Bachelor Thesis

Exploring the interaction potential for drones in rowing

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Abstract

The integration of technology into professional sports has transformed many disciplines into high-performance scenarios with the goal of enhancing performance, increasing engagement or preventing injury. This presents a novel frontier for Human Machine Interaction (HMI) to create unique solutions for athletes, coaches and spectators.

Rowing, as an Olympic discipline, already employs various technological tools for monitoring and analyzing rowing behaviour. However, some of the existing methods like video analysis tools are often limited to an indoor environment, not suitable for the dynamic nature of rowing outdoors on water. Unmanned Aerial Vehicles (UAV), better known as drones have the distinct capability maneuvering freely in 3D space. They offer the unique possibility to track and monitor athletes from unique vantage points in real-time.

This thesis sets out to explore the potential for interactions between drones and rowers. The goal is to leverage the unique capabilities of drone technology to illuminate new ways for increasing either engagement, performance or learning within the sport of rowing. Qualitative research methods like expert interviews and a state-of-the-art review are used to gain knowledge about rowing and drone technology. An iterative design process is used to create a prototype that leverages the unique expressive capabilities of a drone to simulate a competitive racing scenario for the rower in Virtual Reality (VR). The results from an evaluation with 19 participants have shown a potential for increasing the engagement of rowers. Additionally, the drone was found to help athletes with pacing their own speed while rowing. Limitations were identified in connection to the ambiguity of some of the drone's actions. The individual's perception strongly influenced whether the drone's intentions were understood and how they were interpreted.

This study contributes to the growing field of HMI by offering a qualitative analysis of drone's potential to increase engagement and expand training methodologies for athletes and coaches in the sport of rowing.

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1 Introduction

1.1 Background

An increasing digitalization of our world is creating new opportunities for Human Machine Interaction (HMI). In sports many professional athletes depend more and more on technology to support them with monitoring their personal performance and tracking their training progress [1]. Rowing as a highly athletic and competitive Olympic discipline already makes use of these technologies with the help of different on-body and on-equipment sensors tracking kinetic, kinematic and spatiotemporal parameters [2]. Some of these new technologies like video analysis tools [3] rely on standardized camera setups when used for quantitative biomechanical analysis. This often limits applications to a controlled indoor setting not replicating the natural dynamic environment of rowing.

The usage of Unmanned Aerial Vehicles (UAV) commonly known as drones can potentially bridge this gap by creating the opportunity for athletes to be tracked or assisted in a dynamic outdoor setting. A drone's unique ability for free movement in three dimensions creates the possibility to view and track athletes from different vantage points. This increases its' potential for tracking and analyzing the dynamic movements of rower's. Additionally, a drone has the potential to communicate through physical motion like shown by Eriksson [4]. This could give a new meaning to Human Drone Interaction (HDI) by expanding the possibilities for interaction.

In the competitive arena of professional sports, even the slightest margin of error can determine victory or defeat, underscoring the critical role that additional UAV assistance can play. Leveraging new technologies like advanced video analysis techniques [5], drones can potentially offer valuable new training insights for athletes and coaches. They can elevate the experience and performance of rowers by attaining additional parameters informing their rowing behaviour. Improving the understanding of the rowing activity can not only elevate the experience of rowers and coaches but also help in injury prevention and rehabilitation.

1.2 Goal

The objective of this project is to further explore the potential for possible interactions between a drone and a rower. This will inform the design of a drone concept that alters the rowing experience to a desired effect identified in the Ideation phase of this project.

We hope by exploring possible applications within the sport of rowing, we help to illuminate the HDI space and contribute some practical knowledge for future HDI applications. Additionally, the gained insights could benefit the sport of rowing by contributing to a better understanding of rowing behaviour. Drones have the potential to be a new valuable tool in the hands of coaches and athletes and have a positive impact on performance, engagement and learning.

To address this objective, this paper first sets out to explore the needs and requirements of rowers in their natural training environment with qualitative research including interviews and literature research. Then the current state of the art of drone technology and their application in the field of HMI will be analyzed with a special focus on their ability for expressive movement. In the ideation phase of the design process stakeholder needs and requirements will be identified through interviews and observations. Then possible interaction scenarios between rower and drone will be generated and evaluated based on specific evaluation criteria. For the final step an application is chosen, implemented, and then tested with users to learn about the extent of its impact.

1.3 Research questions

The predefined challenges can be formulated into concrete research questions that need to be answered. As a defining question for this project the following needs to be answered:

Main question

- How can a drone enhance the rowing experience?

To answer this question in more detail, this project is divided into different phases, each being guided by their own research questions. The first phase of this project will focus on gaining knowledge by doing background research consisting of a literature review with special focus on HDI and rowing enhanced with technology.

Knowledge questions

- How are drones used in the field of HDI to alter a human's experience?
- How is technology generally used to enhance the rowing experience?

The second stage of the project is focused on the design and evaluation of a potential solution. The following needs to be answered:

Design question

- What is a good design for a drone setup assisting in a rowing scenario?

Design sub questions:

- What are possible interaction scenarios between rower and drone and what are their benefits and drawbacks?
- To what extent does the drone influence the experience of a rower?

2. State of the art

2.1 Related Work

2.1.1 RowerUp

RowerUp [3] is a rowing video analysis and telestration platform for coaches and athletes. The software is designed to analyze the kinematic and spatiotemporal parameters of the rowing activity (lateral) either on an ergometer or in a boat. It depicts relevant parameters for variance analysis of angles and positions of different body joints. Additionally, it illustrates the entire movement with a 2D animation in combination with a graph showing the speed and the sequencing of the back, legs and arms within the stroke. Then it compiles an overall efficiency score making it possible to compare the strokes with each other.

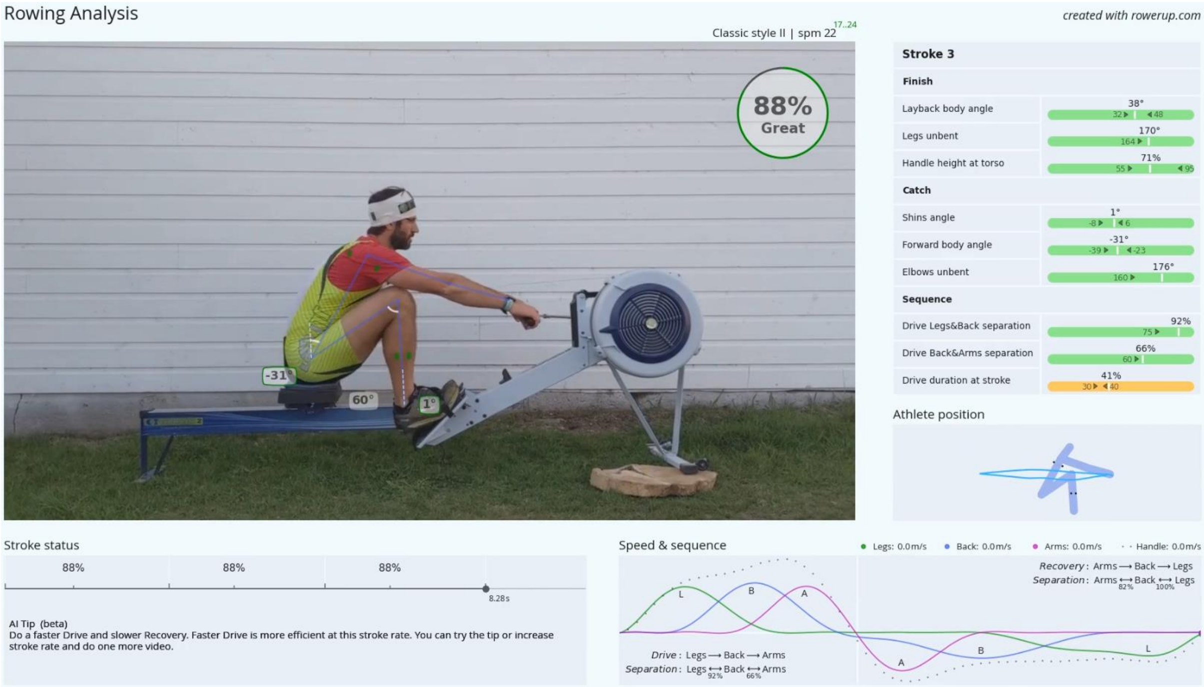

Figure 1: Feedback- Interface of the RowerUp platform

Overall RowerUp is an easy-to-use software, making it possible for rowers of different levels to analyze their rowing technique in more detail without the need for an additional coach. This greatly improves rower's options for improving their technique during training on their own.

A limiting factor of the software however is that it can only evaluate footage recorded from the lateral point of view. This limits the analysis to only 2 dimensions and therefore leaves potential for additional analysis including a third dimension. Additionally, the recoding angle and dimensions of the rowing setup can alter the results of the evaluation. It is not completely clear how these factors influence the evaluation within the software but an additional option to analyze footage taken from a 45° angle or a top view could increase applicability.

2.1.2 Rowing in Motion – Smartphone App

Rowing in Motion [6] is a smartphone application designed to provide real-time performance analysis for rowers and coaches. It aims to offer insights into various metrics of the rowing technique and performance through data collection and analysis. It makes use of many of the smartphone's sensors like accelerometer, gyroscope or GPS to record things like speed, stroke-rate and boat acceleration. In combination with its' web-based data analysis platform "Motion Analytics" it also analyzes how your performance evolves over time. Their application combines data collection, analysis and representation in one.

Figure 2: Rowing in Motion - Smartphone Application

The application also allows for additional attachments like heartbeat sensor to be integrated used and integrated into the analysis. It also includes the feature of "Sonification" [7], translating the boats acceleration into an audible sound for the athletes. Harnessing the additional sense of hearing for direct feedback on acceleration also free's the athlete from visual distractions. The software also lets you compare your training performances of multiple sessions allowing for the monitoring of the training progress.

Rowing in Motion's biggest advantage for athletes and coaches is the ease of use for their product. It increases the individual's capability for tracking performance without the need for any additional equipment. The accuracy of performance tracking is however limited to a single device (with possibly differing hardware) located at one position within the boat. Therefore, it does not track any biomechanical parameters relevant for correct execution of the rowing motion.

2.1.3 “Fast Athletics - Drone-based Motion Tracking”

A project within “Fast Athletics” from the Fraunhofer Institut IFF Magdeburg [5] is focused on optimizing a commercial drone system (DJI Mavic 3) to enhance the performance of a rowing athlete through biomechanical video analysis.

Their concept uses the existing DJI Onboard Software Development Kit SDK to equip a commercial autonomous drone with an additional payload of sensors and an external processing unit. The payload is aimed at optimizing target detection and tracking. It includes an Inertial Measurement Unit IMU, a RGB-D camera and a LiDAR sensor. Object detection and tracking is based on an optimized real-time YOLO-detection [8].

Figure 3: Concept for Drone-based Motion Tracking

The images are then processed by the external processing unit to create a 2D (max. 110 fps) or a 3D (max. 1.8 fps) representation used for performance analysis. Initial object detection issues were solved through iteration and real-time biomechanical analysis was achieved. They identified the drone’s constant speed, constant distance and constant angle towards the athlete to be main factors affecting the reliability of performance evaluation. The detection error between the athlete’s real joint positions and the recreated joints was identified to be a limiting factor for performance-based video analysis.

Implementation of the LiDAR sensor was not achieved due to weight limitations of the payload. The integration of the LiDAR sensor could potentially increase the drone’s ability to keep a constant distance and a constant angle towards the athlete. The additional depth information could also help to create a more accurate 3D reconstruction improving the accuracy of the whole system.

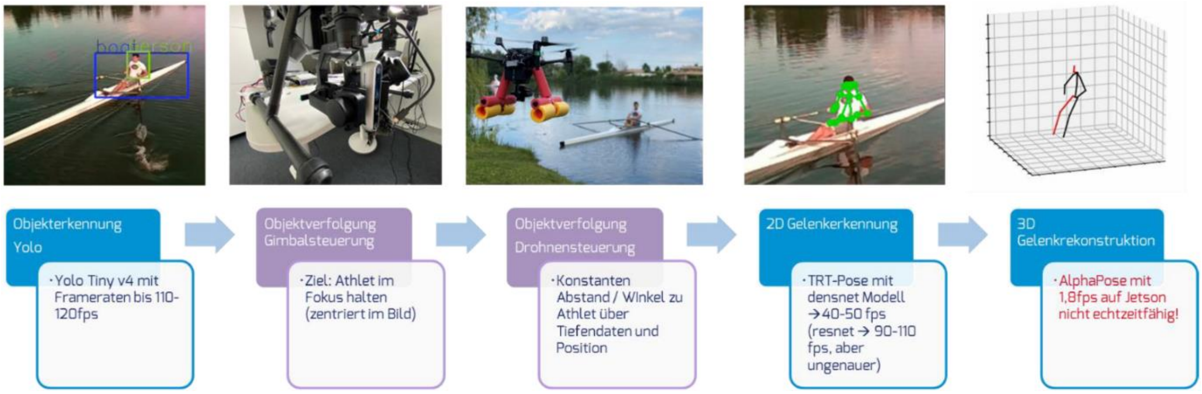

Figure 4: Iterative design process for biomechanical analysis

Overall, the drone system that was used to achieve reliable motion tracking and additional biomechanical analysis is highly customized. An iterative design process was used to adapt and improve the initial system to be able to produce reliable results. Comparable drone systems are not yet commercially available. Similar systems warrant a similarly specialized payload dedicated to the drone's intended purpose.

2.1.4 Conclusion

The sport of rowing has been around for a long time and even though the activity is still the same, new emerging technologies help to inform and progress the sport further. Many of the technologies used within rowing are either used to enhance rowing equipment, or to help athletes and coaches with understanding their rowing behaviour. Some of the most common technologies used are force sensors and GPS-trackers. They are primarily used for the collection and analysis of parameters relevant for the evaluation of the rowing performance. Performance is primarily evaluated with the help of spatiotemporal, biomechanical, and kinematic parameters. Video analysis tools like "RowerUp" [3] help to inform the rowing motion through analysis of biomechanical parameters from prerecorded footage. A smartphone app like "Rowing in Motion" [6] is easy to use and it combines tracking and analysis of kinematic and spatiotemporal parameters in one application. The drone has the potential to be a valuable new tool in the hands of coaches and athletes. It was shown that it can capture standardized video recordings of dynamic motions [5]. This would help to detail the overall understanding of rowing behaviour by providing complementary biomechanical information for performance analysis.

2.2 The rowing motion

The ideation process for a possible interaction scenario between a rower and a drone requires an understanding of the rowing motion. There is a huge corpus of research on what factors are important for an ideal rowing technique. For this exploration we will focus mainly on qualitative factors with a general consensus rather than quantitative details. As a reference we will use information from [9].

The classic rowing stroke is typically divided into four phases consecutively forming a cycle where the main muscle groups legs, back/core and arms are activated in order:

- The catch
- The drive
- The finish
- The recovery

The *catch* is the starting position of the rowing stroke where the rower is coiled forward on a sliding seat with knees bent and arms stretched out. At the catch, the athlete drops the oarblade vertically into the water to initiate the drive.

At the beginning of the *drive* the legs do most of the work while the back is kept straight. As the upper body begins to uncoil, the arms start working by additionally drawing the oarblades through the water. Continuing the drive the hands are moved quickly in a straight line towards the body while the body is getting into a slightly laid-back position while keeping the core activated. At this point the shoulders are slightly behind the hips.

During the *finish*, the oar handle is moved down, to draw the oarblade out of the water. At the same time, the rower turns the oar handle, so that the oarblade changes from a vertical to a horizontal position.

The oar remains out of the water as the rower begins the *recovery* phase, moving the hands away from the body and past the knees. The body follows the hands, and the sliding seat moves forward until the knees are bent and the rower is ready for the next catch.

The overall execution of the rowing sequence requires smooth transitions between the activation of the different muscle groups optimally resulting in one fluent motion. Soper et al. [10] presents a comprehensive analysis of biomechanical factors contributing towards ideal rowing performance.

Even though the rowing stroke is executed in one fluent motion, the force the athlete applies to the water describes a curve with the endings being minimums and the maximum roughly around the middle like seen in *Figure 5*.

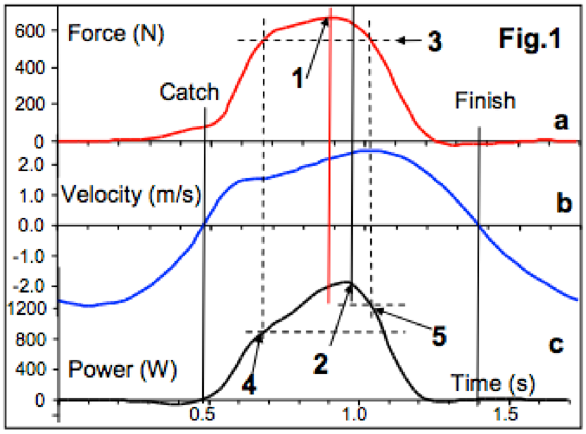

Figure 5: Force, Velocity and Power during a stroke [11]

This creates a slight offset between acceleration of the boat and acceleration of the athlete which could be an important detail when evaluating the position and performance of the whole boat versus the athlete.

Baudouin et al. [12] have investigated biomechanical parameters which are the most relevant for evaluation of the rowing performance. It was found that "the total propulsive power developed by rowers, the level of synchronization between rowers and the total rower drag contribution" were key factors. This gives an indication to what elements of the rowing motion are most relevant for a drone to assist with biomechanical analysis.

Bell et al. [13] have evaluated two different lean back positions during the finish phase. In contrast to the "normal" upright body posture, a more "leaned back" position has shown to produce a higher power output and improved efficiency at the same stroke rate. As a drawback the energy expenditure is comparable higher for the more leaned back position. The concept of energy expenditure can potentially be interesting to explore with a drone, even though technologies like thermal imaging might be needed to detect a body's physical activity.

2.3 Literature Review – Drones and Rowing Technology

2.3.1 Drone Applications in the field of HDI

UAVs have developed from remotely controlled vehicles to being able to act fully autonomously. Over time technology has fueled the capabilities of drones immensely. The increased research in this field has evolved them into small, cost-efficient, high-speed, high-range flying assistants. Their free range of movement and the increasing usability of autonomous drone systems makes them adaptable to very different situations. Herdel et al. [14] have studied many of these domains and give a categoric overview of the fields of application. They noted that in many cases "Interaction techniques are being designed, developed, and evaluated in isolation from applications and domains", meaning that in many cases the interaction context between human and drone is not always clear. Their paper highlights the drone's functional role within the interaction presenting a categoric approach including seven metaphors as a high-level perspective on the diverse roles and capabilities of drones in HDI research as seen in figure 6.

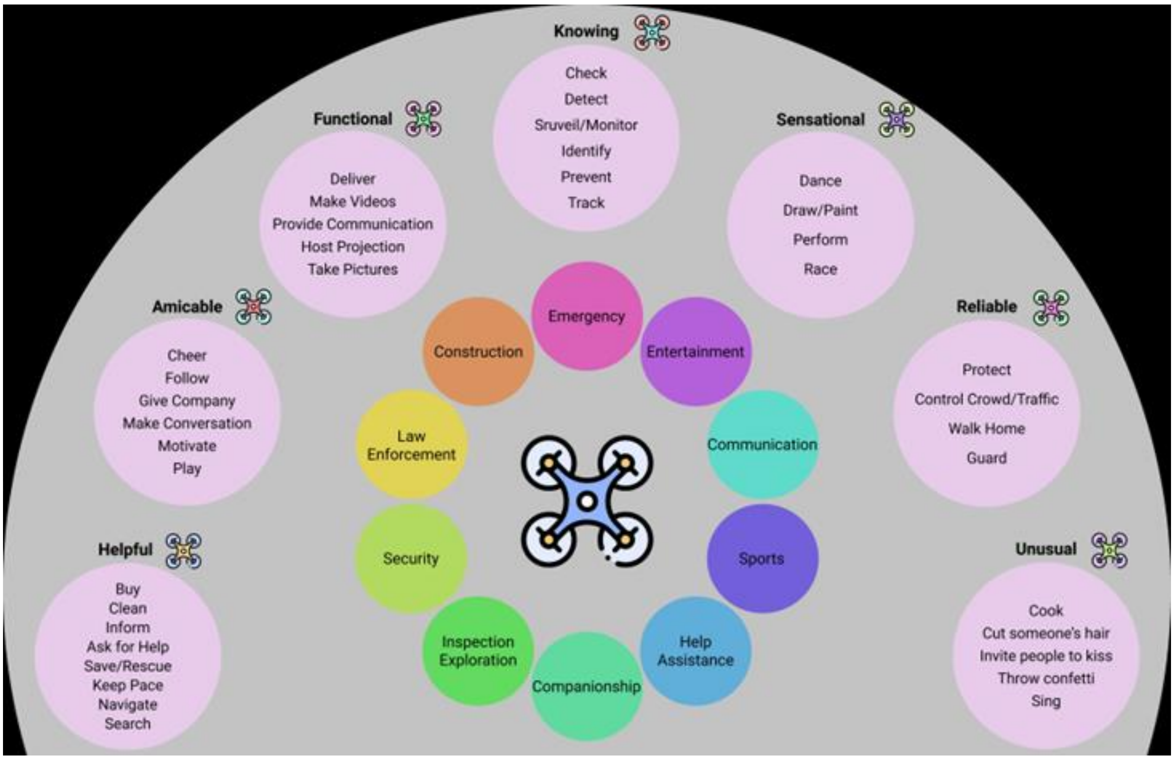

Figure 6: Seven drone metaphors [13]

Their review found that most applications within the field of HDI are in the Emergency sector (15.6%) followed by Entertainment (14.5%) and Communication (10.9%). They can be used as an emergency tool for quick responses in cases like Seguin et al. [15] to quickly deliver a floating device to a drowning victim. In this case the interaction between human and drone is "forced" upon the human without any specific interaction requirements towards the human.

The following three sectors from [14] are Sports (10.0%), Help/Assistance (9.7%) and Companionship (8.3%) affirming an already existing exploration space for drones being used in sports with the capacity to assist or accompany a human. Applications can be found in various sports like running [16–18], Tai Chi [19], hiking, climbing, skiing, dancing [4] and rowing [5]. Their role and tasks strongly differ depending on their purpose and the environment they are used in.

Baldursson et al. [17] have explored a drone's potential to mediate a running group with the visual projection of a circle around the runner. Individual pace is indicated by projecting the circle either more in front or more in the back. This let's runners adhere to the same pace settings remotely without the need to be present with the rest of the group. In addition, Van Son et al. [20] have shown the improvement of youth middle-distance runner's pacing performance by following a drone over a 1500m run. The drone's constant speed was a crucial factor for most of the runners. This study shows a focus on an interaction promoted by the drone (differing projections) with the human reacting to the drone by adjusting his pace.

Seuter et al. [16] have researched an inverse interaction scenario where the human is the actor and the drone is the reactor. They remark that common tools for controlling a drone like remote controllers or smartphone applications are not suitable while running. They explored participants intuitive connection of hand gestures with possible commands for the drone. Most hand gestures were aimed at navigating the drone to a different position, or performing an action like taking a picture or recording a video. Their research indicates high potential for a drone being controlled with hand gestures, but also highlights the complex nature of translating a control command into a clear and easy to detect hand signal.

Cauchard et al. [21] have explored the potential for a visual and gestural interaction interface equipping an autonomous drone with both input and output capabilities. Their testing was done in low lighting both indoors and outdoors, mimicking an application in for example a search and rescue operation at night. Participants were able to use hand gestures to navigate a ground-projected menu and initiate commands for the drone. The projections from the drone hovering closely above them did not bother them also highlighting the potential for interactions at close ranges (<5m). The interaction with the redial menu felt intuitive for most of the participants but there were some issues with the orientation of the menu sometimes changing. The projected interface also being visible to bystanders sparked a gathering around the user fostering increased conversation and exchange. The visibility of a projected user interface in brighter environments like on open water is still a limiting factor for a possible application in rowing. Additionally Azmat et al. [22] shows that technologies like machine learning can be used to warrant a more reliable recognition of human actions and motions. In retrospect Bevins&Duncan [23] indicate that natural communication from drone to human is still underexplored. Various flight patterns were tested to understand how humans would naturally interpret them. It was found that most patterns were interpreted as a command for "do not follow" or "landing". A main distinction between patterns was made by seeing them as a positive signal (like “look here” for the drone moving up and down over a location) or a negative signal (like “danger” or “do not follow” for the drone, moving left to right). Communicating clear commands with the movement of a drone alone seems to still be limited with the main issue stemming from there being no clear framework or guidelines for humans on how to interpret flight patterns.

The exploration of the preferred interaction space of a drone for running by Balasubramaniam et al. [18] has shown that runners preferred the drone slightly above head level (2m) at a distance between 8-12m and an angle of 45° to the running direction. Runners also preferred having both, the sagittal and the frontal view of their running activity, indicating that different perspectives can be helpful for evaluation of different parameters.

A drone can also be used to instruct an athlete’s movements like shown by La Delfa et al. [19]. They have translated the hand movements of a Tai Chi teacher by replicating it with a drone. The student can then follow the instructed moves of the drone while receiving visual feedback (LEDs) about the smoothness of his motions. The idea of extending or replicating motions of the physical body through a drone’s expressive movement holds great potential for new ways of instructing exemplar movement. The extent of the drone’s accuracy in embodying movement is still unclear but also crucial when embodying a “perfect” example.

Eriksson et al. [4] have explored drones in their capacity to perform a dance with a human on stage. They found that there exists an “Intercorporeality” between human and drone that needs exploration and practice to be understood and used for purposeful performance. Their process included iterative feedback from the performer to the drone engineer, to alter the drone’s behaviour based on the performer’s movements. Their study highlights a drone’s potential for performance through expressive movement. It also indicates the need for an iterative process to understand how to properly relate movements between performer and drone for the intended purpose.

Despite the rapid technological advancements in the field of HDI, personalized control options specifically tailored for the purpose of the application are still limited. One main issue for this are the drone’s requirements varying with the purpose of application. Clear identification of the drone’s purpose within the interaction context helps to derive necessary specifications for the drone setup. The unique ability of a drone to move freely in 3D space makes it highly adaptable to dynamic environments like in outdoor sports. Even though the free movement of the drone seems to be its’ most valuable feature, it also is an aspect highly relevant for the accuracy of performance analysis through recreation of biomechanical motions. The free (and possibly autonomous) movement of a drone is in most commercial applications not reliable enough to be used for performance analysis. The design of different control mechanisms and follow patterns with a constant speed, a constant angle and a constant distance towards the athlete can improve reliability for detailed performance analysis.

2.3.2 Rowing enhanced with technology

The sport of rowing has seen substantial technological advancements in recent years, particularly in areas that enhance training, performance analysis, and equipment efficiency. These advancements are largely focused on increasing the precision of performance metrics and enhancing the training experience for athletes. This review delves into various technologies currently utilized in rowing, based on recent academic literature.

Rowing performance can be intricately measured using an array of technologies such as GPS trackers, force sensors, and ergometers. These devices allow for the detailed analysis of stroke rate, boat speed, and force application, providing athletes and coaches with actionable data to refine techniques and strategies [24]. Moreover, the implementation of real-time feedback systems, such as the acoustic feedback system “Sofirow” [7], offers on-water training enhancements by audibly representing the acceleration patterns of the boat. This additional sensory information can aid in the correction and synchronization of rowing strokes.

Advances in biomechanical analysis have been pivotal in enhancing athlete’s mechanical efficiency and skills training in rowing. Technologies that provide real-time biomechanical feedback help shorten the feedback cycle between athlete and coach, enabling immediate adjustments that can lead to significant improvements in performance. The use of high-speed imaging and specific calibration methods allows for precise extraction of kinematic data, which is crucial for technical analysis and injury prevention shown by Xia [25]. The resulting output of the biomechanical analysis can vary depending on the methods used for the analysis. The camera settings, relative movements between camera and target and the digital tools used in post-processing, like video stabilization or model recreation are potential factors influencing the result.

The development of rowing simulators and ergometers that mimic on-water conditions has also been significant. These devices not only replicate the physical dynamics of rowing but also allow for detailed performance tracking. Temraz [26] has shown the effectiveness of using ergometers to develop aerobic capacity and technical skills, providing athletes with feedback that can be used to adjust their training in real-time. The simulation of the rowing activity has also found digital application in the form of Virtual Reality. VR technology is providing immersive training experiences that replicate the complexities of on-water rowing. These simulators allow athletes to train under varied environmental conditions without any logistical constraints. By improving technical skills and mental preparedness, VR contributes significantly to an athlete's performance during actual competitions [27].

The integration of wireless technology and sensor networks on the body as well as on rowing equipment provides a comprehensive view of athletes' physiological and biomechanical status during training. This technology enables the synchronous collection of multiple data, enhancing the understanding of muscle dynamics and rowing mechanics. Such detailed analysis aids in optimizing training regimes and preventing injuries, ensuring athletes perform at their peak while minimizing the risk of strain [28].

The Internet of Things (IoT) has found applications in rowing through the development of systems like the rowing propulsion monitoring system. This system utilizes onboard IoT devices to collect and analyze data such as stroke rate and boat acceleration in real-time. The insights gained from this data help in crafting personalized training plans and optimizing performance strategies [29].

The use of technology in rowing has not only enhanced the way athletes train and compete but has also provided coaches with deeper insights into rowing behaviour. The main purpose for most technologies are to analyze performance, prevent injuries, track motions, visualize feedback and improve general engagement in rowing. As technology continues to evolve, its' integration into rowing is expected to further develop this traditional sport into a high-performance scenario, making it more precise, safer, and potentially more exhilarating for both athletes and spectators.

2.3.3 Conclusion

The goal of this literature review was to explore the interaction potential for a drone in rowing. Therefore, we firstly wanted to get an overview of drone applications within the realm of HDI altering the experience of a human. Secondly, we wanted to find out how technology is currently used in the sport of rowing to improve performance or enhance the rowing experience.

From the research it is found that drones are being used in various environments performing tasks ranging from emergency responses [3] to sports companion [4]. Studies highlighted how drones can facilitate interaction between athletes and coaches, help to track performance, provide real-time feedback, and even replicate movements for instructional purposes. A drone's free movement eliminates the physical constraints that many video capturing systems have making it a valuable new tool in the hands of athletes and coaches.

Moreover, the review elaborated on the use of technology in rowing, showcasing how tools such as GPS trackers, biomechanical analysis systems, rowing simulators, and IoT devices have revolutionized training and performance analysis in the sport. These technologies have enabled athletes and coaches to gather more precise data, optimize training regimes, and prevent injuries, ultimately aimed at enhancing performance on the water.

Drones can be used in rowing to enhance performance by complementing current technologies like video analysis tools with new footage taken from standardized perspectives unique to a drone. Multiple perspectives of the same activity can help in collecting additional data points like angles in three dimensions allowing for a more detailed performance analysis. Some relevant parameters for the characterization of the rowing motion are partly obscured in the sagittal plane. The view from above could help to track complementary angles between boat and oar, and track the position of joints and angles in legs and arms during the stroke. A more complete analysis of the rowing motion in general will contribute to the general well-being of rowers.

Another possible application in rowing could be the extension or embodiment of an athlete's movement or performance like proposed by Eriksson et al. (2019). This could help the athlete to focus on improving a specific part within the cyclic motion.

Many drone systems are still designed with general applicability in mind. But many of the drone's potential capabilities are not yet integrated into customized solutions like a "performance analysis drone" or a "motion embodiment drone". Therefore, the design of drone setups should be tailored specifically with the purpose in mind. Even though not often mentioned in research, rules and regulations are often still a limiting factor for drone applications in urban areas and for commercial purposes. With society's rapid technological adaption however newer drone systems that are even more secure could soon reduce this logistical barrier.

An interesting direction for future research could be the improvement of intuitive control options for drones. New techniques like machine learning could also help to expedite more accurate detection mechanism for gesture control.

3 Methods and techniques

This section will further elaborate on the methods and techniques used. The structure of this report is closely following the Creative Technology Design Process (CTDP) [30] which can be seen in figure 7.

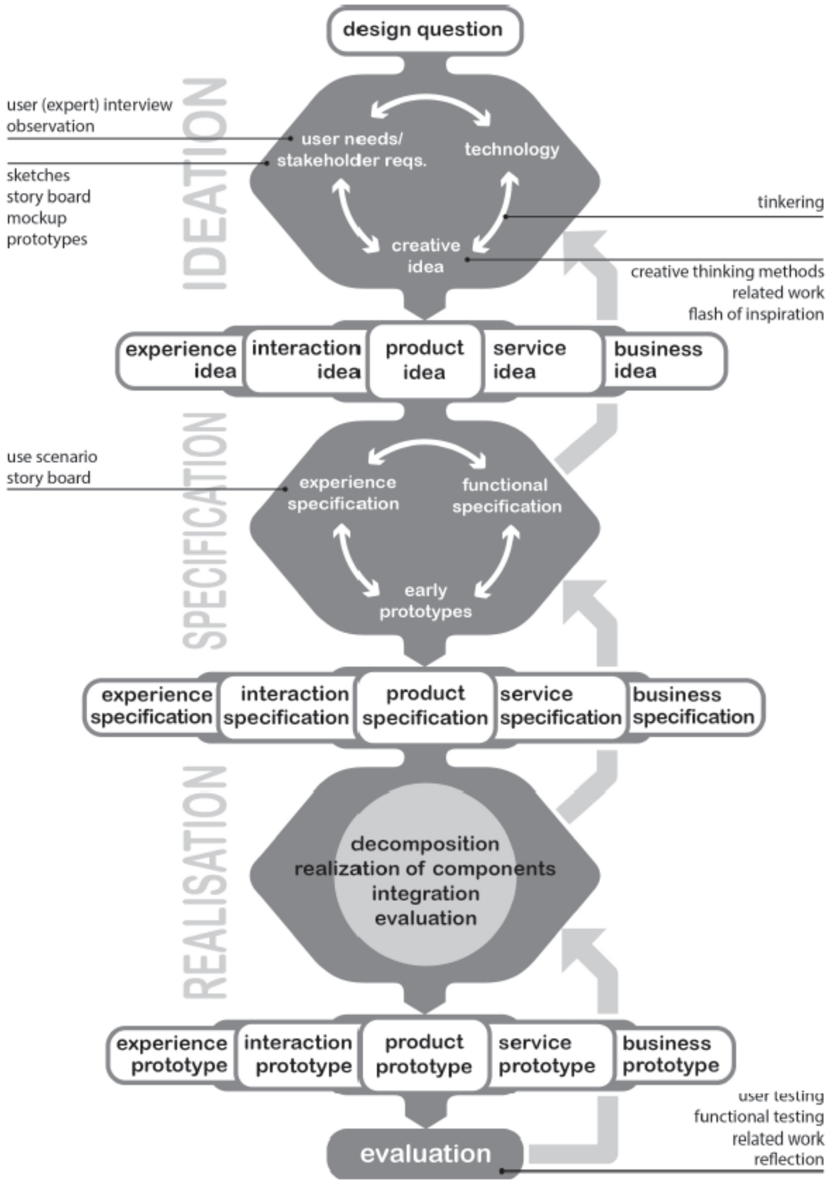

Figure 7: The Creative Technology Design Process [30]

This process stands as a fundamental framework utilized within the Creative Technology Bachelor's program. This design method will first diverge to explore the problem statement with all its' facets and then converge to propose a final concept as a solution. The process delineates four principal phases: Ideation, Specification, Realization, and Evaluation. The Ideation phase holds ground for brainstorming and conceptualization, where diverse ideas and potential solutions take shape. Subsequently, the Specification phase delves deeper into the chosen concept from the ideation phase, determining more detailed requirements for a prototype. The Realization phase is where the concept materializes into tangible form. Throughout this phase the specifications are refined with the help of incremental adaptations streamlining the final design. The Evaluation phase assesses the realized solution through comprehensive testing and critical appraisal in the final stage of the project.

In addition to this primary methodology, there were also other methods used. An initial mind mapping (Appendix E) was done first to get a more structured overview over drone functions and rower's requirements.

3.1 Ideation

The goal of the ideation phase is to find potential concepts to answer the design question posed in chapter 1. This will be done in 5 steps. The first three steps are dedicated for diverging and the last two steps are dedicated for converging ideas into a final concept.

Step 1: Categorize the needs and requirements towards rowing technology with the help of expert interviews and literature

Step 2: Delineate the functional roles of a drone from literature and expert interviews

Step 3: Generate potential interaction scenario

Step 4: Mix & match scenarios to create concepts

Step 5: Evaluate potential concepts based on predefined criteria and choose one

3.2 Realization

The Realization phase of the design process will start with delineating initial considerations that were made for the realization of the prototype. This section will contain specifications as well as an explanation of how they affected the final design. Additionally, the implementation process of the main design elements for the prototype will be described.

3.3 Evaluation

In the Evaluation phase of this project the resulting prototype will be tested with participants in an explorative usability testing. The goal of the evaluation is to answer the design sub-questions posed in chapter 1.3. The benefits and drawbacks of certain drone interactions are already partly explored in the evaluation of the different potential concepts. However, the chosen interactions will additionally be evaluated by participants during the usability testing. This will give additional insight into how the drone's actions are perceived by the rower. The second part of the evaluation is aimed at answering the second design sub-question focusing on how the drone actions affected the rower during the session.

4. Ideation

4.1 Rower's needs and requirements

The insights from interviews held with experts in the field of high-performance rowing have shown that the overall needs and requirements in rowing are mainly comprised of the athlete's, the coxswain's and the coach's requirements towards technology (Appendix A). A distinction between these will be made to help categorize their requirements towards technology individually. There will be no specific distinction based on the different rowing disciplines like sweep rowing or sculling. There will also be no distinction on different boat classes like single, double, quadruple, octuple (with or without coxswain).

4.4.1 The rower

The main requirements identified for the rowing athlete are the following:

- Improve Performance
- Stay in rhythm with crew
- Prevent Injuries: Athletes must maintain a good physical health and fitness to prevent injuries. This includes training practices for strength and coordination, proper nutrition and rehabilitation techniques
- Exercise: Even though this is apparent, the average rower is not primarily trying to improve his rowing performance but is focused on exercising his body to help with mental health
- Compete: A human's inherent motivation to compare himself to other's makes the element of competition a highly motivating factor within sports.
- Fun and Play: Although there is no direct need for fun and play in the sport of rowing, it can be an important tool for exploring new technologies and increase engagement.

4.4.1 The coxswain

The coxswain in rowing is an additional athlete in the boat who is not directly dedicated towards the propulsion of the boat. He is sitting at the back of the boat facing the other direction to be able to communicate with his crew. The coxswains' main requirements are:

- Navigate the boat: The coxswain has the responsibility to keep the boat in the right direction by steering with his hands and potentially even his feet (possibly less accurate). He tries to keep the steering to a minimum to reduce drag.

- Keep the crew in rhythm: This is often done vocally with or without headset. It can include directing members in the rowing crew individually and communicating the progress and position within a race.
- Motivate the crew: Personality and determination are possibly some of the characteristics most important as a coxswain. A coxswain should be energetic, persistent and charismatic in order to effectively lead a crew of rowers
- Keep track of position: The coxswain should be aware of their position within a race for example. This means the coxswain has to be able to shift his focus to keep track of his own crew but also of the position of rival boats.
- Communicate feedback: This includes informing the crew with the most adequate and beneficial feedback depending on the situation

4.4.2 The coach

In high-performance sports the coach plays a very crucial role. Some of his main responsibilities are the following:

- Analyze & improve performance: He uses his experience and available technologies to track and analyze the performance of rower's individually but also as a working whole.
- Keep track of athlete's wellbeing: He is partly responsible for the athlete's wellbeing which means creating training plans, tracking fitness and health and communicate recommendations to athletes
- Keep track of new advancements for rowing equipment or rowing technology
- Manage the rowing equipment: This includes managing the setup of the boat, keeping track of the equipment's condition and adjusting based on performance evaluation

4.2 Identification of drone functions

The distinction between the following drone roles and their functions was made with the help of applications found in literature and interviews with drone experts:

<u>Tracker:</u>

The drone is used to track dynamic motions or dynamic environments.

<u>Communicator:</u>

The drone is used to communicate information through visuals, haptics, audio or expressive movement.

<u>Measurement Tool:</u>

The drone is used to measure things like distances, speeds or the shape of terrain.

Informant:

The drone is used as a flying informant to investigate dynamic environments and perform status updates for dynamic situations.

Navigator:

The drone is used as a tool for navigation. It can be used to scout locations or explore new environments that are otherwise hard to reach. It can also be used as a guide for others to follow its path.

Performer:

The drone can be used to perform certain tasks or motions. The drone can use expressive movement to embody, extend or amplify motions.

Detector:

The drone is used to detect motions, objects, faces and more. They can be used to monitor areas of interest and watch out for activities etc.

Assistant:

The drone can be used to assist a human in various ways. It can deliver objects, run errands, or deliver or record messages.

Impersonator:

The drone can impersonate a potential entity like a friend, or rival.

Motivator:

The drone can be used to motivate a human by e.g. giving company or cheering to a human.

4.3 Generation of potential interaction scenarios

This step of the ideation is focused on diverging, as described in the CTDP [30]. It aims at generating potential interaction scenarios between rower and drone. The initial goal is to explore as many potential interactions as possible to have enough input for a subsequential mixing and matching of scenarios. For this purpose, an interaction matrix will be created, correlating a drone's possible functions with the needs and requirements within rowing. The resulting table can be found in figure 8.

Figure 8: Matrix of interaction scenarios

4.4 Potential Concepts (Mix & Match)

The interaction scenarios created in 4.3 are now mixed and matched with each other to create potential concepts. The benefits and drawbacks of each concept will be considered to help with the evaluation of potential concepts. Subsequently a concept is chosen based on some predefined evaluation criteria.

Concept 1 - "Impersonation of a cheeky rival"

This drone aims at impersonating a rival for a rower to compete with. It will start a race with the rower on a designated cue (possibly vocal). The drone will start next to the boat and anticipate the direction in which the boat is going. Within the race the drone will try to perform a thrilling head-to-head race with the boat. It will change its acceleration pattern to be slightly ahead of the boat or fall behind for dramatic purposes with the intention of engaging rowers with the illusion of a competition scenario. Additionally, the drone can use tactics like making taunting maneuvers similar to an annoying fly circling over your head to engage the rower in the race emotionally.

Benefits:	Drawbacks:
- Simulates a competitive scenario - Potential to increase engagement - Uses expressive movement to communicate - Helps with pacing - Humans love to play (Gamification)	- Special maneuvers by the drone could drain the battery quickly - The effects of the drone motions should be evaluated to guarantee the right purpose

Concept 2 – "Synchronicity Aid for coxswain"

This drone will try to assist the coxswain by communicating information on the synchronicity of the rowers. It will have an autonomous follow mode with a standardized perspective to help indicate which rower is out of rhythm and inform the coxswain whether he has to speed up or slow down. This could be done with a top view of the boat capturing the angular motion of the oar blades. The tracking of angles would give an indication on their stroke synchronicity. The feedback could be provided visually by displaying instructions on who should speed up or slow down to get back into rhythm. The aim of this application would be to provide the coxswain with a more detailed picture of the crew's synchronicity.

Benefits:	Drawbacks:

- It can help to reduce the amount of tasks the coxswain has to perform simultaneously so he can focus on other tasks. - Has potential to improve performance directly	- Potentially post-processing for detection of oar angles required - Similar information can be collected from force sensors in oar joints (high performance) - This application is aimed at high performance and might not have much value for the regular rower

Concept 3 – "Pervasive Instructor"

This drone aims at creating an interactive learning environment for a rowing beginner or even a group of rowers. The drone will act as a flying interactive teacher. It will teach basic knowledge about rowing including how to perform a correct stroke and what to focus on during the motion. It could also teach some historic facts about rowing history like famous competitions and the evolution of the sport in between. The rowing lesson could be designed to have interactive features like giving answers to quiz questions of the drone. Another possible interaction fitting this concept could be the tracking of engagement of rowers by evaluating position or motion. The drone could call out individual rowers if they do not follow the instructed activity. The drone would also benefit from having a unique personality with some characteristic traits (like cracking bad jokes, being dramatic or acting annoyed) to make the interactions more natural.

Benefits:	Drawbacks:
- Potential to increase self-reflection and awareness and promote inclusion into the collective learning experience - It could be used by rowing organizations and schools to guide beginner's efficiently and remotely - Can increase engagement and learning in a group	- A drone might not have enough authority to be taken seriously / listened to - You can't force rower's to listen

Concept 4 – “Condition Checker”

This drone aims at collecting as much data about the rowing conditions as possible. It would check for activity on the water like how many other rowers are currently training. It could collect live weather data like wind conditions, light conditions, water conditions and more. The gathered information would be sent to an external device that would inform coaches when to plan training sessions and what the specific conditions for each training was. This could help with evaluation of the training performance in relation to the environmental conditions. This information could act as a guidance to see what conditions the rower is struggling with and help to focus the training plan accordingly.

Benefits:	Drawbacks:
- Can give a reference what conditions the rowers struggle with - Can help to plan training in varying training conditions	- Not a unique solution since weather stations are a similar solution - There is no direct interaction between drone&rower

Concept 5 – “Fitness Coach”

This drone will try to motivate a rower to reach a predefined fitness goal. The drone will track the total distance travelled by the rower with GPS or use a thermal imaging camera to evaluate physical activity. The drone will follow you around while you row and remind you of your daily goal. The drone will try to motivate you with different psychological tactics to keep you engaged in the rowing activity. When the drone detects that you have reached your daily fitness goals it will reward you with some impressive flight patterns and some music or audio to celebrate.

Benefits:	Drawbacks:
- Would help the overall wellbeing of rowers - An accompanying drone could be a motivating factor while training and also help with pacing	- The drone cannot help in constructing a fitness plan with certain activity goals - The activity goals have to be measurable by the drone - Iterative process might be needed to evaluate exertion/progress status correctly - Battery life might be a limiting factor for continuously tracking fitness/exertion

Concept 6 – “Coordination Challenger”

This drone will train the coordination skills of a rowing crew. It will introduce a game where the rowing crew has to follow the instructions of the drone. The drone will visualize different stroke patterns for each member. The patterns will change randomly skipping some strokes for some crew members or changing their stroke rate for a couple of strokes. The drone will switch between challenging individuals and joing their rhythms in harmony.

Benefits:	Drawbacks:
- Helps to train coordination - Potentially increases awareness about crew synchronicity - Improves understanding about collective effort for performance enhancements	- The game would miss its purpose if instructions for rowers are not clear or sequencing of patterns is too quick and overwhelming - Even though this could train coordination it could potentially also be harmful for the crew rhythm if stroke patterns are changed randomly

Concept 7 – "Co-Coxswain"

This drone will act as a Co-coxswain to help the coxswain with his tasks. The drone could be position on the other side of the boat to improve the coxswains presence in the boat. It would amplify his commands to make it easier for the crew to follow. The drone could also try to track the direction of the boat to also give a steering indication as an additional aid for the coxswain. It can also try to track the position within a race and inform the coxswain about current placement and the lead advantage.

Benefits:	Drawbacks:
- Enhance coxswains presence - Eleviate him of some tasks	- Speakers don't have to fly - There could be some delay complicating communication - An additional dynamic audio source could confuse rower's

Concept 8 – "Biomechanical Tracker"

This drone will focus on performance analysis by tracking relevant footage for biomechanical analysis. The drone will have some predetermined tracking modes: from both sides, from the top and from the front. The main challenge for the drone is to keep a constant speed, constant distance and constant direction towards the target.

Benefits:	Drawbacks:
- Potentially eliminates the need for a performance measurement boat to be used - The coach does not have to film manually from the boat and worry about shaky footage - Multiple drones could be used for multiple perspectives of the same motion	- Exact perspectives need to be consulted with experts for rowing biomechanics -

4.5 Evaluation Criteria & Choice

The created concepts from 4.4 will be evaluated with the help of the following evaluation criteria (2 points per category):

1. Does it solve a problem of the user?
2. Unique solution?
3. Is the solution technically feasible?
4. What's the expert preference?
5. What's the personal preference?

The rationales for these evaluation criteria are the following:

1. Even though the drone can potentially do a lot of things with a customized payload, we want our concept to solve a previously identified problem within rowing.
2. The solution should not only be an alternative to an existing technology but leverage the unique capabilities of the drone to not only replicate already existing solutions.
3. The solution should be evaluated based on technical feasibility to ensure the concept can be realized into a working prototype that can be tested.

4. We want to build on the experience of experts to ground our decision-making in the field of HDI and rowing.
5. The personal preference will help to find a concept that motivates further specification and realization.

Concept	Solves User Problem	Uniqueness	Technical feasibility	Expert preference	Personal preference	Total score
Impersonation of a cheeky rival	**1.5**	**2**	**2**	**1**	**2**	**8.5**
Synchronicity Aid for coxswain	0.5	1	1	1.5	1	5
Pervasive Instructor	0.5	2	1.5	1	1.5	6.5
Condition Checker	0.5	0.5	2	0.5	0.5	4
Fitness Coach	1	1	1	1	0.5	4.5
Coordination Challenger	0.5	1.5	2	1	2	7
Biomechanical Tracker	2	1	0.5	2	1	6.5

Based on the total score for each criteria the "Impersonation of a cheeky rival" is the chosen concept which will be pursued further. The next chapter is dedicated towards the realization of a prototype and explain the decisions that were made during this process in more detail.

6 Realization

6.1 Consideration of physical constraints

There are a couple of reasons that make the evaluation of a drone prototype for rowing especially difficult. The first difficulty arises due to rowing happening on open water. So, any drone intended to race a rower has the risk of falling into the water due to a control error or other reasons. This is a huge hurdle for testing and iterating prototypes. Any mistake can destroy the whole prototype and hinder adaptations and evaluation. Additionally, the drone system that will be used strongly determines the possible control mechanisms that can be used to control the behaviour of the drone. The drone can either be controlled manually or have some degree of automation determining its' behaviour. There are pros and cons for both control methods. Any manual control of the drone will be easily adaptable but could also complicate the evaluation of a prototype due to drone movements not being consistent enough. Automatic control options on the other hand could help to create a racing drone that keeps a constant distance and speed towards the rower. The drone would probably need an advanced tracking system like in [5] to realize this. There are also some safety concerns involved when testing an unfinished drone prototype in close proximity to a human. Any miscalculation of the drone's flight path either by the rower or by the drone could result in a potential crash. Naturally this has to be prevented at all cost.

6.2 Design environment – Virtual Reality

With all these issues in mind it is fair to say that there are a lot of limiting factors when trying to realize and test a racing drone in a real rowing setting. Due to all these factors complicating the testing of a physical prototype, the decision was made in compliance with the supervisor to test the concept of the "Cheeky Rival Drone" in a virtual reality environment. The program "Resonite" [31] is an online virtual reality gaming platform where you can collaboratively play, work and program in a running 3D game environment. A big advantage of Resonite is the possibility to create and test prototype functions in real-time making it a great choice for this project.

The University of Twente has already initiated multiple projects about rowing in virtual reality in the past. Some of these projects emerged under the research project "Rowing Reimagined" [32] and were combined and ported into Resonite. The virtual rowing environment can be seen in figure 9.

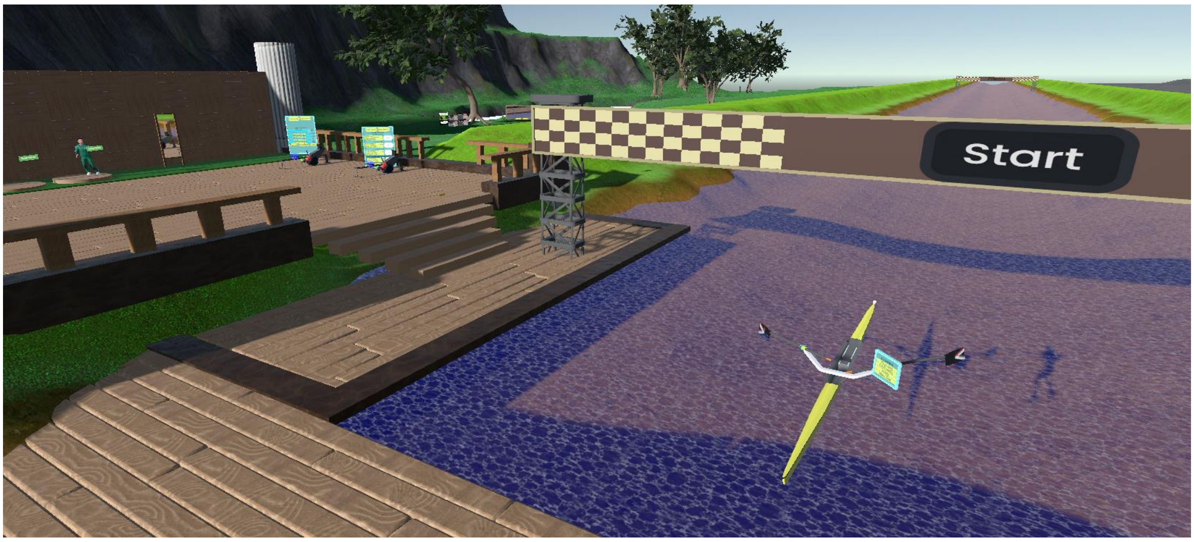

Figure 9: Rowing Reimagined (Resonite) - Virtual rowing environment

Additionally there is a complementing Github repository [33] with information on how to get started with the platform and access different functions within the rowing environment. The realization of the "Cheeky Rival" drone in Resonite overcomes multiple of the initial hurdles that are tied to the evaluation of a real life drone prototype over water mentioned in 6.1. This approach eliminates the risk of the drone falling into the water or crashing into the rower during the evaluation. Additionally, the drone behaviour can be programmed in advance, ensuring that the drone behaviour and the movements stay consistent for each race. The full resulting Resonite code can be found in Appendix D.

6.3 "Cheeky Rival" – In depth

The decision to create a racing drone is primarily based on the idea of using the drone's presence and its' expressive capabilities to make the rowing experience more engaging. At the same time it warrants the opportunity to test different drone "expressions" within the race and evaluate how they are perceived by the rower. This means the drones purpose will not be to primarily increase the rower's performance, at least not to the degree that many other rowing technologies identified in Chapter 2.3.2 do. One of the goals of this project was to include a special focus on the drone's capability to perform expressive movements. This means that the drone can potentially communicate with the rower solely through motion. This concept is also implied in the research of Eriksson [4] where a "harmonic understanding" between dancer and drone needs to be established first. The hope is to create a "dialogue" between drone and human with expressive movement alone. This dialogue between drone and human must be carefully crafted for the human to be able to interpret the motions of the drone correctly.

The main objective of the drone will be to simulate a competitive scenario for the rower by impersonating a racing opponent. Obviously, rowers are used to race against other rowers and not drones. So, to create the illusion of a thrilling race, there needs to be some kind of rivalry introduced between the rower and the drone. Rivalry in general is a deeply psychological phenomenon as it is illustrated by Kilduff et al. [34]. They remark that rivalry is an inherently relational phenomenon strongly influenced by the rival's proximity, their attributes and their history. However, the scope of this project does not warrant the opportunity to create a prior interaction history between the drone and the rower. Therefore, the main focus for creating the illusion of rivalry will be solely on the drone's attributes and its personality.

The primary purpose of the drone serving as a racing opponent will be to challenge the rower during the race. In some of the running drone applications that were identified in the background research like [16] or [20] participants indicated that the drone helped them a lot with their own pacing during their run. Interestingly, many perceived the drone not only as a pacing tool but also described the drone as 'its own entity'. Some characterized the drone as a "companion" and others felt like the drone was more of an opponent challenging them to keep up. This ambivalence indicates that the perception of the drone's intentions can strongly vary depending on the preferences of the user. Therefore the "Cheeky Rival" concept will try to combine the two most promising characteristics, challenging and encouraging to form its own unique racing personality. This decision was made in the hope of leveraging the motivating features of a companion but also have the challenging features of a perceived rival.

Crafting the drone's personality also included the introduction of a voice for the drone. This decision was made to reduce ambiguity when interpreting the drone's movements and intentions through motion alone. The reasoning and approach for this decision is more closely elaborated in chapter 6.8.

6.4 Reference speed

The speed of the drone is highly relevant when supposed to simulate a race consistently for rowers of different speeds competitive scenario suitable to the level of the rower. A classic rowing race is usually held over the distance of 2.000 meters. The completion times for a race of this length strongly depend on the boat setup but also on the level of expertise of the rower. The more rowers are in a boat, the higher is the total force of propulsion for the boat. The weight of each rower also plays a role in how fast the boat can possibly be. This means in contrast to a coxless quad, a setup with coxswain will have the same amount of propulsion, but additional weight of one person resulting in a slightly higher time. World record times range from 05:18m (eight) to 06:41m (single) for men and 05:52m (eight) to 07:23m (single) for women [35] depending on the boat setup. However, these are best times for professional athletes and set over a distance of 2km. Rowing such a huge distance is draining and also unnecessary when evaluating the drone's general potential for interactions and increasing the rower's engagement. Therefore, the setup of the race is not bound to a fixed distance but rather constructed for a practical evaluation of the different individual interactions.

6.5 Race setup

The "Rowing Reimagined" environment in Resonite is an immersive rowing experience trying to replicate the rowing experience as real as possible. It includes different functionalities aimed at giving feedback relevant for evaluating your own rowing performance. The environment includes the opportunity to have multiple boats and multiple rowers in one boat at the same time. However, we want to evaluate the interactions of the drone aimed only at one rower in one boat. The rowing track in the environment is open ended. So, there is no clear start or finish line. The platform is intended for a rowing session limited either by time or by distance. For a race against the drone the rowing track was limited to a certain distance with a "Start" and "Finish" line to give the rower an additional reference for his progress within the race.

Along the rowing track there are multiple colliders between the "Start" and "Finish" line each triggering a different interaction of the drone. The collider setup along the track can be seen in figure 10. The race starts when the rower crosses the "Start" line and ends with him crossing the "Finish" line.

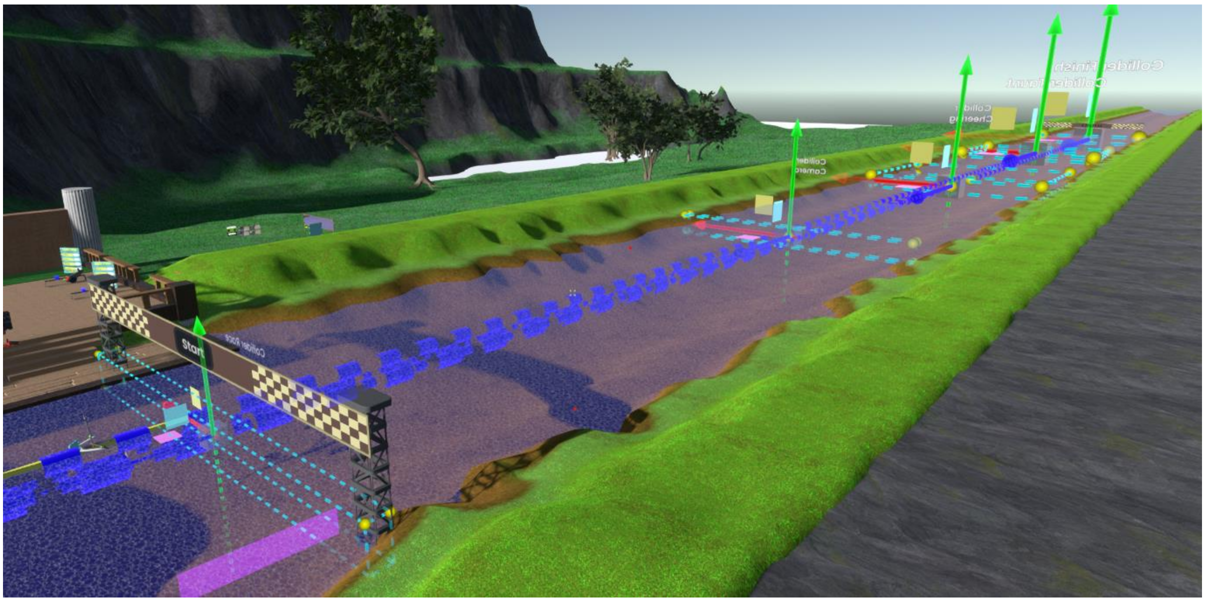

Figure 10: Collider setup for the rowing track

Distances in the virtual environment are not 1:1 relatable with real life, so the distance can only be estimated. The track is roughly 300 meters long, primarily so the interactions have enough distance between them for the rower to distinguish between them. There is an additional velocity multiplier included in the rowing environment, which lets you adjust the boat's speed individually for every rower dynamically throughout the race. The fact that different rowers have different speeds creates a challenge for the distance between interactions. Therefore, during evaluation each rower's speed will be adjusted at the start of the race, to make sure there is enough time between interactions. With the adjusted speed each race will take about 3-5 minutes.

6.6 General drone behaviour

The general goal of a rower in a race is to keep his energy expenditure constant. This will ensure that the athlete can keep a constant pace over the entirety of the race. If the athlete miscalculates his energy expenditure, he might slow down before the race finishes or he arrives without having used his energy optimally.

The basic sequencing of the drone's behaviour will include the following steps:

1. Lag behind:

   Before the rower crosses the "Start" the drone will hover behind the boat. After crossing the "Start" the drone changes it's behaviour to stay behind the rower until the rower hits the first collider. Over the course of the race the drone will mostly stay behind the rower. The main reason for this decision is the orientation of the rower facing backwards. So, every time the drone overtakes the rower, he has to either turn his head to follow the drone, or the drone will be out of sight. To reduce the potential for this happening the drone will only overtake once during the race.

2. First catching up (D.1):
   The drone's position is directly related to the position of the rower. After crossing the "Start" line the drone will start at a relative distance of 5 meters. The distance between the rower and the drone will get smaller the closer the rower gets to the next collider. The first interaction will happen at a distance of about 2 meters from the rower (Drone takes a snapshot).

3. Overtake:
   After the first interaction (Snapshot) is triggered the drone catches back up to the rower and then starts to slowly overtake him. After the drone has passed the rower the next interaction (Drone cheering) is triggered.

4. Second catching up (D.2):
   The drone will catch up to the rower after he has passed the drone cheering for him on the side of the track. The drone then starts to catch up slowly again until it is again roughly 2 meters behind the rower. Then the drone starts to taunt the rower by flying left and right in front of him. After this interaction, the drone initiates a Head2Head race on the final stretch.

5. Head2Head race on final stretch (D.3):
   For the final stretch the drone will again slowly catch up so that it is right behind the rower when the race finishes. Additionally, the drone's speed will alternate slightly making it's behaviour seem more dynamic and effortful.

The idea behind this setup is to mimic a dynamic evolution of the race with the drone changing it's behaviour over the course of the race. These different evolutionary steps hopefully make the race more thrilling and engaging. If the drone just slightly stays behind the rower for the whole race, this would probably help the rower with his pacing like shown by Van Son et al. [20], but at the same time make the interaction with the drone not very engaging. On the other hand, if the drone's speed alternate's too much within the race, this could also break the illusion of a thrilling race for the rower. Because if the rower recognizes that the drone could potentially go way faster, but doesn't, the illusion of a thrilling race would also become less credible.

6.7 Brainwriting

An additional brainwriting session was conducted with 4 participants in the hope of generating more interactions for the drone to perform during the race. At the start of the session every participant received instructions (Appendix B.1) on what's going to happen during the session. It included some background about the project and listed some potential goals of the interactions.

The main goals mentioned for the generated interactions were:

- Motivation / Animation
- Engagement
- Fun
- Performance
- Competition
- Feedback on:
    - Rower's speed
    - Rower's speed in relation to drone
    - Speed of drone

Every participant had 5 minutes to generate ideas and then the ideas were switched clockwise. New ideas are then added in connection and on top of the other ideas until everybody has ideated on each other's ideas. The resulting ideas can be found in Appendix B.2.

Unfortunately, most of the resulting ideas could not be implemented because they would not work in VR. Some ideas like the drone making a flip every time it overtakes the rower were considered but finally also not implemented due to time constraints and the drone mostly being out of view when doing the flip.

6.8 Interactions during race

The interaction space of the rower during the race is limited in comparison to the drone. The drone has its usual degrees of freedom and is not preoccupied during the race. The rower however is actively rowing with both hands holding onto the oars. So, there is no option for the rower to make any gestures without having to compromise his rowing rhythm doing so. Therefore, the interaction scenarios are mainly one sided with the drone acting as the "Sender" of different messages and the rower acting as the "Receiver" for these messages. The personality of the drone was already specified in more detail in chapter 6.3 combining both encouraging and challenging character traits.

The drone will perform the following expressive actions:

1. Mockingly take a snapshot of the rower (D.6)

   This interaction is supposed to make fun of the rower by belittling him while he is rowing. The intention behind this is to create some reluctance towards the drone and establish the idea of the drone serving as an enemy. The hope is to evoke an emotional response in the rower intensifying his drive to win the race against the drone.

Figure 11: Drone taking photo

2. Cheer for the rower at the side of the track (D.7 + D.8)

   This interaction is aimed at encouraging the rower during the race. It is also an attempt at testing how a sudden switch of the drone's personality to a more encouraging character rather than the taunting/challenging one. To reinforce this "personality switch" the drone also flies to the side of the track to impersonate a "cheering spectator".

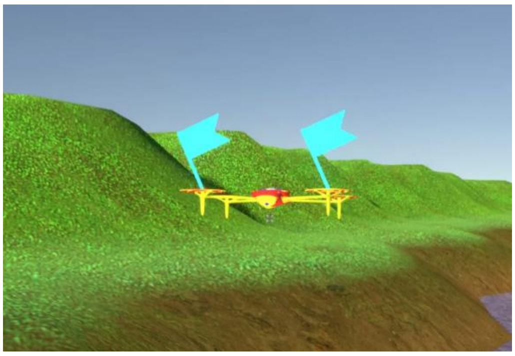

Figure 12: Drone cheering

3. <u>Taunt the rower close to the "Finish" line (D.4 + D.7)</u>

At this point in the race the drone is again close to overtaking the rower. The drone starts to swerve to the left and right alternating between two positions. The taunting maneuvers of the drone serve as another emotional trigger hoping to furthermore intensify the rower's rivalry towards the drone for the Head2Head race on the final stretch of the race.

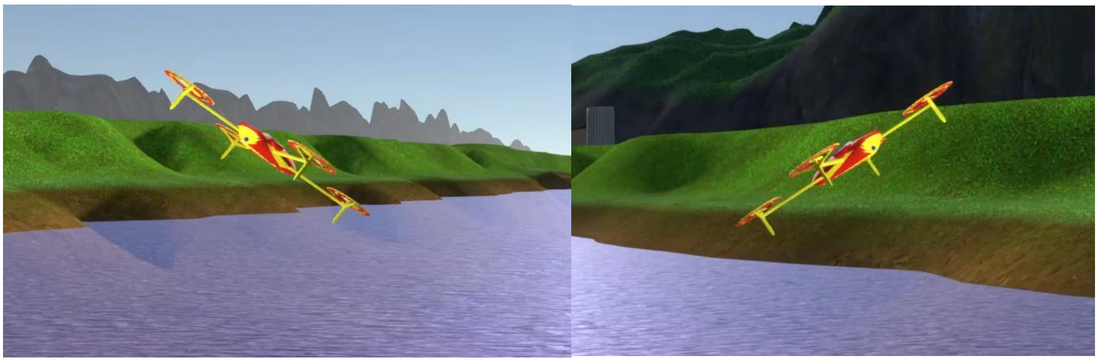

Figure 13: Drone taunting

4. <u>Act upset and fly away (D.10 + D.14)</u>

This final interaction is supposed to confirm the drone's personality by pretending to have an emotional response itself, when losing the race. The "emotional response" of the drone aims at increasing the rower's feeling of accomplishment and serve as a positive ending to his rowing session.

Figure 14: Acting upset and flying away

These drone actions are performed in order with additional audio output also being triggered depending on the current position within the race.

Figure 11 shows a flow diagram of the sequencing of the interactions and the audio outputs of the drone over the course of the race.

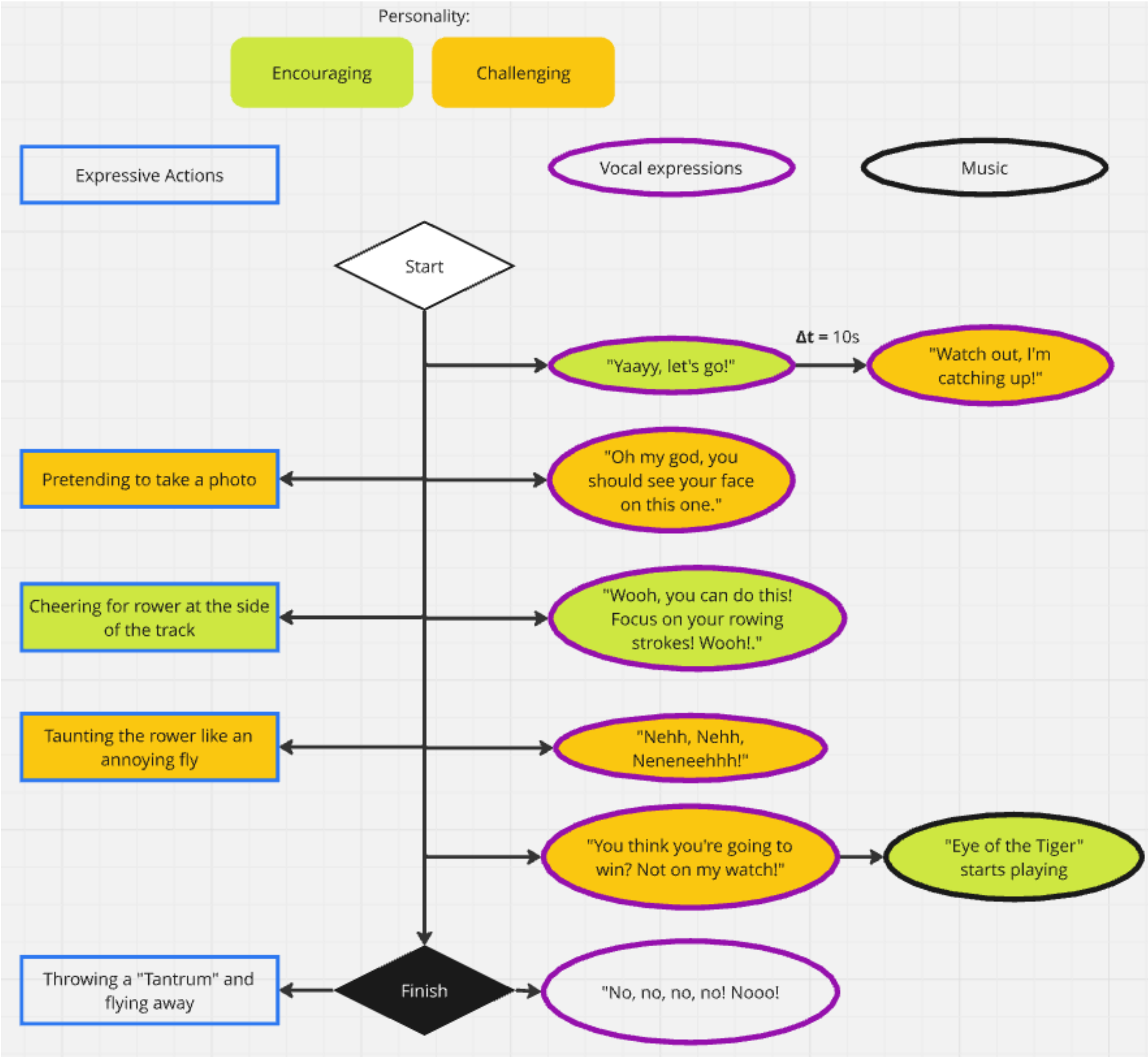

Figure 15: Flow diagram of actions during the race

6.9 Increased Expressiveness

During the implementation of the drone actions, it became apparent that some of the expressive actions of the drone were not explicit enough to warrant easy comprehension behind their intentions. One example for this is the taunting movement of the drone. If the drone would only fly left and right in a taunting motion, it could be interpreted in very different ways. The drone could just be showing off its' agile movement or it could be trying to get a look at the rower from different angles. This issue was prevalent with most of the actions. Identification of the drone's cheering action is also almost impossible without the drone audibly cheering for the rower.

Initially the idea was to only equip the drone with a pitching sound like the droid R2D2 from "Star Wars". R2D2 does not have a real voice but communicates only with pitching sounds giving a rough indication of his mood or intentions. A pitching sound ending in a lower tone is primarily perceived as "sad" and a pitching sound ending in a higher tone is primarily perceived as "happy". These sounds can also be used to reproduce for example a laugh (by repeating the right pitch), or hysteric behaviour by continuous alternating beeping sounds. This way of expression seemed to fit perfectly for the drone due it also being sort of a robot or droid.

For this purpose multiple different pitching sounds were collected from royalty-free sites like Pixabay [36] or Freesound [37]. Additionally, sounds were created with the help of a generative AI tool from ElevenLabs [38]. Various prompts were used to create multiple droid sounds resembling a mocking sound, a happy sound or a laughing sound. However, the range of expression was very limited with this approach prompting the additional implementation of a real voice for the drone. For this purpose, multiple audio snippets were recorded and pitched up to resemble a mechanical droid as close as possible. The audio snippets were created with the program Audacity [39] which is free-to-use and let's you record and edit audio files easily. This approach extended the possibilities for the drone's expression by adding full sentences for the drone to play. Additionally, the drone was equipped with a dynamic drone sound that reacts dynamically to the speed of the drone (D.11)

7. Evaluation

As specified in chapter 3.3 the goal of the evaluation is to answer the two design RQ's from chapter 1.3. The goal is to identify benefits and drawbacks of the implemented drone interactions and analyze to what extent the drone influences the experience of the rower. This will be done with the help of a usability testing with participants. First participants will go through the virtual rowing experience and subsequentially fill out a questionnaire about their experience. Both design RQ's will be covered with their own set of questions in the post-experience questionnaire.

7.1 Setup

The setup for the evaluation consists of a couple of different elements, some physical, some digital. Detailed setup instructions for the virtual rowing environment can be found in the accompanying Github Wiki [33].

The main elements for the evaluation are the following:

- Two PC's each running Resonite (physical)
- Two Resonite accounts with access to the digital environment (digital)
- One RP3 rowing machine which is connected to the PC running the participants Resonite account (physical)
- A digital interface for the RP3 rowing machine (included in [33], digital)
- A data WebSocket to record and save the data of the RP3 rowing machine (included in [33], digital)

7.1.1 RP3 rowing machine

The physical setup of the RP3 ergometer can be seen in figure 10. Three VR trackers are included in the setup which are highlighted in green in figure 12. Before entering the boat in the virtual environment, the VR trackers need to be calibrated for the rowing animation to work. Tracker 1 needs to be attached to the rowing seat, tracker 2 needs to be attached to the handle and tracker 3 needs to be attached to the base of the RP3. The base of the RP3 is freely moving along the rails of the machine which gives a more natural feel to the rowing than a rowing machine with a fixed base. The height of the rail can be adjusted on the back of the machine to fit the weight of the rower. The data cable of the RP3 is connected to the PC via USB. The digital interface of the RP3 let's you choose between different USB ports making it easy to find the right one.

Figure 16: Setup of RP3 rowing machine + Evaluation of competition youth rower (TRV Tubantia)

7.2 Procedure

The evaluation session was set up for one participant at a time and included informing the participant about the research (5 minutes), the virtual rowing session (5-10 minutes) and the post-experience questionnaire (10-15 minutes). Each participant first received an information brochure (C.2) and had to sign an informed consent form (C.3). After participants have signed the informed consent form, they received an instruction pamphlet about the evaluation procedure (C.4) containing the following steps:

- Onboarding in VR: The participant is seated on the ergometer and the machine and headset are adjusted to fit the rower

- The participant is instructed to win a race against the virtual drone
- After the race is finished, the participant is assisted to get off the machine and take off the headset.
- Finally, the participant completes the post-experience questionnaire (C.5) which takes another 10-15 minutes

The calibration of the VR trackers is done beforehand by the researcher. The virtual rowing avatar of the participant is already seated in the boat, eliminating the need for additional adjustments done by the participant himself.

7.3 Participants

The participants for this evaluation were primarily acquired through flyers (C.1) that were distributed on campus, internally (UTwente) with the help of a "Participant Recruitment page for HCI Research" and by inquiring directly at the rowing association DRV Euros. The initial goal for the desired number of participants to test the experience was 20. However, the final participant had to cancel so the total number of participants who tested the experience was 19. Figure 10 shows the demographics of the population including gender, age and their rowing experience. There were 14 male participants and 5 female participants. More than 75% of the participants were between the ages of 18-25 and only 4 participants were 26 or older.

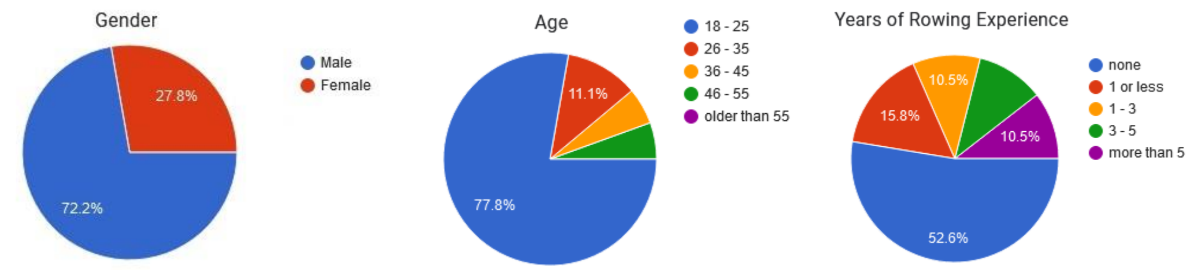

Figure 17: Demographics

Nine out of 19 participants have some previous rowing experience with two rowers having more than 5 years of rowing experience and another two with 3-5 years of experience. The distribution of roughly 50/50 of rowers vs. novices will give insights into how the participants rowing experience might affect their perception of the drone's intentions.

7.4 Results

The post-experience questionnaire includes mainly qualitative questions about how participants experienced the interactions with the drone and how they affected them. However, there are some additional Likert scale questions to get a rough estimation of whether the interactions were perceived as they were intended.

7.4.1 Overall experience

The first section of the questionnaire asks about the general experience of participants. To get a general indication on how to interpret each participants answers, the first questions was about their familiarity with VR technology. The pool of participants was mainly between the ages of 18-25. A younger audience will potentially be more inclined to have previous experiences with new technologies like VR. This is also confirmed by figure 11 indicating that only three participants were not familiar with VR technology at all.

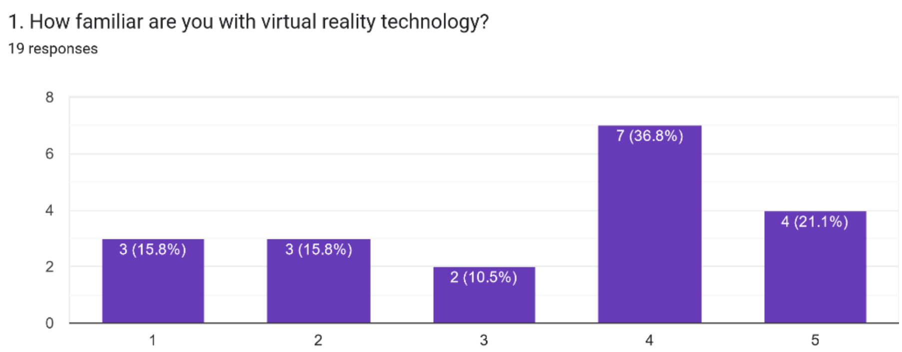

Figure 18: Familiarity with VR

It was asked if they understood the drone's movements and how they felt about the drone's general behaviour like speed and responsiveness. More than half of the participants indicated that they understood the drone movements rather well which can be seen in figure 15. The resulting population mean μ_i for this question is the following:

$$\mu_2 = \sum \frac{x\,p(x)}{n} \approx 3.6\,,$$

where $p(x)$ is the Likert scale score, x is the number of responses for that score, i corresponds to the number of the question and is the total amount of participants.

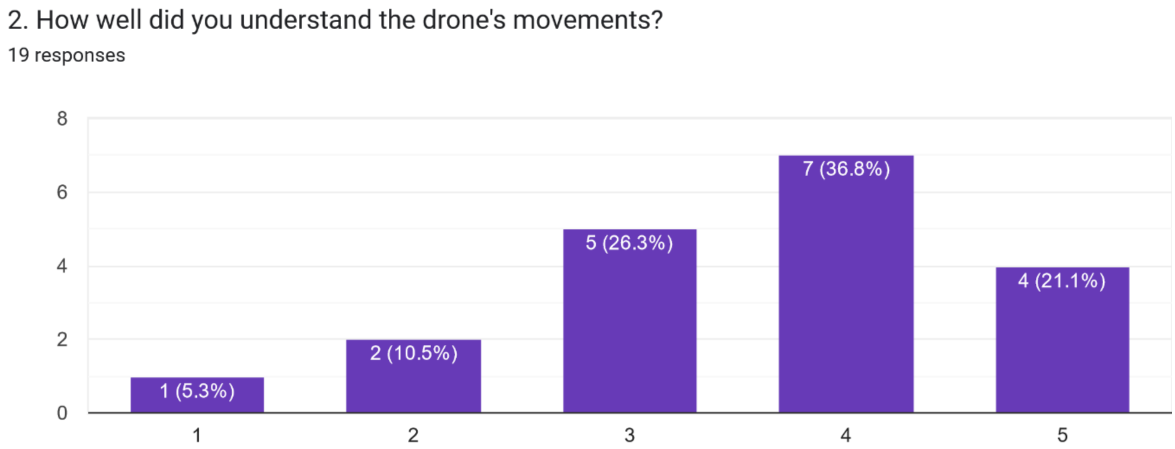

Figure 19: Comprehension of drone movements

Additionally, there were two questions inquiring about the participants general engagement during the experience. The answers result in a population mean of $\mu_{12} \approx 3.9$ (figure 16) when asked about how engaged they were in the race with the drone and an even higher population mean of $\mu_{13} \approx 4.3$ (figure 17) for whether participants felt like the drone made the virtual rowing experience more engaging.

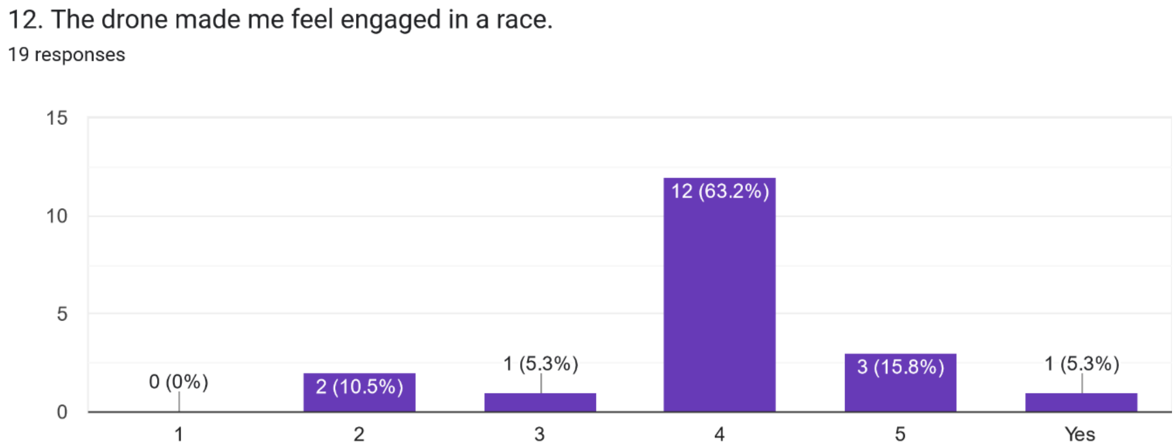

Figure 20: Engagement in the race with drone

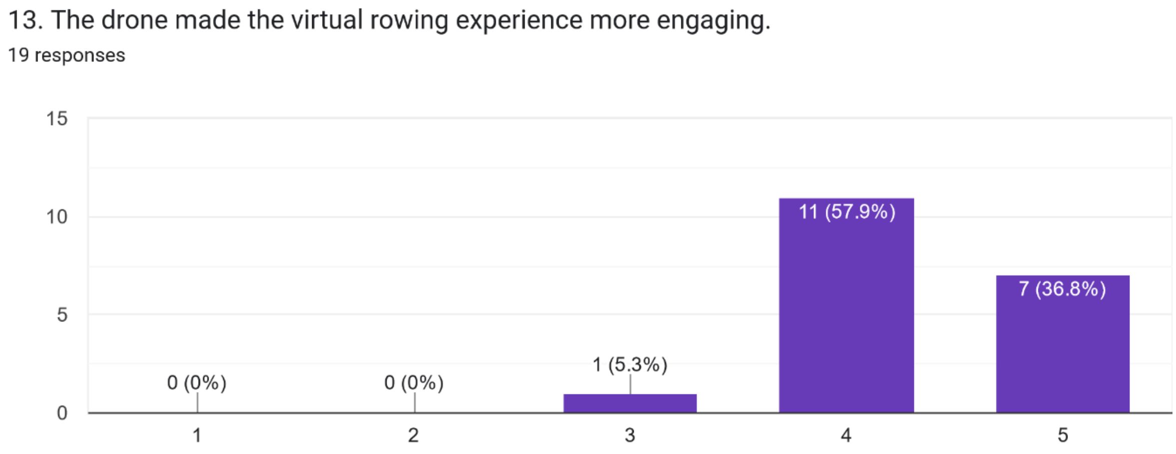

Figure 21: General engagement

The open-ended questions at the end of the questionnaire also gave an impression of what participants liked the most and what they liked least about the experience.

Positive comments were mainly highlighting the dynamic nature of the race, feeling some sort of companionship with the drone which motivated most of the participants. One of the participants with previous rowing experience of 1-3 years indicated that he participated in the VR rowing GP in a previous semester which was held in the same rowing environment. He found the experience more boring back then and said it was nice to have an additional pace introduced to his rowing.

Negative comments were mostly mentioning that the environment could have been more realistic, the rowing animation was too jittery. Many participants mentioned that it was hard to understand the audio of the drone over the sound of the rowing machine (which was later solved by using headphones). For some the animation of the drone seemed too abrupt at times and some characterized the drone as being mean due to its taunting actions. Participants with previous rowing experience also mentioned that they were missing more direct feedback like split times or race progress which they were used to from their usual rowing sessions.

7.4.2 Perception of drone actions

The perception of the amount of drone actions performed varied between participants (Figure 18). More than half of the participants identified 3-5 actions with 4 participants having perceived only 1-3 actions and another 4 participants having perceived 5-10 different drone actions. The question does not specifically distinguish between expressive movements and vocal expressions of the drone which probably resulted in participants counting both as drone actions.

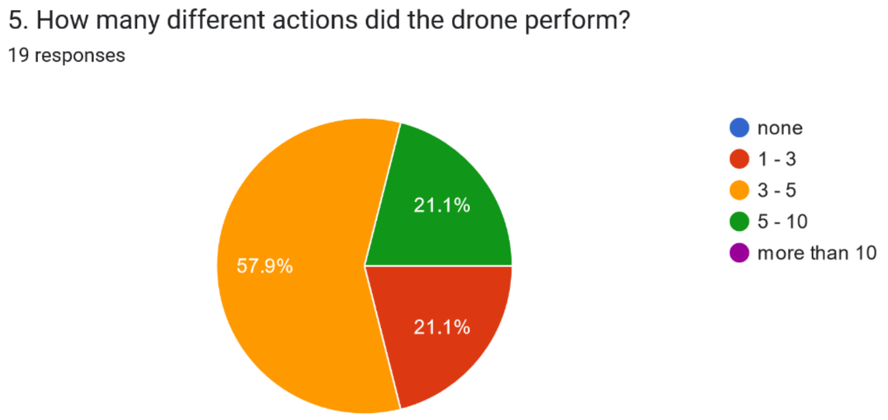

Figure 22: Number of actions performed by drone

The participants were then asked to mention all drone actions they could recollect. The answers contained a range of actions that were perceived or described correctly, but also some that were interpreted differently as they were intended.

11 participants were able to recollect the drone either taunting or mocking them. 9 participants recalled the drone either cheering for them or encouraging them. 5 participants mentioned the drone taking a picture. Some participants also described actions without directly interpreting them. They described the actions more neutral like the drone "changing angles and distance" or the drone "moving left and right". Another three participants identified actions like the drone "exploding", "doing a flip" or "crashing on purpose". One of the participants was referring to the camera flash and the drone's sudden stop when describing it as crashing. A reasonable explanation for differing interpretations is that it also heavily depends on the individual's perception. Some participants also remarked the animations sometimes stuttering during their race. This phenomenon happened primarily when either the VR tracker lost connection momentarily, or the program Resonite has a sudden drop in fps (frames per second) resulting in "teleporting".

When asked about drone actions that were not understood, 8 of the participants mentioned they did not understand the cheering action of the drone. They mentioned that they either did not understand why the drone would "leave the race" and cheer for them at the side. Others didn't notice the action too well because the drone would be behind them when switching into the "cheering mode".

7.4.3 Additional questions

During the evaluation it became apparent that participants were interpreting the drone actions quite differently. This prompted the addition of 4 more questions to the questionnaire inquiring about how they felt during each action specifically.

The following questions were added and answered by only the final 7 participants:

8. How did you feel when the drone mockingly took a picture?

4 of the participants felt bad when the drone took a picture and mocked them, and 3 participants said they felt indifferent.

9. How did you feel when the drone was about to overtake you?

Three participants felt motivated to row faster. Another three participants described it more neutral and said they felt slow or like they had to speed up. One participant said it felt bad because he was already rowing at top speed.

10. How did you feel when the drone was at the side of the track cheering for you?

Three participants did not remember this part in particular. Two participants felt like it didn't help or didn't make sense due to it not being an opponent anymore. The other two participants said they felt nice during this action.

11. How did you feel when the drone was taunting you by flying left and right in front of you?

4 participants felt either annoyed or described the drone as mean. Two of the participants said they felt motivated by it. One participant was indifferent and identified this action as "dancing".

7.4.3. Impact on rowing behaviour

In this part of the questionnaire there is a mix of statements concerning the impact of the drone on participants rowing behaviour and some open-ended questions following up on them. The first statement is there to get a sense of how distracted the participants felt by the drone.

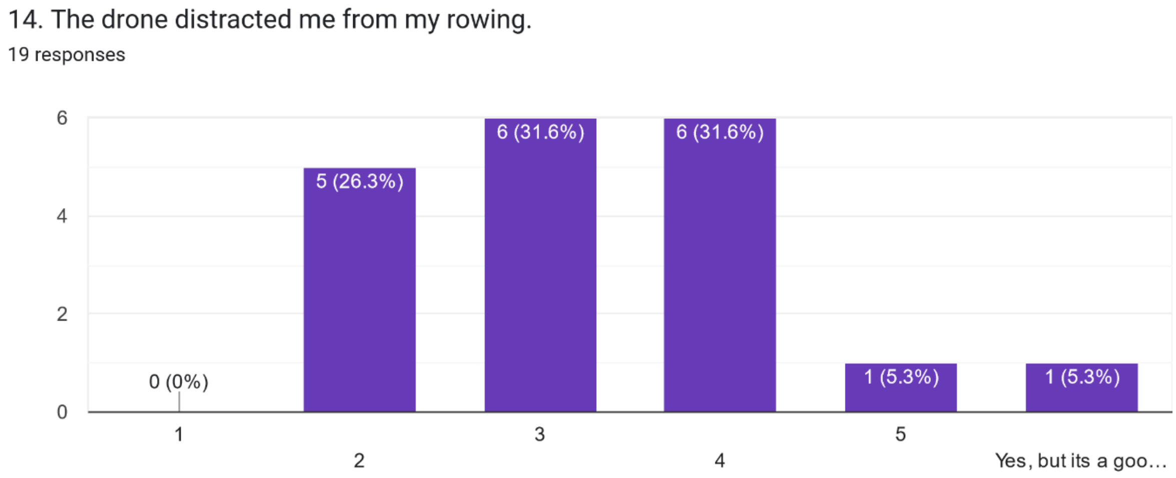

Figure 23: Distraction by drone

The resulting distribution mean of $\mu_{14} \approx 3.3$ shows that participants felt almost indifferent, with only one participant saying he felt very distracted by the drone. Another participant said the drone was distracting, but in a good way (In this one case the question showed up as a non-Likert scale question, hence the 6th option in the graphic). It was already discovered in chapter 7.4.2. that the interpretation of the drone's movements partly depends on the participants individual perception.

The next question inquired whether the participants felt challenged by the drone during their rowing.

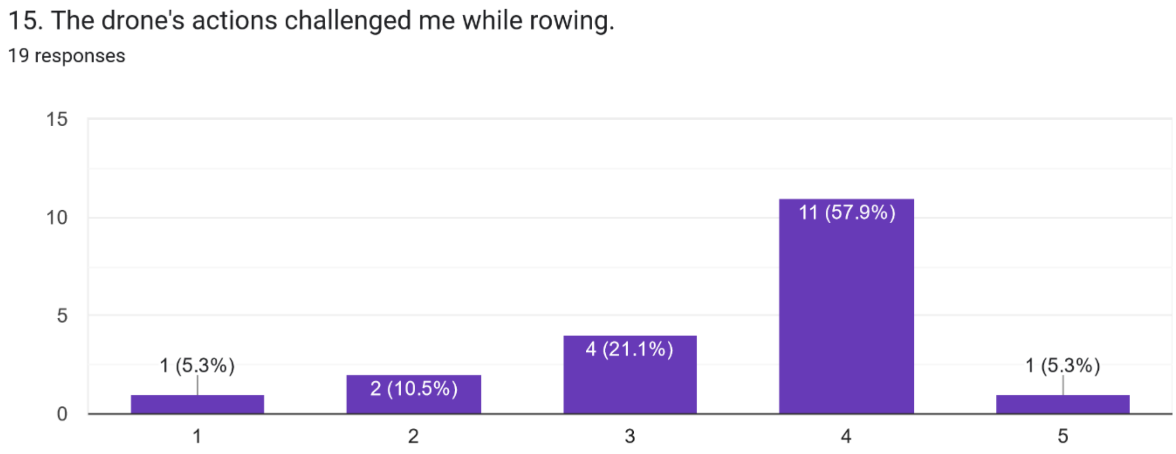

Figure 24: Drone perceived as challenging

The distribution mean of $\mu_{15} \approx 3.5$ indicates that the drone was perceived as challenging to a certain degree. Only one participant found the drone not challenging at all, and two participants felt like the drone did not challenge them much (figure 20).

Figure 21 shows that almost all participants felt generally motivated to row faster due to the drone's presence resulting in a high distribution mean of $\mu_{16} \approx 4.3$.

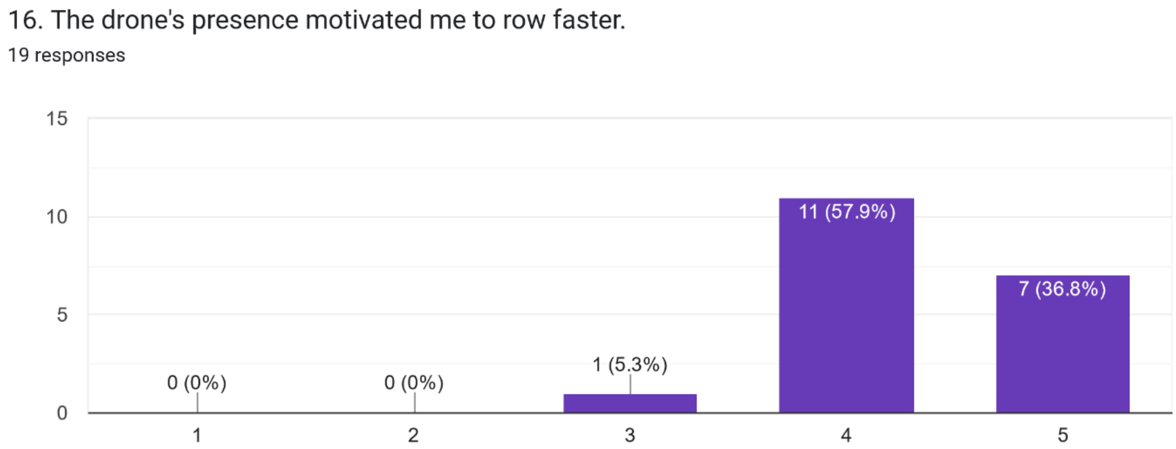

Figure 25: Motivation through drone's presence

The last two questions inquiring about the impact of the drone asked whether the drone should have been more encouraging (Figure 22) or more challenging (Figure 23). These questions were included after the first participant was tested and it became clear that it would be an important measure to evaluate the drone. Therefore, the total number of responses was 18 and not 19.[6]

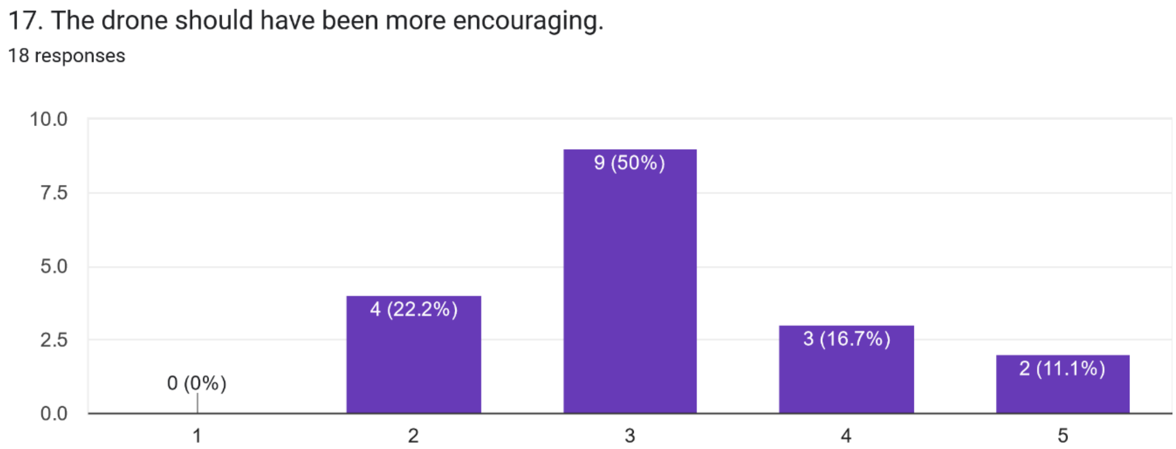

Figure 26: Drone should have been more encouraging

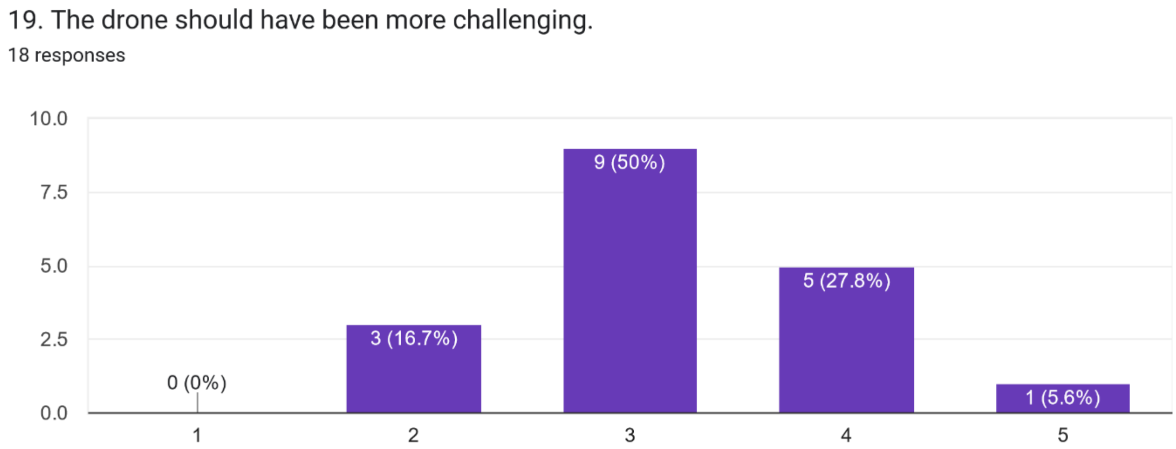

Figure 27: Drone should have been more challenging

Surprisingly, the distribution mean, as well as the distribution was the same for both questions resulting in $\mu_{17} = \mu_{18} \approx 3.2$. 9 participants for each question felt either indifferent or felt that the drone had the right mix of being challenging and motivating at the same time with neither compromising the other. Another approach could have been to combine the two questions into one, forcing a decision of the participants towards either challenging or encouraging. This would have given a stronger indication about the participants tendency but would have also forced them to decide between the two. The idea behind the choice to split these questions was to include the possibility of the drone being neither challenging nor encouraging enough as an outcome. Fortunately, this was not the case.

The follow up questions give additional insight into how the drone either encouraged or challenged participants during the race. 6 participants mentioned the speed of the drone and the process of slowly catching up to the rower as the most encouraging. 8 participants indicated the vocal expressions of the drone to be very encouraging for them. Interestingly 4 participants described the taunting/mocking behaviour as encouraging as well. This again highlights the individual’s tendency whether taunting actions are perceived as encouraging or discouraging.

Concerning the challenging actions of the drone, 8 participants felt like the drone slowly catching up to them challenged them the most during the race. Five participants described the moment when the drone was overtaking them as the most challenging part of the race. Three participants mentioned the drone’s vocal expressions like “Watch out, I’m catching up” or “You think you’re going to win? Not on my watch!” to have challenged them the most.

7.4.4. General feedback and suggestions

The final section of the questionnaire asked about whether participant have additional feedback or any suggestions. The most common answer concerned either the drone animation or the rowing animation being not consistent enough and throwing people off at times. Three participants would have liked more music to be played throughout the experience. Two participants would have liked the experience to be more interactive with multiple opportunities to overtake the drone and vice versa.

Two participants with previous rowing experience were also missing more meaningful feedback which they are used to in their natural rowing environment like a heartrate sensor and split times within the race. 5 of 10 responses providing additional feedback described the experience as either entertaining or engaging and one participant mentioned he would love to have this experience at a gym to make the rowing on an ergometer more engaging and interactive.

8. Discussion

8.1. Design process

During the ideation phase of this project multiple interviews were held to get a better understanding of the topic. Some of these interviews were not structured well enough in advance and they were not focused on solely generating knowledge about the topic which would have been a better approach. One of these interviews (with drone expert) therefore resulted in more of a discussion already evaluating potential decisions and solutions and was therefore not included in the ideation.

The decision to realize a drone prototype in VR was made at the start of the second module after the ideation phase was completed. Therefore, there was limited time to get accompanied with the VR platform Resonite. The implementation of smooth drone animations was therefore partly limited by the expertise with the program itself. More time with the program and its existing functions would have helped to make the transition between drone actions more fluent. Because of this there was also limited time to troubleshoot issues that arose from either the VR trackers losing connection or the program momentarily freezing and therefore causing teleportation issues. If these issues could have been fixed prior to the evaluation, participants would have been less distracted, and their feedback could have been more focused. The amount of drone interactions throughout the race was also limited by the time it took to implement them. Additionally, the implementation of two different drones each focusing on either encouraging or challenging the rower could have been another promising approach to test how they compare with each other.

8.2. Prototype - From virtuality to reality

The goal for the realization of a prototype was to be able to test and evaluate the drone's functions more easily without the risk of the drone falling into the water or crashing into the rower. The virtual environment was additionally helpful in implementing a constant and automatic behaviour for the drone helping the consistency of the evaluation.

However, in combination with this approach, many of the limitations that were disregarded now must be considered when transferring these insights to the real world. The most obvious issues are the physical constraints present in a real-world setting. Is the drone agile enough to recreate the actions? Does the battery life of the drone warrant the completion of a full 2km race? How far can the drone go without losing its connection? Will the drone's sound be loud enough to hear over the sound of the motors? All these questions are relevant and need to be addressed for a real drone. In a virtual setting there is no apparent need for a customized drone setup. Sounds can be played without worrying about attaching a speaker to the drone. The rower can be tracked even though no specialized payload dedicated to tracking the rower like in [5] is needed. The design of a real drone will require a detailed analysis of what functions are necessary to include and which ones can be disregarded. Additionally, some of the actions that were implemented in VR cannot be translated into real life without adaptation. The drone will for example not be able to pick up flags while cheering on the sidelines for the rower. This interaction was intended to be using LED's as additional cheering output but they were replaced with flags instead because the LED's were hardly recognizable in VR.

Even though many rowers mentioned missing more direct rowing feedback, this issue is inherent to VR. In a real life setting the drone is arguably not there to replace the already existing technologies in rowing but rather add a new dimension to the rowing experience. The realized prototype tests the potential of expressive movement in a dynamic race setting. The interactions were aimed at increasing the rower's engagement during the race with the help of emotional triggers through a perceived rival. Different scenarios could also try to leverage the drone's expressive movement capabilities to communicate direct rowing feedback to the rower

8.2 Evaluation

The usability testing helped to collect qualitative data from a total of 19 participants. Half of the participants had some previous rowing experience and the other half did not. This distribution gave a rough estimate of how they perceive the drone's actions differently from complete novice rowers. An important insight from the evaluation was that rowers were missing certain feedback which they were used to from other technologies used during their real rowing sessions. A heart rate monitor and split times were the most prominent mentions that rowers mentioned was missing during their experience. Most of the rower's felt like the drone was a good tool for pacing their own speed. However they remarked, that without direct feedback on their current speed it was hard for them to estimate whether they should speed up or slow down to be able to keep a constant pace over the entirety of the race. This can also be seen when comparing some of the log files from the RP3 machine recording the force distribution of each participant over the course of the race. The output of the RP3 machine has no discrete unit and therefore should be interpreted only qualitatively. The phenomenon of a declining exertion rate can be seen in figure 24.

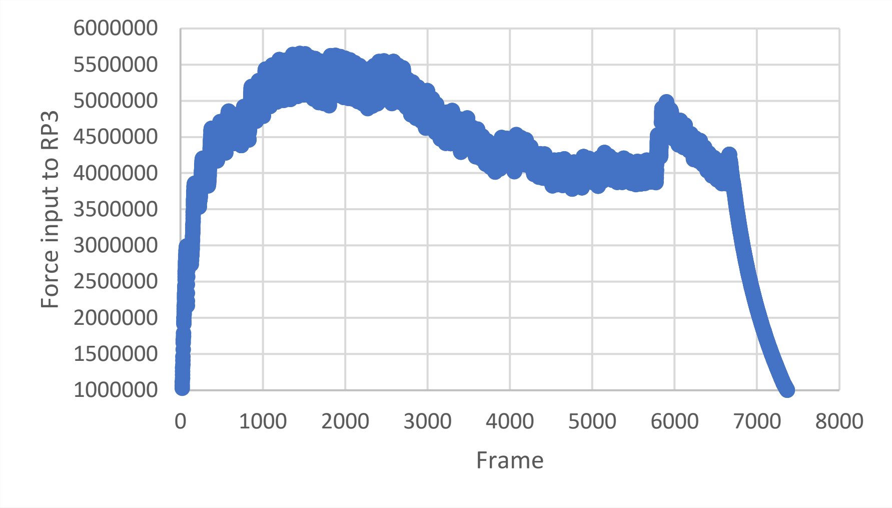

Figure 28: Declining force distribution during race

The participant started with a higher exertion rate at the start of the race. The rate of exertion slowly declines during the race with a spike shortly before the end where the drone encourages the rower again for the Head2Head race on the final stretch. Some rowers were more affected by this issue than others which can be seen in figure 25. Here the rate of exertion is almost constant over the entirety of the race.

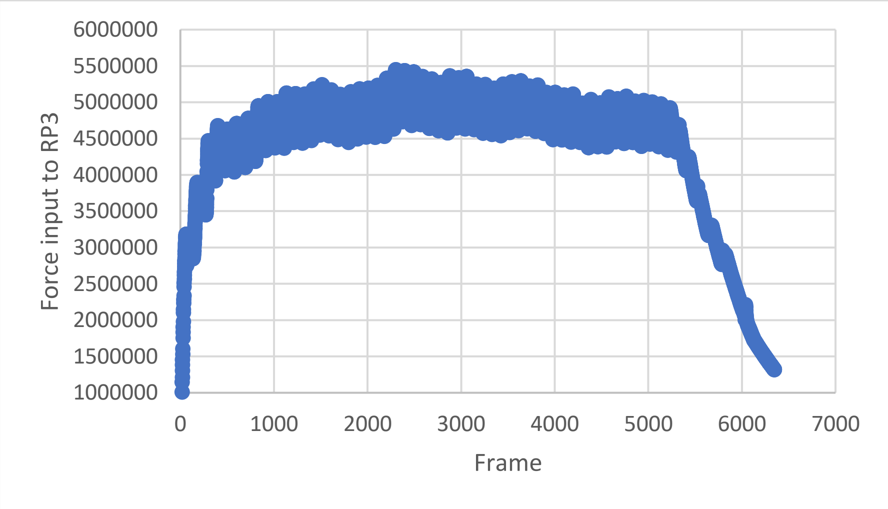

Figure 29: Constant force distribution during race

Additionally, the force distribution curves also highlight participants individual receptiveness for the drones' actions. Figure 25 for example doesn't show much variation on basis of the drone's actions during the race. Other participants were more receptive towards the drone's actions which becomes apparent when comparing figure 25 with figure 26.

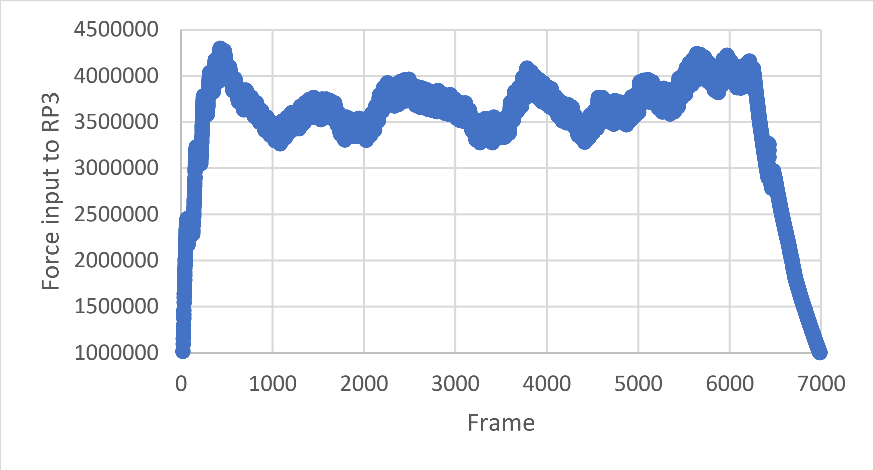

Figure 30: Varying force distribution during race

In this case the participant was affected more strongly by the actions of the drone which can be seen by the exertion rate alternating between a low at around 3.250.000 and a high at 4.250.000. This also confirms the findings from chapter 7.4.3. and highlights the fact that participants individual perception influenced how strongly and in what way they were affected by the drone.

8.4 Future work

The evaluation showed the drone's potential in impersonating a conceptual entity, in this case a cheeky racing rival. The drone was able to engage the rower in a race while influencing their rowing behaviour at the same time. Though already mentioned, how a rower interprets the intentions of the drone is highly dependent on the individual's perception. For this reason, the next possible step could be to do a quantitative analysis of different drone interactions to better understand what actions mostly evoke what type of reaction (emotional as well as physical) in the rower. This approach would give additional insights into what kind of actions have the strongest effect and how these actions should be executed by the drone (speed, direction etc.). Testing the drone with rowers of different level of expertise also limited the options for the drone's reactive actions. Future research could explore even more comprehensive ways of reactive interactions by additionally feeding the drone specific information about the rower, like top speed or stroking rhythm.

9 Conclusion

This section will provide a summary of this project's execution. Subsequently, the principal findings from the evaluation are presented in order to draw conclusions regarding the impact and efficacy of the designed prototype. In conclusion, the research questions posed in chapter 1.3 are addressed.

The objective of the informed design of the drone prototype was to examine potential interaction scenarios between the rower and the drone and to assess the extent to which they impact the rower's experience.

The findings of the literature review and the insights gained from interviews with rowing experts were used to generate a set of potential interaction scenarios. These were then subjected to evaluation based on a set of specific criteria in the ideation phase. The chosen concept “Cheeky Rival” focuses on the dynamic interaction between the rower and the drone, by simulating a competitive racing scenario. The unique capacity of a drone to perform expressive movements is leveraged by using it as a channel for communication throughout the race. The fabrication of a "cheeky" personality was achieved by incorporating both encouraging and challenging elements simultaneously.

The evaluation demonstrated that the interpretation of the drone's actions exhibited some variation due to differing perceptions of each participant. The majority of participants demonstrated an understanding of the drone's overall intentions. Some participants indicated that the personality of the drone was perceived as being too mean and therefore not helpful, whereas others highlighted this characteristic as a source of motivation. This suggests that motivation is perceived and triggered in different ways by different individuals. The short time of contact between participants and the drone was sometimes not enough time for them to ascribe a distinct meaning for every drone action. Furthermore the encouraging vocal expressions of the drone throughout the race increased some of the participants rowing efforts momentarily.

The drone’s presence appeared to enhance the rowers’ engagement and assisted them to a certain extent with maintaining a constant pace. However, the virtual rowing environment was lacking some essential feedback, such as split times and information about heart rate, which many rowers are accustomed to from their usual rowing sessions. The preferred location for the drone in relation to the rower was predominantly behind the boat. The drone should not be overtaking the rower too much, as this observed to confuse most of the participants when the drone went out of their sight. The process of slowly catching up to the rower with the distance between drone and rower slowly minimizing seems to have motivated users most to “keep up” with the drone sparking increased effort.

Answers to research questions:

With the help of these findings, we can give concrete answers to the research questions. Answers will first be given to the design sub questions and then to the main question.

- What are possible interaction scenarios between rower and drone and what are their benefits and drawbacks?

This sub-question was answered in the ideation phase with the creation of multiple scenarios each considering the resulting benefits and drawbacks.

- To what extent does the drone influence the experience of a rower?

The drone engages the rower in a virtual race and is a good indicator for rowers to pace their own speed. People are influenced differently by the expressive actions of the drone strongly depending on what type of actions they find motivating.

The main design question

- What is a good design for a drone setup assisting in a rowing scenario?

was answered during the ideation phase and the short answer is: The design of the "Cheeky Rival" drone.

Finally, the main question can be answered quite similarly.

- How can a drone enhance the rowing experience?

A drone can enhance the rowing experience by impersonating a rivaling racing drone.

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Appendices

A.1 Interview with Kay Winkert and Mark Amort

What are relevant parameters to track when analyzing the rowing motion?

For tracking the rowing motion, the most relevant joints to track are the ankle, knee, hip, shoulder, head, elbow and wrist joints.

The high-end boat measurement system that we use also tracks forces on the boat and equipment like the oarlock. This allows to evaluate how the boat sheers, or stomps (up and down of bow) and how the oar's are positioned during the stroke.

Athlete's also have an individual preference for the timing and amount of feedback that they can/ want to receive/perceive while rowing.

What parameters are still hard to track within rowing?

We still miss detailed information on many biomechanical parameters of the rowing motion. It's possible to qualitatively evaluate the rowing motion either by looking (experience) or with video analysis tools. Video analysis tools still rely on multiple fixed camera positions for a comprehensive 3D-motion analysis. This is however often only possible on a stationary rowing machine.

Environmental parameters like weather or the calmness of the water are also highly relevant for final performance. The dynamic nature of these parameters makes it difficult to track them because they vary with each session. This complicates the evaluation of the results because different conditions cause different results.

What are important technologies and equipment used within rowing?

We use force sensors mainly from "Nielsen-Kellermann", but there is also "peachinnovations" measuring forces, angles and speeds.

Smartwatches like the ones from "Garmin" are often used commercially to track vitals or position via GPS.

Very basic tool are for example a "stroke- or speed-coach" that includes tracking of speed, stroke frequency and 500m pace.

There are apps being used, like "Rowing in Motion".

In Training we often follow the rower on the side with a speedboat also filming from a lateral perspective. Filming from the boat is often difficult and the shots are often shaky and you need an additional person in the boat. In professional rowing the speedboat is following around 70% of the time.

In the future we aim at using artificial intelligence to train systems with all available data (forces, weights, motions) to create a tool for automatic analysis. A simultaneous tracking of biomechanical parameters would perfectly complement the current data and help with training the A.I..

There were also VR headsets used on the water, but they didn't work too well on open water (motion sickness).

How does a typical training session look like?

A training session normally takes between 30-50 minutes. The coach often is in a speedboat next to the rower assisting with feedback during the session (varies). Then there is a break where information is exchanged between coach and rowers. Then the next session is focused on implementing the things the coach mentioned. Video analysis is mostly done in post, after the session is finished.

How did you use a drone in rowing so far?

We used drones for analyzing for example the synchronicity between rowers. This was done by having the drone hover in a fixed position vertically above the boat at the same speed.

We compared the oar's angles within one stroke of each rower with each other to see how far they are in the drive of the motion. This did not tell us a lot about the body movements of each rower.

There was no fixed position for the drone pilot. Sometimes he was on land and sometimes on a separate coaching boat.

What are your general thoughts about the potential of a drone to be used in rowing?

The drone can help a lot with the training of an A.I. system for automated performance analysis. Standardized camera perspectives can help to get more valuable training footage for the A.I. Therefore, a drone (or multiple) can capture the motion from complementary perspectives giving a detailed picture of the whole motion in 3D space.

Complementary perspectives will also help to close information gaps like when a motion is not visible because it's performed out of sight (for example behind the backwing of the boat).

The most important perspective to capture would be laterally on both sides, front, back and from above. Having standardized automatic follow patterns to capture these angles would help to better train the A.I.

Coaches want to worry less about controlling the drone themselves but want an automatic analysis with "the push of a button".

In practice the drone also has to adapt its' location when a motorboat is driving next to the rower.

The use of a drone can also give more space on the water if there is no need for an additional speedboat next to the rowers.

A.2. Interview with Sebastian Ahlhelm

Main insights from interview:

We used a drone mainly for short distances to give the rower a chance to see his posture and technique while rowing. However, the videos were only looked at after they were recorded.

We tried a VR applications that is supposed to give valuable feedback while rowing. The only problem was that you saw yourself from the side, which did not match the direction of the rowing motion that was performed. This resulted in users feeling dizzy very quickly.

If you want to get a good recording of your rowing motion the angle from above is a good angle to evaluate stroke distance and rowing rhythm.

The rowing motion can be described as a horizontal "stretch jump" (German: Strecksprung)

Dr. Valery Kleshnev is a valuable contact if you want to know more about rowing biomechanics

B.1 Instructions for Brainwriting session (German)

Instructions: Brainwriting – Drones for Rowing

Dieses Projekt dient zur Information eines Bachelor-Projekts an der Utwente „Drohnen fürs Rudern". Diese Brainwriting-Session dient dazu weitere Ideen und Konzepte für mögliche Interaktionen zwischen Ruderer und Drohne zu generieren und bewerten.

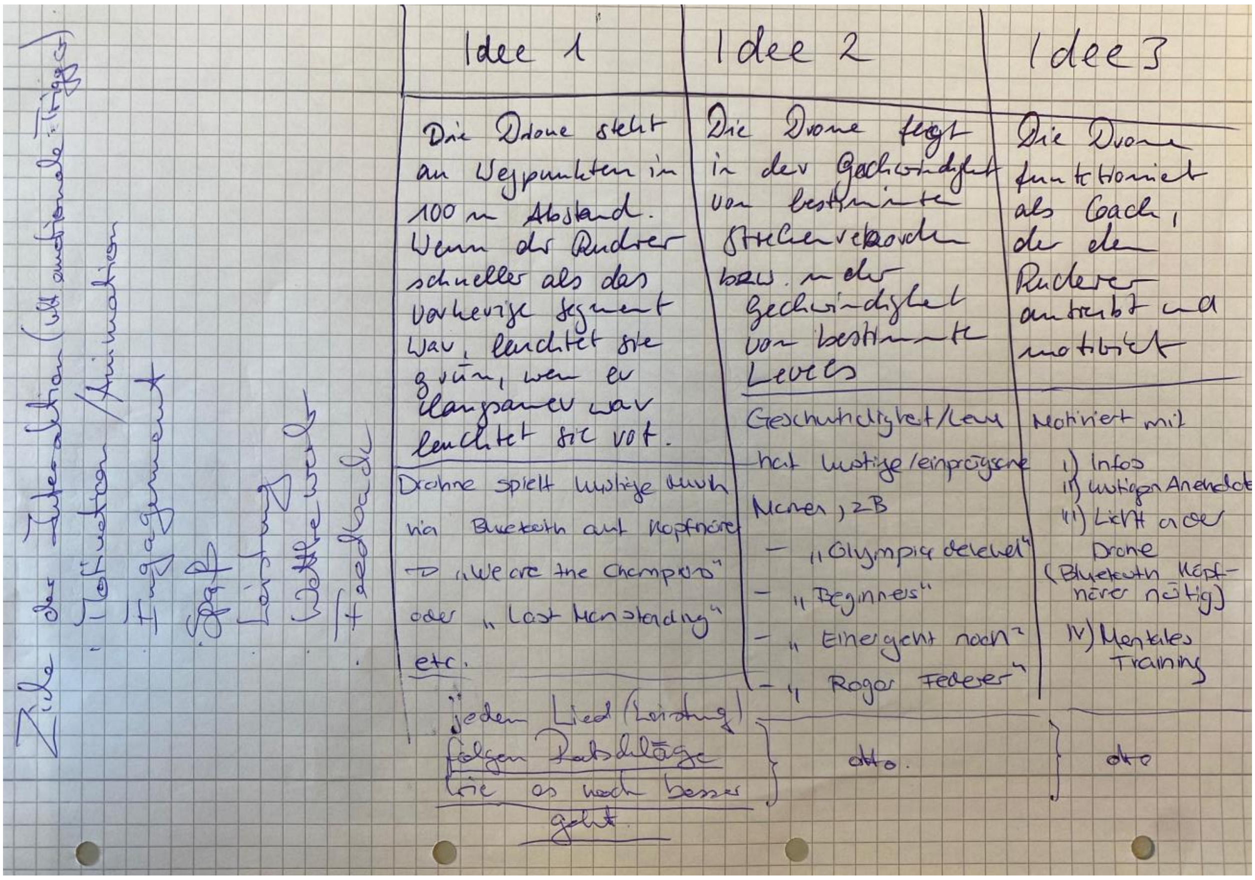
Drohnen haben durch ihre Bewegungsfreiheit das Potential einen Ruderer dynamisch auf dem Wasser zu verfolgen und ihm relevantes oder animierendes Feedback zu seiner Ruderleistung zu geben. Die Drohne fungiert dabei als Renn-Kontrahent, mit den folgenden Zielen für Interaktion zwischen Ruderer und Drohne (Anwendungen für mehrere Ruderer und mehrere Drohnen sind auch möglich):

Ziel der Interaktionen (emotionale Trigger?):

- Motivation / Animation
- Engagement
- Spaß
- Leistung
- Wettbewerb
- Feedback zu:
    - eigener Geschwindigkeit (Beuwsstsein)
    - Geschwindigkeit/Position in relation zur Drohne (langsamer, schneller, führend etc.)
    - Drohnengeschwindigkeit/Position unabhängig von Ruderer

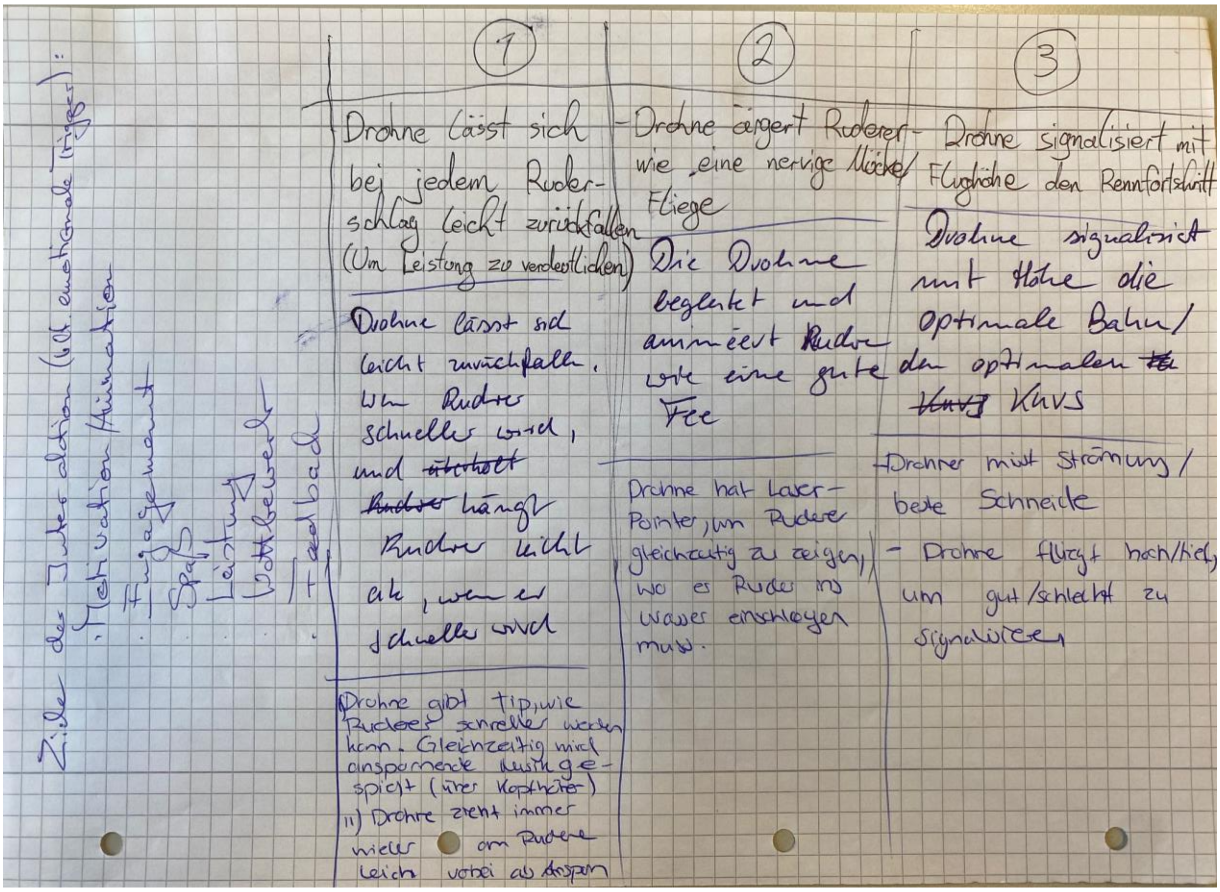
1. Start: Jeder überlegt bitte 5 Minuten und entwickelt 3 oder mehr Ideen.
2. Anschliessend Ideen weitergeben und an die Ideen des Vormanns weitere Ideen anknüpfen oder präzisieren.
3. Abschlusss: Gruppenbewertung der Ideen und deren Umsetzungspotential

B.2. Results of Brainwriting session



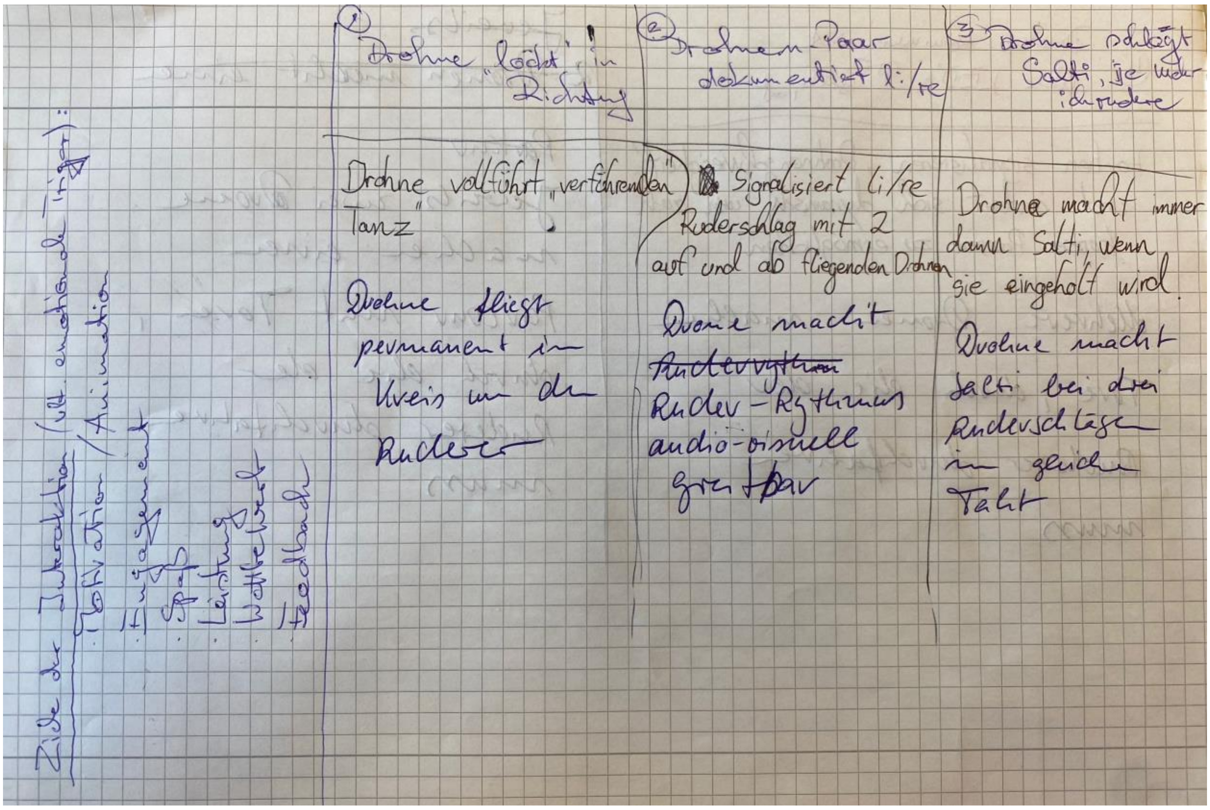
Ziele der Interaktion (ggf. emotionale Trigger):
- Motivation/Animation
- Engagement
- Spaß
- Leistung
- Wettbewerb
- Feedback

Idee 1	Idee 2	Idee 3
Die Drone steht an Wegpunkten im 100 m Abstand. Wenn der Ruderer schneller als das vorherige Segment war, leuchtet sie grün, wenn er langsamer war leuchtet sie rot.	Die Drone fliegt in der Geschwindigkeit von bestimmten Streckenrekorden bzw. in der Geschwindigkeit von bestimmten Levels	Die Drone funktioniert als Coach, der den Ruderer antreibt und motiviert
Drohne spielt lustige Musik via Bluetooth auf Kopfhörer → „We are the Champions" oder „Last Man standing" etc.	Geschwindigkeit/Level hat lustige/einprägsame Namen, z.B. – „Olympia-Level" – „Beginner" – „Einer geht noch" – „Roger Federer"	Motiviert mit I) Infos II) lustigen Anekdoten III) Licht an der Drone (Bluetooth Kopfhörer nötig) IV) Mentales Training
jedem Lied (Leistung) folgen Ratschläge wie es noch besser geht	dto.	dto



Ziele der Interaktion (ggf. emotionale Trigger):
- Motivation/Animation
- Engagement
- Spaß
- Leistung
- Wettbewerb
- Feedback

1	2	3
Drohne lässt sich bei jedem Ruderschlag leicht zurückfallen (Um Leistung zu verdeutlichen)	Drohne ärgert Ruderer wie eine nervige Mücke/Fliege	Drohne signalisiert mit Flughöhe den Rennfortschritt
Drohne lässt sich leicht zurückfallen, wenn Ruderer schneller wird, und ~~überholt~~ ~~Ruderer~~ hängt Ruderer leicht ab, wenn er schneller wird	Die Drohne begleitet und animiert Ruderer wie eine gute Fee	Drohne signalisiert mit Höhe die optimale Bahn/den optimalen ~~Ku~~ ~~Kurs~~ Kurs
Drohne gibt Tip, wie Ruderer schneller werden kann. Gleichzeitig wird anspornende Musik gespielt (über Kopfhörer) II) Drohne zieht immer wieder am Ruderer leicht vorbei als Anspor[n]	Drohne hat Laser-Pointer, um Ruderer gleichzeitig zu zeigen, wo es Ruder ins Wasser einschlagen muss.	Drohne misst Strömung/beste Schneise – Drohne fliegt hoch/tief, um gut/schlecht zu signalisieren



Ziele der Interaktion (vll. emotionale Trigger):
Motivation / Animation
· Engagement
· Spaß
· Leistung
· Wettbewerb
· Feedback

① Drohne „lockt" in Richtung

Drohne vollführt „verführenden" Tanz"

Drohne fliegt permanent im Kreis um den Ruderer

② Drohnen-Paar dokumentiert li/re

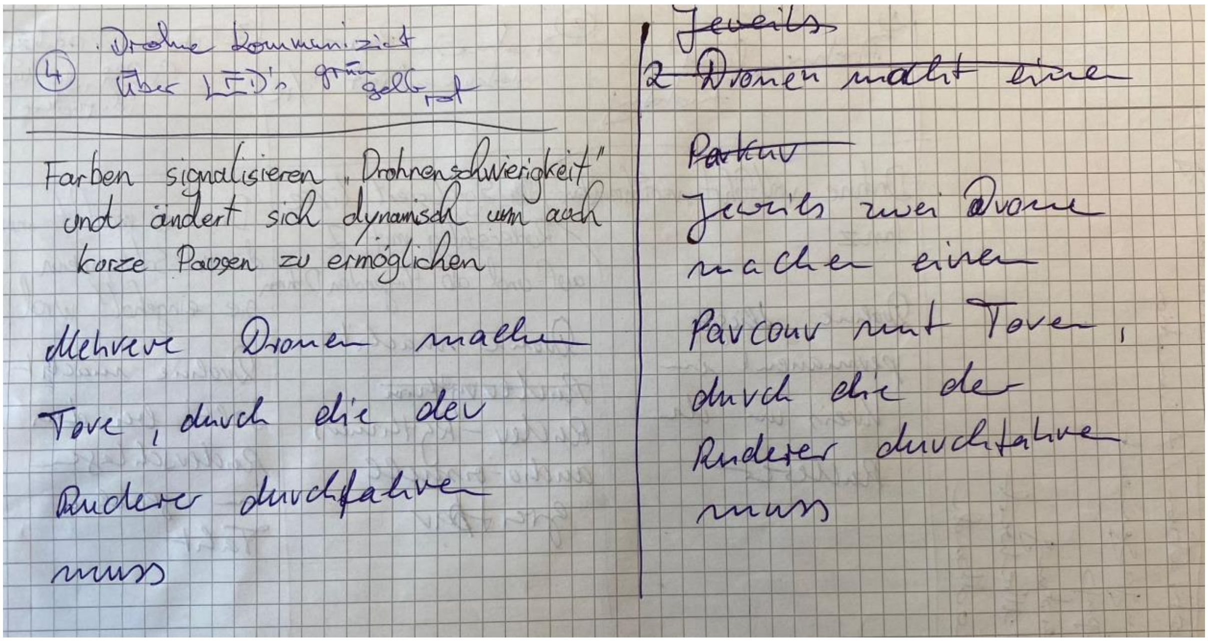
Signalisiert li/re Ruderschlag mit 2 auf und ab fliegenden Drohnen

Drone macht ~~Ruderrythmus~~ Ruder-Rythmus audio-visuell greifbar

③ Drohne schlägt Salti, je mehr ihr Ruderer

Drohne macht immer dann Salti, wenn sie eingeholt wird

Drohne macht Salti bei drei Ruderschläge im gleichen Takt



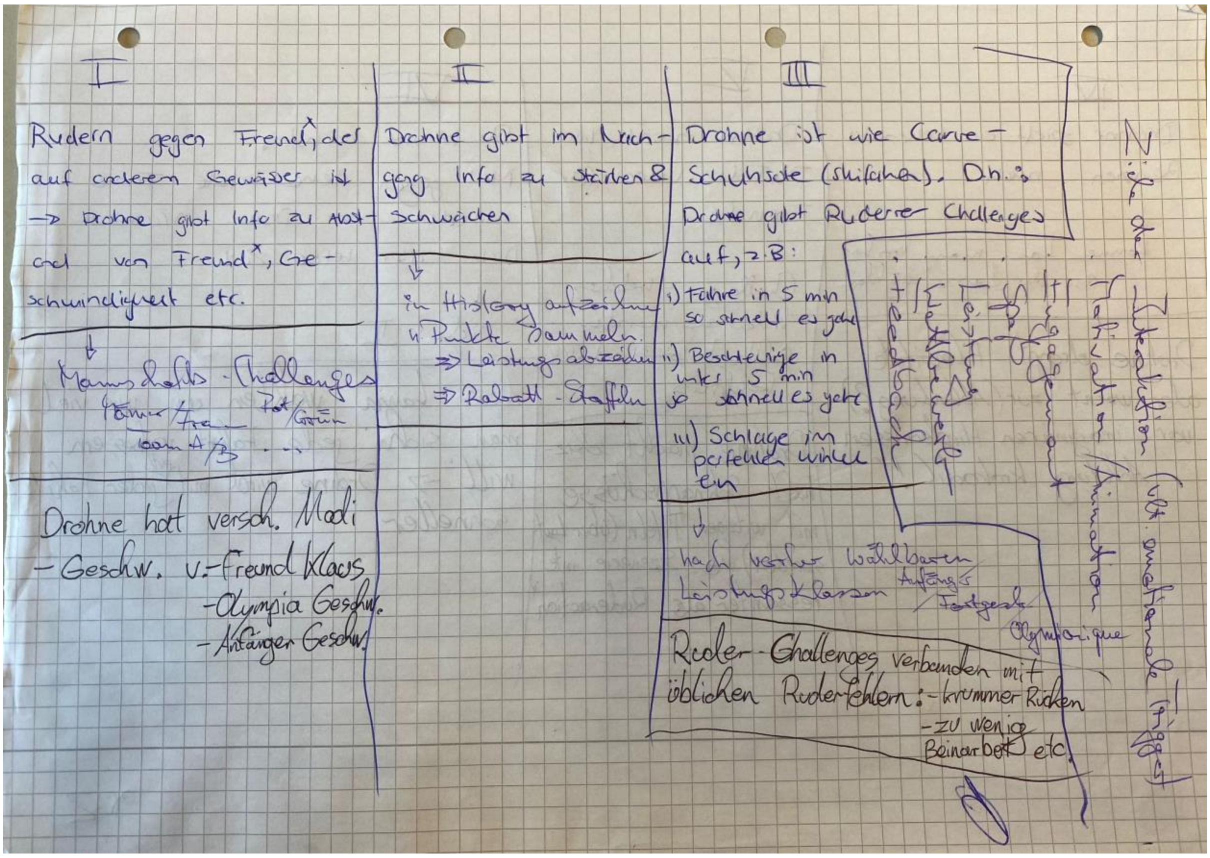
④ Drohne kommuniziert über LED's grün gelb rot

Farben signalisieren „Drohnenschwierigkeit" und ändert sich dynamisch um auch kurze Pausen zu ermöglichen

Mehrere Dronen machen Tore, durch die der Ruderer durchfahren muss

~~Jeweils~~
~~2 Dronen macht eine~~
~~Parkur~~

Jeweils zwei Drone machen einen Parcour mit Toren, durch die der Ruderer durchfahren muss



I

Rudern gegen Freund*, der auf anderem Gewässer ist
→ Drohne gibt Info zu Abstand von Freund*, Geschwindigkeit etc.

↓
Mannschafts-Challenges
Männer/Frauen Rot/Grün
Team A/B ...

Drohne hat versch. Modi
- Geschw. v. Freund Klaus
- Olympia Geschw.
- Anfänger Geschw.

II

Drohne gibt im Nachgang Info zu Stärken & Schwächen

↓
in History aufzeichnen u. Punkte sammeln.
⇒ Leistungs abzeichen
⇒ Rabatt-Staffeln

III

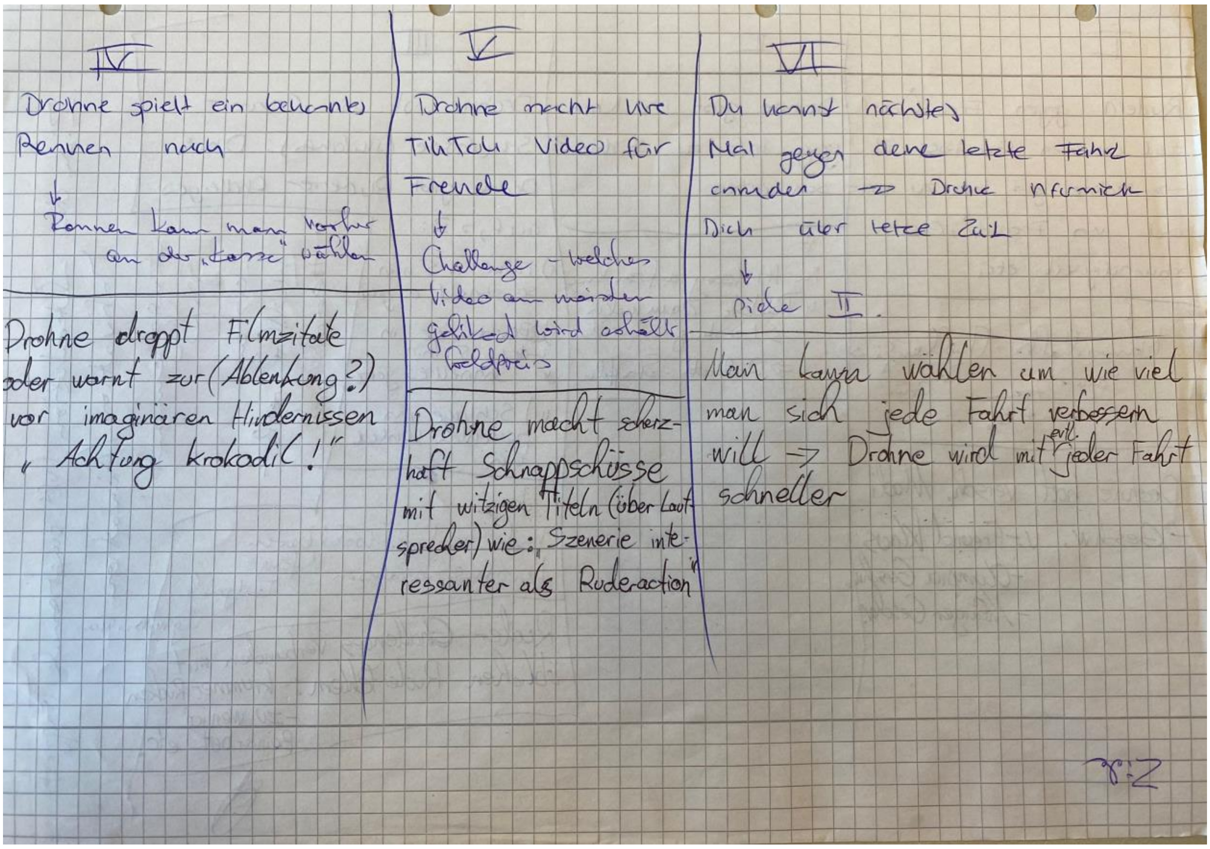
Drohne ist wie Carve-Schuhsole (Skifahren). D.h.: Drohne gibt Ruderer Challenges auf, z.B:
i) Fahre in 5 min so schnell es geht
ii) Beschleunige in unter 5 min so schnell es geht
iii) Schlage im perfekten Winkel ein

↓
nach vorher wählbaren Leistungsklassen Anfänger / Fortgeschr. / Olympionique

Ruder-Challenges verbunden mit üblichen Ruderfehlern: - krummer Rücken
- zu wenig Beinarbeit etc.

+ Spaß
+ Engagement
+ Leistung ↑
+ Wettbewerb
+ Feedback

Ziele der Interaktion (vlt. emotionale Trigger)
Motivation / Animation



IV

Drohne spielt ein bekanntes Rennen nach
↓
Rennen kann man vorher an der „Kasse" wählen

Drohne droppt Filmzitate oder warnt zur (Ablenkung?) vor imaginären Hindernissen „Achtung Krokodil!"

V

Drohne macht live TikTok Video für Freunde
↓
Challenge - welches Video am meisten geliked wird erhält Geldpreis

Drohne macht scherzhaft Schnappschüsse mit witzigen Titeln (über Lautsprecher) wie: „Szenerie interessanter als Ruderaction"

VI

Du kannst nächstes Mal gegen deine letzte Fahrt rudern → Drohne informiert Dich über letzte Zeit
↓
siehe II.

Man kann wählen um wie viel man sich jede Fahrt verbessern will → Drohne wird mit evtl. jeder Fahrt schneller

C. Evaluation

C.1 Flyer for VR Experience

Exploring the interaction potential for Drones in Rowing (VR)

Summarised information about the study:

I am studying **Creative Technology** and my **Bachelor Thesis** is about evaluating the interaction potential of a drone for rowing. Therefore, a dynamic drone was integrated into a virtual rowing environment.

You will be asked to step into **VR** and row on an **Ergometer** while being immersed in a **Virtual Rowing Environment**.

The general objective of the experience is to win a race against the drone. The VR experience will take about 10 minutes. There will be a short questionnaire of about 15 minutes after the experience.

Being immersed in VR for the first time can cause some dizziness or nausea. However you will be seated on ergometer, which reduces the risk of bumping into things.

You will be monitored during your experience and can withdraw at any moment. Drinks and snacks will be provided to the brave who dare.

Contact information:

This study is open for participation the rest of this week **(26.06.-02.07., Saturday and Sunday included)**.

You can apply for a **Time Slot** here (https://calendly.com/j-r-jacob-student/dronesforrowing) or contact me directly.

The testing will be done in the Interaction Lab of the UTwente (Citadel, Hallenweg 15, 7522 NH Enschede, 1st floor on the right)

If you are interested or need more information, please contact: **Jonathan Jacob** (j.r.jacob@student.utwente.nl, +491636314429)

C.2 Information brochure

Drones for Rowing

INFORMATION BROCHURE

The Drones for Rowing project is a research and design project resulting in a bachelor thesis. It focuses on the application possibilities for a drone in a rowing scenario. The project is carried out by a student in collaboration with a multidisciplinary team of researchers. This information brochure provides you with general information about the Drones for Rowing project. More detailed information about this study will be provided orally by the researcher(s) involved. Feel free to ask any questions. Your participation in this research is voluntary and you are free to withdraw from participation at any time.

What is the purpose of this research?
The aim of the Drones for Rowing project is to explore the potential of a drone assisting in a rowing scenario. Can a drone help rowers to *perform better*, *learn faster*, or train in a *more engaging* way? These are some of the questions that we set out to answer. Besides these rowing-specific questions, we are also focusing on the design of the drone system itself. How can we design the interaction between athlete and drone in a meaningful and effective manner?

What will participation entail?
To explore the interaction potential of a drone for rowing, you may be asked to participate in various research activities. Research activities include, but are not limited to:

1. Rowing on an Ergometer while being immersed in VR. For this kind of research activity, you will be accompanied by a drone with the intent to embody a potential rival for the rower to race against and be motivated by. During the experiment, you may be presented with different experimental conditions. For example, to study 'perfect drone positioning', we may ask you to row with the drone being at different locations while rowing.
2. Qualitative research methods. The Drones for Rowing project involves the collection of *qualitative* data. These methods may be used to better understand rowing practice, potential interactions with the drone. Qualitative research methods include: interviews, observations, surveys, self-reports, and other qualitative data collection methods.
3. Quantitative research methods. The Drones for Rowing project involves the collection of *quantitative* data. These methods may be used to better understand the rowers engagement and their emotional response towards actions performed by the drone. Quantitative research methods include: recording movement data through motion capture, computer vision, and VR trackers; recording physiological data through heartrate sensors and respiration sensors.

May I withdraw from the research?
You may withdraw from the research at any time. You do not need to justify your decision to withdraw. If you wish to stop the experiment, simply notify the researcher. If you have concerns after completion of the experiment, you may ask for your data to be removed. This should be done within 24 hours of the experiment.

What will happen to the collected data?
The studies that are carried out in the context of the Drones for Rowing project will involve the collection, use, and storage of research data. The data may be qualitative or quantitative in nature.

To protect your privacy, we will make sure to anonymize all data. In some cases, anonymization, however, might not be possible, as might be the case with video or audio data. We will only record video or audio data when necessary. If possible, we will blur out your face and make your voice unrecognizable so that none of the data can be traced back to you. To further protect your privacy, your data will be labeled – if applicable, any links to personally identifiable information will be removed. Personally identifiable information will never be made public, any data that is used in scientific publications cannot be traced back to you. Anonymized data however, might be made part of a publicly available corpus. You may ask for your data to be removed within 24 hours upon completion of the experiment.

Will I be reimbursed for participation?

If not indicated otherwise, there will be no (monetary) compensation for your participation in this research.

What can I do if I have questions or complaints?
If you wish to seek independent advice or file a complaint, you can contact the secretary of the ethics committee of the University of Twente (ethicscommittee-cis@utwente.nl). For any additional questions regarding this research, please contact Jonathan Jacob (j.r.jacob@student.utwente.nl).

What is next?
With this information brochure, you have been informed about the general scope of the Drones for Rowing project. If you have been fully informed about the purpose of the research, the research procedure, and the relevant research methodology, both in writing and orally, you can sign the informed consent form.

C.3 Informed consent

INFORMED CONSENT
I hereby declare that I am fully informed about the purpose of the research, the research procedure, and the relevant research methodology. I have read and I understand the provided information and have had the opportunity to ask questions.

To the researcher: strikethrough which option is *not* applicable.
I give my consent for the collection of: anonymous / personally identifiable information data, the kind of which has been detailed in writing (in the information brochure) and orally.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost.

Date:
……………………………………………………..

Name:
……………………………………………………..

Signature:
……………………………………………………..

C.4 VR Instructions for participants

Instructions for the "Drones for Rowing" experience

Purpose:

The goal of this experience is to evaluate the potential of a racing drone in a virtual rowing environment.

Procedure:

You will be asked to take seat on the RP3 rowing machine. You will be entering the virtual rowing environment with the help of a VR headset. After putting on the headset you will find yourself already seated in a single sculling boat. The drone will be hovering in front of you, ready to start the race. Your goal is to win the race against the drone. The race will start after you cross the “Start”. After you finished the race you can take off the headset and step off the rowing machine. Afterwards you will be asked to complete a questionnaire about your experience. The expected duration in VR is about minutes at max with a following questionnaire that takes about 15 minutes.

Benefits and risks of participation:

Like already mentioned in the information brochure, you will be using immersive virtual reality technology. This comes with a risk of motion sickness. If you experience any discomfort, physical or psychological, you can adjust the headset or take it off at any time. Additionally you will be observed by the researcher who will intervene in case a participant seems to be in discomfort or get dizzy.

Post-Experience Questionnaire: Perception of Racing Drone in VR

Thank you for participating in our VR study. Your feedback is crucial for understanding how you perceive the actions of the "Cheeky Rival Drone" in the virtual rowing environment. Please take a few minutes to answer the following questions based on your experience. Your responses will be kept confidential and will be used solely for the purpose of this research.

Email *

____

General VR Experience

1. How familiar are you with virtual reality technology?

Mark only one oval.

	1	2	3	4	5	
Unfa	◯	◯	◯	◯	◯	Very familiar

2. How well did you understand the drone's movements?

Mark only one oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very well

3. How did you feel about the speed of the drone?

Mark only one oval.

	1	2	3	4	5	
Too	◯	◯	◯	◯	◯	Too fast

4. How responsive did the drone seem to be in relation to your own rowing?

Mark only one oval.

	1	2	3	4	5	
Not :	◯	◯	◯	◯	◯	Very responsive

Perception of Drone Actions

5. How many different actions did the drone perform?

Mark only one oval.

◯ none

◯ 1 - 3

◯ 3 - 5

◯ 5 - 10

◯ more than 10

6. Can you name some of these actions?

___

7. Did the drone perform actions that you did not understand? If so, which ones?

8. How did you feel when the drone mockingly took a picture?

9. How did you feel when the drone was about to overtake you?

10. How did you feel when the drone was at the side of the track cheering for you?

11. How did you feel when the drone was taunting you by flying left and right in front of you?

ıpact on Rowing Behaviour

ːase assess the following statements:

12. The drone made me feel engaged in a race.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

13. The drone made the virtual rowing experience more engaging.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

14. The drone distracted me from my rowing.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

15. The drone's actions challenged me while rowing.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

16. The drone's presence motivated me to row faster.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

17. The drone should have been more encouraging.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

18. How did the drone encourage you?

19. The drone should have been more challenging.

Mark only one oval.

	1	2	3	4	5	
Stroı	◯	◯	◯	◯	◯	Strongly agree

20. How did the drone challenge you?

ɔen ended questions:

21. What did you like most about the racing drone in the VR environment?

22. What did you like least about the racing drone in the VR environment?

23. Do you have any suggestions for improving the racing drone or the overall VR experience?

24. Please provide any additional comments or feedback:

emographics

25. Gender

Mark only one oval.

- Male
- Female
- Other

26. Age

Mark only one oval.

- 18 - 25
- 26 - 35
- 36 - 45
- 46 - 55
- older than 55

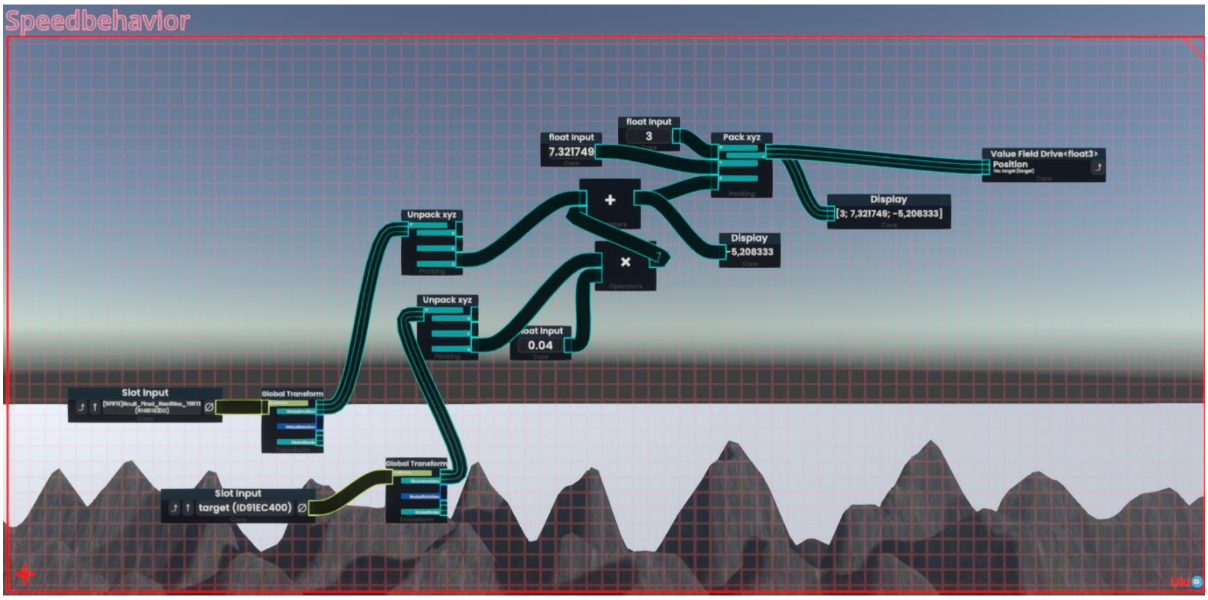
27. Years of Rowing Experience

Mark only one oval.

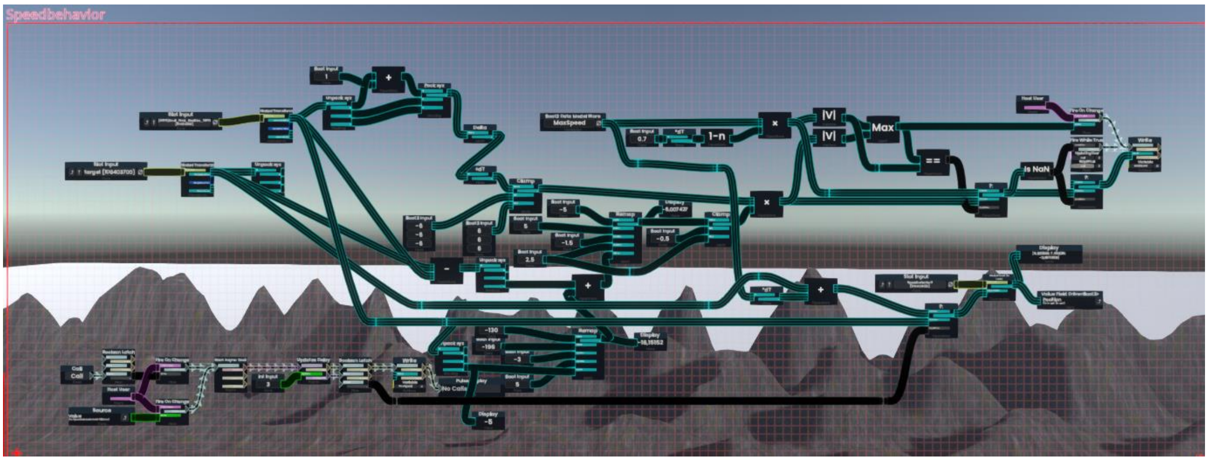
- none
- 1 or less
- 1 - 3
- 3 - 5
- more than 5

D. Resonite code

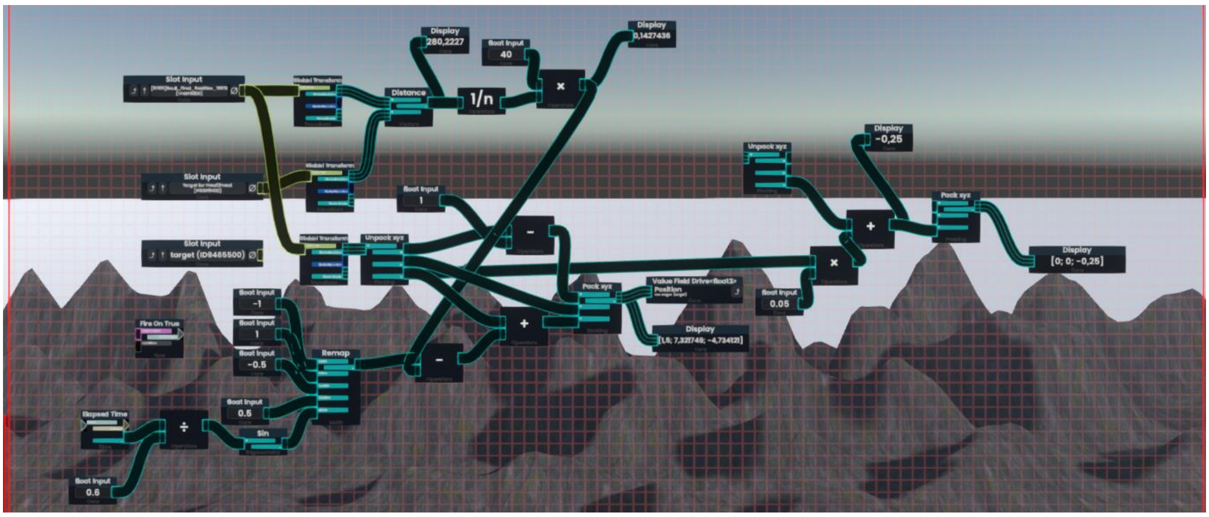
D.1 Speedbehavior 1



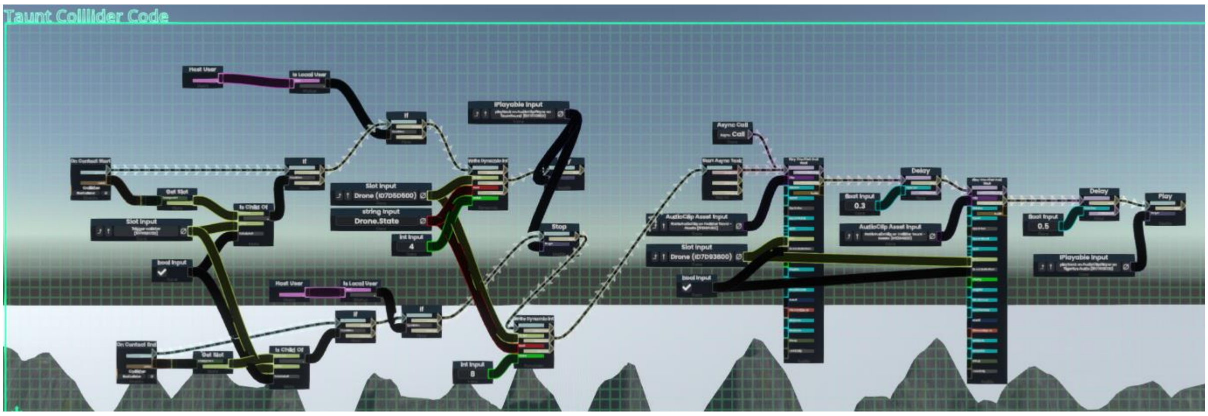
D.2 Speedbehavior 2



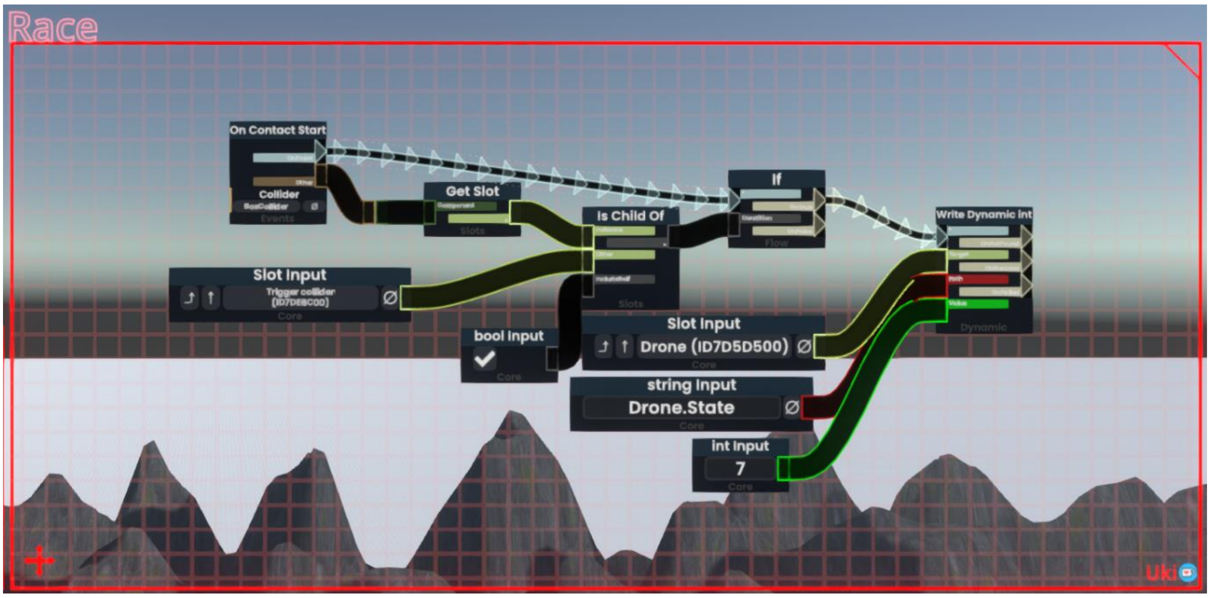
D.3 Speedbehavior 3



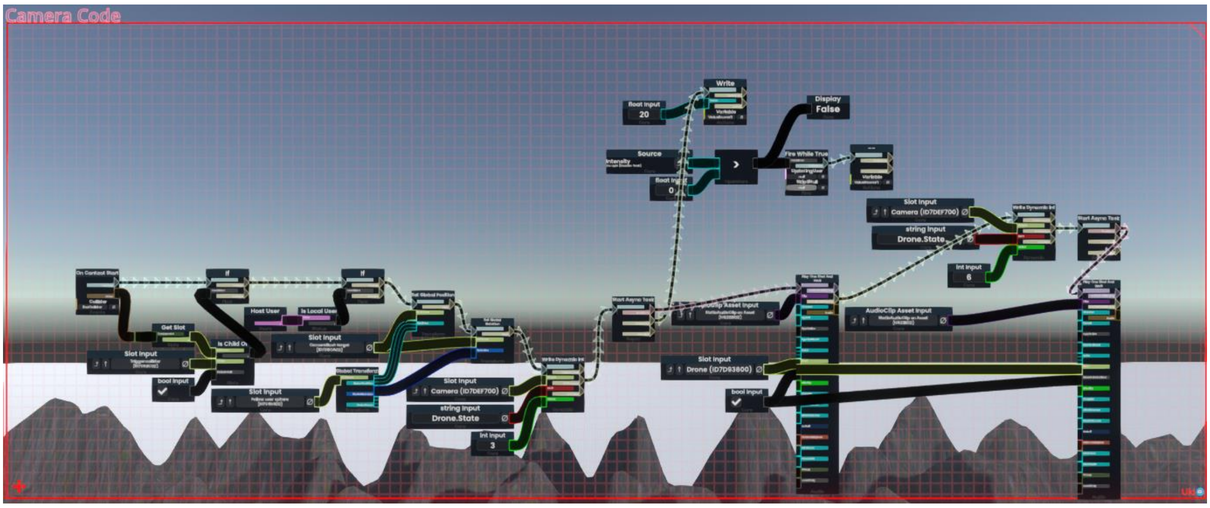
D.4 Trigger Collider Taunt



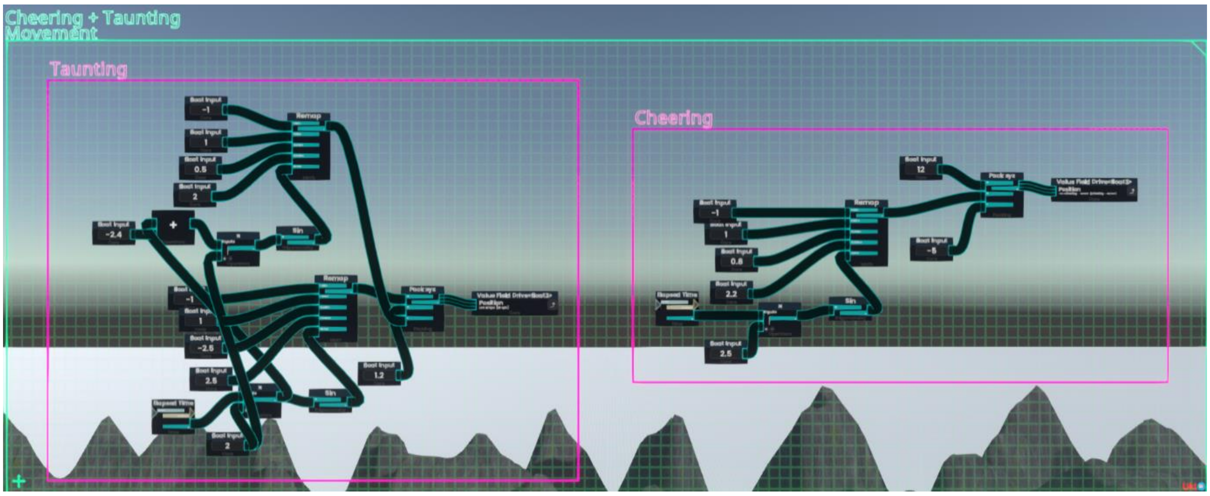
D.5 Collider Speedbehavior 2



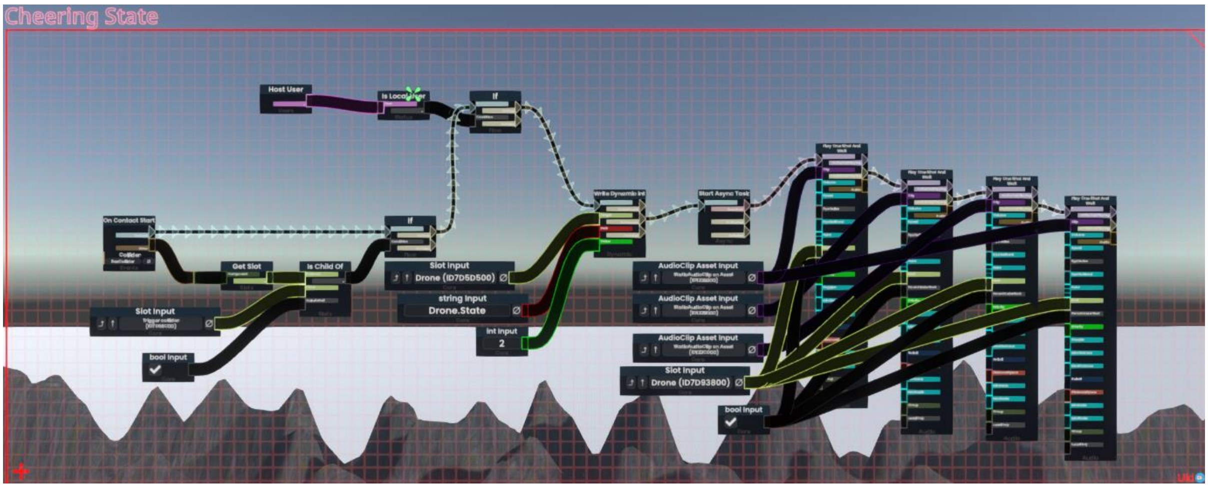
D.6 Camera Collider



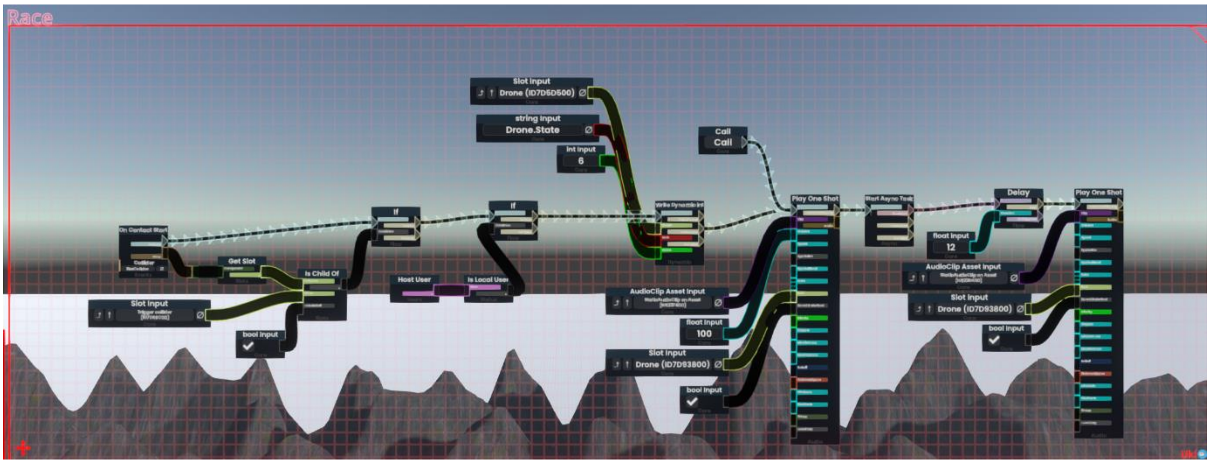
D.7 Cheering + Taunting movement



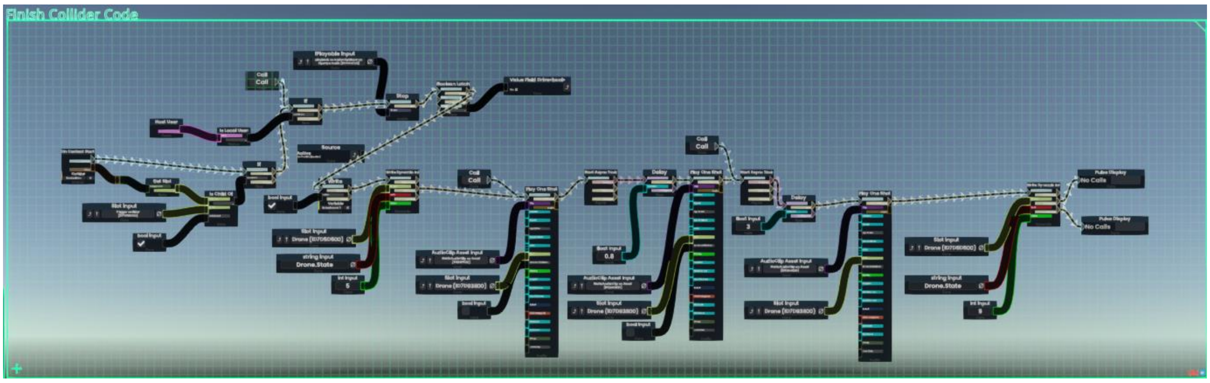
D.8 Cheering Collider



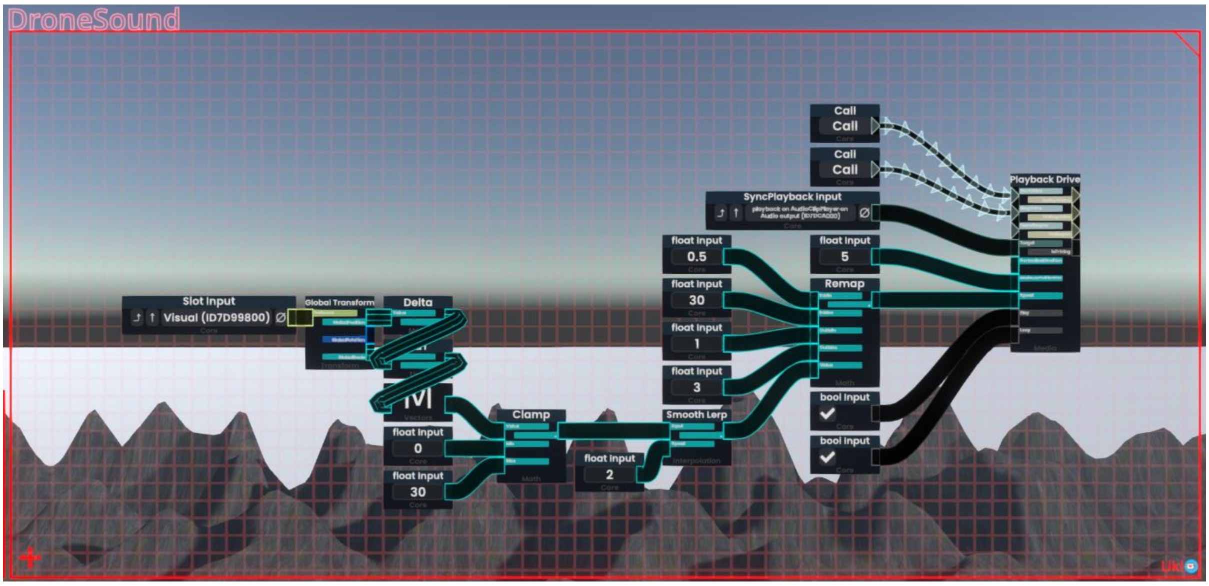
D.9 Collider Speedbehavior



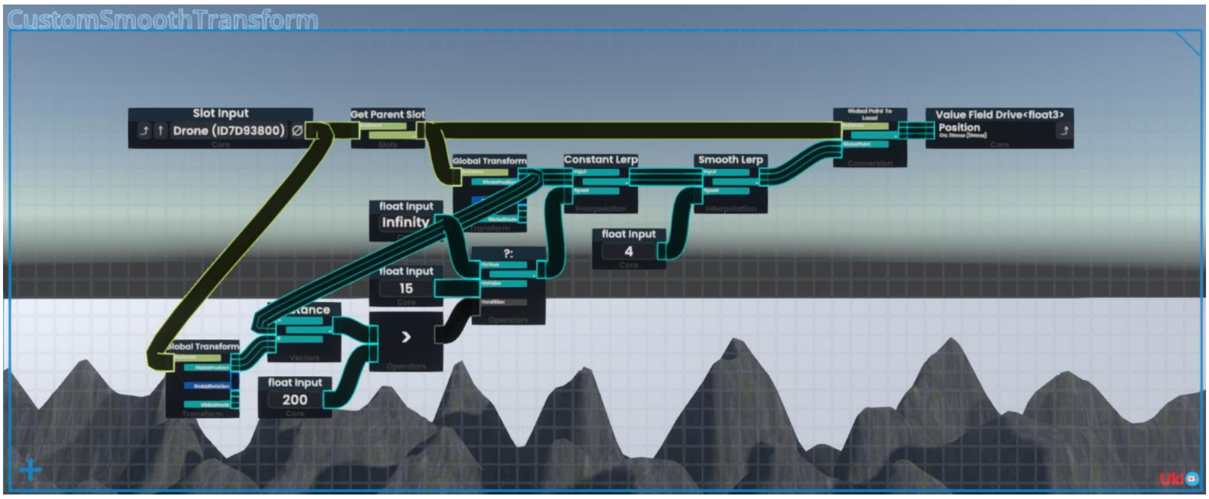
D.10 Finish Collider



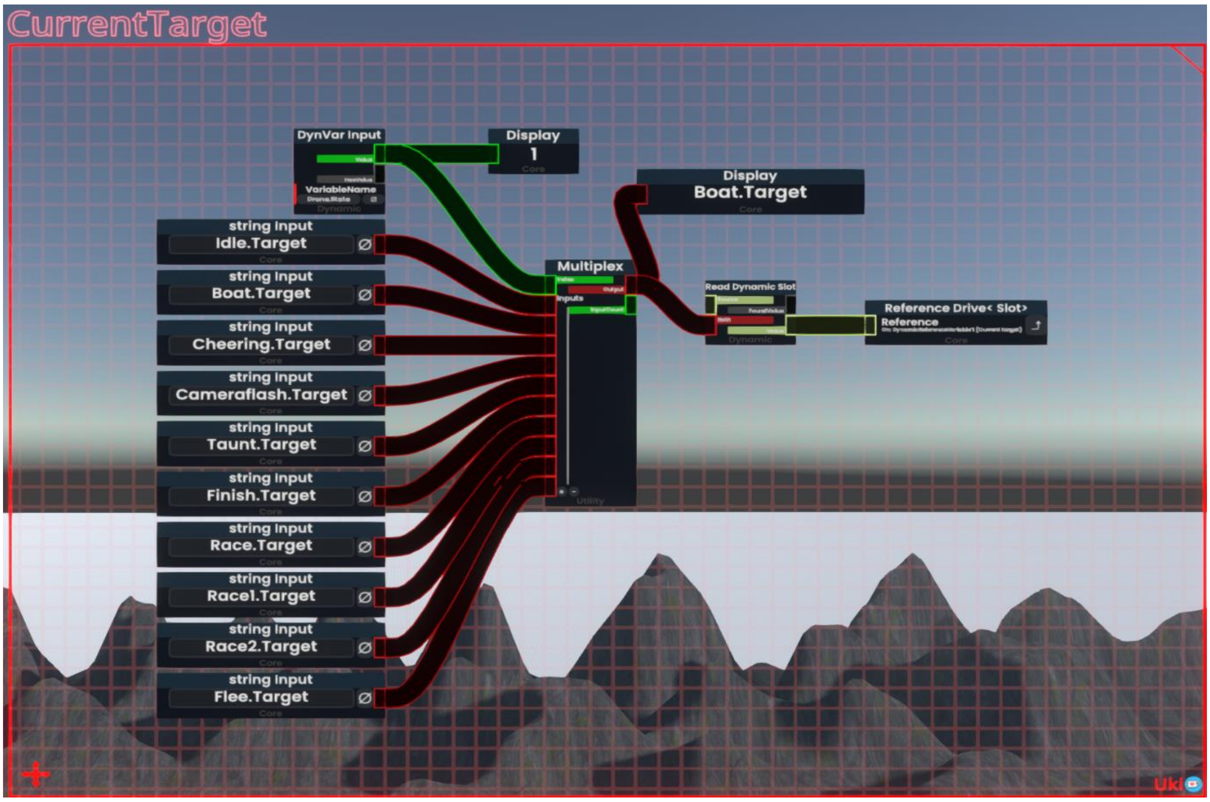
D.11 Drone sound



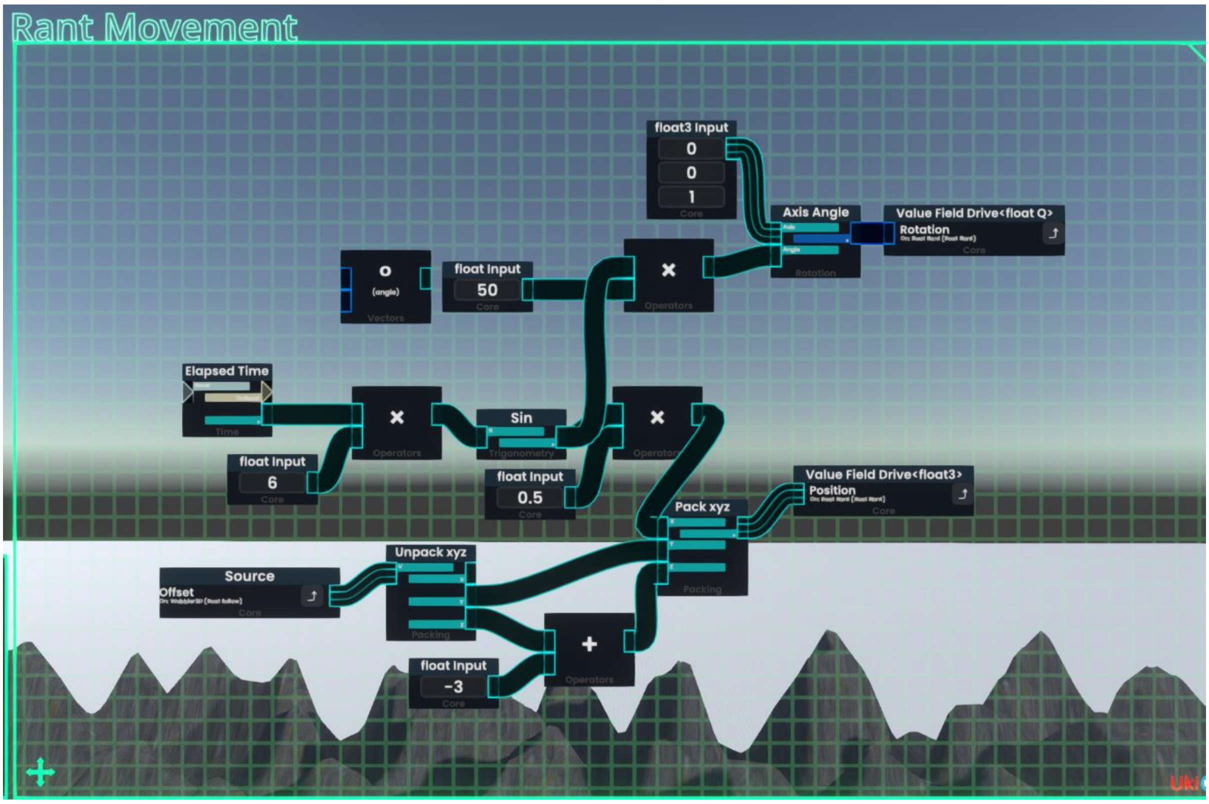
D.12 Custom Smooth Transform



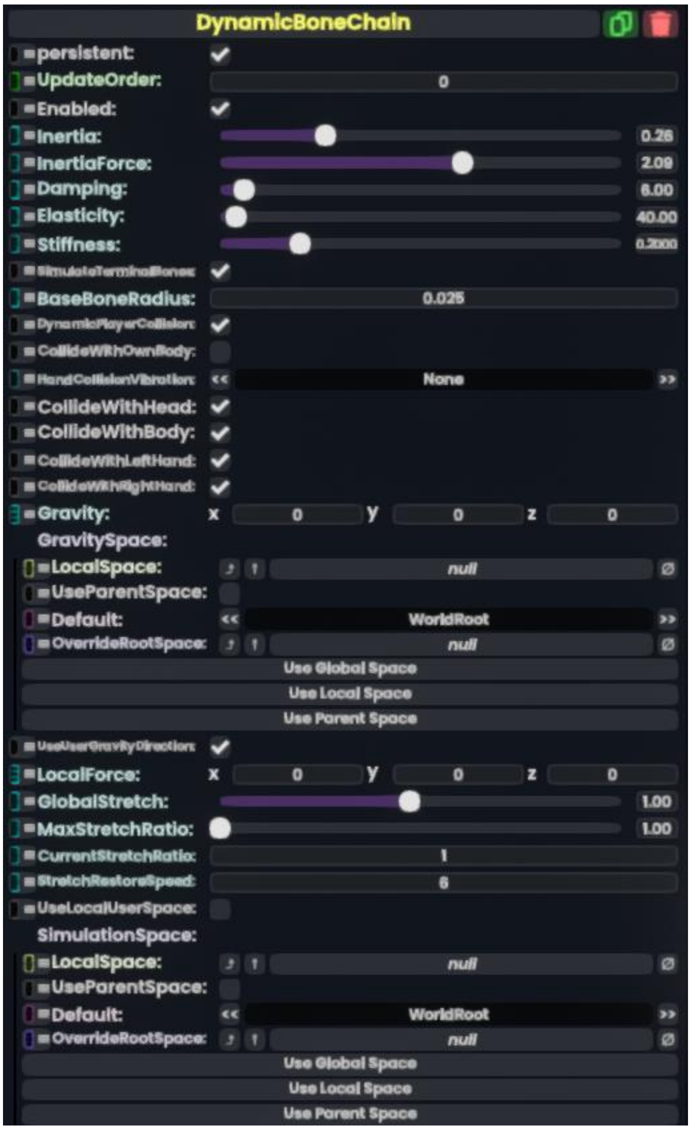
D.13 Current Target



D.14 Drone complaining

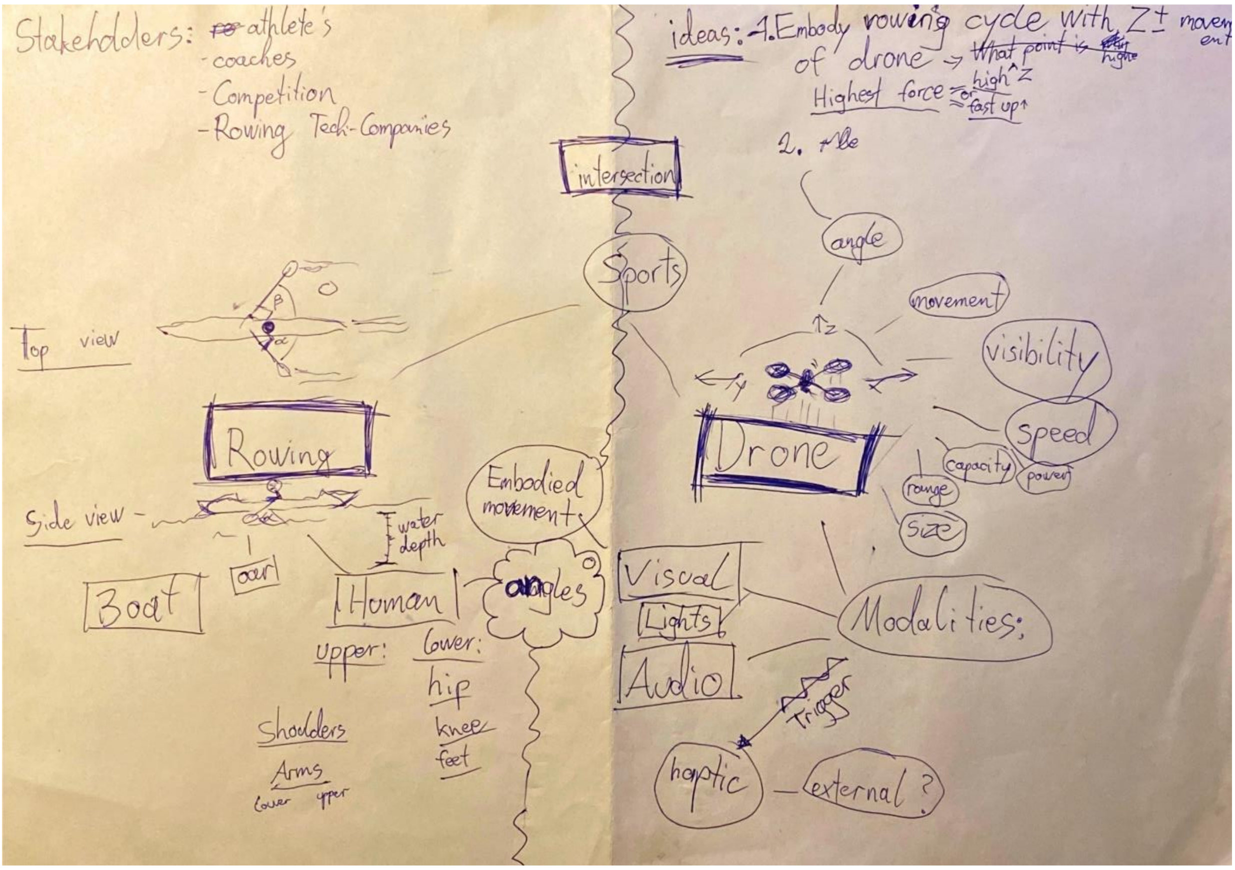


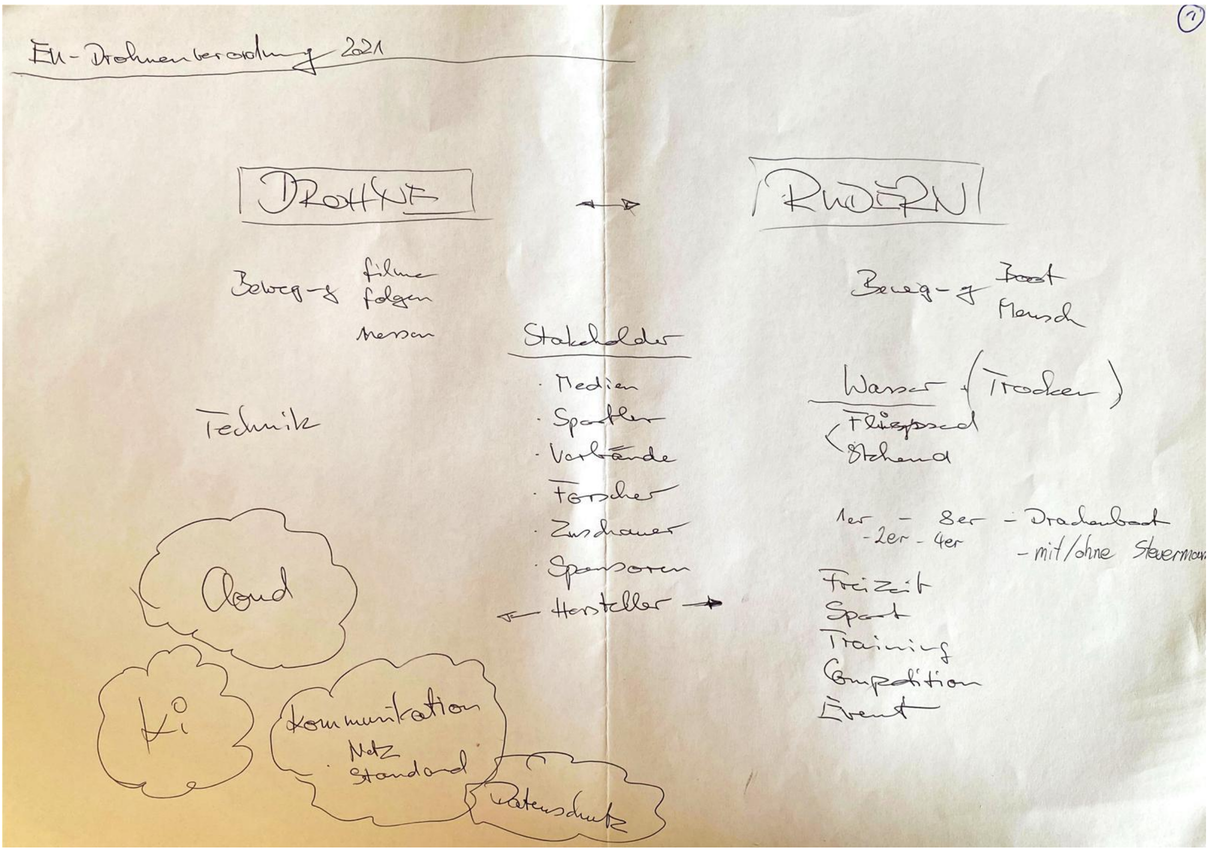
D.15 Dynamic Drone Behaviour

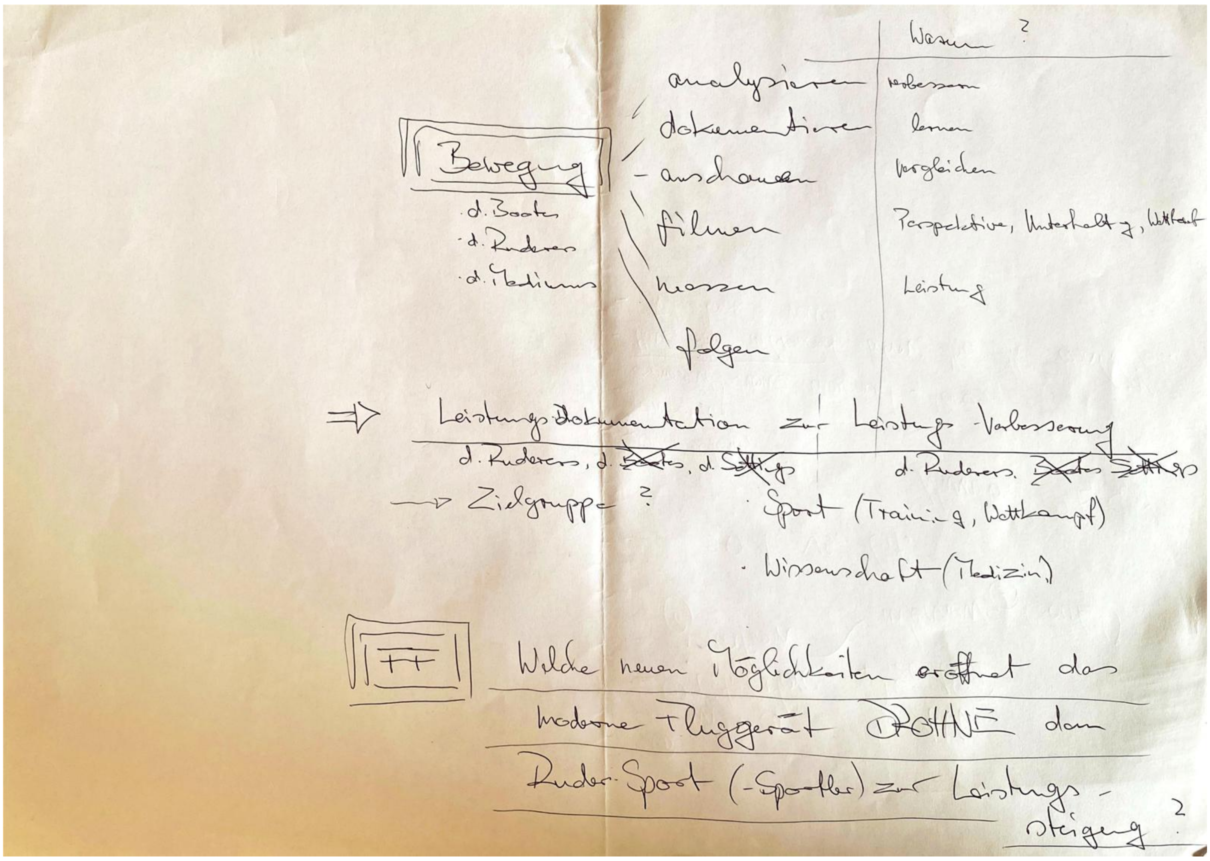


D.16 Inspector Layout of objects

E. Initial Mind mapping






Warum ?
analysieren
verbessern
dokumentieren
lernen
Bewegung
anschauen
vergleichen
· d. Bootes
· d. Ruderers
· d. Mediums
filmen
Perspektive, Unterhaltung, Wettkampf
messen
Leistung
folgen
⇒ Leistungs-Dokumentation zur Leistungs-Verbesserung
d. Ruderers, d. ~~Bootes~~, d. ~~Settings~~
d. Ruderers, ~~Bootes~~ ~~Settings~~
→ Zielgruppe ?
· Sport (Training, Wettkampf)
· Wissenschaft (Medizin)
FF
Welche neuen Möglichkeiten eröffnet das moderne Fluggerät DROHNE dem Ruder-Sport (-Sportler) zur Leistungs-steigerung ?