

# Simulating UAV Flight in Augmented Reality

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# Simulating UAV Flight in Augmented Reality

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## Abstract

This thesis describes the design and development of a UAV simulator application prototype, which uses augmented reality technology and runs on a tablet device. The purpose of the application is to act as a complementary educational tool for unmanned aerial vehicle (UAV) pilots in training. The field of commercial unmanned aviation is rapidly growing, and with it the need for structured and standardised education. Flying UAVs is costly both in terms of time and resources, and a simulated experience could act as an efficient complement. The application is designed with the principles of user-centered design at the core of the process, including evaluating the application from a usability perspective through user testing. This thesis also aims to investigate the Augmented Reality (AR) medium in the UAV training context. The final prototype received positive feedback in the evaluation. It was found that the AR medium comes with both strengths and weaknesses, mainly concerned with realism and the likeness to flying a real UAV. In conclusion, the prototype shows great potential as a complementary educational tool for UAV training.

**Keywords:** Unmanned Aerial Vehicles, Remotely-piloted aircraft, Simulator, Augmented Reality, User-centered Design, Usability



## Sammanfattning

Denna uppsats beskriver design- och utvecklingsprocessen för en prototyp till en drönarsimulatorapplikation som använder Augmented Reality (förstärkt verklighet) på en tablet-enhet. Applikationens syfte är att fungera som ett kompletterande utbildningsverktyg för drönarpilotutbildning. Kommersiell drönarverksamhet är ett snabbt växande område, och med det växer behovet för strukturerad och standardiserad utbildning. Att flyga drönare är kostsamt, både vad gäller resurser och tid, och en simulerad miljö kan bli ett effektivt komplement. Processen för att utveckla applikationen kretsar kring principerna om användarcentrerad design, vilket inkluderar användbarhetsutvärdering genom användartester. Uppsatsen syftar också till att utreda hur AR-mediet fungerar i en drönarutbildningskontext. Den slutgiltiga prototypen gavs positiv feedback i utvärderingen. Vi fann att AR-mediet har både styrkor och svagheter, och att dessa i huvudsak kretsar kring realism och likheten med att flyga en riktig drönare. Sammanfattningsvis visar prototypen stor potential som ett kompletterande utbildningsverktyg för drönarutbildning.

**Nyckelord:** Drönare, Obemannade Luftfarkoster, Simulator, Förstärkt Verklighet, Användarcentrerad Design, Användbarhet

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Lund, June 2022

William Rosenberg and Fatima Sjögren Alpha

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# Acronyms

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**AR** augmented reality

**FPV** first-person view

**LiDAR** light detection and ranging

**LUSA** Lund University School of Aviation

**STA** Swedish Transport Agency

**SUAV** Simulated UAV

**UAV** unmanned aerial vehicle

**UCD** user-centered design

**UT1** User Test 1

**UT2** User Test 2

**UT2020** User Test 2020

**VR** virtual reality

# Chapter 1

## Introduction

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*This chapter introduces the project and its background, purposes and goals as well as the limitations and scope.*

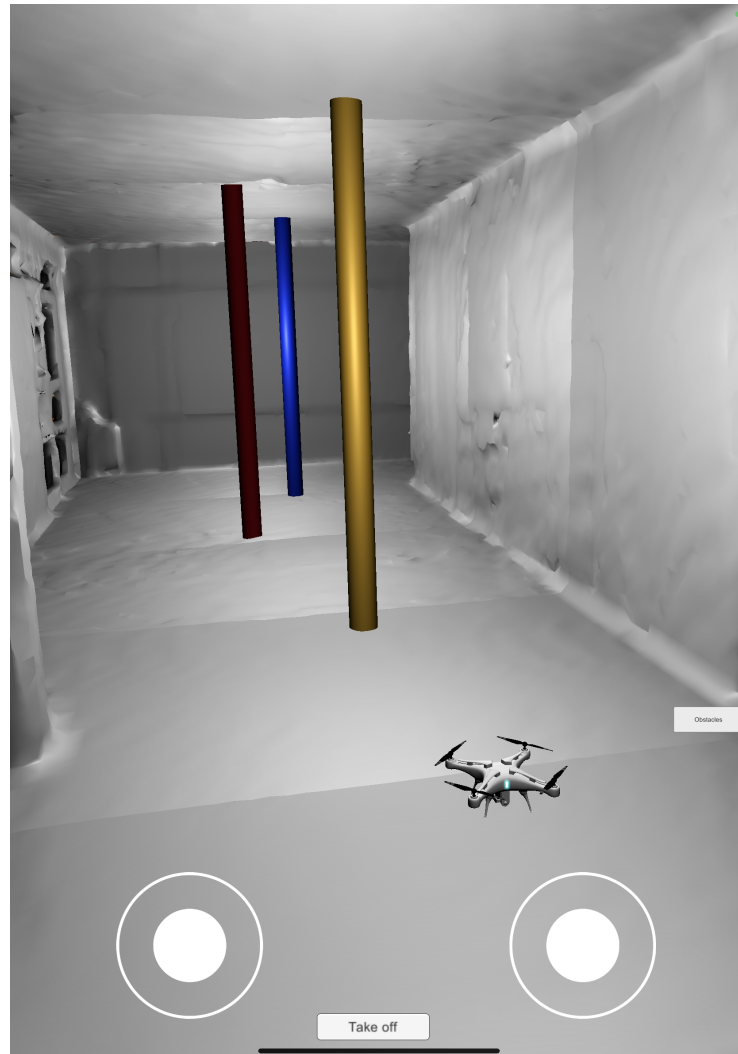
### 1.1 Background

Lund University School of Aviation (LUSA) trains unmanned aerial vehicle (UAV) pilots. It has been observed by teachers that it takes students about five hours of flying to become proficient in the basic controls of the UAV. While five hours may not sound like a long time, UAVs have limited battery capacity and therefore range, and thus five hours entails performing many individual flight sessions, each taking time and effort to set up. There have long been a wish from the staff at LUSA to explore the possibilities of technologies such as augmented reality for educational purposes.

With this background an augmented reality (AR) prototype was designed and developed in 2020, as part of a project course at LTH. The chosen platform was an iPad Pro. What emerged was a prototype for a UAV simulator, in which users could fly a UAV through obstacle courses. Both the UAV and the courses were an overlay on top of the real world, seen through the iPad camera. This gave the users the experience of flying in the real world. Furthermore, through the use of the iPad's light detection and ranging (LiDAR) sensor, the UAV could crash into and interact with actual objects, such as walls, the floor and furniture. User testing confirmed the concept to be a success in many respects. User testing also confirmed a number of bugs and usability issues, while identifying several potential areas of improvement.

This paper describes the continuation of this project, which includes both addressing the previously mentioned issues, designing new features, testing and evaluation, all while keeping the design process centred around the user.

## 1.2 Project 2020



**Figure 1.1:** Project 2020 prototype.

This project is a continuation of earlier work performed in 2020 by Boyner, Berdén and Brodin and Rosenberg. The driving force behind this previous project was the same as it is for this project, but the scope was more limited. LUSA asked for an AR application that could be used in UAV training and a central requirement was the ability to fly and navigate a UAV around obstacles, both real and virtual. The iPad Pro (2020) was chosen as the development platform, both for its AR capabilities and its LiDAR sensor. Development was performed in three iterations and followed by a user test, hereafter referred to as User Test 2020 (UT2020). The earlier iterations focused on creating a basic UAV with controls, after which the LiDAR was used to create a mesh which the UAV could collide with. Later on three obstacle courses (see example in figure 1.1) were built by putting virtual objects in the real world, and these courses were the focus of the user testing.



## 1.3 Purpose and Goals

The purpose of this thesis is to explore how AR can be used as a training tool for flying a UAV. The aim is to facilitate the training of UAV pilots by offering them a complementary training tool that could help reduce costs, risks and downtime during their training.

In order to achieve this, four goals have been defined and four research questions have been established:

### Goals

- Design and develop a prototype to be used for the early phases of UAV flight training.
- Test and evaluate the prototype for usability.
- Investigate if skills obtained by flying a simulated UAV in AR correspond to flying a real UAV.
- Investigate strengths and weaknesses of the AR medium in UAV flight training context.

### Research questions

- How could AR technology benefit students in their UAV flight training?
- How should an AR system be designed so that it as closely as possible resembles flying a physical UAV?
- Which strengths and weaknesses does using AR to simulate UAV flying have?
- Which important UAV flying skills, if any, are suitable to practice in an AR environment?

## 1.4 Limitations and scope

The project is limited by the time it takes to design and implement features suggested by the client or generated by idea generation. It should also be noted that the result of this project is a prototype and not a complete, stable application. The evaluation is limited by time and available testers belonging to the target group.

# Chapter 2

## Background

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*This chapter lays a theoretical and practical foundation. It includes relevant theories and literature as well as descriptions of technologies used in the project.*

### 2.1 Theoretical Background

This section describes relevant theoretical background for the design process to build upon.

#### 2.1.1 Augmented Reality

There are many definitions of Augmented Reality. In “Handbook of Augmented Reality” the definition “a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it” is used [1]. Milgram, Takemura, Utsumi and Kishino defined the reality-virtuality (RV) continuum (see figure 2.1), while also introducing the term Mixed reality [2].

They argued that instead of viewing the real environment and a completely virtual environment as antitheses, they exist on different ends of a continuum. Naturally, AR can be said to exist on this spectrum, and one application of it may lie closer to the Real environment, while another is closer to a Virtual environment. While this paper gave a great foundation to stand on, it was published in 1994, and a lot has happened since. Skarbez, Smith and Wisson discuss some limitations in Milgram and Kishino’s model. For example, it has a narrow view on mixed reality in that it mainly focuses on screens. Skarbez, Smith and Wisson argue that for example sounds, physical sensations and haptic feedback, real or virtual, can all be part of the mixed reality [3].

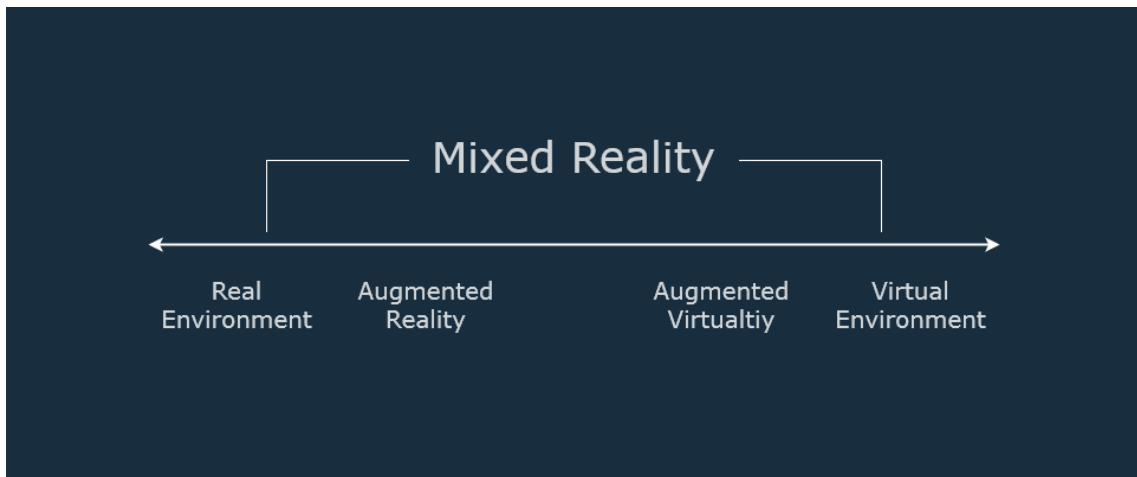


Figure 2.1: Reality-virtuality continuum.

## 2.1.2 User-Centered Design

A term that is frequently used when designing interactive devices in order to increase the usability is user-centered design (UCD). The term UCD was coined in the 1980s by Donald Norman and is a design philosophy that seeks to involve the end user throughout the design process. It is based on the understanding of a user's needs and experiences and aims to increase a product's usability. This has inspired many researchers, designers and policy makers to develop methodologies that revolve around the end user during the design process [4].

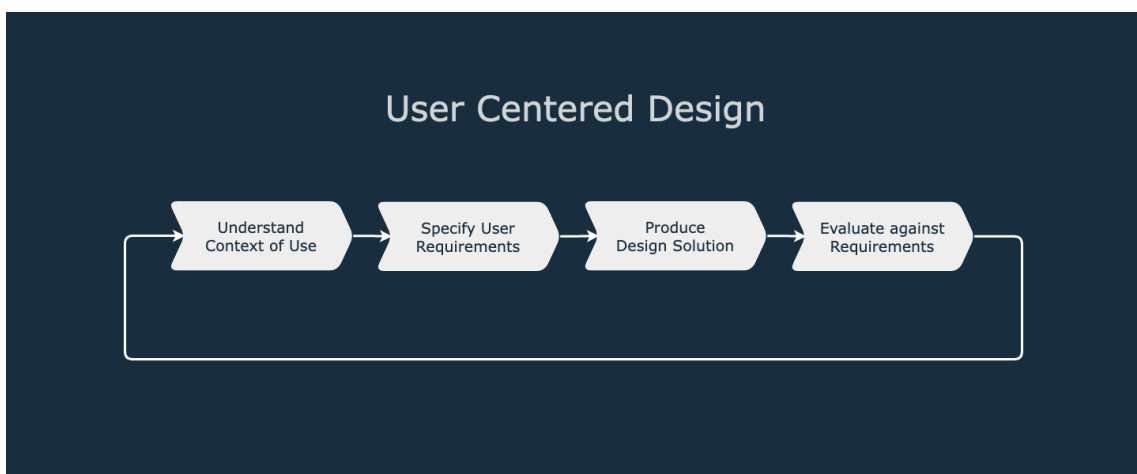


Figure 2.2: The different phases of the user-centered design process.

UCD is an iterative design process that includes four different activity phases (as seen in figure 2.2). The purpose of the first phase is to understand the context of use by identifying

the users who will be using the system as well as the environment in which the system will be used. The second phase is about specifying the user requirements by understanding what the user needs as well as determining the business requirements. This can for example be done by creating personas, journey maps, application diagrams and a list of user needs features. It is not until the third activity phase that different designs are produced. This phase may contain several steps such as generating a design idea, producing mockups and prototypes and finally producing the complete design. The design solution is supposed to be based on the requirements from the previous activity phase. Finally, the design solution is evaluated to make sure that it meets the users' needs and requirements. This can be done by conducting usability tests and collecting feedback through questionnaires [5].

### 2.1.3 Design Principles

When a user interacts with a product, the first step is to find out what the product does, how it works and what actions are possible for the user, this is called discoverability. In order to create good discoverability and understanding of a product, Donald Norman has provided six design principles that designers can follow [6]:

- affordances
- signifiers
- constraints
- mappings
- feedback
- conceptual models

An affordance is the possible action that a product offers the user. It describes the relationship between the product's and the user's properties. For example, a chair affords lifting if a person is strong enough to lift it and the chair is not stuck to the ground. However, if the chair is stuck or the person trying to lift it is not strong enough then the chair does not afford lifting [6].

Signifiers are the signaling components of affordances. They communicate where the affordances should take place. Signifiers come in all shapes and forms. They can be labels, buttons, arrows, icons or even sounds. Anything that the user can interpret in order to discover an affordance is a signifier (even if it is unintentionally placed) [6].

Constraints are clues that guide the user to the appropriate next action. There are four kinds of constraints: physical, cultural, semantic and logical. Physical constraints limits possible actions, e.g. puzzle pieces in different shapes in order to eliminate the certain placements. Cultural constraints are conventions and standards within a certain culture. Cultural constraints can help the user to perform different actions by prohibiting certain activities and encouraging others. Unlike physical constraints, cultural constraints can be violated or ignored. Semantic constraints rely upon the meaning of the situation and the user's knowledge of the situation and the world. Logical constraints use reasoning to determine the alternatives. For example, if there is only one puzzle piece left, there's only one place left for it to be placed [6].



Mapping means the relationship between the elements of two sets of things, for example between the knobs on a stove and the burners. Natural mapping means taking advantage of spatial analogies, which in the case with the stove could be to arrange the knobs in the same pattern as the burners [6].

Feedback is the communicated result of an action. It can be in the form of text, sound, vibration, etc. It is important that there is enough feedback for the user to notice it but not too much feedback, that can sometimes confuse or annoy the user. The feedback needs to be communicated immediately, otherwise the user might misinterpret it or move on to do other things. Feedback also needs to be informative, otherwise the user might not understand what is happening, only that something is happening [6].

A conceptual model is usually a simplified explanation of how something works. Different people can have different understandings or conceptual models of how a product works. The designer has one conceptual model during the development of the product while the user has its own conceptual model (mental model) when interacting with a product. The aim is to design the product so that designer's conceptual model matches the user's as closely as possible. The designer can include different clues in the form of signifiers, affordances, constraints and mappings to convey their conceptual model to the user [6].

## 2.1.4 Usability Testing

Usability testing can be defined in many different ways. Rubin and Chisnell use the following definition: "we use the term usability testing to refer to a process that employs people as testing participants who are representative of the target audience to evaluate the degree to which a product meets specific usability criteria" [7].

A central part of usability testing is creating a test plan. Typical areas to include are purpose and goals, objectives of the test, research questions, participant characteristics, method (test design), task list, test environment, equipment, logistics, test moderator role, data to be collected and evaluation measures, report contents and presentation [7].

Rubin and Chisnell often refer to the test moderator as a single person, and it might be beneficial to have one person with an overall responsibility for the test. It is however possible to share responsibilities during the test, and for example have the test moderator be responsible for leading the tester through the test, while having another person being responsible for making visual observations and noting comments made by the tester.

When it comes to data collection, Rubin and Chisnell describe Performance Data: objective measures of behaviour, such as error rates, time, and counts of observed behaviour elements, and Preference data: the more subjective data that measures a participant's feelings or opinions of the product [7]. Both of these can be analysed quantitatively and qualitatively. A quantitative example of performance data might be recording the number of errors made in a certain task. A qualitative example of performance data could be to analyse the potentially unique manner in which an error occurs. A quantitative example of preference data could be having the tester put a numbered grade on their experience of a certain task. Lastly, a qualitative preference data could be having the tester explain why they think something was hard.

One technique described in the book is "Think aloud" - Asking testers to think aloud while they perform tasks, which offers insights into why problems exist and how testers try to work around them [7].

### 2.1.5 System Usability Scale

The System Usability Scale (SUS) was created by John Brooke in 1995 [8]. It is a 10 item questionnaire intended to give a "Quick and dirty" subjective measure of a system's usability. Brooke argues that the questions "[...] cover a variety of aspects of system usability, such as the need for support, training, and complexity, and thus have a high level of face validity for measuring usability of a system" [8]. The scale results in a SUS score, which is calculated by calculating the sum of the score contributions from each item. Each item will contribute a value between 0 and 4. For items 1, 3, 5, 7, and 9 the value is the scale position minus 1. For items 2, 4, 6, 8 and 10, the value is 5 minus the scale position. The sum of the scores is then multiplied by 2.5, which is the SUS score, ranging from 0-100 [8].

The original article [8] does not describe a definition of what SUS score is considered "good", or "excellent". Bangor, Khortum and Miller added an adjective rating scale [9] to the SUS scale. They added an 11th question to the SUS scale which was: "Overall, I would rate the user-friendliness of this product as:". There were 7 possible answers, ranging from "Worst imaginable" to "Best imaginable". Using data from 959 usability tests with the extended rating scale they found that a system rated as "Good" had a mean SUS score of 71.4, an "Excellent" system 85.5, and "Best Imaginable" 90.9 [9].

### 2.1.6 Storyboard

A storyboard is a step-by-step illustration of a user's interaction with a system for a specific use case. It is used to explore how the user will interact with the product and how the user handles different situations. It is also used to make sure that a coherent experience is created for the user. For each use case in the application, a different storyboard could be made that follows the user throughout the scenario. The user interface is presented in the form of a lightweight, rough sketch that also includes the context of use (social interactions and physical situation). The drawing of the user interface within a cell is physically limited which prevents it from containing too much detail. This helps the designers focus on the overall structure of the application instead of too detailed design choices [10].

## 2.2 Technical Background

This section describes some of the technical concepts used in this project as well as the tools that were used.

### 2.2.1 Unmanned Aerial Vehicles

An unmanned aerial vehicle, commonly known as a drone, is an aircraft without a pilot onboard that can fly autonomously or be remotely piloted. There are usually two types of UAVs: fixed-wing and rotary-wing [11].

The fixed-wing UAV may need a runway for take-off and landing while the rotary-wing UAV takes off and lands vertically. Initially UAVs were developed for military purposes but are now widely available for commercial and private use such as surveillance, smart agriculture and aerial photography [12].

## 2.2.2 LiDAR

LiDAR stands for Light Detection and Ranging. It is an active sensor that sends out electromagnetic waves and receives a reflected signal back. The principle is much the same as that of a radar, which uses radiation in the microwave spectrum. LiDAR, on the other hand, works with a much shorter wavelength, typically around  $1.5 \mu\text{m}$  for eye-safe versions [13]. Applications can include, among many others, autonomous vehicles, geology, biology and 3D scanning.

## 2.2.3 iPad and ARKit

The iPad 2020 Pro includes Apples own implementation of a LiDAR-sensor. Data from this sensor can be accessed and used through Apple's own API for Augmented Reality: ARKit. According to Apple this makes it possible to accurately locate points on physical surfaces, recognise and classify physical objects, occlude virtual objects with real-world objects and enable realistic interactions between virtual and physical objects [14].

## 2.2.4 Unity

Unity is a game engine that allows 3D application development for multiple platforms, among others iOS [15]. It also has support for augmented reality, with packages enabling developers to make use of ARKit features in Unity [16].

# Chapter 3

## Development Process

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*This chapter describes the development process. It consists of a compilation of previous test results and two iterations.*

### 3.1 Method

The development of the application is done iteratively with the focus on the end user's needs throughout the entire process. This is done by following the four activity phases of the UCD process in each iteration and including some of Donald Norman's design principles in the design. The design process is divided into these three sections, which are explained in more detail below:

- Results from User Test 2020
- Iteration 1
- Iteration 2

The process begins with an activity where the test results from UT2020 are compiled. This is followed by Iteration 1 where the first step is to analyse the end user and the environment that the application will be used in. The second step is to analyse the user's needs and the requirements for the end product. After this, different ideas are generated by combining the results from the previous activity phases. Prototypes in different forms are created as well as a user storyboard in order to facilitate the design and implementation process. The development of the iOS application is performed using Unity. The iteration concludes in a user test where the application is evaluated.

Iteration 2 follows a similar pattern to Iteration 1. It begins with an analysis of the user and the surrounding environment based on new findings. This is followed by a re-evaluation of the requirements. The next step is to develop new design ideas and prototypes. These are then implemented and finally tested and evaluated after performing a larger usability test.

## 3.2 Results from User Test 2020

This section consists of an compilation of the test results Project 2020, which corresponds to the fourth activity phase of the UCD process. This results in the groundwork for the upcoming iterations. Five persons participated in the test. All were students at LTH. The mean age was 24. Three out of five participants had previous experience of flying a UAV. The test was conducted as follows: Testers were presented with the iPad and got a verbal description on which route to take through the obstacle courses. They then attempted to fly through the course. If they collided with any object before completing the course, the attempt was counted as a failure. They got to try again until they succeeded, and then move on to the next course. Each user got to try all three courses three times. Data collected were: the number of attempts, time to complete a course, screen recordings from the iPad, comments by testers and observations by the test leader.

The user test from the previous project, UT2020, resulted in some valuable findings. The survey that was conducted for the user test in the previous project shows that the test participants noticed an improvement in operating the UAV after a number of sessions. This can be confirmed by looking at the average completion time for the different obstacle courses for each session, as seen in figure 3.1. The figure shows that the average completion time decreased after each session, which shows an overall improvement for the test participants.



**Figure 3.1:** The mean completion time for the different obstacle courses.

However, data collected through observations highlight a number of issues with the application. Some test participants had difficulties navigating the UAV using the virtual joysticks, determining the depth of the UAV in relation to the surrounding environment as well as knowing when a task is fully accomplished. A consequence of not being able to determine the depth was that it was more difficult to navigate the UAV horizontally than vertically. One of the testers commented that the UAV was too sensitive to vertical changes, compared to horizontal changes. Furthermore they argued that when giving input with the joysticks, the UAV should accelerate more realistically. Another thing that was unclear was the ability to walk around freely while flying the UAV through an obstacle course. Some testers also found it difficult to distinguish the front side of the UAV from the back, which resulted in difficulties rotating the UAV in the desired direction. Another concern expressed by a test participant was that the UAV does not return to its original position after initiating a new obstacle course. One of the testers also expressed the need for some sort of sound feedback. There were also complaints about the ergonomics, more specifically that the way the device needs to be held caused discomfort in the shoulders.

## 3.3 Iteration 1

This section describes the different steps of Iteration 1, the first iteration of the design process, starting with defining the user context and ending with testing.

### 3.3.1 Understanding the Context of Use

The goal of this activity was to gain knowledge about the situation in which the application will be used, and who the end user is. Information was gathered by asking the client at LUSA about the context of use. Perhaps the most important finding was that the application will serve a purpose in different stages of the education process: Early on for practising essential navigation and skills, and later on as a tool to measure and check proficiency. Furthermore the question of the students' previous UAV flying experience was brought up. The answer was that the level of previous knowledge varies from "none at all" to "very good".

It was also important to gain a better understanding about the physical context of the application. It should be possible to use the application indoors as well as outdoors. The indoor context typically means an 8 m ceiling height. It was also suggested that design and development assumes an 8 x 10 m<sup>2</sup> indoor flying area.

While the UAV education at LUSA contains many different steps, one central part is the so called "Checklista för praktisk självutbildning - Multirotor" provided by the Swedish Transport Agency (STA) [17]. It defines, step by step, a number of procedures for UAV students to go through, and if successfully completed, check off. Not all steps of the checklist, for example "contact air traffic control if necessary" were reasonable to implement in the application.

The checklist did however describe seven courses which students could build themselves with traffic cones and fly their UAV through. Different abilities and skills are tested in different courses. For example, one course requires the pilot to fly with the UAV rotated forward, away from the pilot (see figure 3.2) while another requires the UAV to always be rotated in the direction of flight.

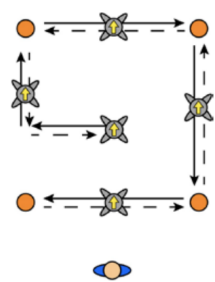
#	Information	Status
Svängar i planflykt		
B7.1	Sväng i planflykt #1 Tilläggsinformation: - Drönarens framsida är hela tiden vänd från fjärrpiloten. - Upprepa svängarna i omvänd riktning.	

Figure 3.2: Course B7.1 from the STA's checklist [17, p.7].

### 3.3.2 Requirements and Idea Generation

The understanding of the user context together with the requirements from the client laid a foundation for the generation of new ideas with the end user and the surrounding environment taken into consideration.

A brainstorming session was performed in order to generate a large number of new ideas. These were intended to solve the issues discovered in UT2020. Due to limited time it was known at this point that not all suggestions would be implemented or tested. Some would make their way into Iteration 1, others would be tried later on in Iteration 2, some would be scrapped and new suggestions would arise during the design process. The main issues and proposed ideas based on data from UT2020 data are presented in table 3.1.

Part of the idea generation also included generating ideas based on the client requirements. Once again, the Swedish Transport Agency checklist and specifically its courses came up. The client wanted all or some of these courses to be included in the application, since they could be used both for practising and as a self checking tool. The general idea generated in this session was to experiment with different interactive 3D shapes and graphical elements, while considering relevant design principles. One example of such interactive 3D shapes are visual checkpoints, which have long been a tool used in computer game design. They are, for example, used to lead the player along a certain route through 3D space towards a predetermined goal. They do however vary greatly in design depending on a number of factors.

**Table 3.1:** Issues from UT2020 and generated ideas.

Issue	Idea
Hard to know which way UAV will fly when giving forward input	<ul style="list-style-type: none"> <li>• Light tracks behind UAV</li> <li>• Lights on UAV</li> <li>• Arrow marking direction</li> <li>• Compass</li> <li>• UAV projecting cone of light</li> <li>• Picture-in-picture FPV camera</li> </ul>
Joysticks not obviously joysticks	<ul style="list-style-type: none"> <li>• More Realistic 3D design</li> </ul>
Easier to perceive vertical flying	<ul style="list-style-type: none"> <li>• Gamepad as input device</li> <li>• Create threshold for flying vertically vs rotating</li> <li>• Visualise threshold with joystick tracks</li> </ul>
Hard to perceive depth	<ul style="list-style-type: none"> <li>• Display UAV distance from device</li> </ul>
Lacking feedback when reaching checkpoint	<ul style="list-style-type: none"> <li>• Visual and audio feedback</li> </ul>
Lacking feedback on course completion	<ul style="list-style-type: none"> <li>• Gold star</li> <li>• Audio feedback</li> <li>• Performance report</li> </ul>
UAV does not reset when completing or changing course	<ul style="list-style-type: none"> <li>• Reset UAV</li> <li>• Allow user to reset UAV</li> <li>• UAV spawns on flying carpet</li> </ul>
UAV placed on start	<ul style="list-style-type: none"> <li>• Possible to choose UAV placement freely at a given distance from device</li> <li>• UAV centred and slightly transparent while placing</li> <li>• Flyable UAV spawns exactly where placed</li> </ul>
UAV sensitive in vertical direction	<ul style="list-style-type: none"> <li>• Experiment with different vertical speeds</li> <li>• Compare app to flying real UAV</li> </ul>
No delay when flying, unrealistic	<ul style="list-style-type: none"> <li>• Experiment with acceleration lag</li> <li>• Compare app to flying real UAV</li> </ul>
Not clear to testers that it was possible to walk around freely	<ul style="list-style-type: none"> <li>• Include example and demo in tutorial</li> </ul>



### 3.3.3 Design

The design phase of Iteration 1 started with storyboarding and sketch making. The purpose of these activities were to generate visual ideas. It resulted in design ideas for course design, UAV placement and UI design among other things. Examples of this can be seen in figures 3.3 and 3.4.

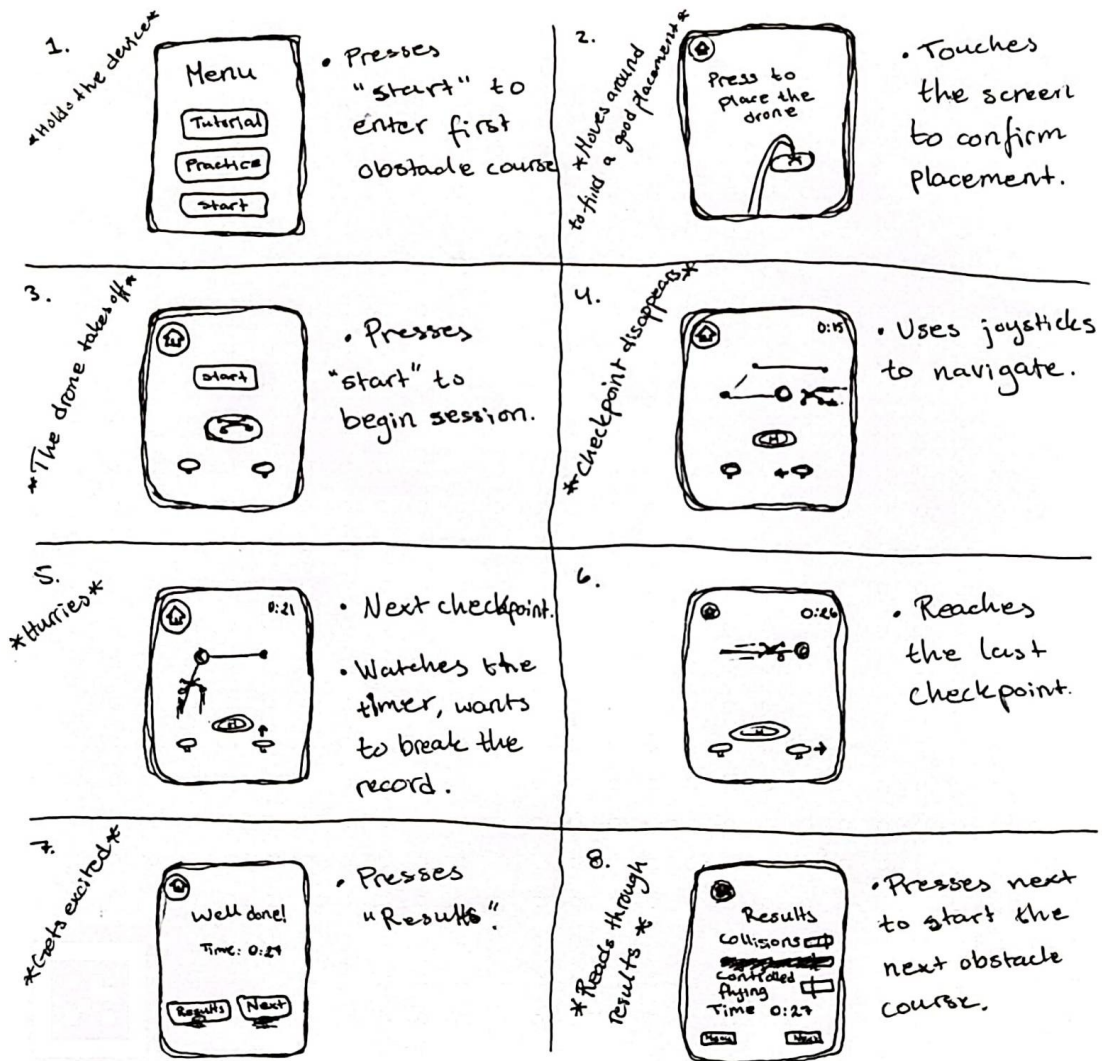


Figure 3.3: A storyboard for Course 1.

### Courses

Since the courses are essential for the purpose of the application, design started with prototyping a course, using orbs connected with cylinders as seen in figure 3.5. While the goal was for the completed application to have multiple courses, it seemed reasonable to begin by putting energy into designing one course, and later reuse the same design idea to construct more courses. This first course was based on the STA Course B7.1 seen in figure 3.2.

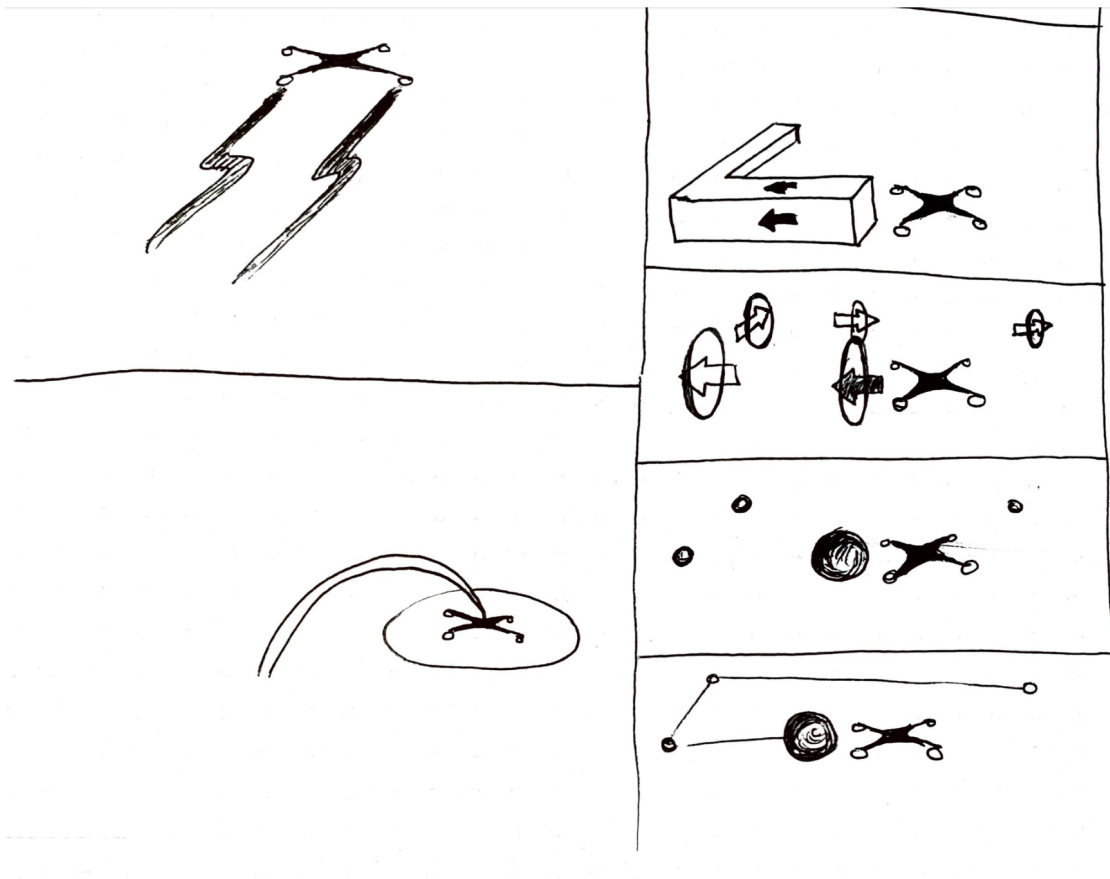


Figure 3.4: Design sketches for Course 1.

The idea was to have the orbs act as signifiers in the form of checkpoints, inviting the user to fly through them in a predetermined order. It was important to really think about how to design the checkpoints to invite interaction. Furthermore it was important for the checkpoints not to be obstacles themselves (which would trigger the UAV to crash).

Paths connected the orbs together to suggest which way to fly between them. Feedback from UT2020 indicated that some users wanted more feedback when reaching a checkpoint. As part of the effort solve this, the sizes of the orbs were manipulated to act as a signifier. When flying, the next orb, which is also the orb the user is supposed to fly to to progress through the course, was made significantly larger than the other orbs.

The first design attempt for the course consisted of six checkpoint orbs connected by paths, all in the same colour. While a great step for the basic structure of the course, it did not appear very interactable and looked fairly static. In order to make it appear more alive and dynamic, light emitting particle systems were added to the orbs, giving them a blue glow. Furthermore, to give the paths the sense of movement, particle systems were added which created small spheres moving along the paths. These small spheres were placed and programmed to move in the same direction the user was supposed to fly in. The final look of the course in Iteration 1 can be seen in figure 3.6.

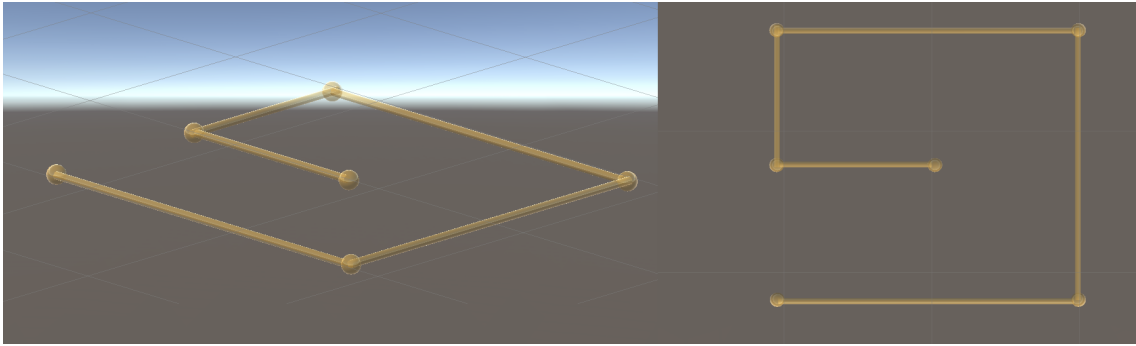


Figure 3.5: An early prototype of Course 1.

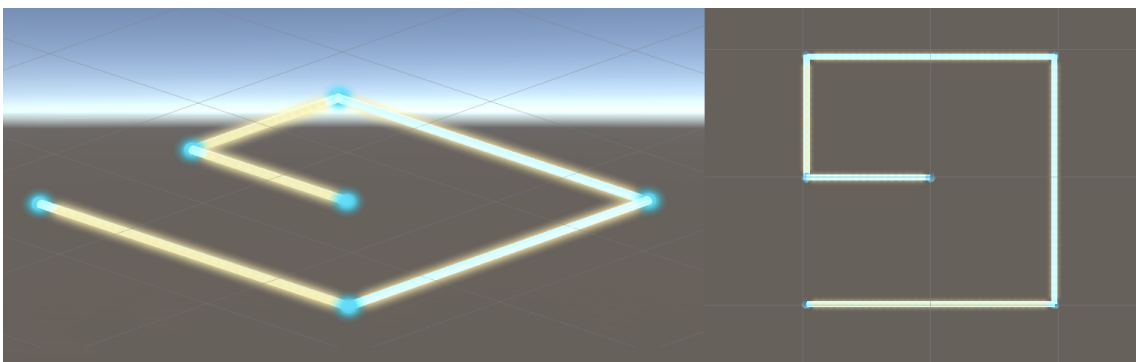


Figure 3.6: Prototype for Course 1 used in UT1.

## Placement

In the 2020 prototype the UAV had a static starting position, meaning that the placement of the UAV in world space depended on the position and rotation of the iPad when the application was launched. A suggestion from the idea generation session was that it should be possible for the user to choose the placement of the UAV. As a first attempt the UAV was locked to the camera when launching the app, meaning that when the iPad moves or rotates around the UAV always stays centre of view. The idea was to create a virtual interpretation of carrying a real UAV in your hand, placing it on the floor, and then taking off. This enabled the user to walk around with the UAV until finding a suitable spot, and then press the screen to confirm the placement, as seen in figure 3.7. This concept can be described as "Point and place".



**Figure 3.7:** Early version of UAV placement.

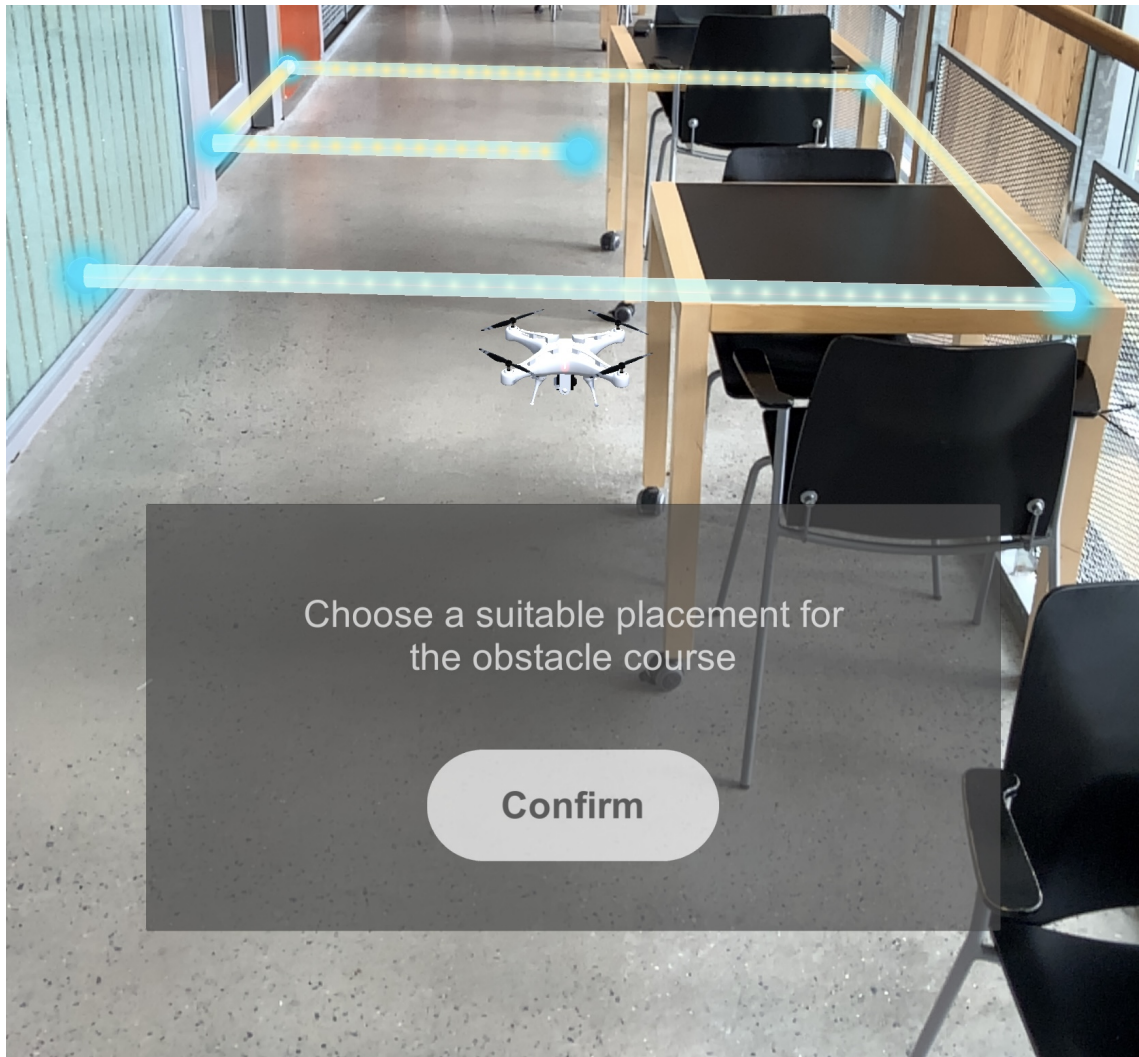
Perhaps even more important in terms of placement was placement of the course. At this stage the course also had a static location in the 3D space, meaning that the location of the course was decided when the application launched. Since the course needs to be placed in a relatively open area as, it was decided that it should be possible to choose its placement, in an identical "Point and place" manner to that of the UAV. For a while, this meant that placement of UAV and course were done in two separate steps. First, the user would place the course, and in the next step place the UAV. A text instruction along with a "Confirm" button was also created at this time. It was discussed whether the wording "Choose a suitable placement for the obstacle course" was clear and intuitive, but this judgement was left to the testers in User Test 1 (UT1).

While reflecting on whether having two separate placement steps for the UAV and course provided a good user experience, and also on whether or not the UAV should always start at the same position relative to the course, the idea of combining these two steps into one was proposed. After trying out this idea it proved to work really well. Combined course and UAV placement is shown in figure 3.8.

## Scanning

LiDAR-scanning the room in order to generate mesh is a key feature in the application. While this feature worked well in the 2020 application, it completely lacked any in-app instructions or explanations. Furthermore it was done continuously as a background activity while the application was running. For Iteration 1 it was desired to separate scanning and flying; The user firstly scans the surrounding environment to build a world to fly in, secondly places the course and UAV, and thirdly starts flying. There were multiple reasons for this: Clarifying the purpose of scanning and making it a conscious activity instead of a background task, actively involving the user. There were also situations where a person would walk in front of the iPad during a flight session and be involuntarily scanned, thus making the UAV crash.





**Figure 3.8:** UAV and course placement in Iterarion 1.

The scanning was designed with a clear beginning and an end, where the user presses a "Scan" button to start scanning, and "End scanning" to complete the process (see figure 3.9).

## Instructions

Based on a wish to make the users' task as clear as possible, it was decided to try implementing instructions which were to be presented before flying the course. The resulting instruction box can be seen in figure 3.10. It contains a text instruction combined with a map describing which way to fly through the course. While these instructions were originally only shown before the user pressed the start button and started flying, it was later decided that it should be visible also while flying. The reasoning was that this would allow users to refer back to the map if they forgot or got confused while flying.

The instructions that were shown when flying the UAV were placed at the top along with the name of the course and eventually a timer. At first, they were in a white font colour

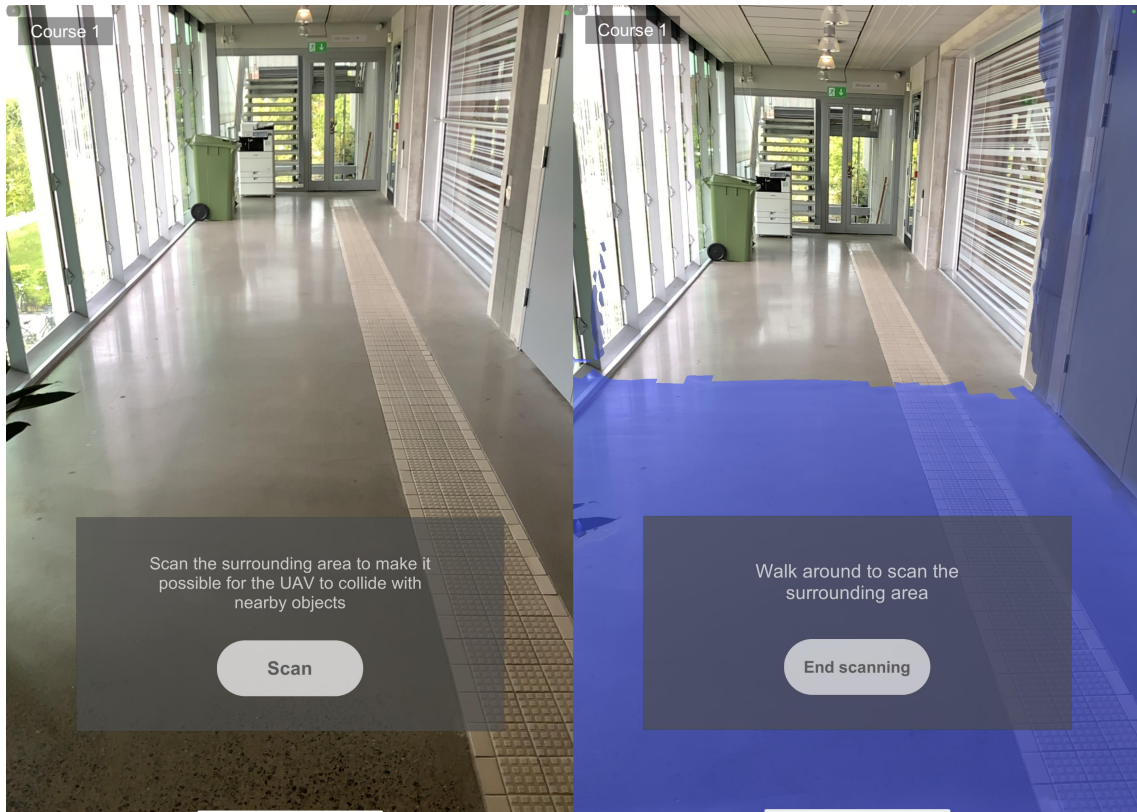


Figure 3.9: Scanning in Iteration 1.

without any background, but this proved to be problematic when the application was tested outdoors. The instructions at the top did not seem visible due to their similarities in colour with the clouds in the background. This was then solved by adding a dark background to the instructions.

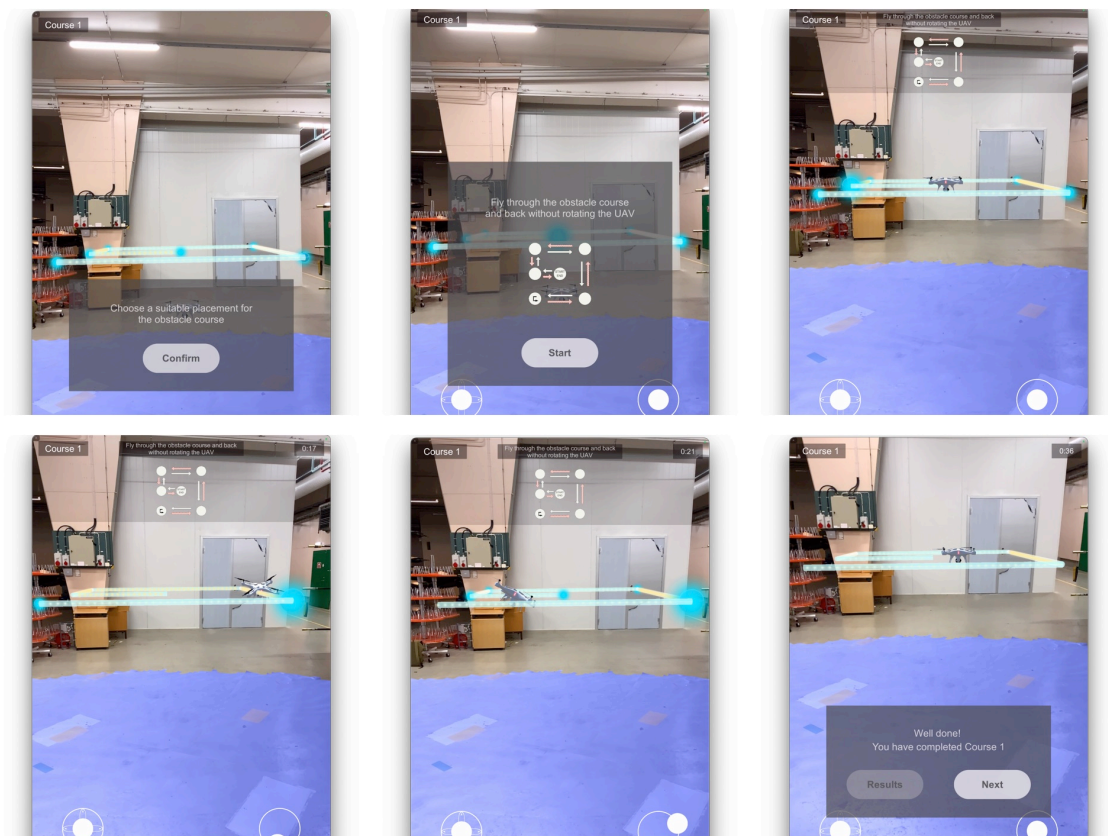
At this stage there was a discussion about just how clear the instructions needed to be in the actual context of use. While it is desirable to have the application be as intuitive as possible to as many users as possible, it can not be designed solely with the goal of having first time users understand everything right away. With this in mind, it was up to the first user test to decide whether more or less instructions was required.





**Figure 3.11:** The different steps in the resulting prototype from Iteration 1: Failed attempt.





**Figure 3.12:** The different steps in the resulting prototype from Iteration 1: Course 1 completed.

### 3.3.4 Evaluation of Iteration 1

This section describes how the first user test was conducted as well as the test results.

#### Method and purpose

The purpose of this session was to evaluate the prototype produced in Iteration 1 and to gather feedback for further development. It was carried out at LUSA with six participants. There were five men and one woman. Ages ranged from 21 to 48 years, and the mean age was 38 years. The participants had different roles in the crew of a polar research vessel. These participants were selected since they were currently undergoing UAV education at LUSA. It should also be noted that they were in the beginning of their education at the time of the test. Due to delays on the test site, available time was limited to under ten minutes per test participant. A formal test plan can be found in Appendix A. The test session consisted of three parts:

1. Introduction
2. Testing the prototype
3. Survey

The test session began with the test moderator introducing the test team and giving a brief description of the application to the test participants. This was followed by a demonstration of the virtual joysticks and how they are used to control the UAV. The test participants were also encouraged to think aloud while using the application. No further instructions were given, and the test participants were given the iPad and told to begin the test.

The prototype for the test included four steps as described in the previous section: Scanning, Placement, Course Info and Course 1. In the best case, test participants were to go through these steps without any intervention from the test moderator. However, when testers expressed confusion or uncertainty, or the test moderator observed that a test participant was stuck, the test moderator gave hints or explanations in order to assist the testers. During the test, data was collected through screen and audio recordings and the note-taker documented observations that could be of interest.

After the test participants completed Course 1, they were asked whether they had any comments about their general experience using the application. The test session was concluded with a post-test questionnaire.

#### Test Results

This section presents the data gathered from UT1, both the qualitative and quantitative data. The data was gathered both during the test through audio and screen recordings as well as documented observations. Data was also collected after the test through a questionnaire and spontaneous feedback.

The data collected from the user test revealed the following bugs in the application:

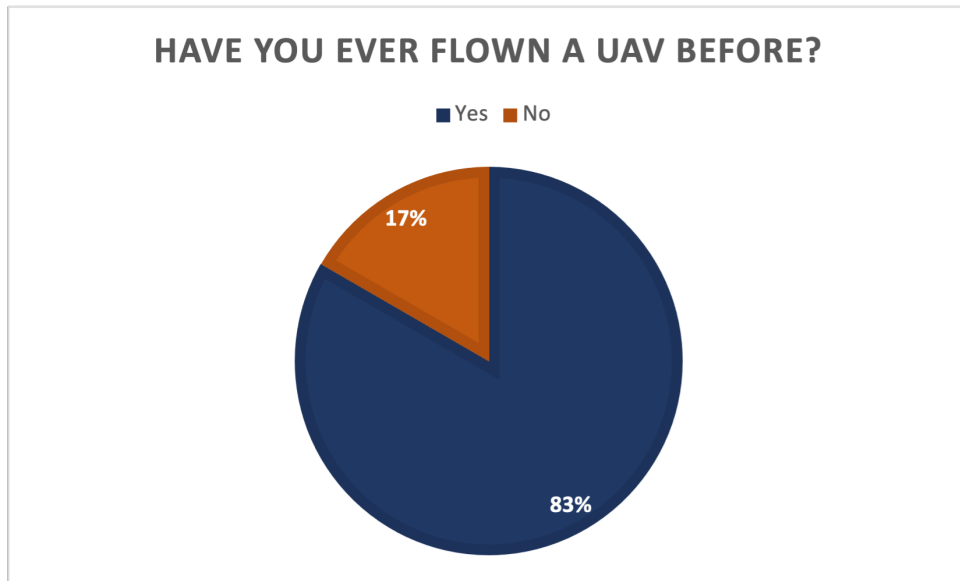
- The UAV crashes when it is placed on or below the mesh before the joysticks receive input from the user.

- When the UAV crashes after placing the UAV (before pressing "Start"), the instructions for the obstacle course disappear and are replaced by information that the UAV has crashed along with a restart button.
- If the UAV crashes after being placed and the restart button is pressed, the UAV returns to its start location but sometimes with the wrong rotation. This does not seem to happen when the UAV crashes during the actual flying session.
- The UAV can trigger the smaller "inactive" checkpoint, and this should not be possible.

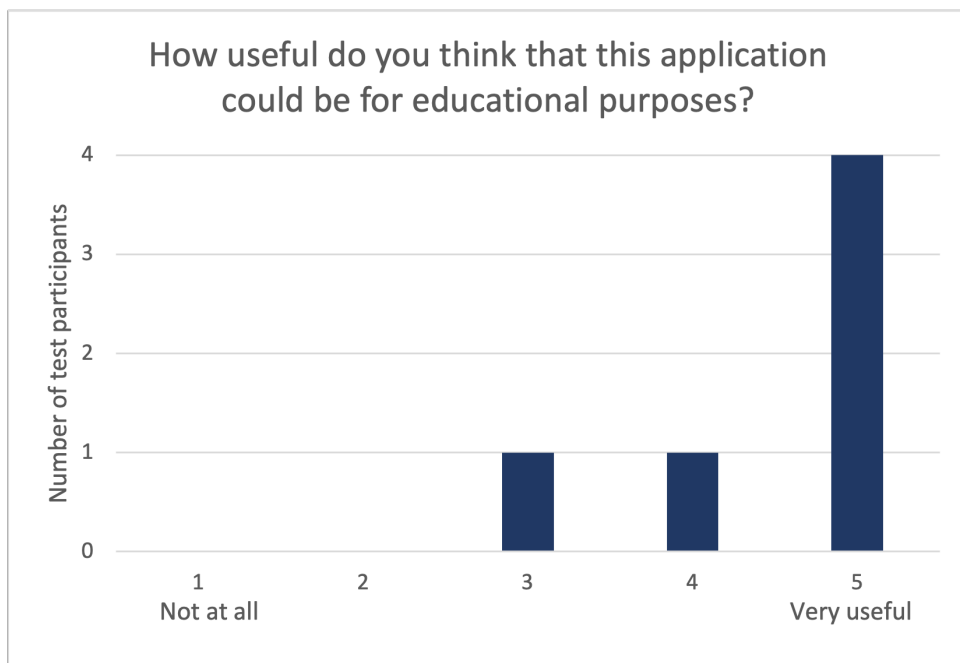
The observations that were documented during the user test as well findings from the screen and audio recordings resulted in the following compilation:

- Some testers chose to fly through the checkpoints in a random order.
- Almost everyone placed the obstacle course above the mesh without noticing that the UAV was below the mesh, which resulted in a crash.
- One of the testers expected that the application would give some sort of feedback for when it was time to stop scanning the room.
- Some testers flew the UAV up and down instead of towards the checkpoint because they could not determine the exact location of the UAV.
- One of the testers expressed that the joysticks were too sensitive.
- The testers did not seem to realise that it was possible to move the device and obstacle course up and down when choosing a suitable placement for the UAV.
- Only one of the testers took use of the possibility to walk around with the device while flying the UAV.
- None of the testers chose to scan the ceiling.
- Some testers did not quite understand the meaning of the mesh, they did not realise that the UAV could crash into it.
- Multiple testers seemed skip past and disregard the written instructions and the map.

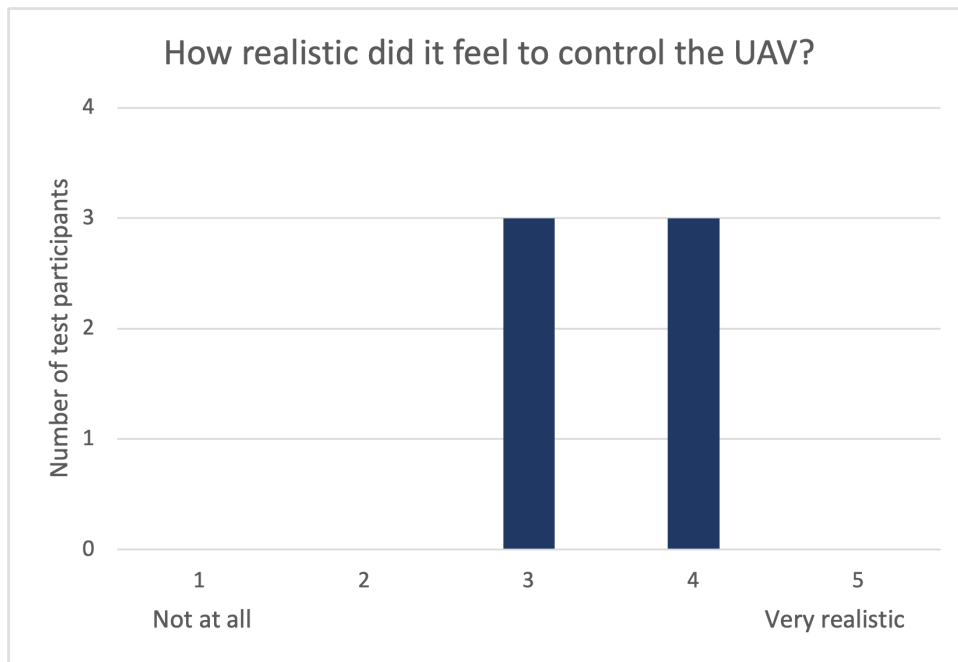
After the test session, the test participants were presented with a questionnaire. The questionnaire consisted of some initial questions about personal information such as gender and occupation followed by questions aimed to gather some quantitative data on previous experience and the test experience. Figure 3.13-3.16 present some of these results.



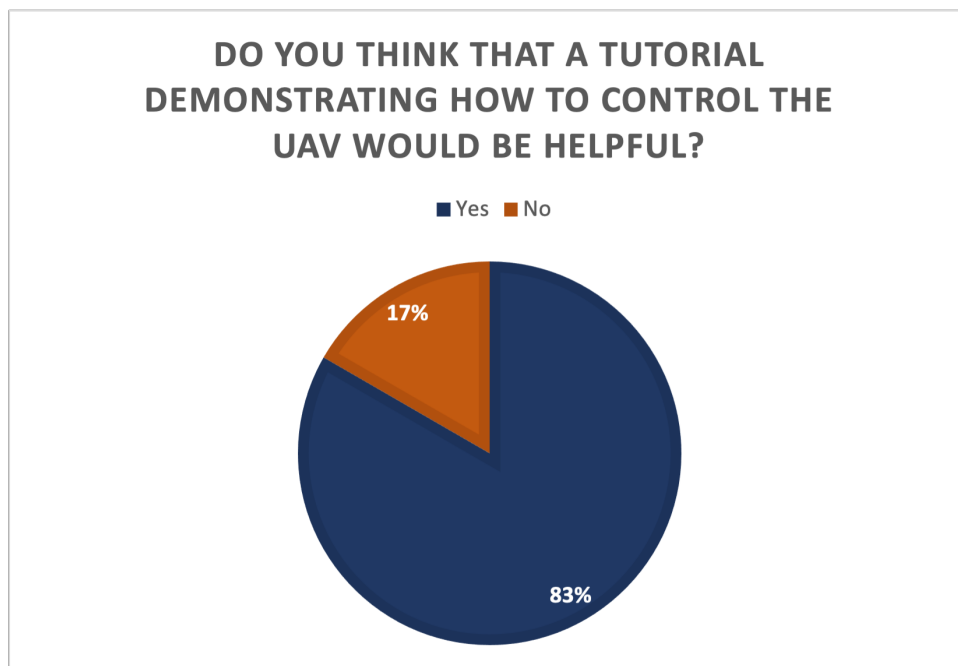
**Figure 3.13:** The test participants' UAV experience.



**Figure 3.14:** The test participants' opinions on the application as an educational tool.



**Figure 3.15:** How realistic it felt to control the UAV according to the test participants.



**Figure 3.16:** The test participants' opinions on the need of a tutorial.

The questionnaire also consisted of some questions in order to collect some qualitative data about the test participants' opinions of the prototype that was tested, which can be seen in table 3.2.

**Table 3.2:** The questions and answers from the questionnaire in UT1.

Question	Answers
The five testers that had flown a UAV before were asked if there were any differences or similarities flying the UAV simulator compared to flying a real UAV.	<ul style="list-style-type: none"> <li>• The controls had the same type of input, but far from the same feeling. Fun to try it out.</li> <li>• Absolutely.</li> <li>• A bit difficult without a real controller.</li> <li>• A bit difficult to judge the distance to obstacles on the iPad</li> <li>• (When flying the simulator) it was harder to judge the distance to follow a certain line.</li> </ul>
Were there any steps of the application where you didn't understand what was expected of you? If yes, which steps?	<ul style="list-style-type: none"> <li>• I expected a popup when I had scanned enough of the room.</li> <li>• No.</li> <li>• Super clear.</li> <li>• What was expected from the test.</li> <li>• How to fly.</li> </ul>
Do you have any suggestions for improvement?	<ul style="list-style-type: none"> <li>• Before the first level, there should be a test level where you get to try out flying the UAV before flying the course.</li> <li>• I want to use a "real" controller. Otherwise, cool application!</li> <li>• Would like to move the joysticks up a bit. A larger course.</li> <li>• Simulator practice combined with real practice is important for mass training.</li> <li>• The task should be clarified: which orb is the starting point?</li> </ul>

## 3.4 Iteration 2

This section describes the different steps of Iteration 2, the last iteration of the design process. It continues where Iteration 1 ended, and concludes with the final prototype.

### 3.4.1 Understanding the Context of Use

In order to proceed with the development of the application, a reassessment of both the end user and the context of use was needed. This was done by combining findings from the user test from the previous iteration with new knowledge derived from discussions with the client.

During UT1 we got some of our initial thoughts about the end user confirmed, for example that the experience of flying a real UAV could vary. We also realised that another thing that was worth taking into consideration was that their overall experience with similar applications and video games could vary as well. This became apparent when some of the testers showed some difficulties in understanding some of the concepts, such as using the virtual joysticks as controllers or following the paths in the course with the UAV. This also indicated that the difficulty level of the application was not too rudimentary. During the user test, we also got the opportunity to familiarise ourselves with the environment in which the application is planned to be used.

In order to acquire more information about the context of use, we had meetings with the client on a regular basis where we discussed the design of the STA courses as well as if the students are allowed to walk around when flying the real UAV or if they should stand still during the whole flight session. The client conveyed that it is intended that the students stand in one place when flying the UAV. This was important to understand in order to create a similar practice experience when using the application.

### 3.4.2 Requirements and Idea Generation

Similar to Iteration 1, new ideas were generated in this part of the design process based on understanding the user context as well as the client's requirements but mostly on valuable findings from UT1. Table 3.3 presents different ideas generated based on the issues that were identified during UT1.

**Table 3.3:** Issues and generated ideas.

Issue	Ideas
Users fly through checkpoints in wrong order	<ul style="list-style-type: none"> <li>• Make only one checkpoint active at a time</li> </ul>
Possible to place course in mesh	<ul style="list-style-type: none"> <li>• Make it impossible</li> <li>• Remove "Confirm" button when placed in mesh</li> <li>• Give feedback for unsuitable placement for example change colour of course to red</li> </ul>
Possible to place UAV under mesh	<ul style="list-style-type: none"> <li>• Move UAV up in line with course</li> </ul>
Testers want to fly with real controller	<ul style="list-style-type: none"> <li>• Try connecting a PS4 controller to iPad and application</li> </ul>
Unclear when to stop scanning	<ul style="list-style-type: none"> <li>• Clarify scanning instructions</li> </ul>
Testers did not realise that the UAV could crash into the mesh	<ul style="list-style-type: none"> <li>• Clarify scanning instructions</li> <li>• Include segment in tutorial</li> </ul>
Doesn't feel realistic flying the UAV	<ul style="list-style-type: none"> <li>• Implement exponential response</li> <li>• Try connecting a PS4 controller to iPad and application</li> <li>• Different exponential curves for the responses based on the size of the UAV</li> </ul>
Difficult to perceive depth	<ul style="list-style-type: none"> <li>• Implement first-person view (FPV) from UAV camera</li> <li>• Draw a line between UAV and next checkpoint</li> <li>• Distance to the tablet and height</li> </ul>



In order to further develop the prototype so that it meets the desired requirements, new features needed to be added to the application. Table 3.4 presents a list of desired features and different idea suggestions.

**Table 3.4:** Suggested features and generated ideas.

Feature	Ideas
Calling back the UAV to original position	<ul style="list-style-type: none"> <li>• Return home button</li> </ul>
Practice flying before the courses	<ul style="list-style-type: none"> <li>• Tutorial scene, learn how to navigate UAV</li> <li>• Practice scene, fly around freely without a obstacle course</li> </ul>
Navigate between different courses and scenes	<ul style="list-style-type: none"> <li>• Main menu with buttons to all the scenes</li> <li>• Main menu button in all scenes</li> </ul>
Restart session	<ul style="list-style-type: none"> <li>• Return to main menu button</li> <li>• Reset original position</li> </ul>
More courses	<ul style="list-style-type: none"> <li>• Implement the STA courses B7.1-B7.5 and B7.7.</li> <li>• Use the same design as in Course 1</li> </ul>

At this point it had long been decided to include some kind of tutorial, drawing inspiration from computer games and other digital tools, where it is commonplace to introduce users to controls and concepts at the beginning. Such tutorials often utilise the interactivity inherent in a computer game. Instead of merely demonstrating how to perform a task they often guide the user towards performing them on their own, following the principle of learning by doing. The idea generation setting concluded that this concept had great potential in the tutorial part application.

### 3.4.3 Design

Iteration 2 design included both the design of completely new features and redesigning or adjusting previous features based on test feedback. This subsection is divided by areas or features, and concludes with a compilation of the final prototype.

### 3.4.4 Implementing Exponential Response

Considering the feedback from UT1 regarding an unrealistic feeling when flying the UAV, it was decided to add an exponential response to the input from the joysticks. In practice, this meant that the input from the joysticks were passed through an exponential function. The result was that, instead of having a linear relation between joystick input and UAV speed, the response followed an exponential curve. Small joystick input resulted in slower UAV speed, and large joystick input resulted in faster UAV speed.

### Adding a Physical Controller

Considering the design decisions leading up to this point, the groundwork was already laid for integrating a physical controller. It should be noted that at this point there was no complete commitment to using the controller, but rather an idea and a plan to try to implement it. The outcome would decide whether to move forward with it and include it in the final evaluation test.

The idea was to map the left and right analogue joysticks on the PS4 controller to the same actions connected to the left and right joysticks. A comparison between the virtual joysticks and the physical controller that was used can be seen in figure 3.17.

Connecting the controller to the iPad and implementing basic support, mapping the controller to UAV up/down/rotation and strafing, for it in the application was a relatively easy process. The developers agreed that this would probably mean a great improvement to the general user experience. It would also bring the application one step closer to flying a real UAV. Therefore it was decided to move forward with implementing the controller. It was also decided to keep and maintain the virtual joysticks, both since they enable another, more portable way of using the application, and to allow testers to fly with both input methods in the same session and compare them.

However, adding the controller was not as simple as just implementing the technical support and integrating it into the application, but rather it changed the whole mode of interaction. When flying with the virtual joysticks a user would hold the iPad in their hands. Adding the PS4 controller, keeping the hands of the user busy, the need arose to design a new setup for the iPad. While there were a lot of ideas, it was decided to mount the iPad in a tablet holder, which was then mounted on an adjustable camera tripod (see figure 4.1). With this setup, the iPad could be mounted at a comfortable height, allowing adjustment for individual variation and preference. The tablet holder was also designed in a way that did not block the iPad's rear facing camera, which was essential for the AR element of the application.

While the controller and subsequently the tripod setup brought several benefits, it also meant that the iPad was now more or less stationary. Previously, users could walk around with the iPad while both scanning the room and while flying.



Figure 3.17: Virtual joysticks in the application and a PS4 controller.

## Changes to the Instructions

During UT1, it became apparent that the user does not always read all the instructions that are presented on the screen. During the test, it was obvious that the test participants did not take their time to observe and analyse the map that was shown with the instructions for the course. It was therefore decided to remove the map used in the Iteration 1 prototype and rely fully on text instructions together with the design of the courses to explain the task. This was made possible partly by having only one checkpoint active at a time that acted as a signifier. As long as the user understands that their task is to fly to the next checkpoint, the map would hopefully be redundant.

## Placement

UT1 also made it apparent that the placement of the course needed to be redesigned. As previously mentioned, the two main issues was that 1. It was possible to place the course over the meshed floor, with the UAV being placed under it, and 2. It was possible to place the course and UAV inside meshed floor, walls or other obstacles.

The first issue was addressed by simply moving the starting position of the UAV up closer to the course, reducing the risk of the UAV ending up under the floor. While this helped, it

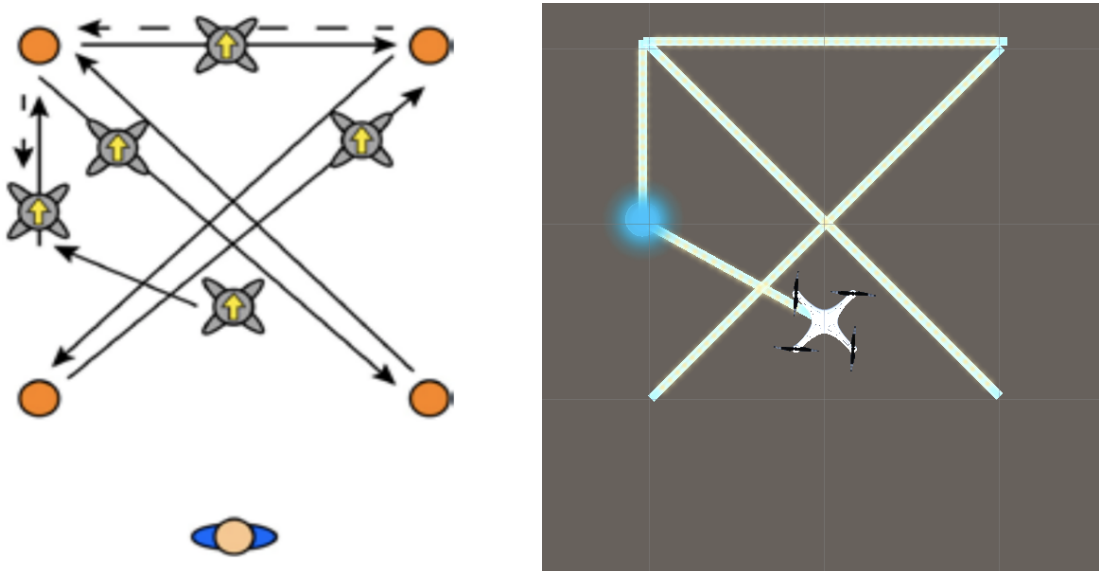
was later decided that the UAV should start at the first checkpoint.

The second issue was addressed by only making it possible to place the course and UAV in clear space. As a signifier that something is not right, the course was programmed to turn red when colliding with the mesh. Furthermore the "Confirm" button was made to disappear when the course was in an unsuitable location, removing the affordance completely by introducing a physical constraint. Both of these features are demonstrated in 3.29.

## Courses

The first issue to be addressed when continuing the course design in Iteration 2 was that of clarifying the task for the user. As previously mentioned, testers expressed confusion over the task (flying through the course in a certain order) and some users flew them in a seemingly random order. The idea here was to add logical constraints. In practice this meant that while the course had six checkpoints, five of these would be inactive at any given time, and only the next checkpoint to be flown through would be visible. This also meant that when the UAV collides with a checkpoint, it disappears and the next checkpoint appears, providing feedback. While this still made it possible to deviate from the suggested flight path, it made it impossible to fly the course in the "wrong" order.

While taking a more detailed look at the STA courses, a few things became clear. Courses B7.1, B7.2, B7.4 and B7.5 are all laid out in the same way. The only thing that differs is the way the pilot should fly through them, more specifically which direction the UAV should be rotated in while flying. For the design this meant that these courses would essentially be identical. The differences exist in which instructions to give the user. The STA Course B7.3, however, has a different layout, as can be seen in 3.18.



**Figure 3.18:** The STA Course B7.3 [17, p.8] side by side with Course 3 in the application.

The STA Course B7.7 actually includes two courses which are called Course 6 and Course 7 in the application. While the other courses are built on the idea of moving from one point to another, the STA Course B7.7 involved flying in a slalom pattern, avoiding obstacles, as seen in figure 3.19. With this in mind it was decided to take a step away from the design thoughts in the already existing courses. In the real world it would probably be unfeasible to erect tall columns just to practice flying around them, but taking full advantage of the AR medium this was just what happened.

Four 3D cylinders were used to create the shape of the course. It is important to note that flying the UAV into these cylinders would cause it to crash. For checkpoints, transparent 3D plane objects were used as to not force the user to fly at a certain height, while still keeping the established idea of flying a predetermined path, one checkpoint at a time. These elements were the core of Courses 6 and 7 and all that was really needed to have implemented it according to the STA's checklist [17]. But since Courses 6 and 7 added new elements, such as flying behind and between obstacles, and the fact that the instructional map was now removed, it was decided to try to design a type of path for the user to follow. A zigzag line of transparent cubes were added to show which route to fly, as can be seen in figure 3.20.

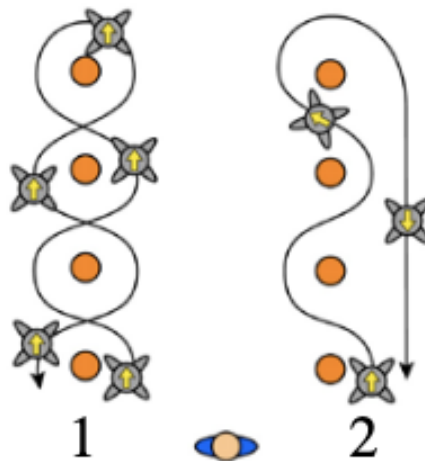


Figure 3.19: The STA Course B7.7 [17, p.10].

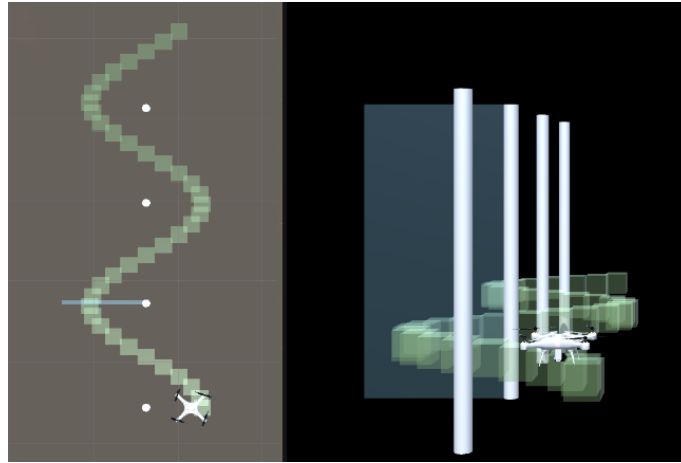


Figure 3.20: Course 7 from above and perspective.

## The Tutorial

The purpose of including a tutorial was to allow the user to try out the different features in the application before flying through more complex courses. Furthermore the tutorial was intended to introduce and give a basic understanding for the controls. Constructing a separate step for this enabled a controlled environment without the complexity of trying to complete a task, flying through a course, while learning the very basics.

In order to begin creating a useful tutorial it was important to first break down the task of flying the UAV through a course into smaller steps. This was done by first making some sketches of basic courses that teaches one isolated movement at a time. The next step was to create sketches of advanced (yet still small) tutorial courses that include a combination of basic movements. A sketch of these tutorial courses can be seen in figure 3.21. It was important that these looked similar to Course 1 created in Iteration 1 in order for the user to be able apply the newly obtained skills on the rest of the courses in the application.

After creating some sketches of the different steps of the tutorial, the design of the tutorial in Unity could begin. The first step was understanding the basic controls. For example, the first task in the tutorial has the text instruction "Drag the RIGHT JOYSTICK to left and right to move the UAV sideways". After the user has been presented with these instructions and clicked "Start", there is a path and a single checkpoint. The task for the user here is to move along the path to the checkpoint. This checkpoint will then disappear, and a new one will appear at the starting position. The user should then fly back to this checkpoint. After doing this, the user is presented with a text prompt reading "Well done!" and providing feedback to the user that this part of the tutorial has been completed. There is also a button to proceed to the next step of the tutorial.

The next step in the tutorial follows the exact same principle, but now lets the user fly forward and back instead of left and right. After this comes a step where the user flies up and down. At this point the tutorial has allowed the user to fly in a straight line in x, y and z directions in 3D space, and to experience themselves which controls result in which action.

After this, there are two steps which prompts the user to rotate the UAV 90 degrees around its own axis, clockwise and then counter-clockwise. The intention behind adding

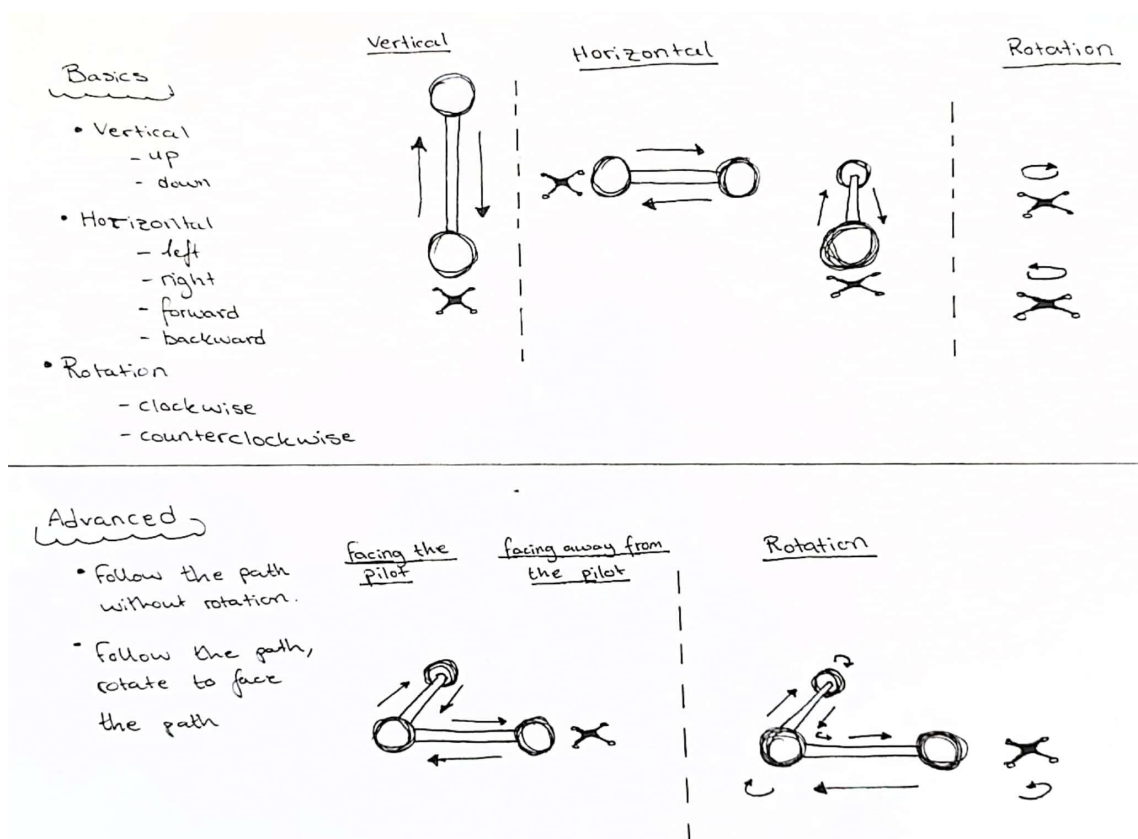


Figure 3.21: A sketch of the basic and advanced courses in the tutorial.

this step was to prepare the users for the courses that specifically required the user to fly with a certain rotation as, for example, Course 2 requires the user to "Fly through the obstacle course and back with the UAV always facing the next checkpoint". In practice this means that the user needs to perform 90 degree turns at every checkpoint, except for the last where there is a 180 degree turn.

One thing that was really important to add to the tutorial was the concept of scanning. In the tutorial, users get to scan the room, place the UAV, and are directly afterwards prompted to "Fly into the scanned area to see what happens!". The first two steps were added in this way to resemble the order of tasks a user would perform when flying the courses. Scanning, then placement, followed by flying. Making the user crash their UAV might seem counter-productive when the goal is to create a training tool, but the purpose was to create a mapping between scanning, the resulting 3D mesh, and crashing the UAV.

At this point the tutorial included a number of basic steps - Flying horizontally, vertically, rotating, scanning, placing, and the concept of checkpoint. It was time to create the more complex courses of the tutorial, where users would get to combine different skills, such as flying both left/right and forward/backward through a small course, in a scanned environment, while rotated in a certain direction. This resulted in three steps, all with different instructions as to which way to rotate the UAV when flying. These last steps could be viewed as a preparation exercise for flying the more complex courses in the application later on. The tutorial is presented in figures 3.25, 3.26, 3.28, 3.29, 3.30 and 3.31.

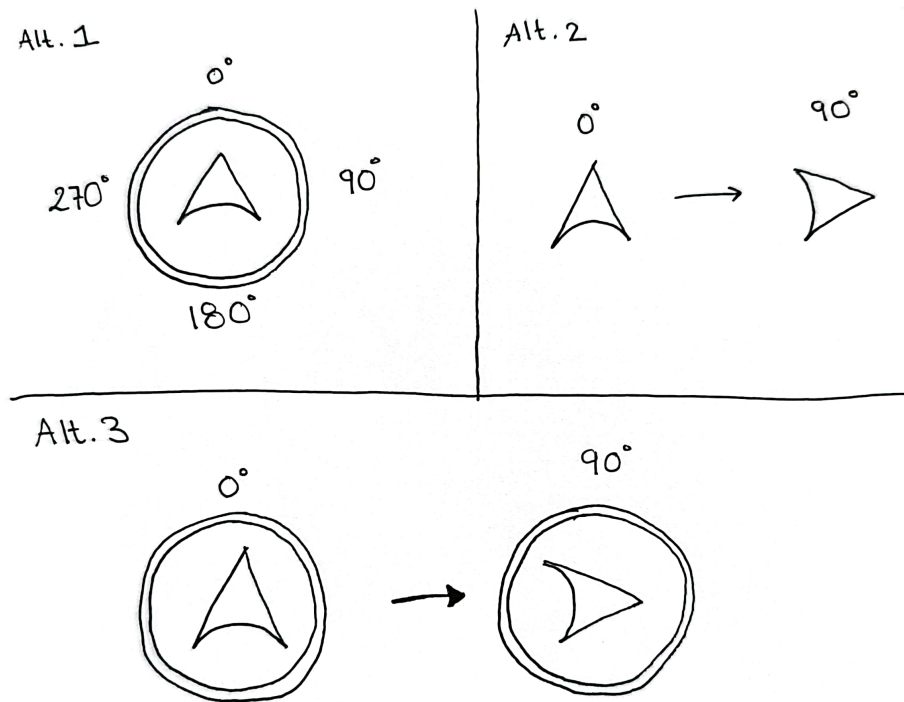
## The Compass

Wanting to address the issue of testers not knowing which direction the UAV was rotated towards after stopping, a compass, or at least some way of displaying the current rotation of the UAV, had long been an idea. While the UAV had LED lights in order to indicate which side was forward and which was back, this was not always enough, especially when flying further away from the camera. Therefore, the compass was created.

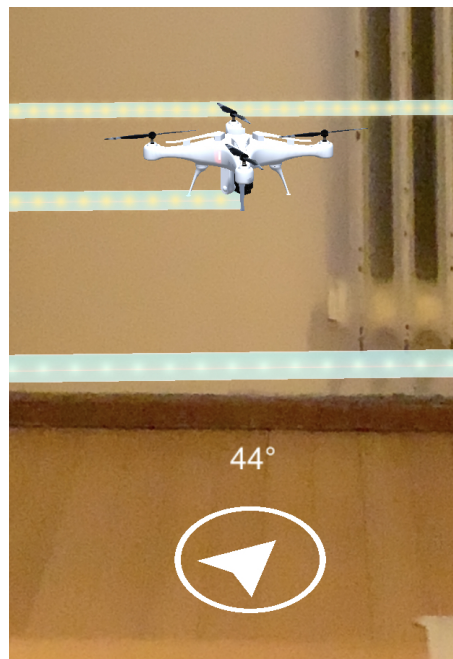
At first, different prototypes were designed as can be see figure 3.22. The first alternative presents a design with static angle values around a circle where only the arrow rotates. The second alternative consist of one angle value at the top that changes based on the rotation of the arrow. These two alternatives were then merged into a third alternative which consisted of the dynamic angle value, the static circle around the arrow and lastly the arrow that rotates with the same rotation as the UAV.

It was then decided to implement the third alternative of the compass in Unity. It consists of slightly tilted arrow pointing in the same direction as the UAV points, along with a reading of the rotation in degrees as can be seen in figure 3.23.





**Figure 3.22:** A sketch of different alternatives for the look of the compass.



**Figure 3.23:** The UAV and compass when the UAV is rotated 44 degrees clockwise.

## Final Prototype - SUAV

The design process in Iteration 2 resulted in a final prototype called SUAV, which stands for Simulated UAV. The different steps in the application can be seen in figures 3.24-3.37.

Figure 3.24 shows the splash screen that is displayed when the application launches as well as the main menu that the user is presented with.

When the "Tutorial" button is pressed in the main menu, the Tutorial scene is launched. The tutorial consists of five basic courses, which can be seen in 3.25-3.28:

- Basic Horizontal - Sideways
- Basic Horizontal - Forward and back
- Basic Vertical
- Rotation - Clockwise
- Rotation - Counterclockwise

In the tutorial, the user is also taught how to scan the surrounding area, place the UAV/obstacle course so that they do not collide with the scanned area, and also what happens to the UAV if it flies into the mesh. These steps can be seen in figure 3.28 and 3.29.

The final steps in the tutorial consist of three advanced courses, which can be seen in figure 3.29-3.31:

- Horizontal - Facing away
- Horizontal - Facing the pilot
- Horizontal - Facing next checkpoint



**Figure 3.24:** The splash screen and main menu of the final prototype (SUAV).

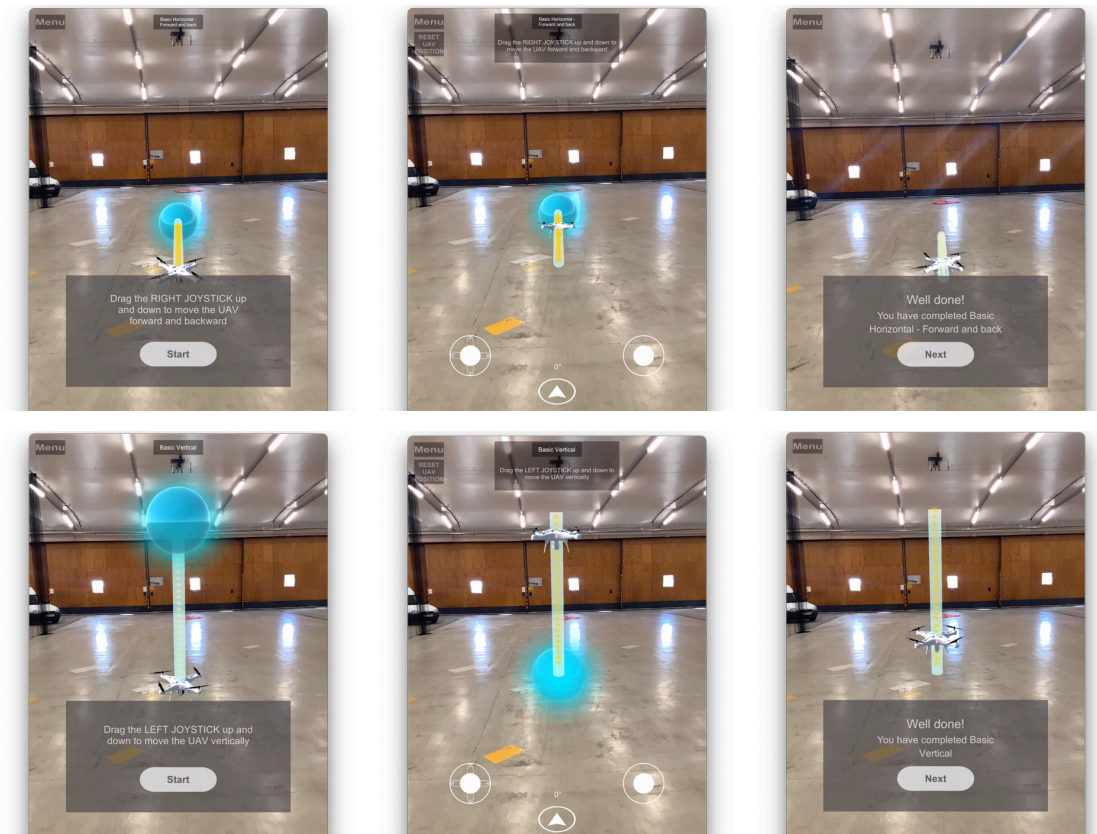
When the "Practice" button is pressed in the main menu, the Practice scene is launched. The Practice scene begins with the user scanning the surrounding area, followed by placing the UAV (see figure 3.32). The user can then practise flying around freely without any obstacle course.

Lastly, the application consists of the courses Course 1-7 which represent the STA courses B7.1-B7.5 and B7.7, where B7.7 is divided into two courses in the application: Course 6 and Course 7. These courses can be accessed when pressing "Start" in the main menu. The session begins with the user scanning the surrounding area and then placing Course 1. The user can then fly through each course after completing the previous one. These steps can be viewed in figures 3.33-3.37.

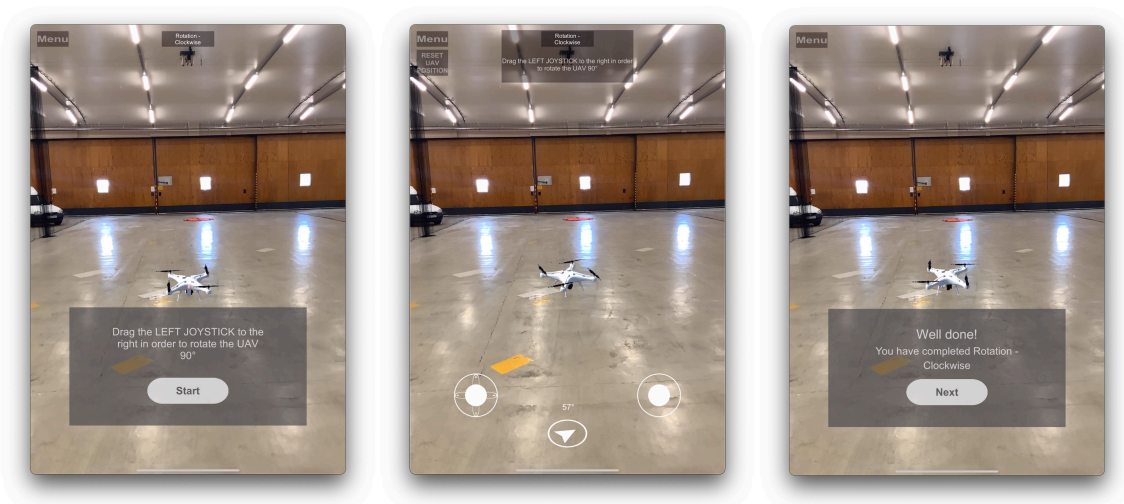


**Figure 3.25:** The different steps in the Tutorial scene in the application SUAV.

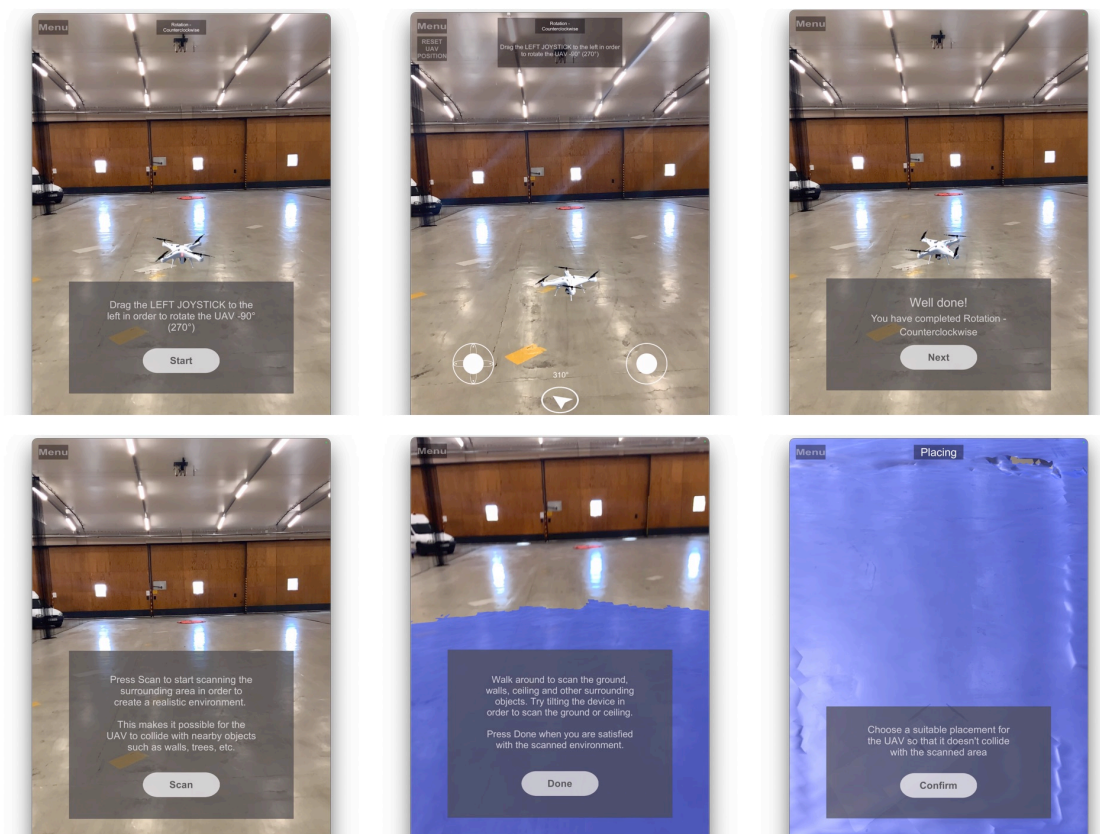




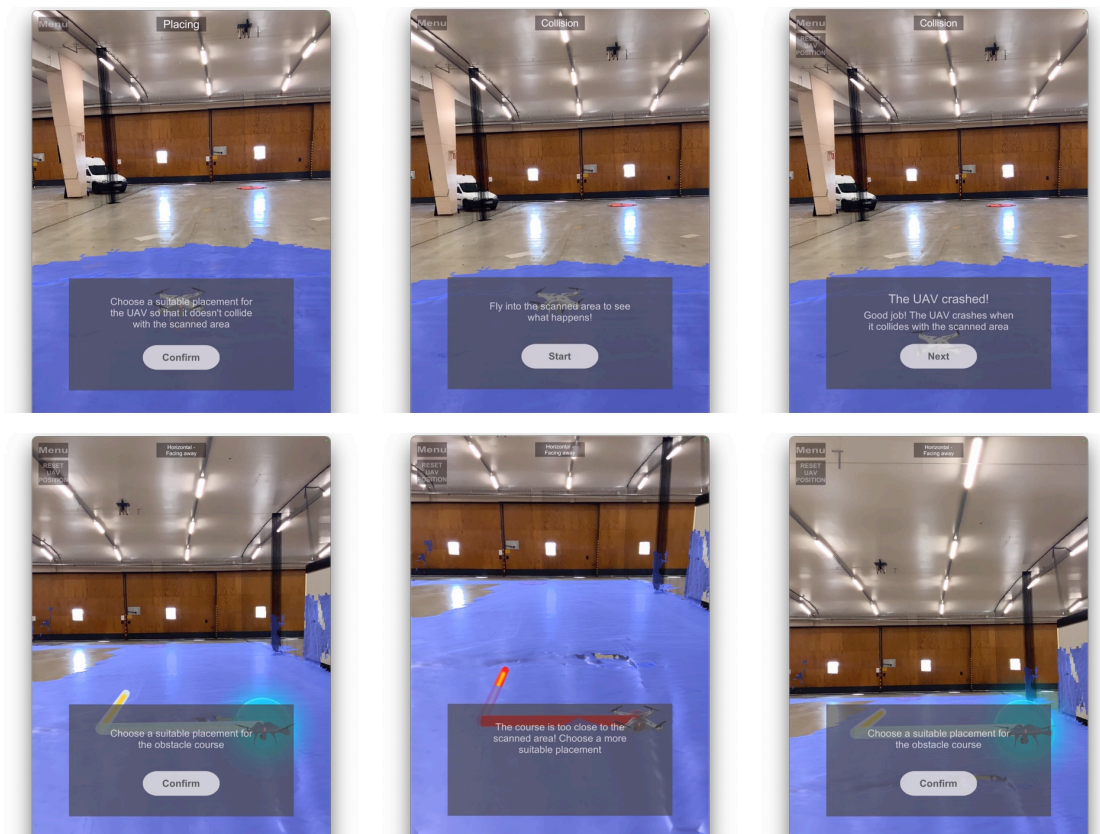
**Figure 3.26:** The different steps in the Tutorial scene in the application SUAV.



**Figure 3.27:** The different steps in the Tutorial scene in the application SUAV.

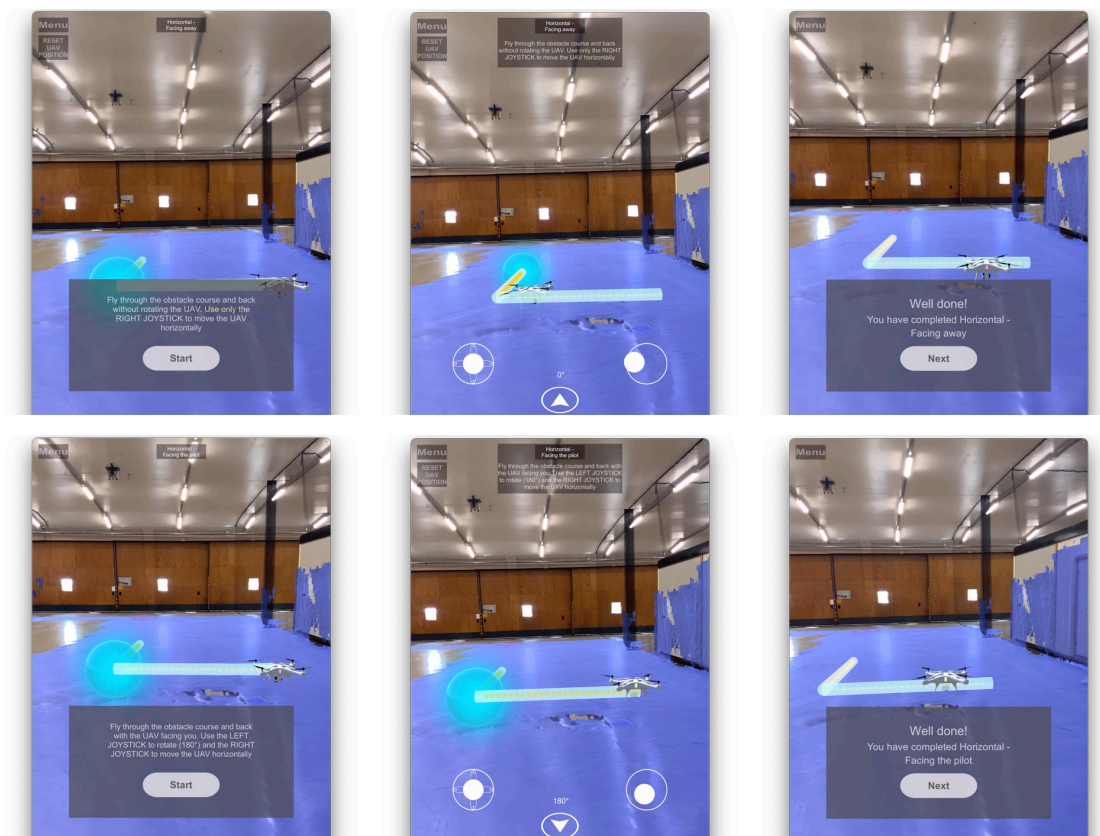


**Figure 3.28:** The different steps in the Tutorial scene in the application SUAV.



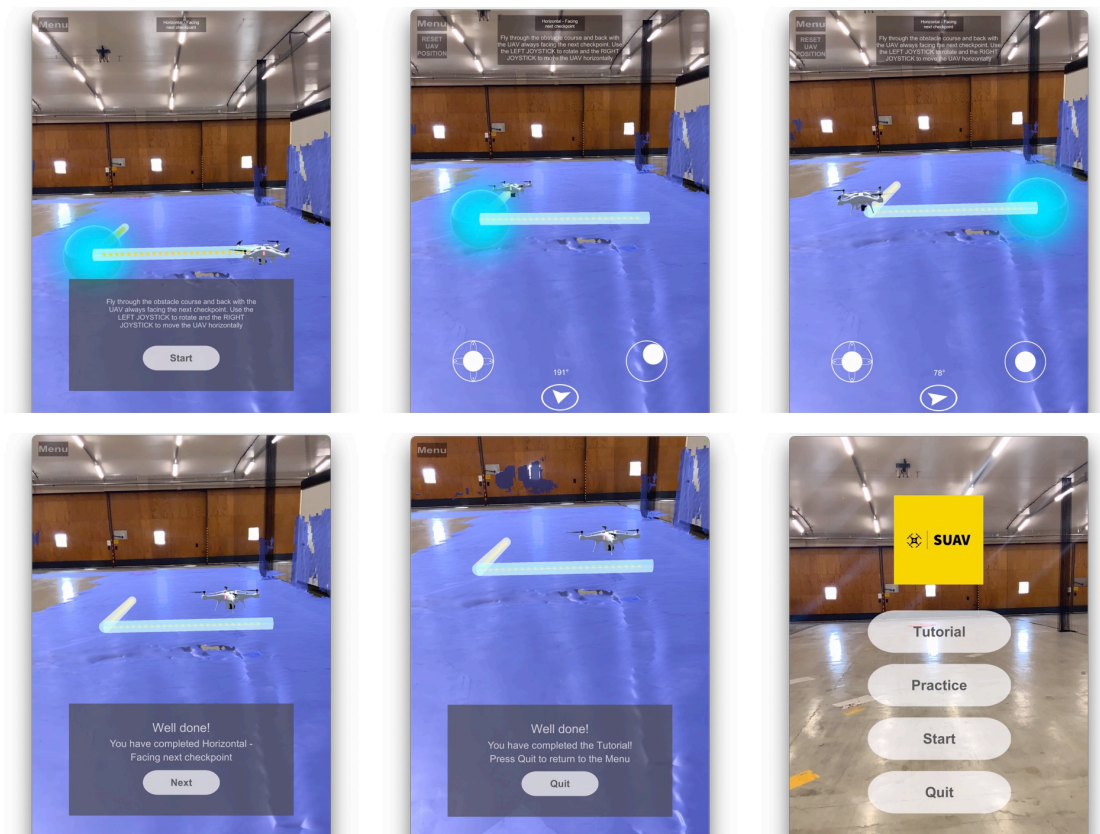
**Figure 3.29:** The different steps in the Tutorial scene in the application SUAV.



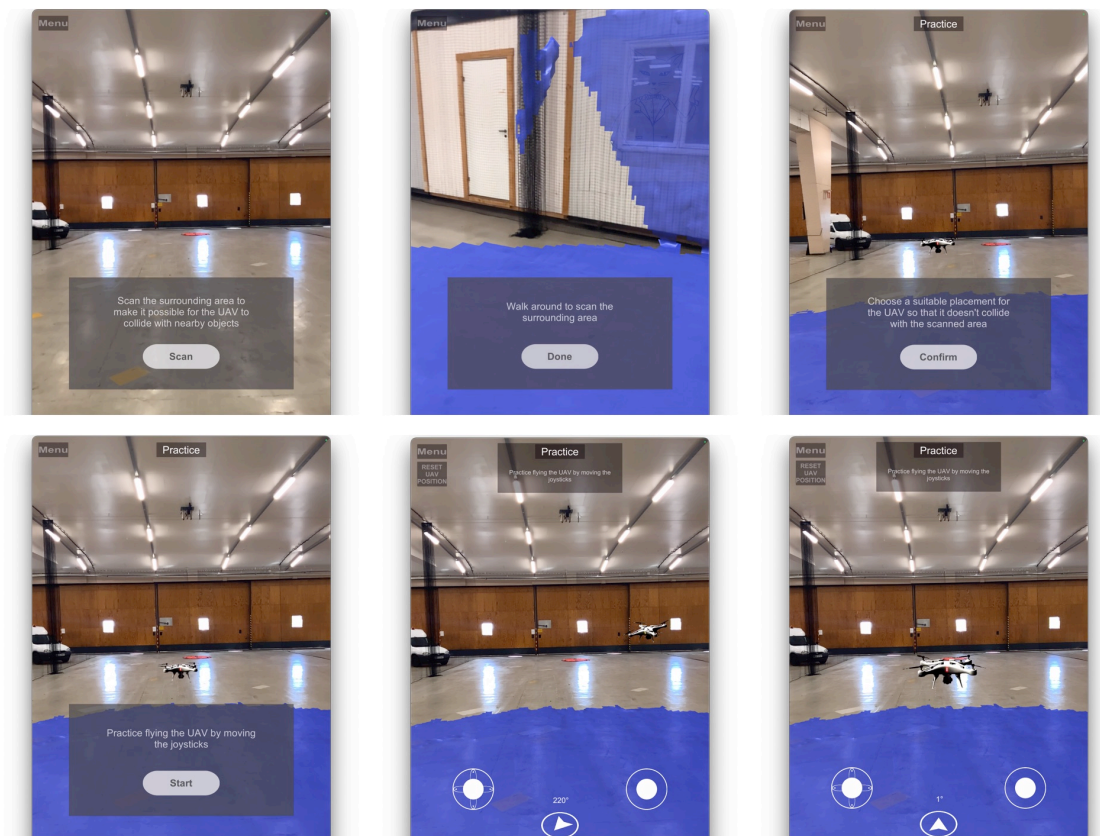


**Figure 3.30:** The different steps in the Tutorial scene in the application UAV.

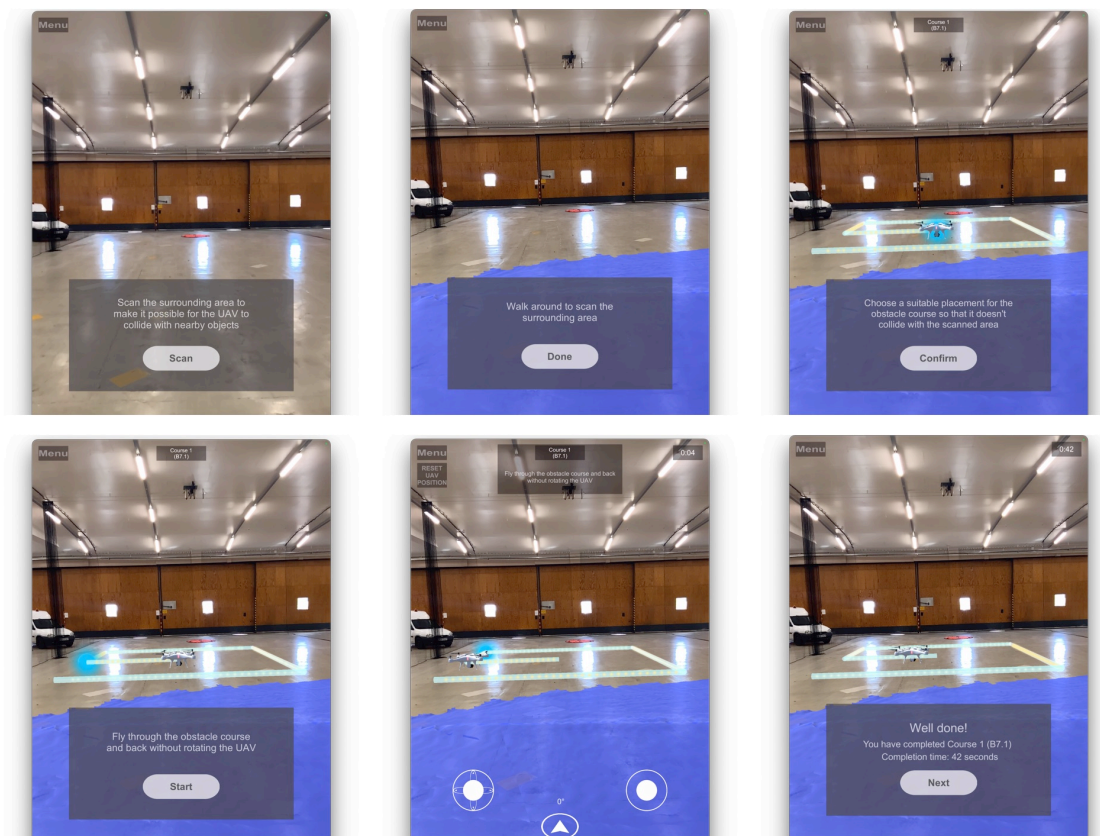




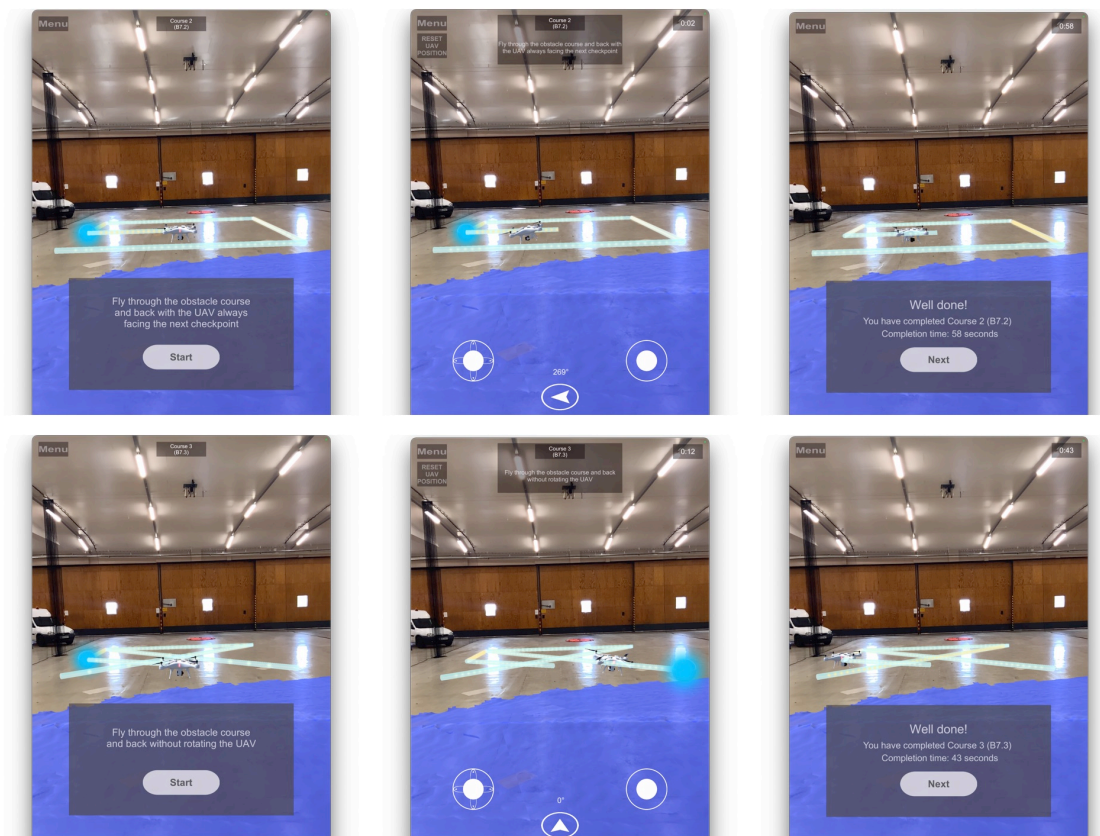
**Figure 3.31:** The different steps in the Tutorial scene in the application SUAV.



**Figure 3.32:** The different steps in the Practice scene in the application SUAV.

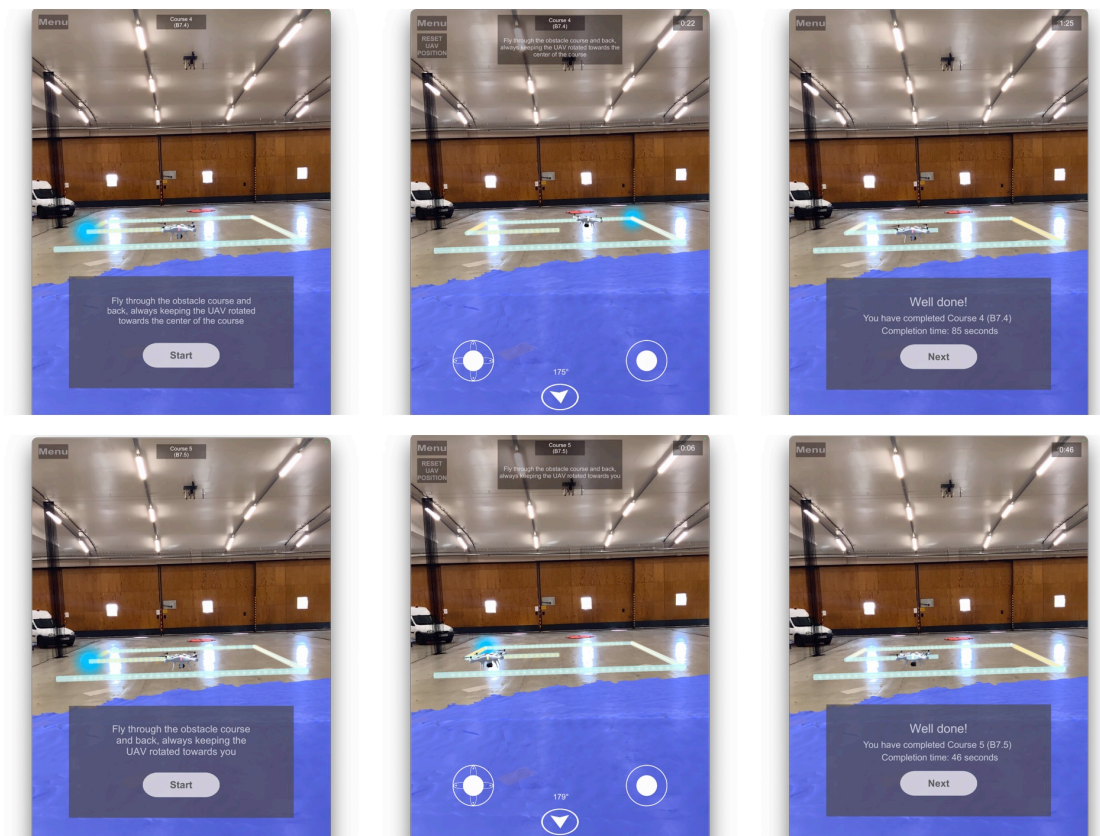


**Figure 3.33:** The different steps when flying through Course 1-7 in the application SUAV.

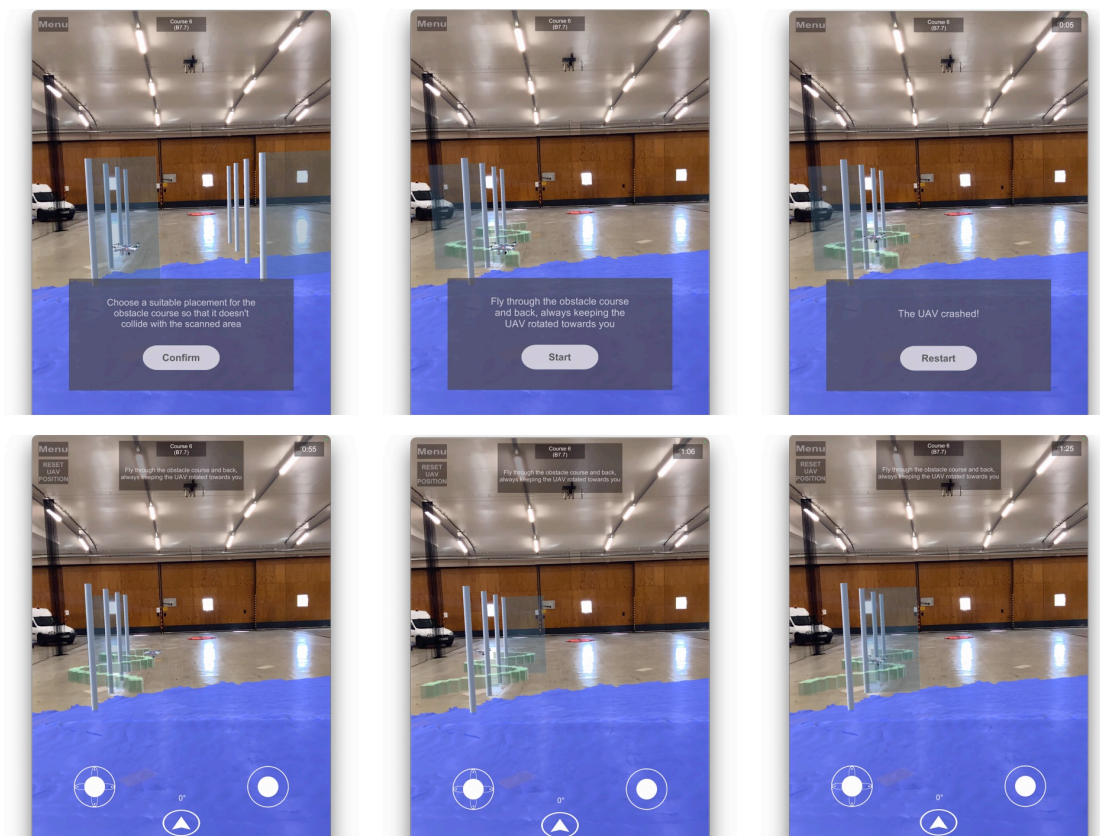


**Figure 3.34:** The different steps when flying through Course 1-7 in the application SUAV.

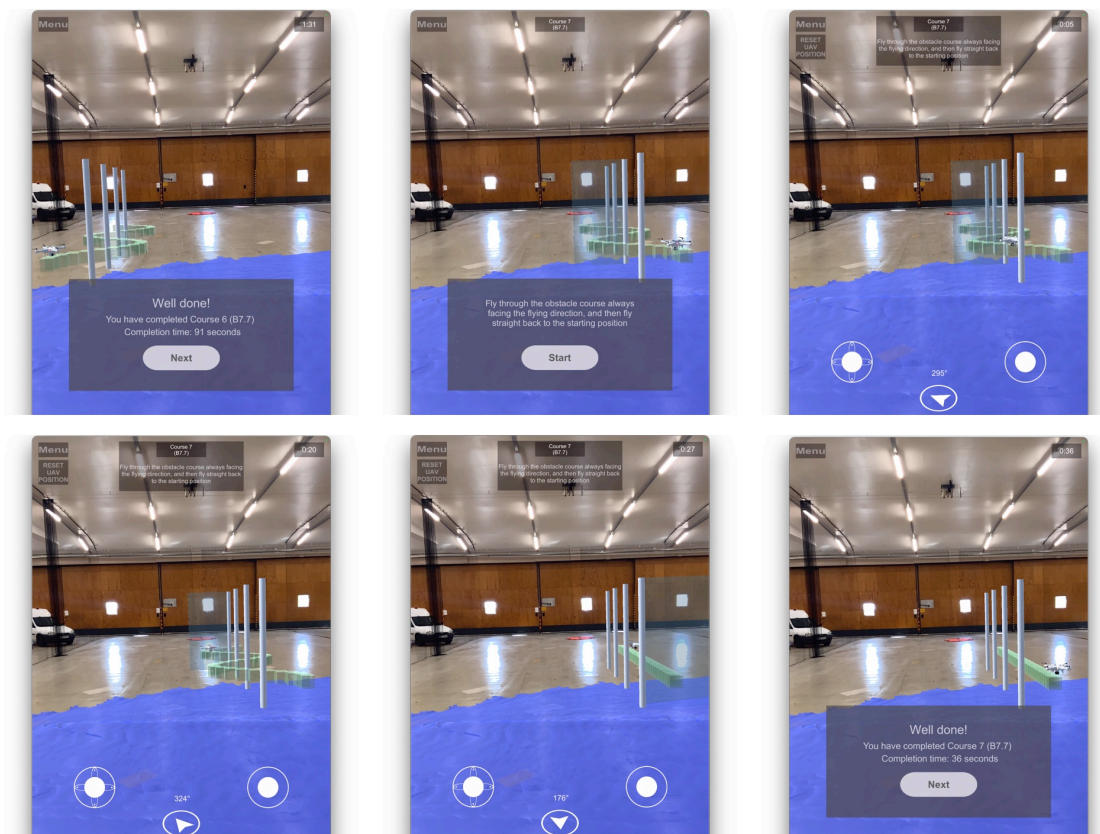




**Figure 3.35:** The different steps when flying through Course 1-7 in the application SUAV.



**Figure 3.36:** The different steps when flying through Course 1-7 in the application SUAV.



**Figure 3.37:** The different steps when flying through Course 1-7 in the application SUAV.

# Chapter 4

## Evaluation

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*This chapter describes the methodology, process and results of the last and final user test.*

### 4.1 Method and Purpose

A usability test was carried out at the end of Iteration 2 in order to evaluate the final prototype for the application, Simulated UAV (SUAV), with the purpose of exploring the usability of the application and identifying different difficulties users may have when using the application. A formal test plan can be found in Appendix B. The user test was carried out at LUSA with four test participants. Before executing the test, the plan was to have five participants, but due to the student's other activities at LUSA it became apparent during the user test that this would be impossible. All participants were men and three of them belonged to the same polar research crew that was present during UT1 and had already tried the first prototype of the application. The fourth person was an employee and assistant professor at LUSA. Ages ranged from 28 to 48 years and the mean age was 41 years. The test participants were chosen since they had experience of UAV flying and specifically UAV education, which makes them a good representation of the intended end user. The test session consisted of four parts:

1. Introduction
2. Test scenarios
3. Questionnaire
4. Interview

The test moderator began with introducing the test team, the purpose of the test as well as giving a brief description of the test.

The test participant then performed different tasks while the observer documented the session. During the test, both the screen and audio were recorded in order to collect as much





**Figure 4.1:** The test setup with the tablet mounted on a tripod.

information as needed. There were four major tasks that each test participant got to perform. The first task was to complete the tutorial while holding the device. The second task was to complete the same tutorial, this time while using a wireless controller as joysticks while the device was mounted on a tripod (see figure 4.1). The device was taken down during the scanning part and mounted back on when the scanning was completed. This was the setup for the rest of the tasks as well. The third task was to enter the Practice scene where the test participant got to fly around freely for up to two minutes, before navigating back to the main menu. The final major task was to complete Course 1-7.

After the test participant performed all tasks, a questionnaire was to be filled in followed by an interview that was also audio recorded.

## 4.2 Test Results

This section presents the data gathered from User Test 2 (UT2), both the qualitative and quantitative data. The data was gathered both during the test through audio and screen recordings as well as documented observations. Data was also collected after the test through a questionnaire and an interview.

### 4.2.1 Observations

Table 4.1 presents a compilation of the observations that were made during the test sessions as well findings from the screen and audio recordings. The user test also revealed the following bugs in the application:

- When the user places the UAV beneath the scanned area during the tutorial and then collides with the area, the UAV seems to re-spawn in the scanned area when pressing "Restart". One has to return to the main menu in order to exit the loop.
- The instructions that are displayed for Course 6 seems to be the wrong ones. The test moderator gave the test participants the correct instructions during the test session in order to be able to perform the test as it was intended.

**Table 4.1:** Observations during User Test 2.

Task	Observations
Tutorial (without wireless controller)	<ul style="list-style-type: none"> <li>• One of the test participants (first time using the application) was confused when he did not see the joysticks when reading the instructions for the first course. He did not realise straight away that he had to press "Start". The same person navigated the UAV to the left then right in the first course (instead of to the checkpoint to the right) since that was the order in which it was stated to fly sideways: "Drag the RIGHT JOYSTICK to the left and right to move the UAV sideways".</li> <li>• Two of the test participants held the device in a downwards angle, so that the camera was facing the floor.</li> <li>• One of the test participants tilted the device upwards at an appropriate angle immediately when placing the obstacle course. The same person managed to complete the "Placement" parts without any issues.</li> <li>• One of the test participants navigated the UAV to face the next checkpoint even though the instructions stated that the user should fly the UAV without rotating (the first advanced course). The test participant followed the rest of the advanced courses without any issues. The same person had some difficulties noticing the instructions for the first course in the Tutorial and steered the UAV away from the area. The same person was also a bit uncertain on how much to scan.</li> </ul>

Continued on next page

Table 4.1 – continued from previous page

Task	Observations
Tutorial (with wireless controller)	<ul style="list-style-type: none"> <li>• One of the participants pressed "Confirm" too fast during the placement of the UAV before the device was placed on the tripod. However, this did not affect his ability to complete the other tasks. The same person also rotated the wrong way at first during the Rotation Course before rotating the right way in order to complete the task. He also rotated the UAV towards the next checkpoint during the first basic course but realised it immediately after.</li> <li>• All test participants showed great improvement in stability, speed and precision in comparison with the previous Tutorial session.</li> </ul>
Practice	<ul style="list-style-type: none"> <li>• All test participants managed to navigate back to the main menu from the Practice scene without difficulty.</li> <li>• One of the test participants placed the UAV under the scanned area. The same person placed the obstacle course under the scanned area during the first Tutorial session.</li> </ul>
Courses	<ul style="list-style-type: none"> <li>• One of the test participants interpreted the instructions "...always keeping the UAV rotated towards the center of the course" as to always keep the UAV rotated towards the path, instead of the centre of the whole area. Another participant also thought that the instructions for that course were confusing and asked what it meant.</li> <li>• All the test participants performed Course 1-3 without any major deviation from the instructions.</li> <li>• One of the test participants managed to perform Course 1-4 without difficulty, however, the test session had to be interrupted in order to have time for the questionnaire and the interview as well before next test session.</li> <li>• Two of the test participants managed to complete Course 6 and 7, there were, however, some difficulties. Both exclaimed that it was difficult to perceive the distance.</li> <li>• One of the two who managed to complete the last two courses collided the UAV more than ten times with the pillars before completing Course 6 in 278 seconds. He then managed to complete the last course without any collision, however, not with the UAV rotated in the desired way.</li> <li>• The other test participant who managed to complete the last two courses only collided twice with the pillars before completing Course 6 in 91 seconds. He then completed the final course without colliding even once in 36 seconds.</li> </ul>

## 4.2.2 Questionnaire Results

The test participants were presented with a questionnaire after performing the test scenarios. The questionnaire consisted of some initial questions about personal information such as gender and occupation followed by questions aimed to gather some quantitative data on previous experience and the usability of the application. The results of some of these questions can be seen in figures 4.2-4.6.

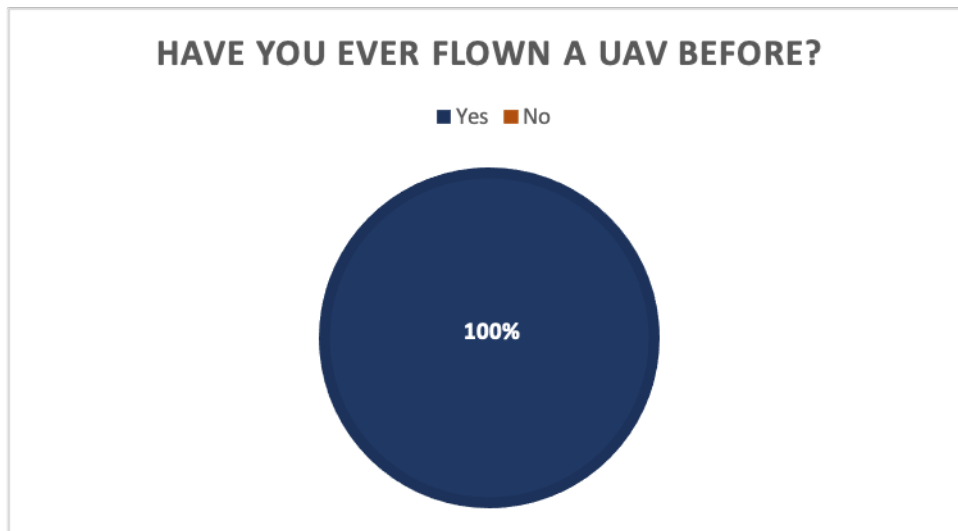


Figure 4.2: The test participants' UAV experience.

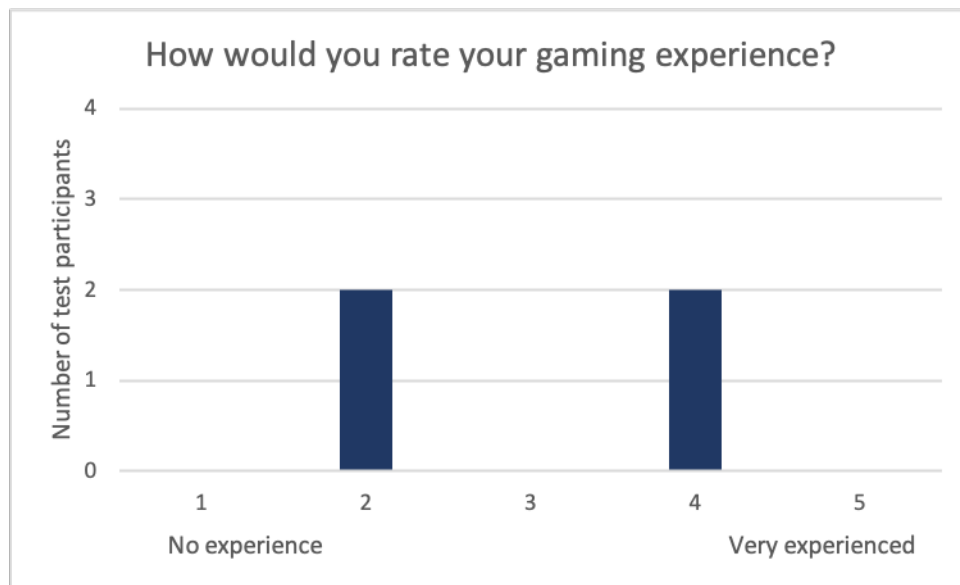


Figure 4.3: The test participants' gaming experience.

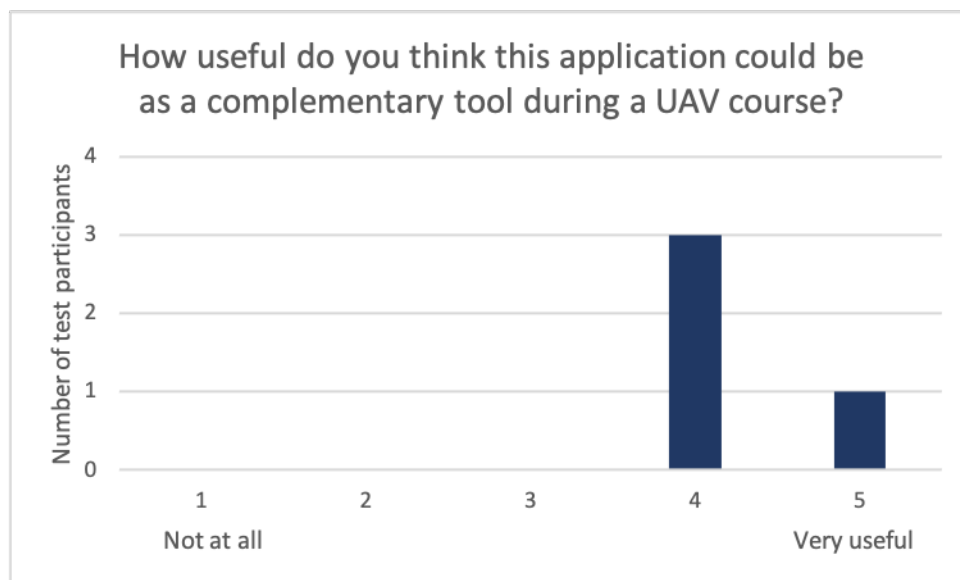
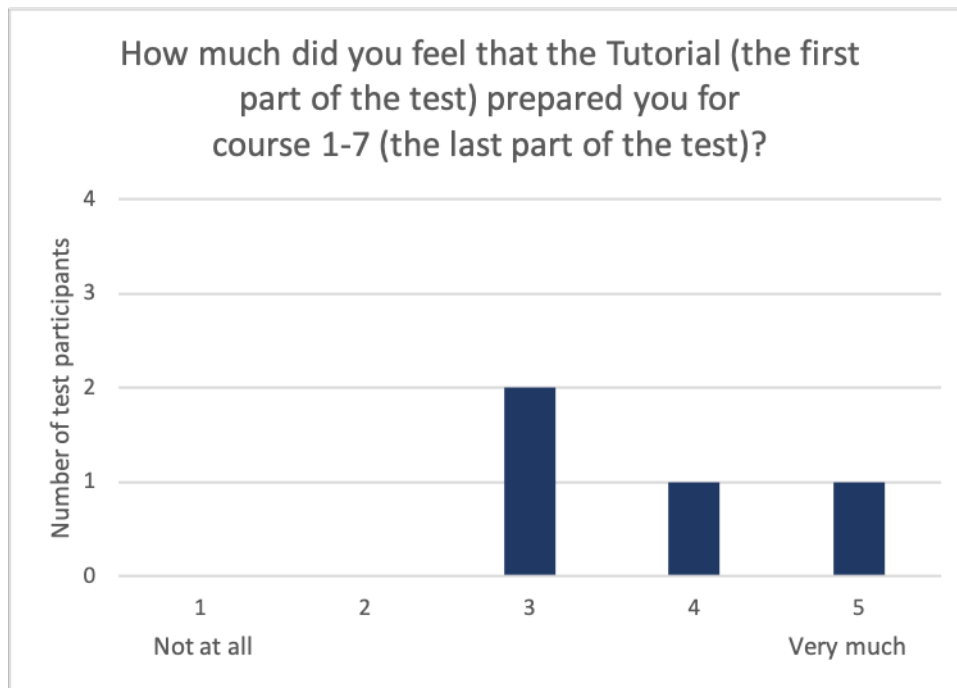
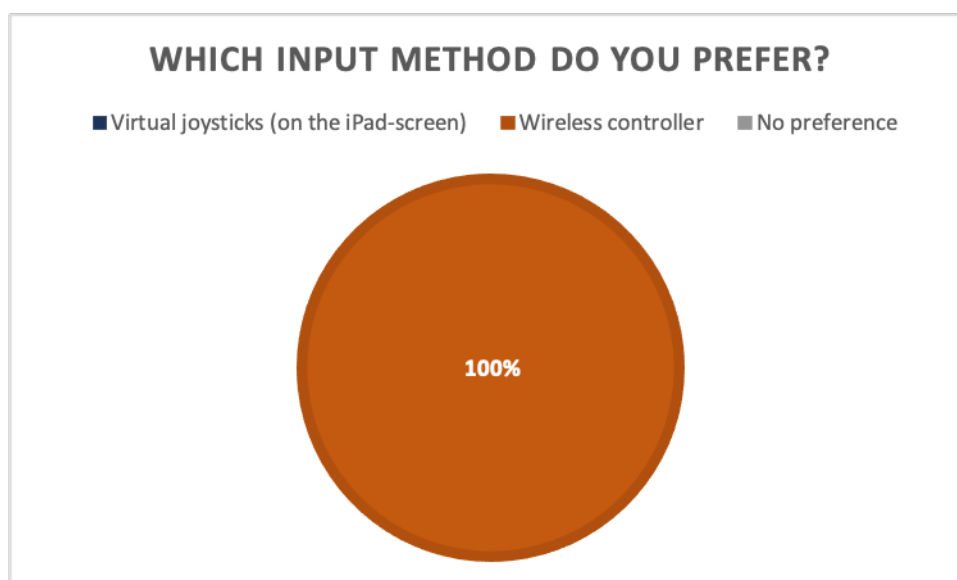


Figure 4.4: The test participants' opinions on the application as a complementary tool.



**Figure 4.5:** The test participants' opinions on the Tutorial as preparation for the courses.



**Figure 4.6:** The test participants' preferred input method.

In order to measure the usability, the questionnaire included a System Usability Scale (SUS), as can be seen in Appendix B, section B.9. The results from the SUS section were extracted in order to calculate the SUS-score for the application, which is presented in table 4.2.

**Table 4.2:** The SUS-score for the application.

Test participant	SUS-score
1	77.5
2	55
3	87.5
4	82.5
Average	76

### 4.2.3 Interview Results

At the end of each test session, the test participants took part in a semi-structured interview. The goal of the interview was to gather some qualitative data such as opinions about their experience from testing the application and some general feedback that could be of interest. The interview was audio recorded and the questions and answers can be seen in table 4.3.

**Table 4.3:** The questions and answers for the interview during UT2.

Question	Answers
Based on your previous experience of flying a UAV, has the application got any strengths that you believe would make it useful as an educational tool?	<ul style="list-style-type: none"> <li>• The controllers and the navigation of the UAV were quite realistic. It is good if you need to learn how to manoeuvre the UAV in preparation for a real flight session.</li> <li>• I think so, it is good to practice flying through courses. I have flown a lot of fixed-wing so this could be good for practising rotary-wing.</li> <li>• Yes, a big difference from the first time. It is much easier with the wireless controllers, maybe one could use a real UAV controller instead? It was a bit difficult to control the joysticks by holding them with two fingers, but you get used to it I guess.</li> <li>• I think it is a great product for beginners. It is a bit difficult with the virtual joysticks but the tutorial helped. It was completely different with the wireless controllers, it was both faster and more stable. In the future there will be people from different backgrounds and places who do not have a lot of experience with games or flying UAVs, and in those cases I think it will be good in order to gain understanding, especially when it comes to rotary-wing. It is more obvious what is front and back on a fixed-wing.</li> </ul>
Based on your previous experience of flying a UAV, has the application got any weaknesses or is lacking anything?	<ul style="list-style-type: none"> <li>• I think it needs to be less sensitive and more stable.</li> <li>• The last course, with the zigzag, it is too tight to be able to fly through it, in order for it to feel realistic. It was unclear if you were supposed to fly into the wall [checkpoint]. When you scan the floor, it turns blue and that became something to avoid. Now, all of a sudden you are supposed to fly into it.</li> <li>• It is a bit difficult to see, perspective-wise, when flying at the same height. I wear glasses sometimes so it is a bit difficult to see clearly. I recently got them and I'm still trying to figure out when to use them and when not to use them. Maybe a bigger tablet?</li> <li>• The last exercise, around the pillars, it was difficult to perceive the depth. I had to guess. It was difficult to see if you were following the green [path]. Maybe if it was at a different angle, in order to get a reference to the distance.</li> </ul>

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Table 4.3 – continued from previous page

Question	Answers
<p>In the questionnaire, we asked if you have a preference when it comes to using the virtual joysticks or the wireless controller, could you please motivate your choice? [All test participants preferred the wireless controller].</p>	<ul style="list-style-type: none"> <li>• More feeling in a physical joystick than on a screen. You can fly with much higher precision.</li> <li>• Gives more feedback and there's more resistance in the wireless controller. They also have more distinct boundaries than the ones on a screen.</li> <li>• It is easier to hold the wireless controller than the tablet. You can also stand more relaxed when you can hold the controller in your hands and look up at the screen at the same time.</li> <li>• Because of the feeling and the habit of using real joysticks both from Xbox and from flying UAVs. It feels more stable and it is easier to have more precision with real joysticks.</li> </ul>
<p>Do you have any other feedback that you'd like to share? Any feedback is welcome.</p>	<ul style="list-style-type: none"> <li>• In the second to last course it was difficult to see the distance to the UAV and the depth. Maybe if you rotate it a bit?</li> <li>• I think it is good with things like this. I think it could be helpful here at LUSA. It feels odd that the application does not follow [the UAV] and that you can fly off screen.</li> <li>• You get a good feeling of how to navigate and learn how to do it. It took a bit of time to get the hang of it in the beginning, with regards to the controllers and perspective. However, it did not take much time to learn.</li> <li>• I think it is a very good beginners guide for people without much experience with flying UAVs. I think it is useful to practice courses in different ways. It is still difficult to fly towards yourself. There is a big difference between fixed-wing and rotary-wing. It is clear what is front and back on a rotary-wing when it is up close. Otherwise you could test flying around a little. With this, if you let go it stops and you have to start over. With a fixed-wing there is no pause button. In the application you could let go, look at the screen and have to start over. This could cause some confusion.</li> </ul>

# Chapter 5

## Discussion

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*This chapter discusses the requirements, evaluation results, UCD process, choice of test participants, realism of the UAV, the AR medium and future work. It aims to connect the results of the project back to the goals and research questions.*

### 5.1 Requirements

Throughout the work process the client at LUSA has based most of their requirements on the checklist provided by the STA, and specifically the courses B7.1-B7.7. However, it was decided midway through the process that only the courses B7.1-B7.5 and B7.7 would be included in the final prototype, and that the remaining course (B7.6) would only be implemented if there was some time left. This was due to the nature of the course, which relies on the pilot navigating the UAV from a FPV through the UAV's camera only. Since this course is so different from the others, it would take a lot of time to investigate how this could be designed in a good way. If this was to be implemented, the user would only see what the virtual UAV's camera could see, which would be the virtual objects in the room and not the actual room itself nor the UAV. This could be problematic if there are not many virtual objects in the room, such as scanned floor or walls that could aid the user in orienting themselves around the area.

Therefore, the other courses may be more suitable for our application since the user can see the UAV itself as well as the surrounding area while being able to practice basic navigational skills and avoiding colliding the UAV with nearby objects. However, including the FPV as a feature while practising flying through more complex courses such as Course 6 and Course 7 might actually help the user in perceiving the depth. Course 6 and Course 7 have pillars that the UAV is supposed to avoid and the FPV feature could help the user in determining the distance from the UAV to such surrounding virtual objects.

During the early stages of the project, the client also requested that the application should be able to be used both indoors and outdoors. The application was mostly tested indoors, both during the design phase and during user tests. However, the application was also tested

by the ourselves outdoors during the design phase which resulted in the addition of a dark background for the instructions in order to make the text more visible.

At some point during the project, it was brought up that the client wanted the application to be useful in the later stages of the UAV flight training course at LUSA and not only in the early stages. The client wanted the users to be able to not only practise the skills required to fly a UAV, but also to be able to check that they have actually completed a certain course in the checklist from the STA and also how well they performed. The aim was to include these features in the final prototype, however, due to time constraints this was not accomplished.

Finally, the requirements that have been met are: the implementation of the courses B7.1-B7.5 and B7.7 from the STA checklist (Course 1-7 in the application), the ability to use the application both indoors and outdoors, and finally that the application would be useful in the early stages of the UAV flight training at LUSA.

## 5.2 Evaluation Results

Taking a step back and looking at the whole evaluation it can be argued that impressions were generally positive. While going through the different steps in the test case, testers managed to follow the instructions and perform the tasks without any bigger issues or need for additional instructions. When looking specifically at how well the testers managed to fly through the courses, there was a huge improvement compared to User Test 1.

This is interesting, since most of the testers were in the very beginning of their UAV training at UT1, and near the end of it at UT2. What this means is that they had had time to practice flying the courses in the STA checklist with a real UAV. Clearly, this could give them an advantage when it comes to understanding the courses in the application, since they are modelled after the courses in the STA checklist. This makes it hard to state that their seemingly improved proficiency at flying in the application is completely due to improvements made to the application since UT1. On the other hand, it could be argued that flying a UAV in the application resembles flying a real UAV to the degree that at least some of the skills translate between the mediums, which is promising.

When asked about the application's strengths as an educational tool, testers gave comments such as the application having realistic controls, being a good training tool, being a good product for beginners as well as being a good tool to prepare for a real flight session, as seen in table 4.3.

During UT1 many testers expressed that they would rather fly with a real controller as opposed to the virtual joysticks. This was implemented before UT2, but the test included flying both with virtual joysticks and a real controller. All testers in UT2 preferred to fly the UAV with the real controller as seen in figure 4.6. When asked why, feedback and the feeling of a real controller was mentioned.

One tester argued that it was easier to hold the controller than the iPad, allowing a more relaxed stance when flying. This was interesting since it not only raised the question of the ergonomic benefits of the controller, but also the ergonomic deficiencies of the iPad in this context. The way the application is designed, a user has to hold the iPad vertically in their hands, while at the same time using their thumbs to control the UAV and looking through the screen. It is easy to understand that mounting the iPad to a tripod and using a controller, which can be held in whatever height and angle feels comfortable, is an ergonomic improve-

ment. Another tester argued that the habit of using an Xbox controller contributed to them preferring the controller.

Combining the generally positive attitude towards flying with the real controller with the observation that all test participants were able to fly better in all regards (more stable, faster and with greater precision), it could be argued that it was a good idea to listen to the feedback from UT1 and implement it.

Moving on to the weaknesses or things that were missing in the application, there were many interesting answers. One test participant argued that Course 6 was too difficult to fly through, as the space between the obstacles was too narrow. Furthermore the tester argued that the task was unclear, since the scanned areas was blue, and so were the checkpoints in Course 6. The colour blue signified something to avoid, but in Course 6 it was something to approach. This raises the question of the importance of being consistent in when designing mappings, especially since the application does rely on separating objects and their actions by colour.

Lastly, the SUS score of 76 gives an indication of good usability, and backs up the feedback from the rest of the evaluation. Referring back to the grading of SUS scores in section 2.1.5, this means that the evaluation resulted in a grade that is greater than the limit for "Good".

## 5.3 The UCD Process

As previously mentioned, including the user throughout the whole process is the core of UCD. User testing can be designed in various different ways in terms of purpose and scope. In this project there were two main user tests. It could be argued that the process could have benefited from more frequent testing, as it would have allowed for issues, both small and big, to be discovered and resolved earlier. This is important since a small issue can grow larger as the rest of the design build upon it. While it is hard to state with certainty, several issues revealed in UT1 and UT2 could likely have been caught if more user tests had been included. An example is the issue of placing the UAV under the mesh.

Since time was a limited resource, more user tests would mean less of other activities. However, less structured, smaller scale user test could probably have been a great addition while not taking up as much time as UT1 and UT2.

## 5.4 Choosing Test Participants

Considering the UCD process applied in this project, it was planned from the start to perform user testing. It was debated whether to perform user testing on people that could be recruited easily in the vicinity, such as friends and/or LTH students, or to try to get as close to the end user as possible, it was decided to go for the latter. Both user tests were performed on essentially the same group of UAV pilots in training. These persons were visiting LUSA in Ljungbyhed for training at certain times during the project, and testing had to be planned around this, while also making sure our testing aligned with their schedule for the actual testing day. This also meant that the number of people available was limited, hence UT2 was planned for five people, and practical reasons during the user test resulted in four people being available for testing.

While having fewer test participants than desired, this arrangement enabled us to create a test plan that assumed both previous UAV flying experience, and experience of the very education that our application is designed to be part of, keeping the process connected to the end user.

## 5.5 A Realistic Virtual UAV

In order to address the issue from UT2020 and Iteration 1 with the UAV not feeling realistic enough to navigate, two main changes were made in the final prototype: a real controller that can be connected to the device, and an exponential response for the joysticks instead of a linear response. The test results from UT2 show that there was a great improvement in how realistic the test participants perceived the navigation of the UAV in UT2, compared to the previous user test.

As mentioned in the previous section, there were also requests to have a real controller in order to navigate the UAV. This received great feedback from the test participants where they felt an improvement in both precision and speed when navigating the UAV.

There were complaints on how sensitive the joysticks were when flying the UAV in both UT2020 (see section 3.2) and UT1 (see section 3.3.4). One test participant in UT2020 even claimed that there was a difference in the sensitivity of the controls depending on if the user navigated the UAV vertically or horizontally. Another tester in UT1 thought that the UAV did not act like a real UAV when stopping.

During the first visit at LUSA, when setting up and preparing the test environment for for UT1, we received some valuable feedback on our application from an employee there (who works with UAVs) on how to make the UAV more realistic. One suggestion was to re-map the output response from the input to the joysticks to a more exponential response instead of a linear one. This meant that for small input values to the joysticks, the output responses would be toned down, resulting in the user being able to navigate the UAV in a more controlled way with more precision. This was implemented in Iteration 2 for the final prototype (SUAV).

Although, there was a big difference in how the users expressed themselves when talking about their experience of flying the UAV between the UT2 and the previous iterations, there was one test participant in UT2 who thought that, although the UAV felt quite realistic to navigate, the same test participant mentioned that he would've wanted the UAV a bit more stable in order to have more control over the UAV when flying.

## 5.6 The AR medium

Designing this application with the augmented reality medium was a learning experience. The tools provided in Unity combined with Apple's augmented reality API, ARKit, made it surprisingly easy to get started. When realising how easy it is to overlay 3D objects on the real world, one could be fooled into thinking that the hard part is over, and that it is now just a matter of placing these objects in the right places. In reality, we learned that designing for AR came with a lot of benefits, but also many challenges, both of which will be discussed here.

A major strength of the way AR was applied in this project is the ability to connect with the real space around you. When combining the camera view with the LiDAR-sensor, this was taken to a next level. If the capabilities of the LiDAR-sensor had not been included, which has been tested during development, then it would have looked like you were flying in the room, but it would feel like you were flying in a picture of the room. Reasons for this is that the LiDAR-sensor makes it possible to create a mesh that receives the same lighting as the rest of the virtual objects and that the UAV can collide with the mesh. As such, the LiDAR builds a bridge between the real world and the virtual world, creating an immersive AR experience.

With this high level of spatial connection it is easy to view the application basically as a digital equivalent to the real world. However, in our prototype there are a lot of differences. The ability to judge depth, in practice meaning to intuitively and in real-time answer the question "How far away from me is the UAV?" has turned out to be a big one. While this issue was discovered already in the 2020 project, we have yet to design and implement a good solution for it. Two suggestions for potential solutions that were brought up during the project were to draw a line from the UAV to the next checkpoint and displaying UAV altitude and distance to then tablet.

Lighting is another area of weakness. In a virtual reality (VR) application it is possible to take full control of the lights, using for example a simulated sun along with various other light sources. In our application, there is an interesting interplay between what the camera sees: An area that might be illuminated by daylight and other lights from different angles, and the virtual overlay which is lit by virtual lights. This could mean that the UAV and obstacles are hit with light from a certain angle, while the real objects in the camera view are hit with real light from other angles, causing a disconnect between reality and virtuality. It should be noted that this project did not go into depth in this area, and that there might be solutions we have overlooked.

## **5.7 Future Work**

In this section we discuss potential areas for future work, including both further evaluation and further design ideas.

### **5.7.1 Further Evaluation**

In the future it would be interesting to evaluate whether using the application has any effect on flying a real UAV. This could for example be done through testing on two groups, A and B, without any UAV flying experience. First both groups could go through a test case (perhaps a number of courses) flying a real UAV, and metrics such as completion time and deviation from the path could be measured. Then group A gets to practice with the application for five hours, while group B does not. After this the first test with a real UAV could be repeated, to see if the groups progressed or improved in different ways.

## 5.7.2 Exploring other Devices

While this project used a tablet device, it could be interesting to explore other devices in the future. One interesting option would be to use AR glasses instead. This could make it possible to move around while using the application and at the same time fly with a physical controller, compared to the current situation where the iPad has to be mounted on a tripod when flying with a physical controller.

This project focused on using augmented reality, but virtual reality could also be an interesting technology for a UAV simulator. While the direct connection to the physical world would be lost, there are potential benefits to using VR, such as having more freedom in building the world and having more control over lighting.

## 5.7.3 Assessment Tool

The document for the STA courses is written as a checklist for self education. What this means is that a UAV pilot in training can work through the steps in the list to assess their own proficiency. This is a direction in which the application could be further developed in the future. Currently, the application tells the user to fly through a course while rotating the UAV in a certain direction. It does not, however, check that this was done correctly. The responsibility still lies on the user. Future work could include designing and developing a system that keeps track of these things. Was the correct rotation used at the right places? How much did the UAV deviate from the path in the course? Were the movements too fast or too slow? All of these metrics could be measured in the background while flying, and presented afterwards in a feedback screen, giving the user information about where they need to improve or practice more. With extensive testing, it would also be possible to set a passing level for these metrics. For example, when flying through a course, the UAV should deviate a maximum of 0.5 distance units from the path, or the UAV should deviate less than 10 degrees from the correct rotation.

## 5.7.4 Expanding the Target Group

In this project the end user was largely referred to as a student undergoing UAV pilot education at LUSA. These students often go through the education to fly UAVs for commercial or scientific purposes. Our application brings value to that process, but it could also bring value to future UAV pilots who learn to fly for private use. Therefore it could be argued that the actual target group is much larger than described in this project.

# Chapter 6

## Conclusion

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*This chapter aims to describe the degree to which the goals of this project were reached, and answer the research questions.*

The design and development of the prototype was successful. Based on testing there is reason to believe that the prototype is useful for the early phases of UAV flight training. The prototype makes it possible to practice UAV flying, cheaply, safely, and in practically any location. It was evaluated with generally positive results, and an average SUS score of 76 as a measurement of usability.

Based on the work in this project, there can be no hard conclusion drawn on whether skills from flying a simulated UAV in AR translate to flying a real UAV, but feedback from testers show promising results. Further work is needed to investigate this question.

Strengths and weaknesses of using the AR medium for UAV flight training were discovered continuously during all stages of the project and especially during testing. Realism is a big strength, as is the ability to create an interactive environment through the placement of 3D objects. Weaknesses mainly include realism aspects where there is work yet to be done and a need for new solutions, such as perspective, depth perception and lighting.

Some important design decisions that makes the experience of using the prototype closer to that of a real UAV are including a physical controller, the ability for the UAV to crash and interact with real objects and the exponential response curve for the inputs.

The AR environment is especially suitable for practising controls in a controlled manner, and learning the basics without any associated risk. In the future the application could be expanded to serve other purposes in UAV flight training, such as working as a validation tool. It could also be used as a training tool for a larger target group than defined in this project.



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# Appendices

# Appendix A

## Test Plan - User Test 1

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### A.1 Scope

Lund University School of Aviation (LUSA) educates students in navigating UAVs and has requested an application in Augmented Reality as a complementary tool that their students can use to practice their skills on. Our work has resulted in a early prototype of an application which we hope could later be used as a training tool for flying a UAV. The goal is to investigate how the AR application could be used as a complementary tool for the students at LUSA and to identify potential issues that may occur.

### A.2 Purpose

The purpose of this test is to explore the usability of the application and what difficulties users may have when using the application. The following list contains the main concerns that need to be addressed:

- Does the user understand how to scan the surrounding area with the LiDAR sensor?
- Does it feel realistic to fly the virtual UAV compared to a real one?
- Does the user understand the instructions for completing the course in the application?
- Are there any difficulties when choosing a suitable placement for the course/UAV?

### A.3 Schedule and Location

User Test 1 is set to take place at the facilities at LUSA the 28th of March (year 2022) between 14.00 - 15.00 and is scheduled for six participants. Each session takes approximately

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10 minutes.

## A.4 Sessions

Each test session consists of four parts and goes on for approximately 10 minutes. The session begins with the test moderator introducing the test team and the purpose with the test as well as giving a brief description of the prototype that is to be tested. This also includes informing the test participant of how the test will be recorded and letting the test participant sign an informed consent form.

The second part of the session is where the test participant performs the test. This part begins with the test moderator introducing the task briefly and encourages the test participant to think aloud during the test. The test moderator then starts the audio and screen recordings on the device. When the test participant is performing the test, the test moderator stands close by as support if needed and the observer takes notes during the whole process.

After the test participant has performed the given tasks, the test moderator asks the test participant for any spontaneous feedback on the prototype.

Lastly, the note-taker presents the questionnaire on one of the laptops while the test moderator prepares for the next test session.

## A.5 Equipment

The user test requires the following equipment in order to be performed:

- iPad Pro 11-inch (2nd generation)
- Laptop 1 - Notes
- Laptop 2 - Questionnaire
- Chargers to all of the above
- Consent forms x7
- Pens

The iPad Pro contains the version of the application that is to be tested. It is also used for screen and audio recording during the test scenarios as well as the audio recording of the feedback after the test. During the test sessions, one of the laptops is used by the observer for taking notes and the other one is used by the test participants when filling in the questionnaire.

## A.6 Participants

The target group of the application is primarily students at LUSA with the goal of learning or practising flying a UAV. Therefore, it is also the target group for this user test. The test participants are primarily chosen by the client, who is responsible for the UAV course at LUSA.

## A.7 Scenarios

During the user test, the test participant is expected to perform a list of tasks (see table A.1) while being encouraged to think aloud. The device records the screen and audio during the whole session.

**Table A.1:** A task list for testing the prototype.

Task	Description	Max. Time
Scanning	Walk around and scan the surrounding area.	1 min
Placement	Choose a suitable placement for the obstacle course.	30 s
Course Info	Read the instructions.	1 min
Course 1	Complete the course according to the given instructions.	2 min

## A.8 Metrics

The observer documents everything that could be of interest that occurs during the test scenarios (qualitative data). This includes comments from the test participants, hints from the test moderator and the test participants movements during the test. This is also collected through audio and screen recordings on the device. Qualitative data is also collected by asking the test participant for feedback after the test as well as through a questionnaire at the end of each test session containing some open-ended questions:

- (Have you ever flown a UAV before?) If yes, were there any differences or similarities flying the UAV simulator compared to flying a real UAV?
- Were there any steps of the application where you didn't understand what was expected of you? If yes, which steps?
- Was there anything that you felt was unclear while using the application?
- Do you have any suggestions for improvement?

## A.9 Quantitative Metrics

During the test session, the observer also documents and records (through audio and screen recordings) quantitative data such as the error rates, successful completion rates and time on task. The questionnaire at the end of each test session also contains some questions in order to gather more quantitative data:

- Have you ever flown a UAV before?
  - Yes
  - No
- How realistic did it feel to control the UAV?
  - Five point scale: Not at all ... Very realistic
- How easy was it to scan the room?
  - Five point scale: Very difficult ... Very easy
- How useful do you think that this application could be for educational purposes?
  - Five point scale: Not at all ... Very useful
- How helpful did you find the instructions for each section in the application?
  - Five point scale: Not at all ... Very helpful
- Do you think that a tutorial demonstrating how to control the UAV would be helpful?
  - Yes
  - No
  - Maybe

## A.10 Roles

The two authors of this report act as usability specialists during User Test 1.

William Rosenberg has the role of the test moderator which includes being responsible for introducing the test session, handing out the informed consent forms, encouraging the test participants to think aloud, handling the screen and audio recordings, resetting the settings between the different sessions, instructing the test participants throughout the session and acts as support for the test participants.

Fatima Sjögren Alpha has the role of the observer and primary note-taker which includes observing the test participants during the test sessions, documenting the outcome of the scenarios for each test participant and other observations that might be of interest and being responsible for presenting the test participants with the questionnaire at the end of the test session.

# Appendix B

## Test Plan - User Test 2

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### B.1 Scope

Lund University School of Aviation (LUSA) educates students in navigating UAVs and has requested an application in Augmented Reality as a complementary tool that their students can use to practice their skills on. Our work has resulted in a final prototype of an application called SUAV (Simulated UAV) which we hope could be used as a training tool for flying a UAV. The goal is to investigate how the AR application could be used as a complementary tool for the students at LUSA and to identify potential issues that may occur.

### B.2 Purpose

The purpose of this test is to explore the usability of the application and what difficulties users may have when using the application. The following list contains the main concerns that need to be addressed:

- Can the user navigate the application from the main menu without difficulty?
- Does the user understand how to scan the surrounding area with the LiDAR sensor?
- Does it feel realistic to fly the virtual UAV compared to a real one?
- Does the user understand the instructions for completing the courses in the application?
- Can the users follow the Tutorial without any help?
- Does the user find the Tutorial helpful in order to understand the rest of the application?



- Does the user prefer using a real joysticks rather than virtual joysticks on the device when flying the UAV?
- Can the user find the menu button easily in the Practice scene?
- Are there any difficulties when choosing a suitable placement for the course/UAV?
- Has the feedback from User Test 1 been addressed properly?
- Is there any difference in the performance between the participants based on previous experience with games or similar applications?

## B.3 Schedule and Location

User Test 2 is set to take place at the facilities at LUSA the 12th of May (year 2022) between 13.00 - 16.00 and is scheduled for five participants. Each session takes approximately 35 minutes.

## B.4 Sessions

Each test session consists of four parts and goes on for approximately 35-45 minutes. The session begins with the test moderator introducing the test team and the purpose with the test as well as giving a brief description of the prototype that is to be tested. This also includes informing the test participant of how the test will be recorded and letting the test participant sign an informed consent form.

The second part of the session is where the test participant performs the test scenarios (see table B.1). This part begins with the test moderator introducing the tasks briefly and encourages the test participant to think aloud during the test, while the primary note-taker starts the audio and screen recordings on the device. When the test participant is performing the test, the test moderator stands close by as support if needed and the observer takes notes during the whole process.

After the test participant has performed the given tasks, the test moderator presents the questionnaire on one of the laptops while the note-taker prepares for the interview.

Lastly, the interviewer conducts an audio recorded, semi-structured interview with the test participant as the final step of the test session.

## B.5 Equipment

The user test requires the following equipment in order to be performed:

- iPad Pro 11-inch (2nd generation)
- Laptop 1 - Notes
- Laptop 2 - Questionnaire

- Chargers to all of the above
- Tablet tripod mount
- Tripod
- PS4 wireless controllers (Sony DUALSHOCK) x2
- Consent forms x8
- Pens

The iPad Pro contains the version of the application that is to be tested. It is also used for screen and audio recording during the test scenarios as well as the recording of the interview (audio). During the test sessions, one of the laptops is used by the observer for taking notes and the other one is used by the test participants when filling in the questionnaire. During the test scenarios where the test participant uses the wireless controller as joysticks to navigate the virtual UAV, the iPad is mounted on a tablet mount that is fixed on a tripod.

## **B.6 Participants**

The target group of the application is primarily students at LUSA with the goal of learning or practising flying a UAV. Therefore, it is also the target group for this user test. The test participants are primarily chosen by the client, who is responsible for the UAV course at LUSA.

## **B.7 Scenarios**

During the test session, the test participant is expected to perform a list of tasks (see table B.1) while being encouraged to think aloud. The device records the screen and audio during the whole session.

**Table B.1:** A task list for testing the prototype SUAV.

<b>Task</b>	<b>Description</b>	<b>Max. Time</b>
Tutorial without wireless controller	<ol style="list-style-type: none"> <li>1. (Give the device to the test participant).</li> <li>2. Start the Tutorial from the main menu.</li> <li>3. Place the course.</li> <li>4. Fly through the basic courses.</li> <li>5. Scan the surrounding area.</li> <li>6. Place the UAV, avoid the scanned area.</li> <li>7. Crash the UAV into the scanned area.</li> <li>8. Place the course, avoid the scanned area.</li> <li>9. Fly through the advanced courses.</li> <li>10. Return to main menu.</li> </ol>	10 min
Tutorial with wireless controller	<ol style="list-style-type: none"> <li>1. (Place the device on the tablet mount).</li> <li>2. (Give the wireless controller to the test participant).</li> <li>3. Start the Tutorial from the main menu.</li> <li>4. Place the course.</li> <li>5. Fly through the basic courses.</li> <li>6. (Give the device to the test participant).</li> <li>7. Scan the surrounding area.</li> <li>8. (Place the device on the tablet mount).</li> <li>9. Place the UAV, avoid the scanned area.</li> <li>10. Crash the UAV into the scanned area.</li> <li>11. Place the course, avoid the scanned area.</li> <li>12. Fly through the advanced courses.</li> <li>13. Return to main menu.</li> </ol>	10 min
Practice with wireless controller	<ol style="list-style-type: none"> <li>1. (Give the device to the test participant).</li> <li>2. Scan the surrounding area.</li> <li>3. (Place the device on the tablet mount).</li> <li>4. (Give the wireless controller to the test participant).</li> <li>5. Place the UAV, avoid the scanned area.</li> <li>6. Return to main menu.</li> </ol>	2 min

Continued on next page

Table B.1 – continued from previous page

Task	Description	Max. Time
Courses with wireless controller	<ol style="list-style-type: none"> <li>1. (Give the device to the test participant).</li> <li>2. Press "Start" in the main menu.</li> <li>3. Scan the surrounding area.</li> <li>4. (Place the device on the tablet mount).</li> <li>5. (Give the wireless controller to the test participant).</li> <li>6. Place the course.</li> <li>7. Fly through course 1 to 7.</li> <li>8. Return to main menu.</li> </ol>	20 min

## B.8 Metrics

The observer documents everything that could be of interest that occurs during the test scenarios (qualitative data). This includes comments from the test participants, hints from the test moderator and the test participants movements during the test. This is also collected through audio and screen recordings on the device.

A semi-structured interview takes place after the test participants has performed all test scenarios (see table B.1) and filled in a questionnaire. The interview is recorded (audio) where the interviewer asks the following questions to the test participant:

- Based on your previous experience of flying a UAV, has the application got any strengths that you believe would make it useful as an educational tool?
- Based on your previous experience of flying a UAV, has the application got any weaknesses or is lacking anything?
- In the questionnaire, we asked if you have a preference when it comes to using the virtual joysticks or the wireless controller, could you please motivate your choice?
- Do you have any other feedback that you'd like to share? Any feedback is welcome.

## B.9 Quantitative Metrics

During the test session, the observer also documents and records (through audio and screen recordings) quantitative data such as the error rates, successful completion rates and time on task.

The test participants are presented with a questionnaire after performing the test, containing input fields for age, gender and occupation followed by the following questions:

- Have you ever flown a UAV before?

- Yes
  - No
- How would you rate your gaming experience?
  - Five point scale: No experience ... Very experienced
- How useful do you think this application could be as a complementary tool during a UAV course?
  - Five point scale: Not at all ... Very useful
- How much did you feel that the Tutorial (the first part of the test) prepared you for course 1-7 (the last part of the test)?
  - Five point scale: Not at all ... Very much
- Which input method do you prefer?
  - Virtual joysticks (on the iPad-screen)
  - Wireless controller
  - No preference

The questionnaire also includes a System Usability Scale (SUS) where the test participants submit their answers on a five point scale that ranges from Strongly Agree to Strongly disagree for the following ten statements:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

## B.10 Roles

The two authors of this report act as usability specialists during User Test 2.

Fatima Sjögren Alpha has the role of the test moderator which includes being responsible for introducing the test session, handing out the informed consent forms and questionnaires, encouraging the test participants to "think aloud", changing the settings between the different test scenarios, instructing the test participants throughout the session and acts as support for the test participants.

William Rosenberg has the role of the observer, primary note-taker and interviewer which includes observing the test participants during the test sessions, documenting the outcome of the scenarios for each test participant and other observations that might be of interest, being responsible for the screen and audio recordings as well as conducting the interview at the end of the test session.

# Appendix C

## Distribution of Work

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Both authors contributed equally to the project. When having meetings, the roles of moderator and secretary were switched around on a regular basis. Over the two user tests, both authors got to perform both roles of test leader and observer/note-taker. Both authors took active part in design and development.

