areas that had the context of use as security, video conferencing, delivery, education, and environmental support have all had one publication count each. These low numbers may indicate several aspects that limits researchers to address them, such as technical limitations and policies on using domestic drones. In the next section, we will discuss the under presented application areas further and point the reader towards possible research directions.

4 DISCUSSION

Our results showed that there are interesting trends emerging from the research in domestic drones. In terms of application areas, we noticed that nearly half of the papers (28/61) included in the collection were classified to be generic without a specific application. This could be explained by several factors. First, currently drones still have many technical limitations (i.e. battery life, load bearing capacity, noise) that could prevent their wider use in some contexts [54]. Another factor that could refrain domestic drone research is policies and regulations, which may mean that drones cannot readily be integrated in different contexts. Acceptability of drones by the general public is also not fully established which may mean that researchers are skeptical in utilising drones for a wide variety of social applications. In summary, our review on the usage of domestic drones has unearthed a number of application areas which are unaddressed or not tapped into. We find this unusual as other domestic social agents (humanoids, virtual agents, and more) are very popular in such scenarios. Some of these aspects are discussed below.

Education and Children: Research in using social robots in education is growing rapidly [12, 38, 61]. While the field of social robots for learning is seeing a standardisation of platforms and learning scenarios, we believe that it is the right opportunity for domestic social drones to enter this application area. Our review showed that only one publication to have investigated the use of drones in education. However, drones could provide novel ways of learning and novel collaborative interactions, such as through imitation, gameplay, cooperation, virtual projections, and more. Extending and relating to this, child-drone interaction is also a seemingly absconding research area in the field of domestic drones. This may primarily be due to safety, ethical and privacy regulations, which makes children not the primary users of domestic drones. In our results, there were very few instances of children being mentioned as users of domestic drones, including the work presented by Rubens et al. [69] and Kljun et al. [46]. Future research should also investigate new ways for drones to be safe for younger users. Novel forms of caged drones could be a promising in that sense.

Accessibility, Elderly Care, and Health: In general, research on accessible and inclusive design and health informatics have expanded to the HAI and HRI areas to derive research that can support individuals in all situations and different user needs; in particular focusing on individuals with motor and/or cognitive impairments. Moreover, many research efforts have been put towards assistive robotics for elderly care that investigate the area from different prospective; for example, see review by Kachouie et al. [40]. To the best of our knowledge, very little has been done on the use of social domestic drones in elderly care or healthcare applications. One exception in our pool of papers was the example presented in [7, 8], where a drone was used for the purpose of navigating blind users. We interpret that this low number of papers in the health domain may happen due to regulatory, ethical and, safety obstacles or hurdles. Thus, we foresee the need of research on utilizing social domestic drones to address accessibility and elderly care application areas. This could easily be extended to general healthcare applications, for example promoting healthy outdoor behaviour in the companionship of a drone.

Operating Environment: The majority of the presented publications in Table 1 had their setup in an indoor (mostly controlled) environment (62%). This might indicate that the majority of the drone setups are dependent on indoor hardware systems (e.g. tracking systems), such as the work presented in [51], or they are restricted by ethical implications of flying drones outdoors [82]. In addition, our results revealed that approx. 33% of the setups had a Wizard of Oz approach, which can additionally support the fact why the majority of drone setups were conducted indoors. Other aspects that could have contributed are lighting and wind conditions; i.e. in visual projection based setups, controlled lighting is a must and a stable flight path is required. We also noticed that most of the indoor settings mentioned in the pool of research papers were controlled lab settings and not in natural environments such as homes or offices. Drones are still a work-in-progress as an instrument, with the public generally may not be fully accustomed to drones in their daily life. Technical limitations or operational regulations as mentioned earlier may mean that drones need to be operated in highly constrained and invigilated environments.

Other areas: The implications of conducting the majority of research in indoor experimental setups may explain the low number of the mentions in domains such as environmental sustainability, video(photo)graphy, shopping, advertisement, delivery services, and security applications. In the context of these applications, outdoor settings can be essential elements to investigate domestic drone operations. Though, art and entertainment applications had three mentions each, one would have expected to see more work done in these applications areas. We can suspect that their low number in our set of papers is perhaps due to the complexity of the setups and unreliability of use in front of public audiences.

Interaction Trends: Now, we also shed light on some of the interaction trends that were observed within the set of application areas surveyed in the collated publications. It is apparent from the results that the use of domestic drones have increased to include a wider range of applications from 2015 onwards as evidenced in Figure 1. One of the application trends that we identified is the use of visual interaction via projected graphical displays on indoor/outdoor surfaces (approx. 27%). We believe that this trend can further lead to introducing drones as ambient-interfaces that enable augmenting human capabilities in their domestic daily tasks. This includes utilizing domestic drones to introduce visual, sound, and movement representations in our environment to subtly allow for a more seamless interaction with the drone. Therefore, further research is needed to support these trends to enable further design for such interactions.

Furthermore, natural bodily interaction is one of the main trends within the range of the different application areas (combined: hand, body, proxemics, and expressive interactions are approx. 48% of the papers). In this context, human-drone communications are achieved by various bodily gestures. While we might see this as a form of intuitive and user-friendly way to interact with technology, we also believe that a sense of social empathy associated with a drone as a living-being is a large factor in supporting the acceptance of natural interactions with domestic drones; in a similar way to how we intuitively use gestural interaction with our pets (as illustrated in the results presented in [17]). In addition, we stress here that the interaction is bidirectional, thus reactive bodily expressions demonstrated by the drone are equally important to establish this social empathy bond. Therefore, research in the direction of deriving guidelines on what makes natural gestural interaction plausible with domestic drones in context of different application areas would be very timely and welcome.

5 OVERARCHING FUTURE RESEARCH

In summary, we conclude our analysis by highlighting several overarching future directions that were identified as research gaps of high importance to investigate domestic drones and their context of use in our daily environments. The following list can serve as the bases for some of the future efforts for the HAI/HRI communities:

- Increase applied research for scenario based systems so that the uptake of drones can occur in real world contexts and out of the lab settings.
- Investigate low represented research application that could boost the positive impact of domestic drones, such as inclusive design of assistive drones, child-drone interaction and educational drones.
- Natural outdoor environments research could lead to investigating novel application areas such as entertainment, tourism, and environmental sustainability.
- Develop bi-directional natural communication channels that the research community can build on. Some natural communication channels are under researched such as speech interaction between human and drones, and a creative setup (i.e. using phone speakers or headphones) could allow users to establish dialogue with their accompanying drones.

Limitations

One of the limitations of the work presented is that the scoping for related literature might have excluded journal and other research articles that are not listed in the ACM DL. In addition, we are aware that the field has other words that represent a "drone" such as UAV, a quadcopter or a flying robot, which may have eliminated potential relevant papers from the inclusion in the presented set. Moreover, we did not consider more technical engineering research repositories such as IEEE in our collection, which could have expanded our pool of publications further. However, we believe that the extent of terms used in the search and the ACM DL gave us a good sample that reflects on the general research work on domestic drones within the HAI and HRI communities. Lastly, we acknowledge that the choice of applications and the categories therein are by no means exhaustive or mutually exclusive. Therefore, some application areas may have unintentionally been excluded in our analysis.

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