Task Design in Virtual Reality Environments for Drone Pilot Training

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Abstract. Drones currently play a very important role in various fields of application. Their applications range from recreational activities, pilot training, educational uses, and the development of skills for specific and risky tasks such as agriculture, construction, military use, mining, etc. This implies that different types of users need to acquire the necessary skills to pilot these devices safely taking into account the type of tasks to be performed and the specific device. Having virtual reality environments that allow users to perform specific training tasks allows them to develop their skills to solve real problems without the need for a physical device. I feel the training is a playful and motivating activity for learning and skill acquisition. This work presents the design of tasks under the Hamsters notation for the production of virtual reality environments focused on teaching drone piloting in simulated and real scenarios.

Keywords: virtual reality, interactive environments, drones, education, task design

1 Introduction

Unmanned aerial vehicles (UAVs), commonly known as drones, are those devices that refer to aircraft that are capable of being remotely controlled and under which there is no crew [26]. According to the U.S. Federal Aviation Administration, there are currently 870,911 registered drones, of which 356,686 are for commercial use and 510,721 are for recreational use, i.e. for entertainment, photography, video, tourism, and education, among others. In addition, there are also approximately 234,605 registered pilots.

Drones, being devices capable of being remotely controlled without putting the pilot at risk, offer several advantages that allow them to be used for various applications, among the most common are the collection of cartographic data, civil logistics, precision agriculture, defense, monitoring and preservation of species in forests, and there are promising forecasts in the field of commercial logistics and product delivery [20, 3, 21].

In addition, the use of drones has reached other fields of application such as education and entertainment due to their low cost and variety of devices.

Table 1. Applications of the use of drones, inspired by [26].

Civil Engineering	**Environment**	**Defense**	**Education**	**Entertainment**
Photography	Air quality monitoring	Combat aircraft	Developing motor skills and hand-eye coordination.	Visual shows
Construction	Soil monitoring	Medical supplies for war zones	Teaching coding	Film and photography
Mining	Crop monitoring	Espionage	Teaching the laws of physics	Racing
Deliveries	Water	Border surveillance	Development of intellectual and creative abilities	Entertainment or leisure
Logistics	Submarine	Bombing	Teaching mathematical tools	sporting events
Disaster Management	Mountain survey	Missile launching	Development of interpersonal skills	tourism
Surveillance			Developing intellectual and creative abilities	

Being small size devices compared to manned aircraft, they are of low energy consumption and can also carry a variety of sensors and cameras according to their use [26]. Table 1 presents some of the most representative applications of drones.

In this sense, the types of drone users are diverse and increasing, so it is important to have strategies that help to focus efforts on their proper use where a safe, low-cost environment is considered, and where users can also be trained in training and education as drone pilots performing specific tasks [4, 25]. Virtual environments can be a strategy to have scenarios that abstract situations of reality in which users can perform various tasks in the training and handling of drones [6, 24].

Some examples that can be mentioned are those where the user performs a high-risk task with a specific type of drone and in case the drone is damaged or lost while performing the task it could imply in reality a high cost and risk for the user [2]. In many fields of application, simulation has been an important part of performing various tasks as a training measure. This can be commonly found in video games to simulate the driving of cars, airplanes, and trucks, among others, playfully and recreationally [17, 7], as presented in the example in Figure 1.

Fig. 1. American Truck Simulator and Flight Simulator 2020, virtual environments with scenarios that simulate driving a truck and piloting a commercial aircraft [17, 7].

Regarding UAVs, the design of user tasks within virtual environments can represent an aspect of importance, since it is allowed to represent specific scenarios inspired by reality. It is also possible to represent suitable drone types with specific characteristics and environmental conditions that can hardly be found in reality [8].

In this work, the design of tasks in virtual reality environments is proposed as an alternative design of these virtual environments to train users in the use of drones under a user-centered approach. And also that these tasks are following existing official standards to train drone pilots safely and playfully.

2 Related Work

In the literature, there are several proposals in which the use of virtual environments helps the simulation of scenarios with drones to perform complex tasks in various fields of application. Some of these proposals are described below:

Andersen [1] focuses on the use of virtual environments to simulate situations in the mining context, where evacuation training and handling of emergencies have to be performed without stopping production during drills. So the Mine Evacuation Training Simulator (METS) is a virtual training scenario in which workers can have an immersive experience. So, production can continue while some employees take evacuation and emergency training.

Park et al. [18] focus on identifying basic content for drone flight training, this includes basic flight skills including existing drone types. To achieve this, it is proposed to use video game platforms such as XBOX taking advantage of the type of controller used in these consoles as a standard radio controller for drones.

Works such as that of Gabriel et al. [5] focus on measuring the workload in drone flight situations within a simulator. The objective is to know the relationship of workload with the tasks performed inside the simulator and thus to know its clear effects on mental demand. This type of study can also help to measure the perception of tasks proposed under virtual training systems.

Mairaj et al. [13] present a compilation of UAV simulation platforms. For certain tasks, the use of this type of environment offers low-cost cost-effectiveness and reliability by being fault tolerant and flexible for reconfiguration. In addition, an analysis of platforms such as HEXAGON Flight Simulator, VAMPIRE PRO, SUAAVE, and Flight Gear, among others, is presented.

Postal et al. [19] present an immersive virtual environment for drone pilot training through the use of interaction devices. The objective is to improve the user experience in training tasks. To accomplish this, the Microsoft Kinect platform was used as an input medium to control the drone and the Oculus Rift viewer to visualize the scenario in an immersive way.

In the educational field, Schaffhauser [22] presents the use of drones as an effective solution by educators to mitigate problems of low attendance, improve discipline and raise student satisfaction. In this sense, the use of drones is increasingly considered a strategy to support STEAM [19] (science, technology, engineering, arts, and maths), allowing improved knowledge retention and the development of skills such as fine and gross motor skills in students when piloting drones. Even being a playful and recreational alternative that helps to motivate students in learning [20]. UAVs are increasingly used in various tasks for various fields of application, this can be an opportunity to propose virtual reality environments, where the tasks that the user performs are under a user-centered design context and can be carried out safely under specific guidelines so that these environments can help users to train in the best way.

3 Types of Drone Pilots

In this section, a classification of drone pilots is presented, this classification takes its basis mainly from the Federal Aviation Administration (FAA) [28], in which specific rules and regulations are established for each type of user. In this sense, a classification of users is presented, which is generalized into four major types, as can be seen in Table 2.

Recreational users are generally those who are new to drones and their application refers to photography and video, tourist use, and recreational and leisure applications. In general, the drones used are accessible and low-cost and can even be used by teenagers and children for domestic use.

Certified users and commercial operators are those who have vast experience in the handling of drones for logistics, security, and all activities related to commerce, they are also certified users by endorsed aviation institutions.

Security and government users are those who have experience in handling drones and their use is more complex and refers to official applications, such as police monitoring, mapping applications, and agriculture, among others.

These last two types of users must know the technical and regulatory aspects of drones. They must be familiar with airspace and radio spectrum regulations, safety, and environmental aspects.

Finally, educational users are those such as teachers and students who use drones to provide learning and educational experiences.

Table 2. Classification of drone piloting user types.

User type	Description
Recreational user	- Users who primarily perform flights that are purely for fun and personal enjoyment. - Users owning drones weighing less than 55 pounds.
Certified pilots and commercial operators	- Users who own a small drone weighing less than 55 pounds. - They may fly for work or business following the guidelines established for this category.
Security and government	- Public safety and law enforcement agencies. - Tasks aimed at deterring, detecting, and investigating unauthorized or unsafe UAV operations. - Assist public safety and law enforcement professionals in understanding safe drone operations and their authority.
Educational users	- Teachers or students looking to incorporate drones into their curriculum.

Piloting a drone is as important as any other vehicle; existing regulations, safety guidelines, and restrictions must be taken into account. Therefore, it is necessary to acquire previous learning that allows one to know the key elements according to the needs of each user.

4 User-Centered Task Design

This section presents the modeling of the user's task using the HAMSTERS (Human-centered Assessment and Modelling to Support Task Engineering for Resilient Systems) tool which is a tool designed for the assessment of safety-critical systems (SCS) [10, 12] or a life-critical system. These are systems whose failure or malfunction may result in one (or more) of the following outcomes: death or serious injury to people, loss or severe damage to equipment on the property, environmental damage, etc [27].

In unmanned aerial vehicles flight can be operated under remote control by a human operator, such, as remotely piloted aircraft (RPA) or with various degrees of autonomy, autopilot assistance, up to fully autonomous aircraft that do not provide for human intervention [9]. For this reason, a drone is considered a critical system because if it does not respond to the commands that the operator is making the drone can cause great damage.

For user task modeling first, identify the customization needs according to the scope of analysis, then to the application domain a modeling environment is prepared and after this, the task modeling technique is applied and finally, the process is modeled according to the scope of task analysis [15].

5 Task Design for Virtual Reality Environments for Drone Pilot Training

In drone pilot training, drone tasks are highly dependent on the motor, cognitive and perceptual skills and actions. The user tasks performed during exercises are also highly dependent on the experience one has in handling a drone, as well as the information processed by the pilots. Therefore, a task modeling notation is required to support the description of training exercises. Through the HAMSTERS tool, this represents embedding elements to represent motor, cognitive and perceptual actions, as well as elements to represent the temporal order of actions and elements to represent manipulated objects and information. Therefore, the HAMSTERS notation helps to meet these user task design requirements.

HAMSTERS is a tool-supported task modeling notation for representing human activities in a temporally ordered hierarchical manner, intended to support modeling of large sets of user tasks [16, 14] as well as supporting consistency and conformance between user tasks and interactive systems [16, 11].

In this section, a case study is presented to show the use of HAMSTERS for the design of user tasks for drone pilot training. This case study focused on an unmanned system such as a drone and the tasks presented to have the objective that the user can be trained to fly a drone.

Figure 2 shows the model of the task design for flying a drone from a general perception. It starts with the pilot who, depending on the type of user he represents, is the training he can carry out. For example, there are 3 types of users, the basic one with 4 training exercises, and each exercise has a set of instructions to be performed.

For professional pilots, there are 8 training exercises and for pilots representing training and governmental entities, there are 9 training exercises. In principle, to pilot a drone, the user must become familiar with the controls and the pilot must know what function each command has to obtain prior knowledge before performing the training exercises.

Figure 3 shows a model which presents the tasks that a user must perform to fly a drone, specifying what each command does when the pilot decides to move the joystick. Once the user is familiar with the basic commands, the user can perform the training exercises. For basic pilot training, there are four training exercises detailed in Table 3.

Once the user tasks for the basic pilot are defined, the next step is to establish a modeling of these tasks with the HAMSTERS tool. Figure 4 presents the modeling of exercise number 1 where first the user is placed in front of the drone and it is indicated first that with his left hand, he moves the controller upwards, the command is sent to the drone, the drone receives the command and the user observes that the drone rises, then, the user analyzes if the drone is ten meters away and keeps this way for 10 seconds until the exercise is finished.

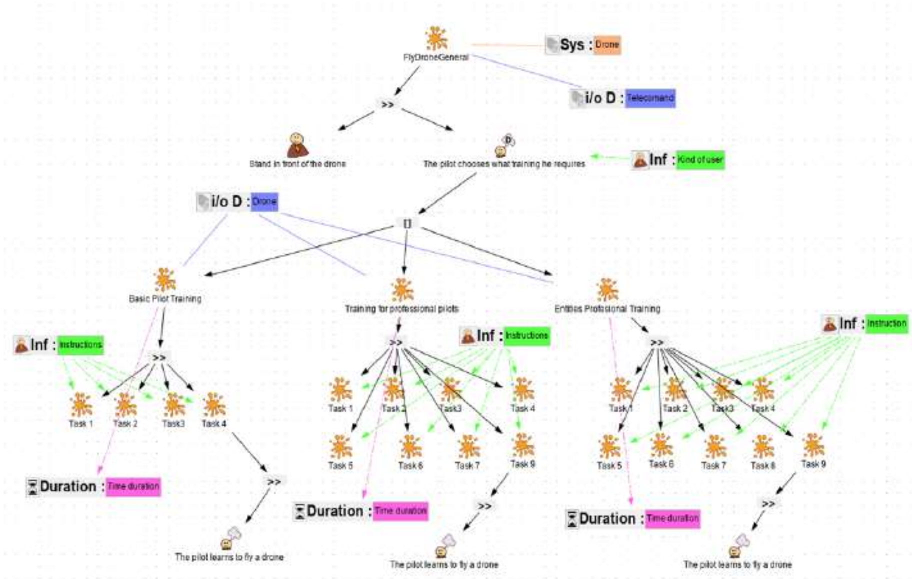

Fig. 2. General model for flying a drone according to user type.

Table 3. Basic pilot training exercises.

Exercise	**Graphical representation**
1- Take off the multicopter 10 meters away from you. Raise it to the height of your eyes and keep it in stationary flight for 10 seconds.	
2- Steer the drone forward in slow flight at a height of 20 meters. During its trajectory, make it move in ZigZag (S-shaped trajectory) making a minimum of 4-course changes.	
3- Same as exercise 2 but make the drone fly backward (towards you/pilot). Try to make the aircraft face you, so that the controls are reversed if the drone does not have a headless node.	
4- Steer the multicopter sideways, both to the left and to the right, making it reach a distance of up to 30 meters to each side of the pilot.	

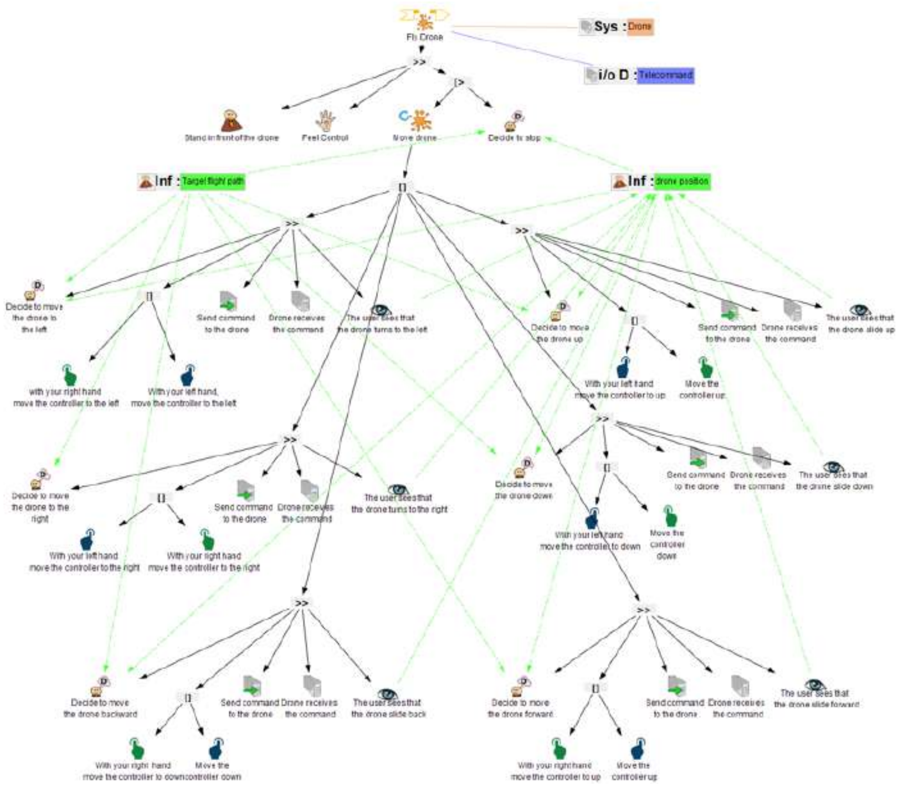

Fig. 3. Drone flight task design.

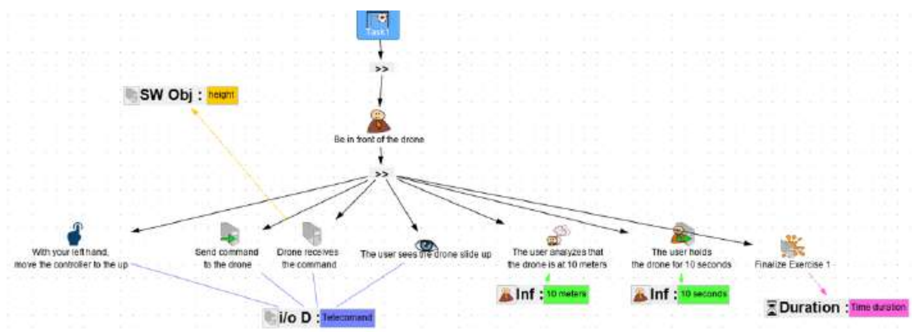

Fig. 4. Task modeling for exercise 1.

In Figure 5, the modeling of exercise 2 consists of the user standing in front of the drone, the user moves the controller from left to right so that the drone moves to the left and right, and the user repeats this 4 times until the exercise is completed.

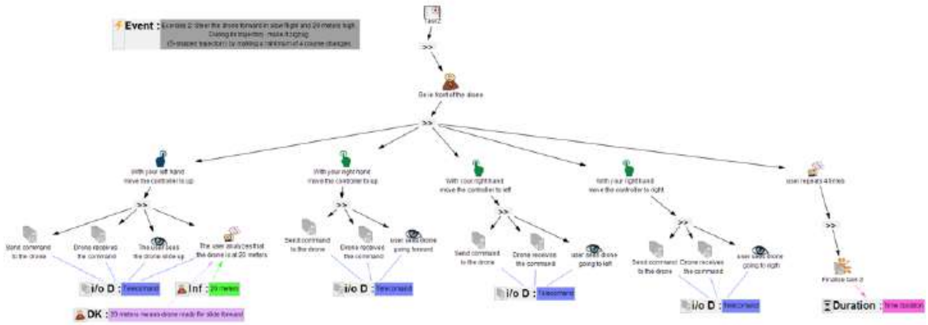

Fig. 5. Task modeling for exercise 2.

In the same way as in the exercise, the model in Figure 6, only now the drone has to return to the user and is placed in front of the drone, move the drone from left to right until it returns to the user, this is repeated 4 times and ends the exercise.

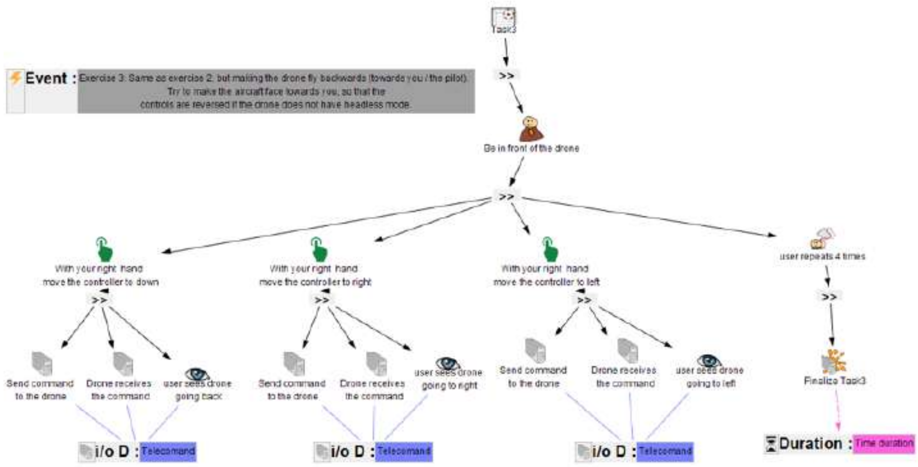

Fig. 6. Task modeling for exercise 3.

Finally, In Figure 7 the exercise 4 consists of the user moving the controller to the left with his right hand and sending the command to the drone, the drone receives it and the user analyzes that he has moved to the left 30 meters, with his right hand he moves the controller to the right, the drone receives the command

and the user analyzes that the drone is 30 meters to the right and ends exercise 4.

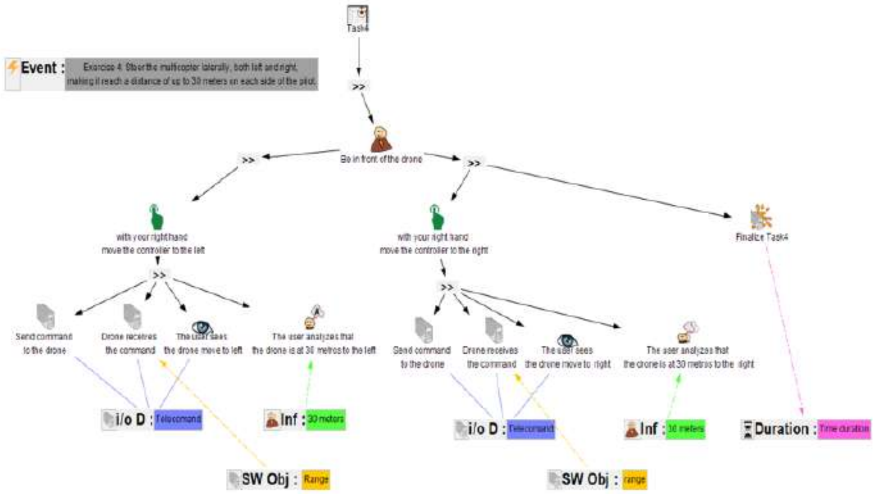

Fig. 7. Task modeling for exercise 4.

Once the models of the training exercises are available, the next stage consists of the development of an application for the user to train to learn how to pilot a drone.

6 Implementation of Virtual Reality Environment for Drone Pilot Training.

In the following, the design elements and the implementation of the virtual reality environment oriented to recreational users under the presented task modeling are presented. The virtual reality environment consists of two versions:

- The first version, where the scenario contains 3D elements and represents a training area for flying drones.
- The second version uses augmented reality to allow the user to indicate the physical area and provide a sense of realism by combining real-world elements with virtual elements.

Both versions use a drone with four rotors and four propellers, being this type of drone is more common for recreational users, as shown in Figure 8. When the user starts the application he can select one of the two available versions. A 3D version that resembles a video game as it contains animated elements and the scenery simulates a flight and training area. On the other hand, the augmented reality version adapts to the physical space indicated by the user.

Fig. 8. Virtual reality environment for training recreational users. 3D version (left). AR version (right).

After selecting a version, a set of instructions for use is presented in the form of audio, at the end of the instructions an option is enabled on the screen to start with the activities, and the basic controls of the drone operation are shown, these controls follow the design guidelines described in the task modeling. At the beginning of the interaction, the application executes an audio that indicates to the user the instructions related to exercise 1, after being completed the instructions are given to perform exercise 2, until completing the 4 exercises established for a recreational user.

Within the application, in each exercise, the user must collect a series of coins that help the user as a guide to performing the indicated movements. The system was presented to 50 university students between the ages of 20 and 25 years old for its use and evaluation and to know the user's experience during the use of the application.

The procedure consisted of providing them with the system so that they could install it on their Android mobile devices. Afterward, the user was asked to follow the instructions (see Table 3) that the system provided until completing the four drone pilot training exercises. These exercises are designed under the practices that are performed to train drone pilots for recreational users. The design of the exercises can be seen in Figure 9.

As the last stage of this case study, an evaluation was carried out to know the user experience and the perception of the system, through a survey based on the UEQ [23] (User Experience Questionnaire) evaluation instrument. The following section presents the results obtained from this case study.

7 Results

Through a survey applied after the use of the mobile application, it was found that approximately 86% of the students have no experience in handling drones, and only 13% stated that they had flown one at some time. It was also observed

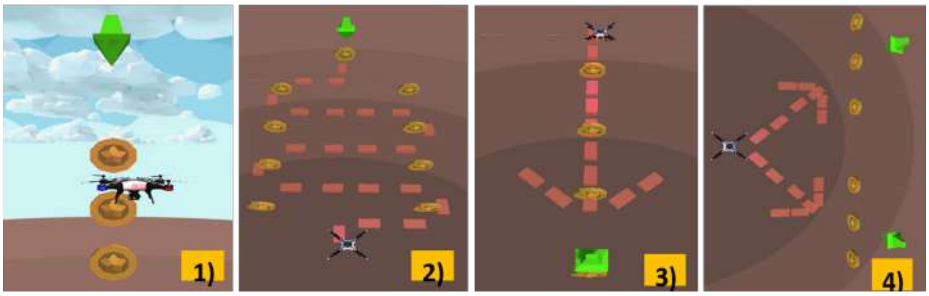

Fig. 9. Exercises for recreational users. 1) Takeoff and elevation of the multicopter. 2) Movements in trajectory S. 3) Orientation of the aircraft to the user. 4) Lateral movements left/right.

that, of the two versions proposed, the 3D version had a 72% preference by the students, against 13% for the augmented reality version.

The student's argument for the preference for the 3D version lies in the fact that the training scenario is visually more attractive because of the 3D objects present and the scenario design resembles a training field. As for the augmented reality version, the students expressed the feeling of difficulty when combining the real scenario with virtual objects, they expressed a feeling that the drone at some point was going to get lost or get out of control of the camera.

Regarding the basic control interface of the drone, most of the students expressed as an additional comment in the survey, that they are difficult to use at the beginning because of the sensitivity with which the drone moves, but as time goes by and they perform the exercises they acquire the ability to control the drone. It can be concluded from this preliminary case study that, for most of the students, the application was enjoyable.

8 Conclusions and Future Work

This paper proposes the design of user-centered tasks under virtual reality environments as an alternative to drone pilot training. Task modeling and its stages are presented as part of the production of virtual environments that also consider the existing rules and regulations for drone pilot training. This work also presents the user-centered design and development process using the task model under the HAMSTERS tool, this tool is a big step towards the systematic integration of usability and user experience evaluation data in the artifacts designed by modeling user tasks in a critical system such as a drone. Finally, a case study is presented in which a virtual reality environment oriented to recreational users is implemented, a set of exercises based on task modeling is defined and a basic drone operation control user interface is presented. The results lead us to conclude that the use of these environments can help to support the training in the use of drones. In future work, we are working on the incorporation of new task models to have exercises for professional users and governmental, recreational, security, and governmental entities. As well as incorporating new types of drones and generating new scenarios according to the design of tasks proposed. Finally, to integrate new strategies for the evaluation of the user experience that can provide feedback for the production of these virtual reality environments.

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References

1. Andersen, K., Gaab, S.J., Sattarvand, J., Harris Jr, F.C.: Mets vr: Mining evacuation training simulator in virtual reality for underground mines. In: Proceedings of the 17th International Conference on Information Technology: New Generations (ITNG 2020) (2020)
2. Angeles, K.T.L.: 11-month-old girl injured after private drone crashes in pasadena (2020), `https://abc7.com/news/babyinjured-after-private-drone-crashes-in-pasadena/987551/`
3. Bamburry, D.: Drones: Designed for product delivery. Design Management Review **26**(1), 40–48 (2015)
4. Beers, G..: Documento del plan estratégico de drones (2018), `http://www.gisandbeers.com/documento-del-plan-estrategico-de-drones/`
5. Gabriel, G., Ramallo, M.A., Cervantes, E.: Workload perception in drone flight training simulators. Computers in Human Behavior **64**, 449–454 (2016)
6. Grupping, J.: The story of flight simulator (2001), `https://fshistory.simflight.com/fsh/versions.htm`
7. INTERNATIONAL TRUCK INTELLECTUAL PROPERTY COMPANY, L.: American truck simulator (2021), `https://americantrucksimulator.com/`
8. Khuwaja, K., Chowdhry, B., Khuwaja, K., Mihalca, V., Tarca, R.: Virtual reality based visualization and training of a quadcopter by using rc remote control transmitter. In: IOP Conference Series: Materials Science and Engineering (2018)
9. Kim, D.H.: Regulations and laws pertaining to the use of unmanned aircraft systems (uas) by icao, usa, china, japan, australia, india, and korea. Unmanned Aerial Vehicles in Civilian Logistics and Supply Chain Management pp. 169–207 (2019)
10. Knight, J.C.: Safety critical systems: challenges and directions. In: Proceedings of the 24th international conference on software engineering. pp. 547–550 (2002)
11. Larson, E., Wood, W., Clark, F.: Ciencia ocupacional: desarrollo de la ciencia y la práctica de la ocupación a través de una disciplina académica". E. Crepeau, E. Cohn, & B. Boyt, Terapia Ocupacional pp. 15–26 (2005)
12. Machida, F.: N-version machine learning models for safety critical systems. In: 2019 49th Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W). pp. 48–51. IEEE (2019)
13. Mairaj, A., Baba, A.I., Javaid, A.Y.: Application specific drone simulators: Recent advances and challenges. Simulation Modelling Practice and Theory **94**, 100–117 (2019)

14. Martinie, C., Palanque, P., Barboni, E., Ragosta, M.: Task-model based assessment of automation levels: application to space ground segments. In: 2011 IEEE International Conference on Systems, Man, and Cybernetics. pp. 3267–3273. IEEE (2011)
15. Martinie, C., Palanque, P., Bouzekri, E., Cockburn, A., Canny, A., Barboni, E.: Analysing and demonstrating tool-supported customizable task notations. Proceedings of the ACM on human-computer interaction **3**(EICS), 1–26 (2019)
16. Martinie, C., Palanque, P., Ragosta, M., Fahssi, R.: Extending procedural task models by systematic explicit integration of objects, knowledge and information. In: Proceedings of the 31st European Conference on Cognitive Ergonomics. pp. 1–10 (2013)
17. Microsoft: Microsoft flight simulator (2021), `https://www.xbox.com/en-US/games/microsoft-flight-simulator`
18. Park, M.A., Yun, C., Woo, T.: Developing a virtual drone flight training contents for beginner. Journal of Korea Game Society **19**(5), 53–62 (2019)
19. Postal, G.R., Pavan, W., Rieder, R.: A virtual environment for drone pilot training using vr devices. In: 2016 XVIII Symposium on Virtual and Augmented Reality (SVR). pp. 183–187. IEEE (2016)
20. Puri, V., Nayyar, A., Raja, L.: Agriculture drones: A modern breakthrough in precision agriculture. Journal of Statistics and Management Systems **20**(4), 507–518 (2017)
21. Schaeffer, D.M., Olson, P.C.: Drones in the classroom. Journal of Computing Sciences in Colleges **32**(3), 85–91 (2017)
22. Schaffhauser, D.: Drones take off in education (2018), `https://thejournal.com/articles/2018/07/25/drones-take-off-in-education.aspx`
23. Schrepp, M., Hinderks, A., Thomaschewski, J.: Construction of a benchmark for the user experience questionnaire (ueq). IJIMAI **4**(4), 40–44 (2017)
24. Setiawan, J.D., Setiawan, Y.D., Ariyanto, M., Mukhtar, A., Budiyono, A.: Development of real-time flight simulator for quadrotor. In: 2012 International Conference on Advanced Computer Science and Information Systems (ICACSIS). pp. 59–64. IEEE (2012)
25. SimTrain: Benefits of simulator training (2020), `http://www.simtrain.net/benefits.html`
26. Singhal, G., Bansod, B., Mathew, L.: Unmanned aerial vehicle classification, applications and challenges: A review (2018)
27. Sommerville, I.: Software engineering 9th edition. ISBN-10 **137035152**, 18 (2011)
28. of Transportation Federal Aviation Administration, U.D.: Unmanned aircraft systems (uas) (2021), `https://www.faa.gov/uas/`