Human-Drone Interaction: state of the art, open issues and challenges

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ABSTRACT

In the evolution of the Human-Computer Interaction discipline, it is interesting to evaluate the users' experience within the interaction between users and a specific category of robots, which are characterized by peculiar features: the unmanned aerial vehicles (UAVs). Drones are becoming more and more diffused, being used with different purposes. Hence, the interaction with these devices is getting common and here we aim at investigating how they can be exploited by means of different users' interfaces and with different interaction mechanisms.

In this paper, we present a review of the state of the art in the context of the human-drone interaction, so as to study and discuss the main open issues and challenges currently highlighted and reported in research projects and papers available in the current literature.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI); User studies; • Applied computing → Computers in other domains.**

KEYWORDS

HCI, UAVs, Drones, Human-Drone Interaction

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1 Introduction

Human-Computer Interaction (HCI) is a well-known and acknowledged interdisciplinary topic, diffused starting from the 1950s with the spread of the first computers and of automated machinery in industrial contexts [37]. Such a discipline has evolved during the last decades, with different possible overlaps with other fields, such as psychology, cognitive ergonomics, etc. [5]. Some specific aspects and sub-domains of the HCI discipline were born and evolved thanks to the diffusion of the Web, which significantly showed that user's interface and interaction with digital systems play a key role in the success and in the effective usability of software and applications [22]. This is particularly true in those situations characterized by contextual limitations (e.g., environmental noise, lights) or limitations due to specific users' preferences and needs [33]. In this sense, we can take into account users with disabilities, who enjoy digital content and applications by means of assistive technologies or who access with limitations in terms of input interaction (due to physical impairments) or in terms of output exploitation (due to sensorial and/or cognitive disabilities, e.g., blindness, deafness, reading disabilities [18]). The wide diffusion of mobile devices have brought the evolution of the most currently used interaction mechanisms, related to the needs of users of interfacing with objects characterized by specific issues, such as screens with limited dimensions, limited keyboards, accessed by means of a multi-touch display (often used with just one hand), input by means of vocal interactions [32]. Nowadays, the HCI discipline is engaged in a new evolution, related to the diffusion of innovative and brand new devices, such as the wearable ones [20] and the game consoles [8], which let the user interact by means of the recognition of gestures (the hands ones, and of body movements [39]). A further promising evolution is bringing interesting developments: intriguing novelties and research directions are represented by the interaction with smart objects in Internet-of-Things (IoT) contexts [9] and by the interaction with robots (Human-Robot Interaction, HRI) [23]. In this latter context, the users' experience and the interaction between users and a specific category of robots are characterized by peculiar features [34]: the unmanned aerial vehicles (UAVs) are becoming more diffused, being used with many and different purposes [14]. Hence, the interaction with these devices is an interesting subject of investigation, letting us study how they can be exploited by means of different users' interfaces and interaction mechanisms [19]. The aim of this paper is to present a review of the state of the art in the context of the human-drone interaction, discussing the main open issues and challenges currently highlighted and reported in research projects and papers. The methodology we have adopted to select the papers to review has been the following one: papers have been selected starting from a research on Google Scholar, inserting the keywords "Human-Drone Interaction" and "Human-UAV Interaction". Such keywords have been searched in the titles, abstracts, and in the whole content of the papers. We have evaluated the first 100 papers resulting from those searches. Among them, we have chosen the 60 papers more adherent to our keywords and to the purpose of our literature review. We have analyzed them, identifying common dimensions and open issues, to select a further subset composed of 40 papers we have deeply and detailed studied and reviewed. Such dimensions and open issues are the following ones: the role of the drone, the context of use, indoor VS outdoor usage, and the interaction mode. Our work aims at presenting the state of the art, providing some reflections on this research topic, supporting the study and the definition of guidelines and best practices in the context of the design and development of Human-Drone Interfaces and Interaction systems. The remainder of the paper is structured as follows. Section 2 presents the methodology we have adopted to select and analyze the papers related to the Human-Drone Interaction. Section 3 reports the state of the art, grouping the papers according to some interesting dimensions: the drone role, the context of use, indoor vs outdoor usage, and the interaction modes. Section 4 discusses the open issues and the challenges emerged from our literature review. Finally, Section 5 concludes the paper reporting some final considerations and remarks.

2 Methodology

The methodology we have adopted to select the papers to review has been the following one: papers have been selected starting from a search on Google Scholar, inserting the keywords "Human-Drone Interaction" and "Human-UAV Interaction", looking for them in the titles, abstracts, and in the whole content of the papers. We have evaluated the first 100 resulting papers, fitting the scope of computer science and engineering, published between January 2012 and December 2018. Among them, we have chosen the 60 papers more adherent to our keywords and to the purpose of our literature review, distributed over the years as follows: 3 papers in 2012, one in 2013, 5 in 2014, 6 in 2015, 15 in 2016, 18 in 2017, and 12 in 2018. This distribution, though influenced by the Google Scholar ranking algorithm, lets emerge a surge of interest during recent years. We have analyzed these 60 papers, defining common dimensions and open issues, so as to select a further subset composed by 40 papers, which are the ones we have deeply and detailed studied and reviewed. Among them, 3 papers were published in 2012, one in 2013, 5 in 2014, 4 in 2015, 9 in 2016, 11 in 2017, and 7 in 2018. All of them were published in conference proceedings or in scientific journals in the subject area of computer science and engineering. We categorized the papers on the basis of the following dimensions.

Figure 1: More used keywords word cloud

The drone role. We investigated the role the drone plays in each study. In other words, we analyzed the function assumed or part played by a drone in a specific situation. In particular, to provide here some examples, a drone can be used as i) companion, ii) personal drone, iii) agent, iv) sensing tool, and so on and so forth.

The context of use. Drones are increasingly used to perform the most varied tasks. These tasks can range from simple companion during a walk, to serious activities such as helping in rescue missions. In the state of the art analysis, we extracted such tasks to provide a better idea of the potential of drones as a tool to augment several contexts.

Indoor VS outdoor usage. Drones can be used indoor and/or outdoor. This is a relevant aspect since the interaction modes can be affected by the space available and the site conditions. Intriguing can be also to verify if relevant correlations exist between the context of use and indoor/outdoor usage.

The interaction mode. The way to interact with drones is central in several papers. The interaction can be touch-based, voice-based, video-based, using natural gestures, and so on. The interaction mode can involve just one drone or can be applied to a team of drones (multi-drones) that need to be controlled.

3 State of the Art

To provide a first visualization of the main concepts emerged by our analysis, Figure 1 depicts a word cloud with the more used keywords of the selected papers. As expected, the more visible words are Human, Drone, and Interaction. This result is clearly aligned with the way we selected the papers. Looking at the other words in the cloud, they are related to different concepts, such as the interaction mode (i.e., gesture, control, visual, multimodal) and the context (i.e., missions, rescue, sensing, environment). In the next Subsections, we present details about the different dimensions.

3.1 The drone role

Several studies investigated the role of drones as personal devices ([1–3, 11, 12, 15, 17, 30]). The considerable number of papers analyzing this aspect is a signal that drones are becoming easily accessible to the public and this lets emerge news research issues that need to be addressed. Among the cited studies, a few of them investigate the possibility of using drones to help people with disabilities, and in particular, blind users, in navigating the environment while walking or running [2, 3]. Drones have been also investigated as motivator and supporter of runners in their endeavours, during amateur running races [40]. The authors of [26, 27] remark the attention on the use of the word companion, to emphasize the positive effect a drone can have as a personal device. Interesting is that the authors investigated the users' perception against drones, concluding that most people wanted the drone which has characteristics of tolerable predictability, adorability, necessity for others' care and so on. The idea to use a drone as an agent is investigated in [38], where the authors present a case study concerning the use of a drone to support us to keep the environment clean. Drones are also investigated as helping devices in case of emergency and search and rescue tasks [6, 10, 16, 43] and as tele-operator in dangerous and unreachable environments [46]. This scenario opens challenges in the way the operator can interact with the drones considering that he/she is not fully dedicated to the drones, but involved in search and rescue tasks. In [24], the authors analyzed drones usability considering their usage as a safety inspection assistant. Thanks to the way drones are implemented, they can be used as an educational tool, exploring the transdisciplinary potential of drone methodologies in the context of physical geography [21]. Drones have also been used to augment users' vision skills, exploiting the drone-mounted camera. Examples are presented in [29] and [16].

3.2 The context of use

The high diffusion of drones, available to an affordable cost, increased the number of scenarios where a drone can be used, being useful. An interesting scenario is related to navigation systems, where drones can provide way-finding indications [2, 3, 15, 26]. A creative application is the one investigated in [7], where the drone is used to design interactive maps. A different scenario, an amateur running race, is at the basis of a study where drones are used as motivators [40]. Drones allow exploring dangerous or impassable areas safely from a distant point of view, exploiting the concept of drone- augmented human vision [16]. Moreover, drones are investigated for search and rescue missions activities in Alpine scenario [6, 10], and in rescue mission (earthquake) and in a Mars rock sampling mission [43]. An interesting study analyzed the usability of drones in the specific context of the construction industry, where special attention should be paid to avoid endangering the safety of the workers in the jobsite [24]. In the context of volumetric and visual geographies, drones can be an interesting tool [21]. The environment has also been investigated by [38] as another scenario where drones can be employed. A pioneering study analyzed drone-based privacy interfaces for smart environments and Internet of Things scenarios, considering indicators and controls that can arrange themselves in relation to specific devices and sensors as needed, is presented in [42]. The main idea investigated by the authors is to use future nanocopters able to interact in swarms indoors, in order to visualize otherwise opaque data flows in the environment, indicate exposure and data leakage, and act as tangible privacy controls to re-configure privacy settings. The authors of [28] present Flyables, a system adjusting flying tangibles in 3D space to enable interaction between users and levitating tangibles. A creative usage of drones has been made in [44]. The main idea is to transform the drone in a flying spherical display that can show high resolution and bright images in all directions from any- where in 3D space. This spherical display can be employed in different scenarios, such as guidance application, applications that present information to the surrounding people, and tele-presence systems capable of freely moving in 3D space. In the study presented in [31], the authors investigated the use of the drone as a projector of images on the floor (together with the foot gesture recognition), presenting three different case studies: emulation of a piano keyboard; navigation on a real-time map; a football game application.

3.3 Indoor vs outdoor usage

The majority of studies we reviewed investigated Human-drone interaction in the outdoor context. A list of papers falling into this category are: [2, 6, 7, 10, 11, 15, 21, 26, 35, 38, 41, 43]. Few papers focus on indoor interactions with drones. For example, in [16] the authors described the use of drones in the indoor environment as a tool for augmenting human vision. The study presented in [24] analyzed the use of drones inside construction facilities, where issues such as workers being distracted or even hit by drones should be carefully considered. Indoor smart environments and Internet of Things scenarios are investigated as primary environments where drone-based privacy interfaces can be exploited [42]. The authors of [3] explore the use of drones both on indoor and outdoor scenarios, to support users with visual impairments. Both the scenarios are also considered in [29], where drones are evaluated considering indoor, semi-outdoor, and limited outdoor settings. Results show the feasibility of the authors approach under two limitations: an environment relatively free of major obstruction for drone flying, and the need to rely on a laptop computer for most of the required computation (due to the fact that the used drone has got a very limited on-board processing power).

3.4 Interaction modes

As expected, the modes used to interact with drones are the focus of most of the selected papers. In particular, from the analyzed papers it is clear that, thanks to the advances in hardware architectures and sensors technologies, and the integration of machine learning algorithms and techniques, rich user interaction has become possible in many domains. Natural gestures are investigated in [11], where users were asked to define the gestures to control the drone. The authors discovered that people interact with drones just like with a person or a pet, using interpersonal gestures, such as beckoning the drone [25] is a study investigating different drone gestures (such as orienting towards the counterpart and salutation gestures) to acknowledge the human presence and clarify suitable acknowledging distances. The authors of [35] presented a study where they designed and implemented an end-to-end far-to-near situated interaction between an uninstrumented human user and an initially distant outdoor autonomous drone, investigating a dual armwaving gesture to attract the drone attention from distance, an integrated visual tracking and serving system to bring the robot to the close proximity of the user, and a closerange interaction with the UAV after the approach. In [15] the authors explore the movements of the drone itself as a potentially rich and expressive communication medium between flying drones and human pedestrians. Instead, the authors of [31] investigated foot gestures as a mode to interact with projection. Different control modes are investigated in [6], such as: autonomous, i.e., the robot can plan and execute a complex task without the human support; manual, i.e., each robot can be directly tele-operated by a human; mixed-Initiative, i.e. the user can execute some operations, while the autonomous system reacts or reconfigures itself accordingly. In doing that, they investigate also different modalities (joy-pad, gestures, speech, tablet, etc.) at different levels of abstraction (task, activity, path, trajectory, motion, etc.). In [17], speech, body position, hand gesture and visual marker interactions are used to directly command tasks to the drone. The interactions are based on devices like the Leap Motion Controller, microphones and small size monocular on-board cameras which are unnoticeable to the user. Additionally, the proposed strategies allow for multi-modal interaction between multiple users and the drone by being able to integrate several of these interfaces in one single application. The authors of [24], analyzed the usability of a safety inspection assistant drone, informing designers with requirements this kind of drone should have, such as autonomous navigation, voice interaction, environmental applicability, high-resolution cameras, multitasking application, and collaborative user interface environment.

Leap Motion Controller is investigated also in [4] and [41]; while, a semi-autonomous interface is provided by XPose [29] to control the drone through gesture on a touchscreen, issuing higher-level commands at the task level. Gaze tracking with an eye tracker is presented in [46], where the authors state the feasibility of their approach so as the need to improve the ability to discriminate intentional gaze gestures from otherwise normal gaze activities exploiting machine learning algorithms. In [30], t-shape gesture for stopping, palm out stop gesture, beckon, frame gesture for taking photos, and sounds are evaluated with users. Persuasion effects with the drone (i.e., Visual, Audio, and Visual+Audio) are exploited in [38]. In [28], the authors propose a technique allowing a drone to forecast future hand gestures.

A touch-based human-drone interaction is tested in [1]; while a exocentric control/exocentric view is analyzed in [16]. In particular, the latter one introduced two interaction techniques for flight control and navigation in the occluded space without hitting obstacles: pick- and-place (pick a drone by looking at it and applying a pinch gesture) and gaze-tosee (using the view vector and eye position provided by oloLens, one can calculate the point of interest a user is gazing at by intersecting the viewing ray with the scene model). Voice commands are at the basis of the approach presented in [3]; the user can issue verbal commands, e.g., 'navigate me to the office'; while in [26], the authors present a character that represented the drone's facial expressions, which was designed in the Smart Watch, together with messages. In [12], the range of personality traits and emotional attributes are investigated so as to be encoded in drones through their flight paths (drone's flight path and speed); encoding data into the flight path will better support multiple users' interactions, as only one person can have the remote control, but all can look at the flight path. A multimodal interaction that allows the user to interact with the agents using speech- and gestures-based communication is presented in [10]. Another interesting issue to investigate is related to the simultaneous control of a swarm of drones. In [36], the authors present their approach addressing two main issues: the use of spatial hand gestures given with the help of a tangible input device, the relative localization and positioning between a human and a robot swarm based on face detection and the assessment of face poses (exploiting machine learning algorithms).

4 Open Issues and Challenges

Drones are increasingly attracting the interest of the public, and this opens new challenges and issues related to the Human-drone interaction discipline. In fact, as presented in this analysis, recent studies tend to investigate the use of drones as personal devices, or even, companion. This scenario lets emerge new issues related to the way users feel confident in interacting with the drone. Moreover, considering a scenario where drones could be used in our daily activities, new concerns need to be tackled. Important issues related to privacy and ethics need to be addressed to allow users to positively enjoying the use of these new personal devices. Drawing on this line, a few recent papers already started to investigate some relevant issues, such as privacy mechanisms and ethics perception [13, 45]. In this context, also the perception aspect plays an important role. Despite the advances with technology, users have a (often) wrong perception of drones and tend to deal with them as with pets (as stated by different studies, i.e., [11]); but drones are much more. This device has a strong potential that should be explored in order to improve the quality of life of people in several contexts and everyday settings. This is why the Human-drone interaction field is becoming increasingly relevant in the HCI scenario and it is expected a relevant growth during the in coming years, exploring topics that go also behind the mere interaction modes (i.e., privacy and ethics), including also creative aspects.

5 Conclusion

We have presented a review of the state of the art in the context of the human-drone interaction, with the aim of studying and discussing the main open issues and challenges, currently highlighted and reported in research projects and papers. We have initially selected 100 papers on the Google Scholar repository, searching for the keywords "HumanDrone Interaction" and "Human-UAV Interaction" in the title, abstract, and in the whole content of each paper. Then, we have selected the most significant 40 papers and we have analyzed them in detail. The final set of papers was published between 2012 and 2018, including conference proceedings and scientific journal articles. We have identified some interesting dimensions and we have classified and reported the papers on the basis of: the role of the drone, the context of use, a comparison between indoor and outdoor usage, and the interaction mode. Some considerations about open issues and challenges are here discussed.

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