Investigating users' natural spatial mapping between drone dimensions and one-hand drone controllers

Sebastian Büttner
sebastian.buettner@th-owl.de
Institute Industrial IT, Ostwestfalen-Lippe
University of Applied Sciences and Arts
Lemgo, Germany
Human-Centered Information Systems,
Clausthal University of Technology
Clausthal-Zellerfeld, Germany

Rami Zaitoon
rami.zaitoon@stud.th-owl.de
Institute Industrial IT, Ostwestfalen-Lippe
University of Applied Sciences and Arts
Lemgo, Germany

Mario Heinz
mario.heinz@th-owl.de
Institute Industrial IT, Ostwestfalen-Lippe
University of Applied Sciences and Arts
Lemgo, Germany

Carsten Röcker
carsten.roecker@th-owl.de
Institute Industrial IT, Ostwestfalen-Lippe
University of Applied Sciences and Arts
Fraunhofer IOSB-INA
Lemgo, Germany

ABSTRACT

Using remote control transmitters is a common way to control a drone. For the future, we envision drones that are intuitively controllable with new input devices. One possibility could be the use of one-hand controllers, e.g. 3-D mice. While developing such a device, we investigated the users' natural spatial mapping between controller and drone dimensions. In this paper we present our insights about this mapping and show why relative position control is an important control concept for novice users.

iHDI '19 - International workshop on Human-Drone Interaction, CHI '19 Extended Abstracts, May 5, 2019, Glasgow, Scotland, UK, http://hdi.famnit.upr.si

Figure 1: Currently, most non-autonomous drones are controlled by more or less complex remote control transmitters (RCT). The image shows one of the complex models.

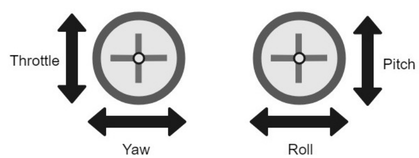

Figure 2: Even though there are numerous different control devices available, the control concept follows in most cases the image shown above. This concept shows the difficulties of mapping two planes on the four degrees of freedom (DOF) of a drone.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Interaction devices**.

KEYWORDS

human-drone interaction, unmanned aerial vehicle, 3-D mouse, spatial mapping

ACM Reference Format:

Sebastian Büttner, Rami Zaitoon, Mario Heinz, and Carsten Röcker. 2019. Investigating users' natural spatial mapping between drone dimensions and one-hand drone controllers. In *Proceedings of International workshop on Human- Drone Interaction (iHDI). Workshop at the ACM CHI Conference on Human Factors in Computing Systems 2019.* ACM, New York, NY, USA, 8 pages.

INTRODUCTION

In recent years, drones (also known as multicopters or unmanned aerial vehicles), are widely available and have become increasingly popular due to the growth of low-cost hardware (e.g. sensors). They are utilized in multiple applications such as film and photography, leisure activities, search-and-rescue, product delivery, or industrial maintenance. Apart from completely autonomous drones, using two-hand drone remote control transmitters (RCT) is a common way to control a drone. Using classical RCTs tend to be difficult to use for a non-experienced user, requiring a long period of both training and understanding how the drone will react to user inputs. To create more intuitive interfaces and a better user experience while controlling a drone, we envision semi-autonomous drones that are controlled by new input devices. In this context, we develop a first exploration that uses a 3-D mouse (also known as space navigator) to manually control a semi-autonomous drone with a single hand. When using this input device, it is essential to find a mapping between the spatial dimensions of the 3-D mouse and the dimensions of the drone that feels natural to the users (compare [10]). In this paper we present first insights about our investigation of the users' natural spatial mapping.

STATE OF THE ART

There are different strategies for controlling drones, depending on its specific use case. The requirements range from completely autonomous drones (e.g. for delivery) over semi-autonomous drones, where users can influence movements of an autonomous drone (e.g. the concepts shown in [2]) to manual controlled drones, where actively flying the drone is part of the experience (e.g. drones for leisure activities). This section gives an overview of the state of the art of human-drone interfaces.

Remote Control Transmitters (RCT)

The most common way to manually control a drone is using an RCT (see Figure 1). These transmitters are devices held with two hands, ranging from very small ones with only few buttons to complex programmable models that have displays and numerous additional input controls, such as buttons and slide controls. Typically RCTs consist of two separate control sticks. Each stick has two degrees of freedom (DOF) allowing the user to have four DOF inputs in total. The stick on the left is used to send commands for throttle (drone moves up and down) and yaw (drone rotates around z-axis). The second stick on the right is used to send commands for pitch (drone moves forward or backward) and roll (drone moves sideways left or right). The mapping of the stick movement to the drone is illustrated in Figure 2. RCTs require the coordination of both hands for the 2-D degrees of motion of each stick to transform into the variety of motions available in a 3-D space. Obviously, it is impossible to find a natural mapping of these dimensions and the mapping described above is a convention which requires inexperienced users to learn how to control the drone.

Tablets or Smartphones

Smartphone or tablet applications have been used to replace RCTs, especially for low-cost drones for leisure activities. The control concept of the applications is usually the same as of RCTs: two virtual control pads replace the two sticks. While this control concept has haptic restrictions, the screen of smartphones and tablet offers further features, e.g. to show live images of the drone camera.

One-hand Controllers

As described above, two-hand controllers require a certain coordination of both hands. Such coordination might pose a challenge to inexperienced users or people with physical disabilities (compare [8]) and restricts the use case as well, if the user needs to perform additional tasks, while manually flying the drone. Furthermore, the mapping between the 2-D controls and the 3-D drone movements are not intuitive. Consequently, there were efforts to develop one-hand devices for better interaction with drones. One concept first published in 2016 by the South Korean company "this is engineering Inc." [13] is the drone controlling system Shift that allows to control a drone with a stick held in one hand and a ring that is worn on the thumb of the same hand. Moving the thumb in relation to the stick controls the drone. While this concept created huge interest on the crowdfunding platform Kickstarter and was funded, the project was canceled at the end of 2016 and since then, there has no been any further notice about its sales launch [6]. A second successful Kickstarter campaign relates to the development of the "FT Aviator Drone Flight Controller" that, according to the developers, will be launched until mid-2019 [7]. The controller can be used with only one hand by using a normal joystick to navigate pitch, roll and yaw and thumb and index fingers to control the throttle value. Using a thumb to control the throttle can eliminate the complexity and the need of using two hands with natural and cognitive translation of hand-to-device movement. The glove-based controller PULSIT is another one-hand controller that is currently under development by the French startup WEPULSIT

Figure 3: The device SpaceMouse® Compact from 3Dconnexion [1] was used for our exploration.

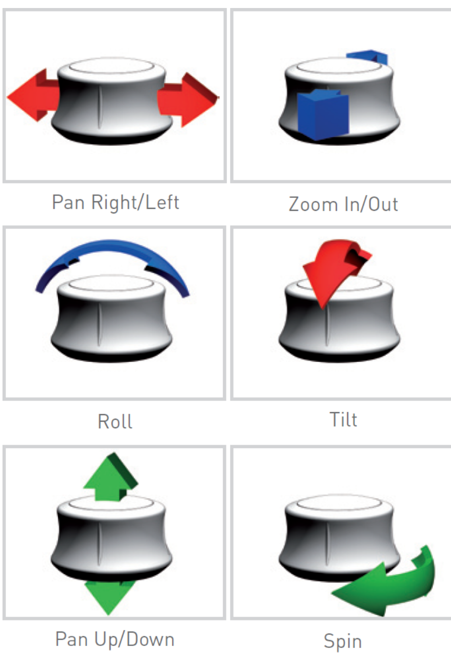

Figure 4: Degrees of freedom (DOF) of the 3-D mouse used in our exploration (Figure based on [12]).

[14]. Wearing PULSIT, users can control a drone by moving their hand and making specific gestures with their fingers. In summary, it can be said that one-hand controllers are currently still in a development stage.

Natural Drone Interactions

Beyond physical controllers, different natural interaction techniques have been proposed to interact with drones more naturally, such as control by hand or full-body gestures or language control. Cauchard et al. [2] analyzed natural ways of interacting with drones in a Wizard-of-Oz study. They found out that interpersonal gestures are intuitively used by people, e.g. if a drone should be stopped or fly back to the user. Fernández et al. [4] used a leap motion controller [9] as an input device for gesture control. Compared to the work of Cauchard et al., their defined gestures have no meaning in interpersonal communication. Rather they map the movements of the hand to the movements of the drone. They state that users had to get used to this interaction first, but "experiencing the connection of the hand with the drone made this [...] natural and fun" [4]. The same authors also explored the use of voice commands [4]. Peshkova et al. [11] provides an overview on different natural interaction techniques for drones, which also includes approaches with gaze trackers or brain activity. But natural drone interaction possibilities are not only a topic for research. First consumer products are already in the market that realize the gesture control concepts described above: DJI's consumer drone Spark has an optical system for tracking users' gestures for controlling the drone and for taking photos with the built-in camera [3] using gestures similar to the work of Cauchard et al. [2].

EXPLORATION: 3-D MOUSE AS DRONE CONTROLLER

While classical remote control transmitters are a suitable input device for experts and – as mentioned – for some hobby pilots, where expertise contributes to the experience, we envision a future, where a lot of drones can navigate autonomously. In that world, operators of drones will only fly manually if necessary. Our use cases relate to industrial settings, such as plant monitoring. If, for example, an operator visually inspects a plant with a drone and wants to navigate to a certain spot, he might manually control the drone while his eyes are focused on a screen. In this scenario a natural and intuitive one-hand controller might be a good choice. We therefore want to explore possibilities of a 3-D mouse as drone controller. 3-D mice are originally designed for navigating through computer-generated 3-D imagery and commonly utilized in Computer-aided Design (CAD), 3-D modelling and 3-D visualization. For our exploration we use the 3-D mouse SpaceMouse® Compact from 3Dconnexion [1] (see Figure 3). This device has six DOF (see Figure 4) and is to be operated with one hand. It has two additional buttons and can be connected with a computer via a USB port.

UNDERSTANDING THE NATURAL SPATIAL MAPPING OF USERS

A typical drone has four DOF, which are composed of the three dimensions of movement in the physical space and the possibility of rotating the drone around the own z-axis (some drones can also flip over, which corresponds to another dimension, but this is uncommon for larger industrial drones, so we excluded this 5th dimension from our consideration).

During the development process of our exploration, we involved potential users to evaluate whether users could intuitively use the drone with the 3-D mouse and to find a natural mapping between the six DOF of the 3-D mouse and the four DOF of a drone. Furthermore, we wanted to understand whether users consider themselves or the drone as reference point for the movements.

Method

Figure 5: Study setup. During the study, the participant sat in front of the 3-D mouse and had to control a simulated flight.

To find answers on these questions, we ran a Wizard-of-Oz (WoZ) experiment in our lab. In the experiment, users had to take a simulated flight with the 3-D mouse, without receiving any prior information about the 3-D mouse. The setup is shown in Figure 5: The participant sat behind the table in front of the 3-D mouse. The drone was placed in front of the user. The observer sat next to the user and told the user to do seven specific drone movements (e.g. "Start the drone straight up in the air," "Fly one meter into the direction of the telephone," "Fly sideways to the right. During the flight turn the drone 90° to the left.") The movements on the controller were observed and at some points questions were asked, such as "What would you expect to happen to the drone, if you release the controller now?" An assistant carried the drone through the room to simulate the flight according to the commands. After this simulated flight, the users were asked about the possible movements with the 3-D mouse to find out whether users understood the device without any introduction. Afterwards, Figure 4 was shown and users were asked how they would map these dimensions to the drone dimensions. Obviously, this second mapping was different from the mapping observed in the experiment, since most participants did not recognize all axes of the 3-D mouse during the experiment.

For the experiment, we recruited 9 participants (1 female, 8 male), aged 24 to 36 ($\mu = 30.6$, $\sigma = 3.5$), all employees of our institute, but none of them involved in any projects related to drones. 4 of the participants had never flown a drone before, 3 had tried out a drone before (2 with RCT, 1 with tablet) and 2 own a drone (1 with RCT, 1 with smartphone). 7 participants had never used any 3-D mouse before, 2 had experience with this device (1 from CAD applications, 1 from controlling a robot).

Results

Even though there were only a small number of participants, the results show a trend about the users' intuitive understanding of the controller and the natural mapping.

Point of Reference. First, we analyzed the users' understanding of the point of reference. Common drones need to be controlled in a way that takes the drone as point of reference for the movements ("direct position control", see [5]). With this mode, steering left means that the drone moves left from its own perspective. Our experiment showed that about half of the users (5 out of 9, including the 2 participants, who own a drone) used the controller in this way. However, the others (4 out of 9, most of them inexperienced with drones) used the devices as "relative position controller" (see [5]), so they steered left, if the drone had to move left in relation to the user. These results show a strong need for supporting relative position control, if a drone controller is designed for novice users.

Intuitive Understanding of the Input Device. Considering the supported DOF of the input device (see Figure 4), most participants intuitively understood the directions Tilt (all), Spin (8 out of 9), Roll (all), and Pan down (7 out of 9). However, only 3 participants recognized that they could move the controller upwards (Pan up). One of them showed doubts: "Maybe I can move it up. I don't want to destroy it." The directions Zoom and Pan left / right were only used by the participant who had controlled a robot before with a similar device. The other 8 participants did not use or recognize these dimensions for the drone movement.

Natural Mapping between 3-D Mouse and Drone. Most participants (8 out of 9) used Tilt and Roll to move the drone forwards, backwards, and sideways right and left as mentioned above with different points of reference. Only one participant used Zoom and Pan left/right instead. Also, turning the drone around the z-axis was done by most participants (8 out of 9) with the Spin action. The participant who did not recognize the Spin function of the controller explained that he would have expected a button for turning the drone. The results for starting and landing were more diverse: 2 participants used the Pan up function, 3 used a button for the start, 2 used the Pan down function (1 explained that he would push the button down as long as the drone should be in the air), 1 assumed that he can control the height by turning the controller (Spin) and 1 participant assumed that the drone starts automatically, if he starts to move it forward with Tilt. In the same way, participants had different ideas about how to land the drone. Most participants (4 out of 9) expected the drone to land with a button on the device. Even though most users recognized the possibility to pan the button down, only three used it for landing, since the others had used this function already for other flight maneuvers. One participant used the button for flying and stated that he expected the drone to land as soon as he releases the button. One participant used a double-click on the controller (Pan down) as an input for landing.

Implications for Design. Our study reveals the strong need for relative position control if a drone controller is designed for novice users. Mapping the spatial dimensions of the 3-D mouse simply with the drone movement is not as intuitive as it might seems at first glance. Especially movements up-and downwards were not intuitively understood by the participants. With drones becoming more autonomous, we suggest to control starting and landing operations with buttons separate from the control. The same is valid for ascending and descending movements. Finally, for our particular device, we suggest to make no difference between Tilt and Zoom and between Roll and Pan left / right, since users were not aware of this difference and controlling the dimensions independently requires prior training with the input device.

SUMMARY AND CONCLUSION

In this paper, we investigated the natural mapping of users between the spatial dimensions of a 3-D mouse and the dimensions of a drone. This investigation was a first step towards the development of a one-hand drone controller. While the development of our specific controller is ongoing work, we could gain important insights in users' intuitive mapping, which is important knowledge when designing controllers in general. We argue that future semi-autonomous drones will be controlled by more intuitive devices than contemporary RCTs. Considering our results, relative position control should be the standard control concept for novice users.

REFERENCES

[1] 3Dconnexion. 2019. 3Dconnexion SpaceMouse® Compact. https://www.3dconnexion.com/spacemouse_compact/en. [Online; accessed 06-February-2019].

[2] Jessica R Cauchard, Kevin Y Zhai, James A Landay, et al. 2015. Drone & me: an exploration into natural human-drone interaction. In *Proceedings of the 2015 ACM international joint conference on pervasive and ubiquitous computing*. ACM, 361–365.

[3] DJI. 2019. DJI Spark. https://www.dji.com/spark. [Online; accessed 06-February-2019].

[4] Ramón A Suárez Fernández, Jose Luis Sanchez-Lopez, Carlos Sampedro, Hriday Bavle, Martin Molina, and Pascual Campoy. 2016. Natural user interfaces for human-drone multi-modal interaction. In *Unmanned Aircraft Systems (ICUAS), 2016 International Conference on*. IEEE, 1013–1022.

[5] Markus Funk. 2018. Human-drone Interaction: Let's Get Ready for Flying User Interfaces! *Interactions* 25, 3 (April 2018), 78–81. https://doi.org/10.1145/3194317

[6] Kickstarter. 2016. Shift: The New Generation of Drone and Controller. https://www.kickstarter.com/projects/1937904185/shift-the-new-generation-of-drone-and-controller. [Online; accessed 06-February-2019].

[7] Kickstarter. 2018. FT Aviator Drone Flight Controller. https://www.kickstarter.com/projects/fluiditytech/ft-aviator-a-revolutionary-single-handed-drone-con/. [Online; accessed 06-February-2019].

[8] Márcio Martins, António Cunha, and Leonel Morgado. 2012. Usability test of 3Dconnexion 3D mice versus keyboard+mouse in Second Life undertaken by people with motor disabilities due to medullary lesions. *Procedia Computer Science* 14 (2012), 119–127.

[9] Leap Motion. 2019. Leap Motion. https://www.leapmotion.com. [Online; accessed 06-February-2019].

[10] Don Norman. 2013. *The design of everyday things: Revised and expanded edition*. Basic books.

[11] Ekaterina Peshkova, Martin Hitz, and Bonifaz Kaufmann. 2017. Natural interaction techniques for an unmanned aerial vehicle system. *IEEE Pervasive Computing* 1 (2017), 34–42.

[12] Uwe R. 2018. Space Mouse for Cura auf thingiverse. https://drucktipps3d.de/space-mouse-for-cura/. [Online; accessed 19-February-2019].

[13] this is engineering Inc. 2019. this is engineering Inc. http://www.thisiseng.com. [Online; accessed 06-February-2019].

[14] WEPULSIT. 2019. WEPULSIT – Smart Equipment for Drones. http://www.wepulsit.com/. [Online; accessed 06-February-2019].