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Location-Based Tower Defense

Designing an Outdoor Exergame

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Master of Science in Computer Science
Submission date: June 2016
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Abstract

Increasing problems of physical inactivity has led to a growing interest in the field of exergaming. Exergames aim to use video games' ability to excite and engage, and combine it with elements of physical activity and exercise. This has the potential to reach an audience living particularly sedentary lives.

This study has explored the possibilities and challenges of outdoor exergames. A review of the field led to the design and development of a prototype of a location-based tower defense exergame for the smartphone platform. The user's location is tracked using GPS and displayed on a map of the area. The game takes place on the map, requiring the player to physically move in order to change the position of her in-game avatar. The goal of the game is to stop computer-controlled enemies from reaching your base by building defensive towers and collecting power-up items.

The game was tested on five male students with an interest in video games and exercise. The tests took place in a public park. Each participant played the game once, sessions lasting from 10 to 24 minutes. Observations and interviews indicated that the game was successfully able to engage and entertain the players, encouraging physical exertion. The players reported that it reduced focus on the physical effort expended. They were somewhat positive towards including such a game in their exercise schedule, on the condition that it included a multiplayer mode. Challenges associated with outdoor exergames were identified. These include inaccuracies in the location tracking, the risk of injury, and social barriers involved with playing games in public.

Sammendrag

Mangel på fysisk aktivitet er et stadig økende problem. Dette har ført til økt interesse for *exergames*. *Exergames* kombinerer dataspills evne til å begeistre og engasjere med fysisk bevegelse og trening. Dette har et potensiale til å nå en målgruppe som lever spesielt stillesittende liv.

Denne studien har utforsket mulighetene og utfordringene knyttet til utendørs *exergames.* En undersøkelse av fagfeltet førte videre til design og utvikling av et lokasjonsbasert *tower defense exergame* til smarttelefoner. Spillerens plassering spores via GPS og vises på et kart over området. Spillet foregår på dette kartet, og spilleren må fysisk bevege seg for å påvirke posisjonen til spillkarakteren hennes. Spillets mål er å hindre datastyrte fiender i å nå basen din ved å bygge forsvarstårn og samle verdifulle gjenstander.

Spillet ble testet på fem mannlige studenter med interesse for dataspill og trening. Testingen skjedde i en offentlig park. Hver testdeltager spilte spillet én gang, og rundene varte fra 10 til 24 minutter. Observasjon og intervjuer indikerte at spillet var i stand til å engasjere og underholde spillerne, samtidig som det oppmuntret til fysisk aktivitet. Spillerne rapporterte at spillet tok vekk fokus fra den fysiske anstrengelsen. De var nokså positivt innstilt til å inkludere et slikt spill i treningsplanen deres, gitt at det inkluderte en flerspillermodus. Det ble identifisert spesielle utfordringer knyttet til utendørs *exergames*. Disse inkluderte unøyaktig posisjonssporing, risiko for skader, og sosiale sperrer knyttet til å spille dataspill i offentlige rom.

Preface

This thesis concludes my Master of Science in Computer Science at the Department of Computer and Information Science (IDI) at the Norwegian University of Science and Technology (NTNU). The work builds upon a preliminary research project carried out during the fall of 2015 [1].

I would like to thank my supervisors Alf Inge Wang and Kristoffer Hagen for their guidance and input throughout the project.

I would also like to express my gratitude to everyone who participated in the user testing and provided me with valuable feedback.

Audun Brandt

Trondheim, June 17, 2016

Contents

Part I

Introduction and Research Methodology

In this part, I will introduce the motivation and objective of the study, along with a presentation of the research questions and methodology structuring the work.

1. Introduction

In this chapter, I introduce the motivation and objective for the research presented in this thesis. I also describe the outline of the report.

1.1 Motivation

People are living increasingly sedentary lives. Both at work and at home, more time is spent sitting down than ever before, and levels of physical activity are below the recommended amount [2]. Technology is playing a big part in this development, increasing the number of desk jobs and introducing seated activities such as watching television and playing video games. Time spent playing video games in particular has increased by large amounts in recent years, and especially the younger demographic has taken to the controllers, keyboards, and smartphones for this digital form of entertainment [3]. Research has shown a sedentary lifestyle and lack of physical activity to be a risk factor for several health problems, including high blood pressure, coronary heart disease, anxiety and depression, and certain cancers [4].

Even though digital entertainment is seen as one of the major causes for the trend of physical inactivity, researchers and industry now see the potential in using the technology to encourage movement and exercise. The emerging field of exergaming aims to use video games' ability to excite and engage, and combine it with elements of physical activity and exercise. Research indicates that playing exergames may be a viable alternative to traditional fitness activities and could be a part of an overall exercise program [5, 6]. This approach could be particularly effective in activating those who spend a large amount of time playing traditional, sedentary video games, a factor that has been shown to be negatively correlated with levels of physical exercise [7].

1.2 Objective

The purpose of this research and an outline of the process is described in the project proposal text by Alf Inge Wang:

> In this project, the goal is to come up with new game concepts and game technologies for exergames - games where the player carry out physical exercise at the same time. There are several approaches for exergames, and the challenge is to find the balance between something that is fun to play as well as you get a real physical exercise from playing the game.
>
> The first phase of the project will consist of a theoretical study of exergames and mechanisms for how games can be used as a motivator. The second phase focuses on implementing a prototype using various technologies. In third and final phase, the prototype will be evaluated and tested.

1.3 Report Outline

The thesis is organized into five parts, with a total of 18 chapters.

Part I will be concluded by Chapter 2, presenting the research questions and methodology shaping the rest of the work presented in the report.

Part II provides relevant background information, taking a closer look at the problem of physical inactivity, enjoyment in video games, game genres and a review of the exergaming field.

Part III covers the game design and implementation.

Part IV presents the evaluation of the implemented exergame, describing the methods used and the resulting data.

Part V contains a discussion of the results of the research and concludes on the answers to the research questions. An outline of future work is presented.

2. Research Questions and Methodology

In this chapter, I present the research questions and methodology guiding the work done throughout the thesis. This includes an overview of the overall research process structuring the work, the research strategy, and data generation methods.

2.1 Research Questions

Studies have pointed out differing motivations for participating in sport-oriented and fitness-oriented activities [8]. Participants of sports are motivated by interest, enjoyment and building of competence. On the other hand, the motives for participating in fitness-oriented exercise focus on enhancing health and physique. Intrinsic forms of motivation, like those associated with sports, have been shown to facilitate long-term adherence [9]. With this in mind, I would like to explore the potential of exergames inspired by the enjoyable form of exercise typical of sports.

The goal of this research is to investigate how to design a playful, outdoor activity that utilizes video games to motivate physical activity. The research questions I wish to answer are as follows:

RQ1: What genres of video games are well suited in this setting?

This research question investigates different genres of traditional video games and their suitability as an inspiration for exergames. Basing an exergame on a popular game genre can make it appeal to the audience of traditional video games, a population shown to be less active than the general demographic.

RQ2: What kind of technology is fit to support the activity?

This research question focuses on the range of different technologies available as potential platforms for exergames.

RQ3: What new challenges arise from this combination of video games and outdoor physical activity?

This research question is focused on the challenges accompanying the suggested take on exergames, not present in indoor video gaming or outdoor physical activities. These include practical, technical and social challenges.

RQ4: How does an exergame like this affect the motivation and engagement of the users?

This research question investigates how psychological principles utilized in traditional video games can be used in the realm of exergames to make the user experience engaging and self-motivating.

RQ5: To what extent are players willing to exert themselves physically during the activity?

This research question focuses on the physical outcome of playing the resulting Exergame, and to what degree the players are interested in making a physical effort.

2.2 Research Methodology

This section will provide an overview of the methodology underlying the research.

2.2.1 Research Process

The research presented in this thesis is structured according to Oats' model of the research process [10] (see Figure 1).

The first components of the process make up the prestudy phase of the project. Personal experiences and motivation guide the researcher towards a specific field of study. To gain insights and knowledge of the chosen area, the researcher then reviews the existing literature. The literature review serves as a basis for the conceptual framework for the research, providing structure to both the topic and the design- and implementation process. Based on the acquired knowledge and personal motivations, the researcher decides on research questions. The purpose of the remainder of the work will be to answer these questions, adding new knowledge to the field of study.

Next, the researcher must choose one or more research strategies, based on their suitability to answer the research questions. The strategy will vastly influence the shape of the research, in combination with the data generation methods. These are various ways to produce relevant data of either quantitative or qualitative nature. The last part of the process involves analyzing the collected data, discussing their meaning and using the results to answer the research questions.

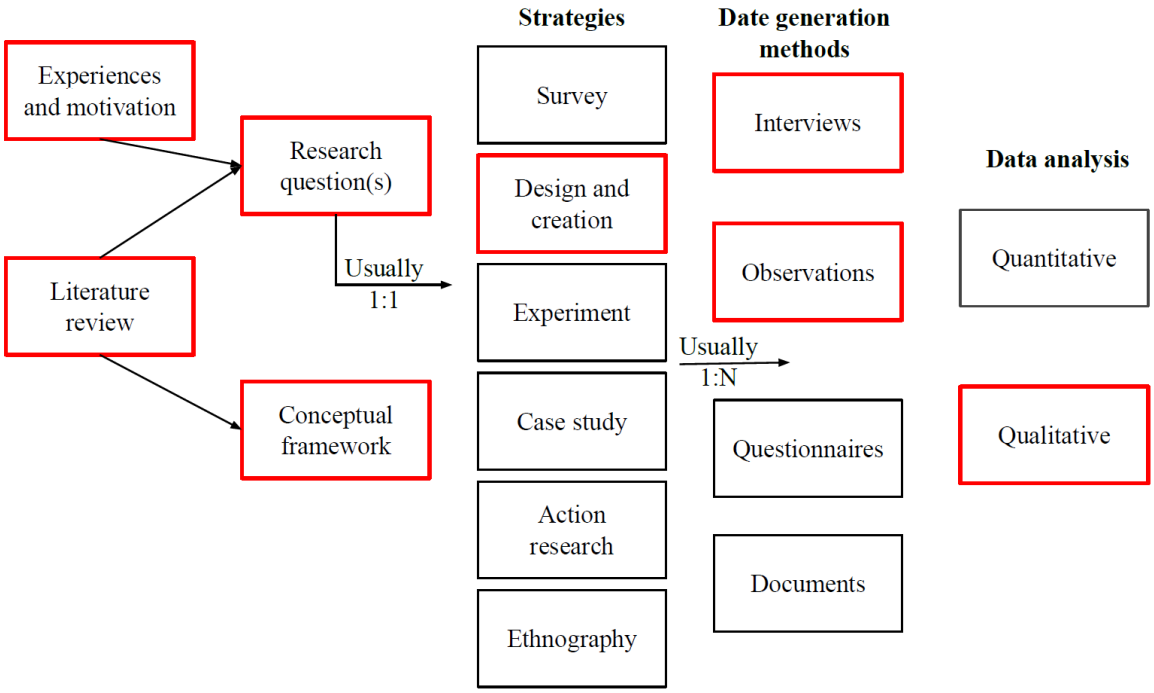


Figure 1. The research process, following the model proposed by Oates [10].

2.2.2 Literature Review

During the literature review, I acquired the background knowledge of the chosen area of study. By studying existing work, I built a foundation necessary for posing new research questions able to add to the pool of knowledge in the field.

2.2.3 Research Strategy

The project description states that the research should include the implementation and evaluation of an exergame concept. This corresponds to the research strategy of design and creation in Oats' model. The strategy involves the development of new IT *artifacts*, a term including constructs, models, methods, and instantiations. Constructs are IT-related concepts like objects and classes; models combine constructs in new ways to aid developers and researchers. Methods describe ways to use models to gain some value in IT-related work. Instantiations are implemented IT-systems demonstrating and evaluating some idea or theory.

In this thesis, the developed artifact will be an instantiation, namely the implementation of a prototype of an exergame. This exergame will be evaluated and help answer the research questions posed in Section 2.1.

The development methodology used in this project consists of two main stages. The first stage of this process was an analysis of the problem area, taking the form of a literature and technology review. Next came a phase of iterative game design and implementation, transforming the initial game concept into a working game prototype.

After the exergame had been completed, it was evaluated through user testing. A description of the evaluation is presented in Part IV of the thesis.

2.2.4 Sampling

When selecting participants for user tests, there are a series of aspects to consider. The sampling frame is the total population from which you can draw relevant participants. There are many different ways to select a sample from the sampling frame. There is a distinction between so-called probability sampling and non-probability sampling [10]. Probability sampling implies that the technique with some certainty leads to a sample representative of the sampling frame, while non-probability sampling does not. A representative sample has the advantage of providing results that can be generalized, applying the findings to a general population. However, this is not always feasible, and can take a lot of effort and resources to get right. One specific type of non-probability sampling is called convenience sampling [10]. This technique implies selecting test participants based on ease of recruitment. It has a serious impact on the ability to generalize the results but might occur out of necessity.

2.2.5 Data Generation Methods

Data generation methods are ways to gather data relevant to the questions you are seeking to answer. The most common methods are interviews, observations, questionnaires, and documents. Interviews are ways to gather data through structured conversations. Observations involve watching people in a setting relevant to the research area. Questionnaires are written lists of questions. Documents can be any written material, either preexisting or produced through the research. This includes images, audio, and any stored data.

These methods may very well be used in combination. This can both lead to the production of more data and provide the researcher with more than one view of the phenomenon under investigation. Using more than one method is commonly known as method triangulation [10]. It is considered an effective way to increase the validity of your results, or to uncover inconsistencies worth further investigation.

The choice of data generation methods will depend on factors like field of study, research strategy and practical concerns like time, resources, and the availability of test participants.

2.2.6 Data Analysis

The methods described above produce either qualitative or quantitative data. Qualitative data is descriptive data and not measurable with numerical results. This includes text, voice recordings, images, and video tapings. Quantitative data, on the other hand, consists of numerical values. This can be the scores on a survey measuring enjoyment, the length

of a user test in minutes, or the percentage of users expressing an intent to continue using a product.

Once gathered, the data must be analyzed. This involves looking for patterns. Quantitative analytics use mathematics and statistics, while qualitative analytics search for recurring themes in statements, actions or any other qualitative data collected.

Part II

Prestudy

In this part of the report, I review relevant areas of background information. This will provide a basis to build upon when exploring the different opportunities for the design of an outdoor exergame. First comes a closer look at the trend of increasing physical inactivity. Next, a description of the qualities of video games that make them engage and interest people, and act as a source of motivation and fun. Traditional video game genres will be covered, followed by a chapter on exergames presenting their history and relevant technological platforms.

3. Physical Inactivity

Globally, the population is getting increasingly inactive. 25 % of the world's adults and a staggering 80 % of the adolescents are not getting a sufficient amount of physical activity. This poses serious health risks, placing insufficient physical activity among the top ten risk factors for death worldwide [2]. Sedentary jobs and leisure time activities, along with passive means of transportation, play a big part in the reduction of physical activity. While inactivity during the time at work and transportation may be due to practical restrictions, the reasons underlying free time inactivity are more complex. Research has shown that people intending to exercise but failing to do so express beliefs that it would be too tiring and time-consuming [11]. Male adolescent participants in a Canadian study reported that they preferred to engage in technology-related activities rather than physical exercise. This included watching TV, using the internet and playing video games [12].

The negative effects of increasing inactivity and the popularity of video games serve as the primary motivations for investigating the potential of exergames.

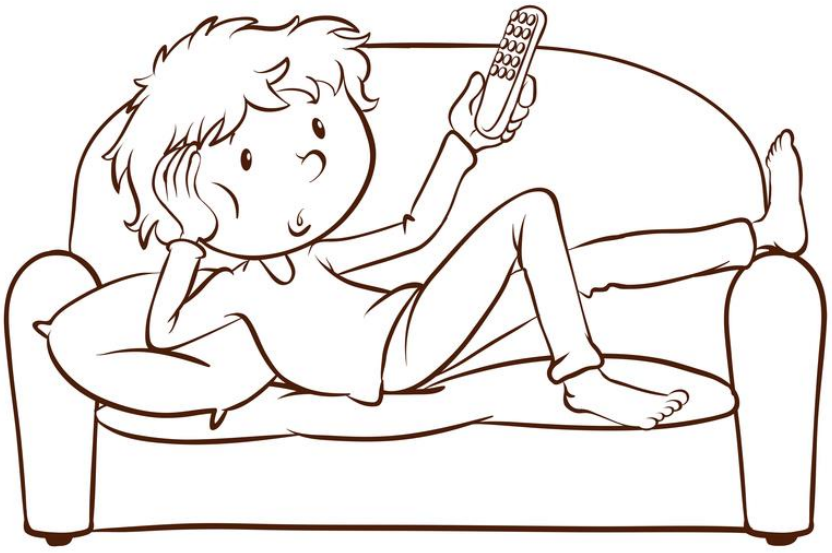


Figure 2. Physical Inactivity.

4. Enjoyment in Games

The most important property of any video game is its ability to produce enjoyment. Players usually play a game for no sake other than having fun, if the game does not provide this feeling of enjoyment, it is of little use. Following is a look at existing theories on what makes activities in general, and games specifically, enjoyable.

4.1 Flow and Gameflow

Gathering and analyzing data from thousands of people around the world on what makes experiences enjoyable, Csikszentmihalyi coined the term *flow* [13]. It describes optimal experience, a feeling of great pleasure and enjoyment. Flow experiences occur through very different activities, but eight recurring elements were noted. First, there needs to be a *completable task*. Second, the task must be one that allows for and requires *concentration*. This concentration is possible due to the third element, *clear goals*. Fourth, *immediate feedback* on performance needs to be provided. Fifth, the experience should be accompanied by a sense of *personal control*. Sixth, the task should produce *deep involvement*, reducing awareness of the surroundings. Seventh, a *feeling of reduced self-awareness* should occur, along with element eight, an *altered sense of time*.

An activity able to bring about the flow experience will be self-motivating and –rewarding, as people strive to achieve the accompanying enjoyment. Looking at the elements comprising such experiences, it is obvious that video games fit the mold – a typical, well-made video game has an obvious goal, it requires deep concentration, provides instant feedback, and leaves the player in full control of the outcome.

Sweetser and Wyeth present a model for player enjoyment in games based on flow, called *gameflow* [14]. It closely resembles the elements of flow, with the following eight elements:

- *Concentration*: The game should require the player's concentration, and the player should be able to concentrate on it. An appropriate workload helps accomplish this.
- *Challenge*: The game's difficulty should match the player's skill, with increasing levels of challenge as the player improves.
- *Player Skills*: The gameplay should help the players learn how to play the game, starting at the level of complete beginner and steadily increasing their skills through the game.
- *Control*: Players should have a feeling of control over what happens in the game, both in terms of their actions, the game interface and the way they want to play the game.
- *Clear Goals*: The players should be provided with clear goals, directing their efforts in the game. Multiple goals at different levels make sure the player does not lose sight of the objectives.

- *Feedback*: Feedback should be provided to the players, both immediate feedback regarding their actions, and feedback on their progress toward the goals of the game.
- *Immersion*: Games should create an immersive experience for the players, reducing self-awareness and awareness of their surroundings, altering the sense of time and producing emotional involvement.
- *Social Interaction*: Games should facilitate social interaction, allowing cooperation and competition between players, in addition to providing means of communication.

This model omits an element describing the task itself, which in this context is the actual game, and it includes "Social Interaction", which is a central motivational factor in many video games. It is worth noting how well video games fit within a model trying to describe optimal, self-motivating activities. Taking advantage of this knowledge, game designers can more systematically come up with gameplay that serves as a source of motivation and engagement.

To tailor the concept of flow directly to exergames, Sinclair et al. propose their model of *dual flow* [15], seen in Figure 3. They focus on the dimensions of attractiveness and effectiveness, capturing the gameplay and exercise elements of exergaming.

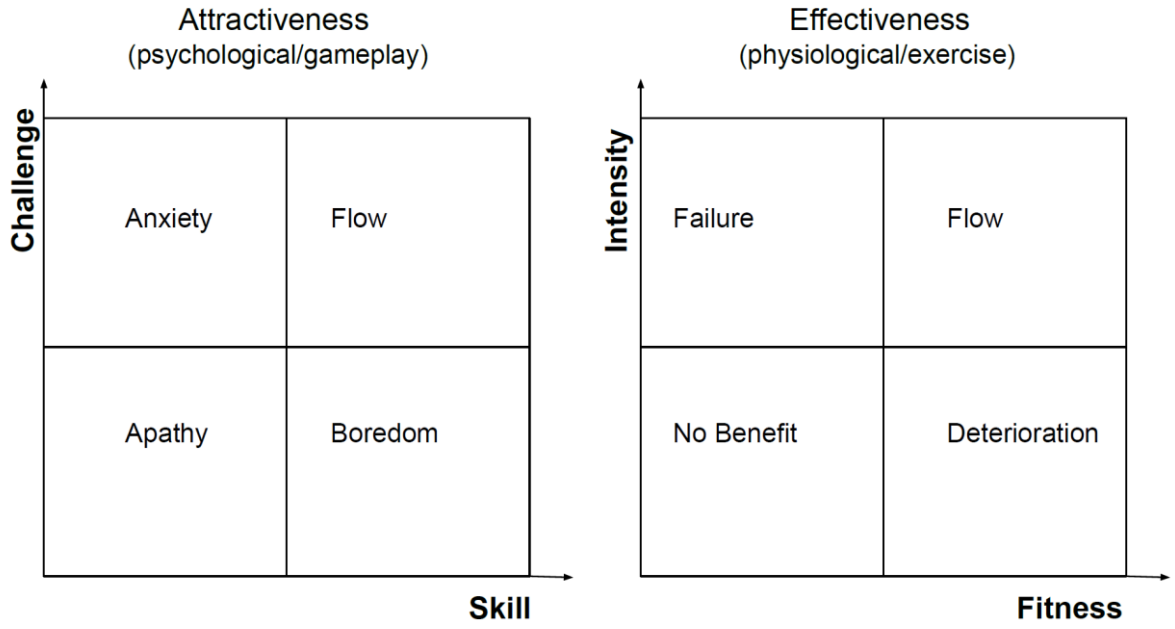


Figure 3. The Dual Flow Model for Exergaming [15]

To achieve psychological flow, the challenge of the game must be balanced with the skill of the player. If the game is too easy, the player is bored, while if it is too hard, the player will experience anxiety. If neither challenge nor skill is present, the player turns apathetic. Physiological flow is reached by matching the intensity of the exercise with the fitness of

the player. Too high intensity results in failure, and if the intensity level is too low, the player's level of fitness will deteriorate.

4.2 Challenge, Fantasy, and Curiosity

Another framework, presented by Malone [16], aims to describe what makes video games fun, organizing the characteristics into three categories: challenge, fantasy, and curiosity.

For a game to be *challenging*, the player needs a goal to strive for, without knowing whether it is achievable or not. The goal needs to be obvious and unambiguous, and the player should receive feedback on his progression along the way. The outcome of the game must remain uncertain until it is over, and this uncertainty can result from several techniques. First, the difficulty level can be variable. Second, the game can contain multiple goals on different levels. Third, some information can be hidden from the player to keep the uncertainty of outcome. Fourth, employing randomness in the gameplay can be a way of avoiding a predefined result.

Fantasy is an element utilized by most video games to increase immersion and fascination. Gameplay wrapped in worlds of magic, lethal action, or adventure excites and enthralls in powerful ways. Malone points out that game fantasies able to stir the emotions of the players are the most effective, and points to the vast amount of games revolving around war and destruction [16].

Curiosity, the desire to learn or know, can be evoked by games to keep the player interested and wanting to keep going in order to see what happens next. The game environments need to be appropriately complex to surprise and excite the player, without being overly confusing. There are two different kinds of curiosity. *Sensory curiosity* describes the interest we have in extraordinary visual and audio effects. Video games can use graphics and sound to trigger this curiosity in its players. In addition to representing the game world, these sensory cues work well as a reward mechanism. *Cognitive curiosity* is concerned with the human urge to make sense of the world, creating a consistent and complete picture of knowledge. This can be exploited by presenting the players with incomplete information, or introducing inconsistencies in their knowledge.

By incorporating challenge, fantasy, and curiosity, along with the elements discussed in the previous section to achieve flow, exergames can provide experiences engineered to enjoy the players, keeping them focused on the gameplay and taking attention away from the physical exertion. If implemented well, the principles can also help increase the games' lifespan, ultimately leading to more health benefits for the players.

The frameworks presented in this chapter will help guide the design of my exergame, making the experience of playing the game enjoyable. They will also be used in the evaluation of the game.

5. Game Genres

Exergames can take inspiration from a range of games already proven successful. Video games are commonly organized into genres, categorizing the games based on their gameplay. While researchers are discussing how to most effectively classify video games [17], there is a general consensus in the industry regarding a set of genres. This chapter will be based on the genres used by Steam, the top distribution platform for games on PC [18]:

Action games Action games are characterized by a focus on fast-paced gameplay, requiring a high level of precision. Hand-eye coordination and reaction time are often crucial to achieving success in these games. Popular subgenres include fighting games, platform games, and shooter games.

Adventure games The main characteristics of adventure games are a focus on story, exploration and puzzle solving. These games typically do not depend on fast reactions and allow the players to interact with the environment at their own pace.

Role-playing games In role-playing games (RPGs), the player assumes the role of a character placed in a game world. The gameplay involves storytelling, tactical combat, and character development. Sandbox-RPGs and massively multiplayer online role-playing games are notable subgenres, adding non-linear gameplay and a persistent game world with thousands of simultaneous players.

Simulation games Simulation games share the common trait of trying to imitate some area of reality. The games will copy a specific aspect from a real (or imagined world), and recreate this as a game mechanic as accurately as possible. The subgenre of city-building games allows the player to design, construct and run a city, while vehicle simulation games let players control life-like digital versions of cars, planes and other vehicles.

Strategy games The common traits of strategy games is the focus on planning and tactical thinking. Managing resources, controlling units, and building structures are typical activities within games of this genre. Two main subgenres are real-time and turn-based strategy games. The former involves continuous action, while the latter splits the gameplay into rounds, allowing the player(s) to perform actions only at certain intervals. Tower defense is another subgenre with a simple form of gameplay, focused on the building of towers to stop enemies from reaching a certain point on the map.

Sports games Sports games aim to recreate real world sports in the form of video games. The level of realism varies, but physics and rules of the original sport are generally the focus. The genre encompasses the subgenres of physical sports games and racing games.

The game genres presented in this chapter will serve as inspiration in the process of coming up with a novel exergame design. Developers of new game designs should not strive to fit within any existing genre, but as a framework for organizing current and previous work, the genres presented above can aid in the design process.

6. Exergames

Exergaming is a term describing video games that include some element of physical exertion as part of the gameplay. The physical effort required to play ranges from waving of arms to running and weight lifting. Exergames have emerged from two separate motivations: to make video games more fun using bodily movement, or to enhance exercise using game elements. To gain a better understanding of the field of exergaming, the following sections will present a summary of the history of exergames and a look at a selection of technologies.

6.1 History of Exergames

The idea of combining video games with physical activity is not a recent one, numerous takes on the concept have appeared through the years. Until recently, however, there had been few successful products able to spark interest and excitement in users.

In the early 1980s, the Atari game consoles brought the first generation of exergames. Even though none of them were major successes, they set the stage and introduced ideas that would reappear in the games from thereon after. First off was the *Amiga JoyBoard* [19, 20], a balance board controller used to control a skiing game, called *Mogul Maniac* (Figure 4a). Exus released the *Foot Craz* [21], a floor mat controller with pressure sensors, letting the player control the speed of an on-screen avatar by physically running and pressing the buttons with their feet (Figure 4b). Atari themselves were planning on releasing the *Puffer*, an exercise bike that hooked up to their consoles and could be used to control custom-designed games (Figure 4c). The system was abandoned before launch, however, as Atari declared bankruptcy in 1984 [20, 22].

(a) (b)

(c)

Figure 4. (a) The Amiga JoyBoard. (b) The Exus Foot Craz. (c) The Atari Puffer

Nintendo also joined the exergame stage early on. In the late 80s, they introduced the *Nintendo Power Pad* (*Family Trainer* in Japan, *Family Fun Fitness* in Europe), a floor mat game controller to be used with the *Nintendo Entertainment System* (NES) console (Figure 5b). At the end of the decade, they also released the *Nintendo Power Glove*, a motion sensing device intended to control existing games in a new way, using gestures and movement (Figure 5a). It turned out to be almost unusable at the time, but the idea of controlling video games using hand movements would be reintroduced with the *Nintendo Wii* almost 20 years later, this time to great success.

Figure 5. (a) Nintendo Power Glove. (b) Nintendo Power Pad.

Ever since the 80s, a range of companies have produced gym equipment enhanced with gamification and virtual reality (VR) elements. Some products were intended for fitness clubs, like the Tectrix *VR Bike* (Figure 6a) and *VR Climber*, with prices thereafter. Others were supposed to connect to home consoles, including the *Extertainment System* for the Super Nintendo Entertainment System (SNES) and the *Cat-Eye Game Bike* for the PlayStation and PlayStation 2 (Figure 6b). The functionality of the games ranged from simply pedaling through virtual landscapes, to more advanced single- and multiplayer gameplay.

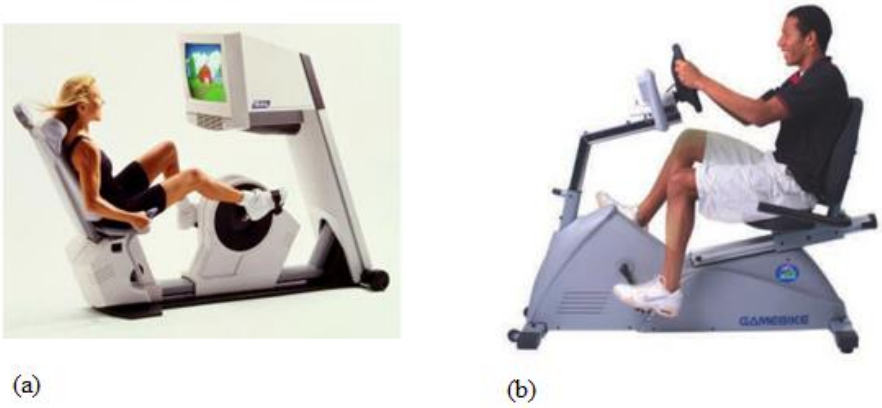
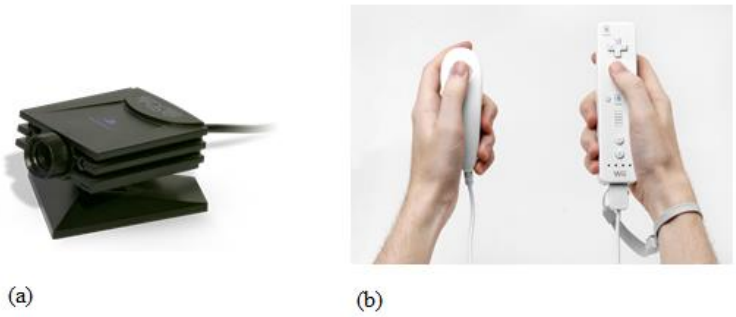


Figure 6. (a) Tectrix VR Bike. (b) Cat-Eye Game Bike.

At the end of the 1990s, Konami's *Dance Dance Revolution* (DDR) [23] appeared in arcades around the world (Figure 7). The first major success of the exergame genre, this dancing game provided players with a simple, four-button interface on the floor, letting players dance along to the music and moves shown on screen. Soon, home console versions of the game were released, using floor mat controllers greatly resembling the *Power Pad* of the 80s. DDR received the status as an official sport in Norway in 2003 [24].

Figure 7. Dance Dance Revolution.

The new millennium brought the rise of another branch of active video games. Starting with the *EyeToy* camera for the PlayStation 2 [25], the players' bodies were turned into game controllers (Figure 8a). Making use of computer vision technology, the EyeToy allows users to play games using motions. Following along the same lines, Nintendo released its *Wii* [26] console a few years later (Figure 8b).With it came the Wii Remote, capable of detecting movement in three dimensions, allowing a more fast paced and precise experience than the EyeToy was able to produce. The new controller's motion sensing capabilities were effectively used to simulate sports such as tennis, bowling and boxing, and the console quickly became a best seller. The *Wii Fit* exergame [27] was specifically designed to provide exercise; it came bundled the *Wii Balance Board*, a peripheral device able to track the user's center of balance. It also became extremely popular, beeing used in living rooms, health clubs, and nursing homes.



(a) (b)

Figure 8. (a) PlayStation EyeToy. (b) Nintendo Wii.

Following the immense success of the *Wii*, Sony revealed their similar solution with the *PlayStation Move*. Microsoft's *Xbox 360* console went with a more advanced version of the EyeToy, the *Kinect* [28], able to capture data in 3D and track the placement and movement of the entire body, without the use of a physical controller. Despite well-functioning technology, no system has been able to replicate the initial success of the *Wii*.

With the widespread adoption of modern, sensor-equipped smartphones comes new possibilities and opportunities to merge digital gaming with physical play. Location aware games like *Ingress* [29] turns the outside world into a game environment, having players move around in order to play (Figure 9a). *Zombies, Run!* [30] turns your everyday jog into a race to gather supplies and outrun the zombie horde (Figure 9b).

(a) (b)

Figure 9. (a) Ingress. (b) Zombies, Run!.

A wave of VR products is currently on its way that could make a substantial impact on exergaming. Head Mounted Displays (HMDs) like the *Oculus Rift* [31], *HTC Vive* [32] and *PlayStation VR* [33] enable a new level of immersion in games, and with that follows the urge to move realistically in the virtual worlds (Figure 10). There are several products on the way with the potential of providing engaging physical experiences, including the *Virtuix Omni* [34] omnidirectional treadmill and Activetainment's *ebove B/01 Bike* [35] bike simulator.

Figure 10. From Left to Right: HTC Vive, Oculus Rift, and PlayStation VR.

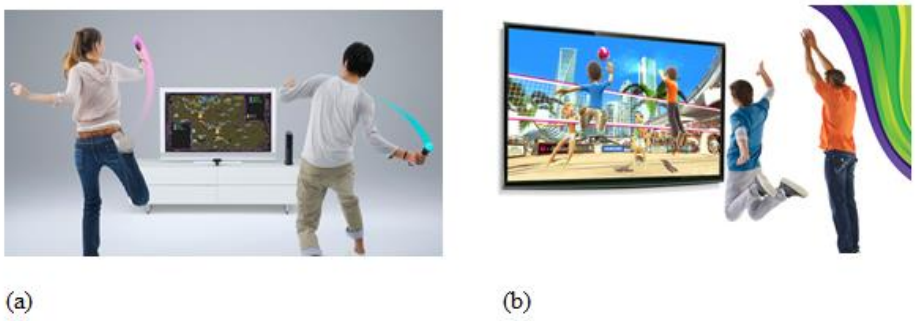
6.2 Technology Review

As seen in the previous section, progress and innovation in technology has resulted in a great variety of platforms available for exergame developers. This section will describe a selection of the alternatives in greater depth.

Motion-tracking systems Video game hardware to track players' movement has been around since the Nintendo Power Glove in the late 80s, and today all of the major video game console producers have such a system. Nintendo's *Wii U* [36] uses the same controllers as its predecessor, the Wii. The Wii Remote more closely resembles a TV remote than a classical game controller. It can sense motion using an accelerometer and infrared pointer technology, and requires a small optical sensor bar near the monitor. Attaching the MotionPlus expansion device, which is included in the Wii Remote Plus, enables a more precise tracking using a gyroscope.

The PlayStation Move motion controller, seen in Figure 11a, is very similar in use to the Wii Remote. It is a wand controller equipped with an accelerometer and an angular rate sensor, tracking motion and rotation of the device. At the head of the wand is a light emitting orb, enabling tracking by a peripheral PlayStation camera.

Microsoft's Kinect technology takes a different approach to motion-tracking. It does not rely on controllers, but instead solely uses a camera-like sensor device (Figure 11b). The Kinect uses an infrared camera as well as time-of-flight camera for sensing depth to provide full-body 3D motion capture. It can track up to six people at once, measuring their heart rates and tracking 25 individual joints per player.



(a) (b)

Figure 11. (a) PlayStation Move. (b) Xbox Kinect.

Virtual Reality 2016 is a milestone year for virtual reality technology, with three prominent producer's releasing head-mounted displays (HMDs) targeted at the VR consumer market. For PC, Oculus Rift and the HTC Vive have already arrived, while the PlayStation will get its own headset in the PlayStation VR. The type of gameplay inspired by these headsets is very exciting for exergaming. The VR HMDs allow players to feel like they are physically present in the game world, bringing about an urge for a more realistic way of interaction than a controller or mouse-and-keyboard. Third party developers are well underway with peripherals to achieve just that. The Virtuix Omni is an omnidirectional treadmill, allowing the player to walk and run in all directions, as well as jumping and sitting down (Figure 12a). Activetainment' ebove B\01 Bike is an

advanced exercise bike with movable handlebars, breaks, and gears (Figure 12b). It responds to users' sideways tilt, adjusts incline and decline according to the game world, and takes the type of terrain into account.

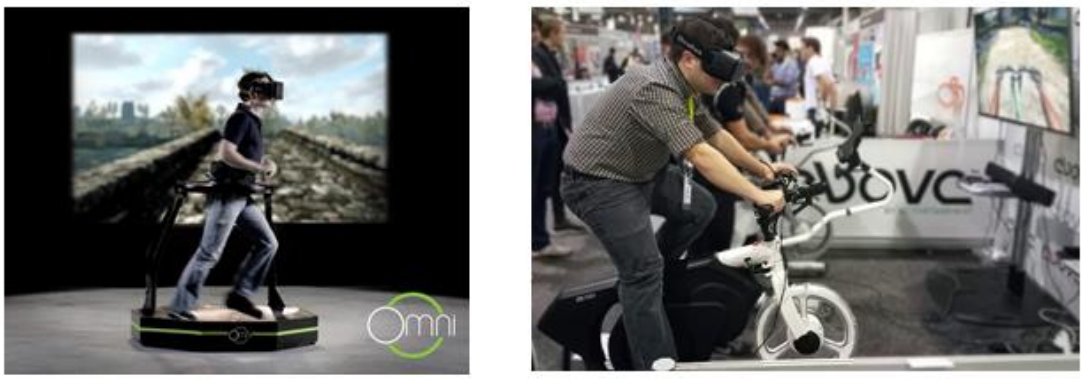


Figure 12. (a) Virtuix Omni. (b) Activetainment ebove B\01 Bike.

Augmented Reality (AR) Closely related to virtual reality, augmented reality involves overlaying a live view of the real world with computer-generated imagery. This allows video games to merge with the player's physical environment, providing new and immersive experiences. Like VR, this encourages natural physical movement as part of the gameplay and turns the real world into a playing field. As of this writing, the technology is still in its infancy. Smartphones do have the capabilities of running AR programs. However, the limited processing power and minimal field of view limit the practical applications. Several technological giants are currently working on dedicated AR devices. Microsoft is currently developing the *HoloLens* [37], a head-mounted display primarily targeted at business customers, but with obvious potential as a video game platform (Figure 13a). Google's *Google Glass* [38] is a very compact AR device in the shape of a pair of eyeglasses (Figure 13b).

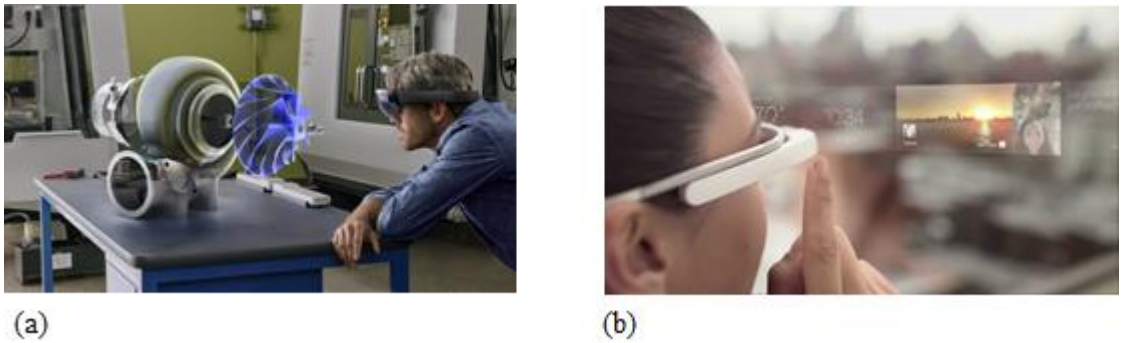


Figure 13. (a) Microsoft HoloLens. (b) Google Glass.

Smartphones Modern smartphones come packed with cutting edge technology and can run many kinds of games. The array of sensors available provides possibilities for innovative gameplay and makes it possible to create a mobile exergame platform. Standard in most phones are sensors for tracking movement and location, both of which can be utilized to create active video game experiences. Equipped with accelerometers, digital compasses and gyroscopes, the units' orientation and motion is accurately measured. GPS provides the capability to track the device's position and place it on a map, enabling location-aware games.

Fitness Equipment Using fitness equipment in combination with video games was one of the earliest ideas in the realm of exergaming. Many systems exist, with a varying degree of availability to independent developers. The previously mentioned Activetainment ebove B\01 Bike is one example of advanced equipment taking a central part in the game experience. In the other end of fitness equipment spectrum, Gamercize [39] has released several accessory devices, such as steppers, rowing machines and cycles (Figure 14). Usable with traditional games, these plug into a console or PC. While not directly influencing the gameplay, they require the player to keep exercising by pausing the game if the movement stops.

Figure 14. Gamercize stepper.

When designing an exergame, choosing the right technological platform is of vital importance. The categories all share the ability to incorporate physical activity into video games but do so in widely different ways. They also target differing groups of users, varying in numbers and demographics.

Inspiration from the tried-and-tested existing exergame ideas, along with knowledge of the available alternatives in technologies, will be an important foundation in the design process of my exergame.

Part III

Design and Implementation

Based on the prestudy, I propose a game concept for an outdoor exergame. This part of the report presents reasoning for the chosen platform and technology, game concept and -design, and an overview of the implementation of a prototype of the game.

7. Choice of Platform

As described in Chapter 6, there are several excellent platforms for developing active video games. For developing an outdoor game, however, there are some major physical restrictions to take into consideration. The player needs to be able to move freely around in the environment, implying a lightweight, battery-powered piece of technology with the computational power to run an actual game.

I decided to develop a game for smartphones. These devices are small and easy to carry around. Over the last years, their processing and graphical powers have increased by leaps, making them more than capable of running advanced games. Most of the technological platforms presented in the previous chapter are not suitable for outdoor use, making the choice of developing for smartphones natural. While not readily available at the time of this work, light-weight augmented reality glasses should be the target of future work.

Smartphone gaming has seen explosive growth the last years [40], as the devices have become widely available. At the beginning of 2015, 84 % of Norwegians above the age of 15 with access to the internet reported having a smartphone [41]. The fact that a substantial part of the population is equipped with such a versatile gaming device, introduces entirely new opportunities. Smartphones have an easy-to-use touchscreen, sensors that can track motion, and the capability to track the user's location.

Designing games for mobile phones bring about both restrictions and new possibilities. The phone itself will act as controller and screen at the same time, which can pose challenges when including motion in the gameplay. The screen is also small in comparison to other video game platforms, limiting the amount of room for information and graphics. On the other hand, the devices' small size is its major strength, as it can be carried around without effort.

(a) (b) (c)

Figure 15. (a) Samsung Galaxy S6 Edge. (b) iPhone 6s. (c) Microsoft Lumia 950 XL.

8. Technologies for Mobile Game Development

The three main software platforms on modern smartphones are Google's *Android* [42], Apple's *iOS* [43] and Microsoft's *Windows Phone* [44]. Together, these operating systems are found running on 99.3 % of the world's smartphones, with Android towering at 82.8 %, iOS at 13.9 % and Windows Phone at 2.6 % [45] (Figure 16). To cover the maximum number of target devices, I decided to use a cross-platform framework, allowing a single codebase to build the game to all major mobile operating systems. Following is a brief discussion of the selection of development software.

Unity [46] and Unreal Engine [47] are two widely used and freely available game engines. Mainly aimed at 3D game development, they also support 2D games. The engines are heavy pieces of software, usable to create high-performance, graphically advanced games. The extra power comes at a cost, as it requires a relatively large effort to get proficient with the tools. For this project, a more lightweight framework would be sufficient. There are a series of viable tools in this category, including the open source frameworks Cocos2d-x [48] and libGDX [49], and the proprietary Corona SDK [50] by Corona Labs Inc.

Based on some initial testing, I decided that Corona SDK would suit the needs of this project. Directed at 2D game development for mobile devices, developers avoid unnecessary overhead required for complex 3D games. Corona provides a device simulator and a debugger, making it very well suited for rapid prototyping. It is based on the Lua programming language, widely used for scripting in the game industry [51]. The downside with the choice of development platform is the lack of support for native API calls in the free version. However, initial testing showed that the core functionality of GPS location was available.

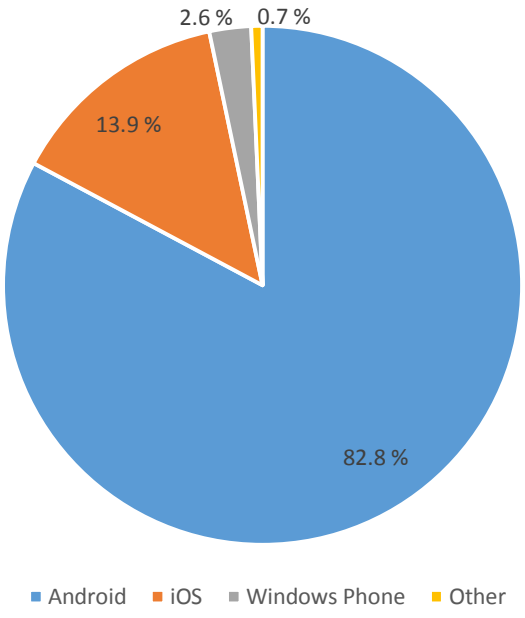


Figure 16. Worldwide smartphone OS market share.

9. Desirable Properties

The desirable properties in an exergame for the smartphone platform are in some aspects similar to those of video games in general, some are shared with all exergames, and some are specific to this exact type of game.

Starting in the general end of the spectrum, the most important aspect of such a game, as in any other, is fun. If the game experience is not enjoyable for the player, there is no motivation for playing beside the benefits of the exercise, eliminating the entire purpose of the exergame. This must be kept in mind during the entire design process, making sure enjoyment is not ignored in favor of other aspects, typically concerning effectiveness of the exercise.

The game should be designed to promote flow experiences during play. According to the model of gameflow, the game should be immersive, and require the player's concentration. When designing exergames, it is easy to overemphasize the attention on the exercise, leaving the gameplay incapable of distracting the user from the physical exertion. The flow model in Section 4.1 describes the importance of clear goals and immediate feedback. In the case of an exergame, these elements will help avoid a feeling of disconnection between the physical movement and the game. Including social interaction through multiplayer game modes is also beneficial. Introducing human competition and social aspects in games have been shown to increase enjoyment, motivation to keep playing in the future, and levels of physical exertion [52, 53].

In accordance with the dual flow model for exergaming, a successful game will have to correctly balance both player skills and challenge, as well as fitness and physical intensity. This is one of the central challenges of all exergames, and it should receive a great deal of consideration when creating a design. Players will vary widely in terms of previous video game experience, and even more in their level of fitness. The game needs to handle variations in both dimensions at the same time, with mechanisms for adjusting them separately. If the difficulty of physical and gameplay challenges are linked, the experience can easily become imbalanced. A player who is fit but unskilled at the game risks a situation where the physical intensity is too low, and the gameplay is too hard, leading to simultaneous psychological anxiety and physiological deterioration. As another example, an out-of-shape player risks being overwhelmed by physical exertion while finding the game mechanics to be boringly easy.

When incorporating physical exertion in a video game, I will strive to make it a natural part of the gameplay. Treating movement as an additional tool to create exciting and innovative games will hopefully lead it to be smoothly integrated with the other game elements, adding to the overall experience.

Designing a game based on movement requires careful consideration of core game concepts. First, movement should be rewarded. If the player gains an advantage by standing still, there is a mismatch between the gameplay and the goal of activating the player. To avoid the player reaching exhaustion too early, the game also has to allow for natural breaks from the physical activity.

The nature of smartphones means the interface between the user and the game is limited to a small screen. When adding physical movement and the potential of physically exhausted players, it is of great importance to make sure the user interface is simple and clear. Another factor when dealing with location-aware games depending on GPS for tracking the player is the limitations of the technology. The inaccuracy of the GPS chips in Android devices was measured to be 5-8 meters in 2011 [54]. This should be taken into consideration when designing applications, as it essentially determines the resolution of the playing field. The typical GPS update rate of once a second should not pose a problem in light of the existing error in the measurements.

10. Game Design

This chapter covers the design of my exergame. I describe the genre chosen, followed by a detailed look at the gameplay elements.

10.1 Genre

Aspects from several genres can benefit an exergame. The fast paced gameplay of action games can be an inspiration for high-intensity physical activities. Progression elements known from role-playing games can add to the motivation for a long lasting experience. Sports and simulation games can offer insights into how gamification of real-world sports can be done. Strategy games serve as example of how gameplay centered around a map view should be implemented.

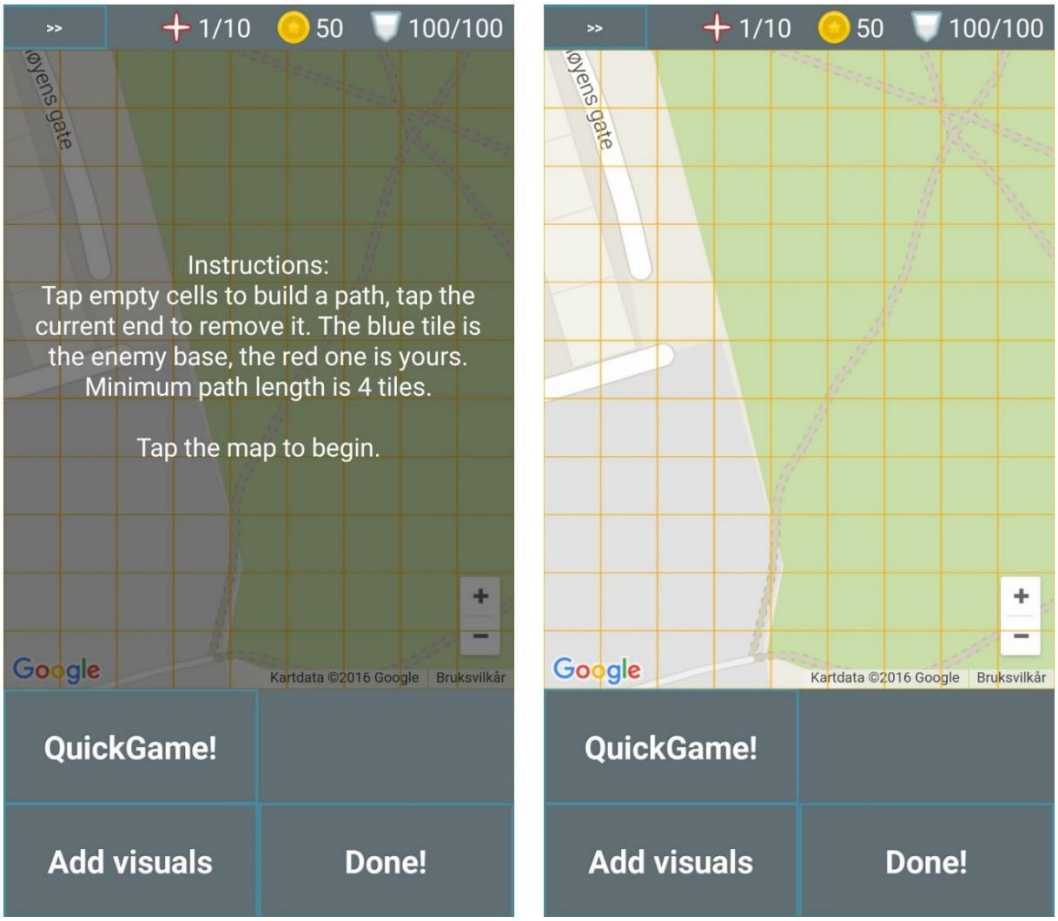
The developed exergame is an adaption of the *tower defense* genre. In tower defense games, the player builds towers to stop enemies from reaching her home base. The enemies appear at one or more places on the map and move towards their goal. They travel in groups called waves, spawning according to a timer. A variety of towers with differing abilities provide depth to the games, and the player's choices of which tower to build, where to build them, and which towers to upgrade typically make up the core gameplay. Many games of the genre have the enemies move along a pre-defined path, while others let the player affect the movement of the enemy units through the placement of towers. In traditional tower defense games, the player views the map from above, placing towers by clicking the location on the map. Figure 17 shows a screenshot from the popular game Kingdom Rush [55], presenting a typical view of a tower defense game scenario.

Figure 17. Tower defense game Kingdom Rush.

The tower defense genre was chosen as it possesses multiple characteristics that make it suitable for a location-based exergame setting. First, the top-down map view corresponds very well to how we are used to navigating using digital maps. This makes the game intuitive and easy to use. The basics of tower defense are very simple, enabling first-time players to get started without difficulty. At the same time, the games can offer depth and challenge to more experienced players, increasing the lifespan of the game. Tower defense inherently induces a sense of urgency in the players, as they struggle to keep the enemies away from their base. It requires non-stop concentration, as a moment of inattention can lead to a group of enemies reaching the goal and the player losing the game. As mentioned in a previous section, this reduces the player's awareness of the physical effort. Tower defense games do not rely on advanced controls or motoric precision, which would be troublesome when playing on a smartphone while moving. The genre's natural gameplay structure of alternating action and breaks also lends itself elegantly to an exergaming application, as this lets the players rest in between rounds of physical exertion.

10.2 Gameplay and Design

My exergame is location-based, mirroring the player's movements onto the game map. The game will display a map of the user's surrounding area, which will act as the playing field. When starting the game, the user will see the map, overlaid with instructions (see Figure 18a).

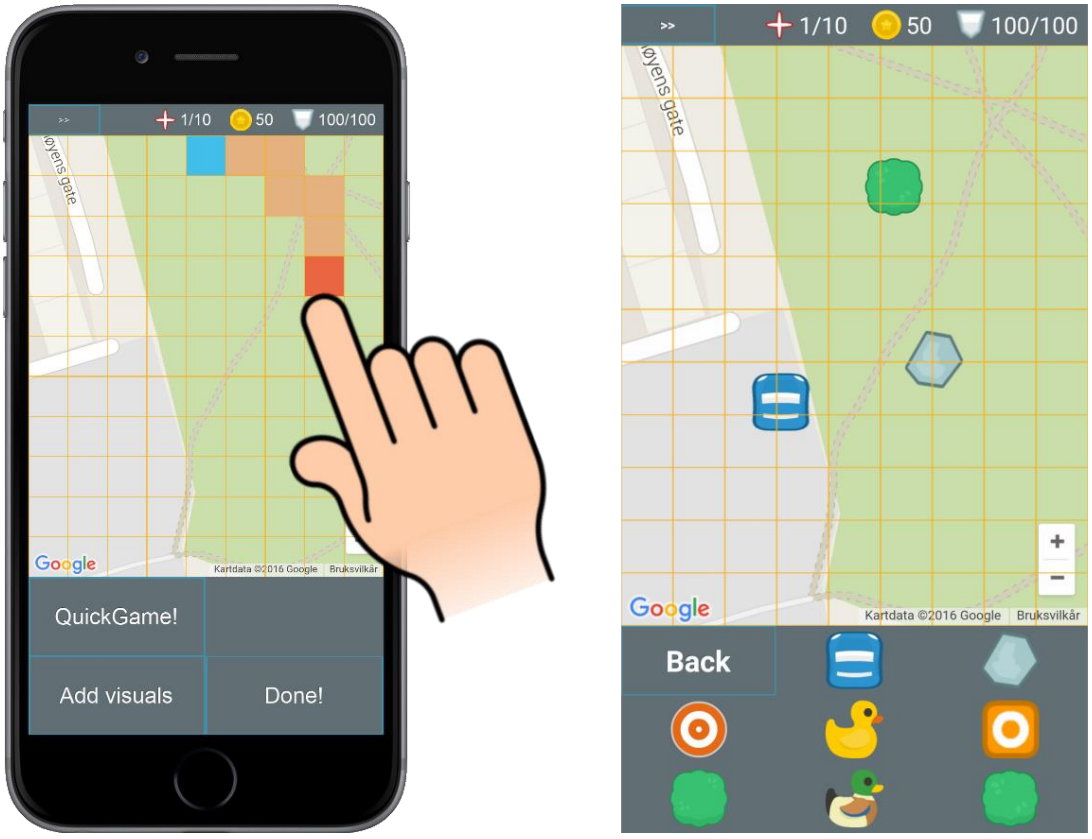


(a) (b)

Figure 18. (a) Game interface with instructions. (b) Game interface without instructions.

Game Map Setup Before starting a new game, the user must define the path for enemies to follow. This is done by tapping successive cells or by pressing the 'QuickGame!' button to use a predefined path for the map (see Figure 19a). To make it easier for the player to connect the game world with the physical environment, there is an optional mechanic allowing you to add purely visual items to the map. This can be used to mark the position of cars, trees, rocks or the like on the game map (see Figure 19b).

Including the possibility for users to define their own game maps is important. It allows players to play the game regardless of their location and increases replay value by making the number of possible game maps virtually infinite. The main reason for choosing a grid layout of the field is based on the inherent inaccuracy of the GPS. To reduce the amount of frustration caused by incorrect data, the grid divides the map into larger chunks. The probability that the player is inside a certain grid cell is higher than that of her being at the exact position reported by the GPS.



(a) (b)

Figure 19. (a) Customizable game path. (b) Visual items

Difficulty Adjustment Before the game starts, the user can adjust the speed of the game using a slider (see Figure 20). This will increase or reduce the movement speed of the enemies, the firing rate of the towers, and the timers of the power-up items. The difficulty can be readjusted later in the game.

This way of adjusting the difficulty of the game was included for the purpose of the user testing as it is a simple but effective way of making sure people of various skill and physical levels are all able to play the game.

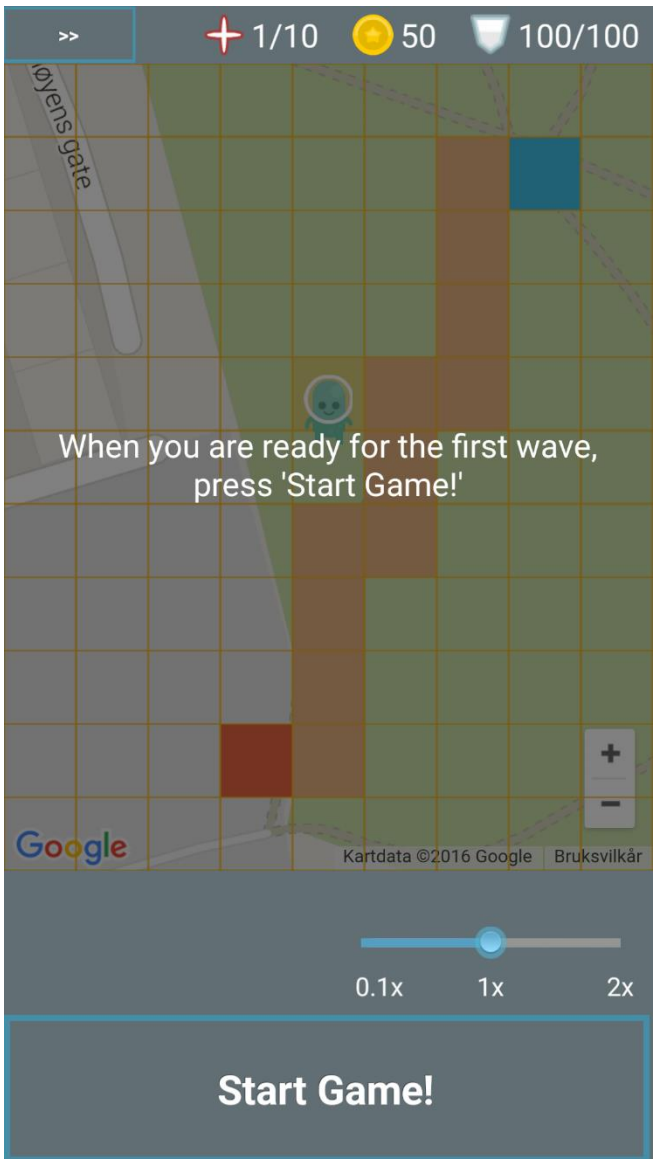


Figure 20. Pre-game difficulty slider.

Game Status Information At the top of the screen, there is a status bar with central information (see Figure 21). The level field indicates the current wave level. The credit field displays the player's amount of gold. Gold is the currency in the game, used to build new towers or upgrade existing ones. The hit point field shows the status of the player's base. If this reaches zero, the game is lost.

The amount of information presented to the player was intentionally kept low. While complexity can add to the depth of a sedentary video game, a movement-based exergame should stay fairly simple in order not to overwhelm the player.

Figure 21. Status bar. Icons from left to right: wave level, credits, hit points.

Player Avatar The player can see his in-game avatar on the map. The avatar moves around the game map in response to the player moving in the real world. The cell currently occupied by the player is highlighted.

The avatar is graphically large and easy to see on the map. This is important as the player will have to frequently check his position on the map when deciding where to move next. Highlighting the player's cell makes the location unambiguous.

Figure 22. Player avatar.

Waves and Enemies When the game begins, the first wave of enemies will start appearing (see Figure 23). Spawning in the enemy base (blue square), they will make their way towards the player's base (red square). If a minion reaches the player's base, it will deal a certain amount of damage. The hit points and damage dealt increases with every new wave level.

The enemies moving toward the player's base is the main motivator for action in the game. Seeing a wave of minions gradually getting closer will make the situation seem urgent and call on the player to act.

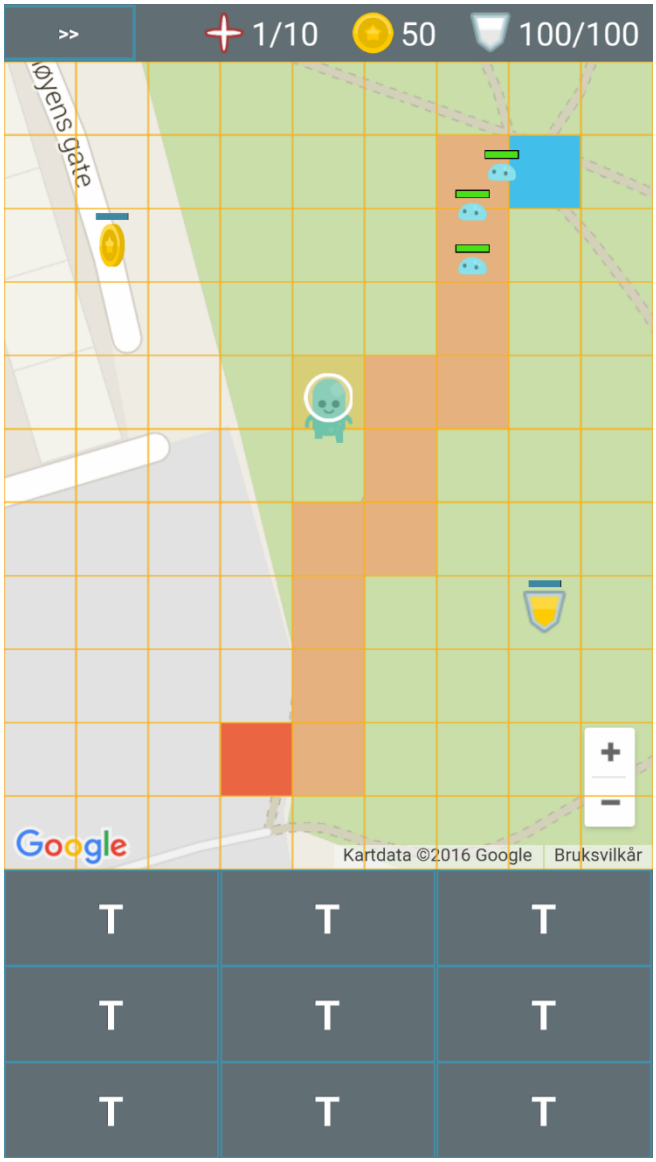


Figure 23. First wave underway.

Tower Building The player can use the interface at the bottom of the screen to build towers defending her base from the enemies (see Figure 24). The three-by-three grid of buttons corresponds to the cells on the map surrounding the player's avatar. Pressing a button once lets the player preview the tower placement, and a second press will place the tower. The towers will automatically fire at the enemy with the lowest amount of hit points within its range.

The tower building interface was designed to make it easy for the players to quickly place the towers at their intended location. The reason for allowing towers to be built both at the player's location and in any of the surrounding cells was once again attempting to reduce the negative effects of GPS inaccuracy.

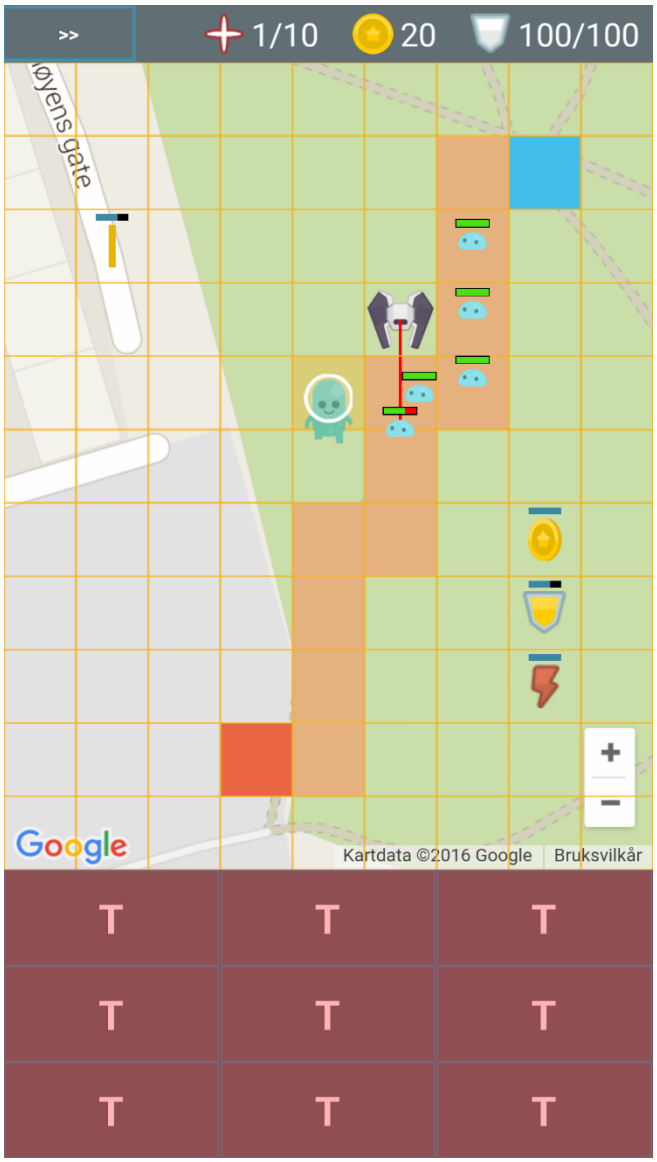


Figure 24. A tower is firing at enemies.

Power-up Items At fixed intervals during the game, power-up items will appear on the map. By reaching their location before a timer runs out, the player can gain advantageous effects. There are three different power-ups in the game: gold coins, shields, and zappers (see Figure 25). The gold coin increases the player's amount of gold. The shield is a defensive item, adding extra hit points to the player's base. The zapper is used offensively, dealing damage to all enemies currently on the map.

Power-ups are not part of the traditional tower defense gameplay. They were added to encourage and reward movement, as the actual building of towers does not occur very frequently. Three different kinds of items were included to increase the feeling of choice and strategy.

(a) (b) (c)

Figure 25. (a) Gold coin. (b) Shield. (c) Zapper.

Breaks If the player clears all enemies, the wave is completed. The game now enters the resting phase. In this phase, no enemies are spawned, and the player can catch her breath. This is also the time to upgrade or sell towers, as well as readjusting the speed of the game (see Figure 26). The break lasts for a maximum of 30 seconds.

The alternating phases of action and rest are very well suited to an exergame. They allow the users to fully exert themselves during the waves, while the breaks provide an opportunity to recover. This can extend the length of the game sessions, leading to increased physical benefits from playing.

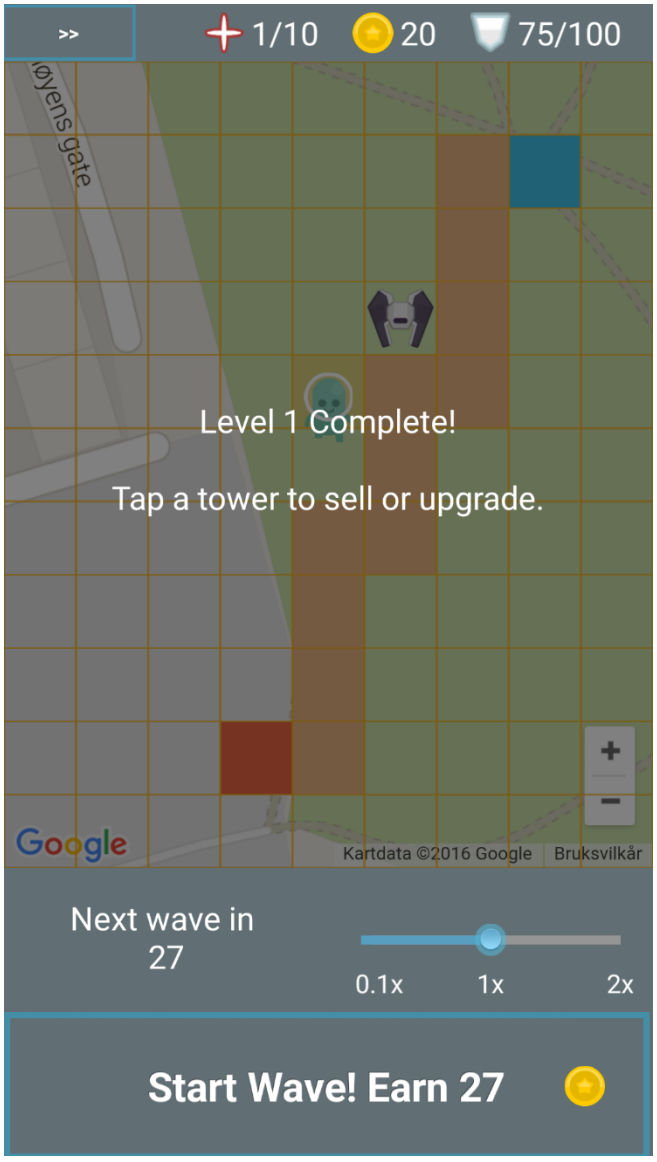


Figure 26. Break between waves.

Tower Upgrades Towers can be sold or upgraded by selecting them with a tap. Once selected, the player navigates the menus to either sell or upgrade (see Figure 27). When upgrading, the player can choose between increasing the damage, range or slow effect (see Figure 28). Selling the tower will refund its entire value.

As with the variations in power-ups, multiple upgrade options introduce depth and make the gameplay more interesting for advanced players.

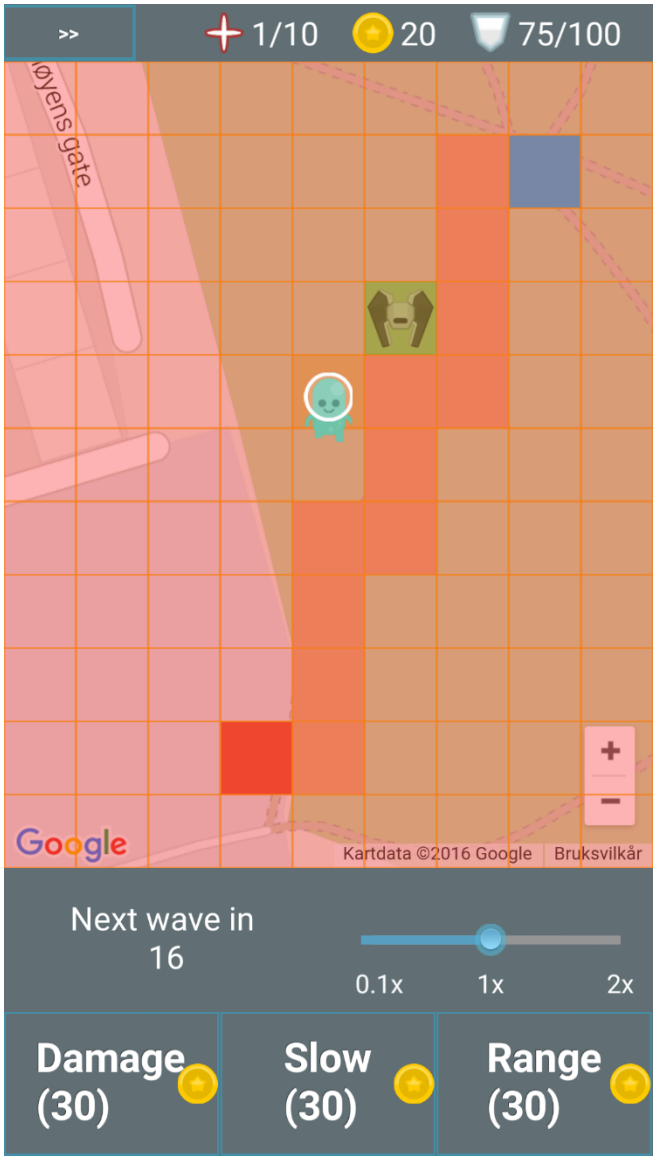
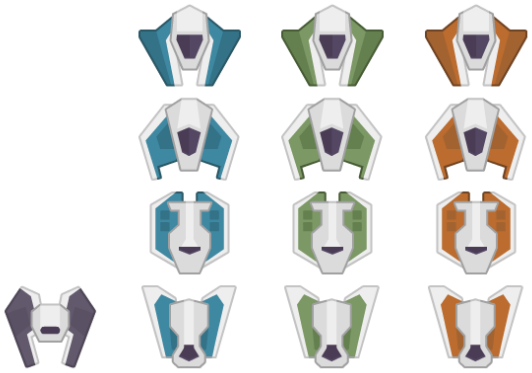


Figure 27. Tower upgrade menu.



(a) (b) (c) (d)

Figure 28. (a) Basic tower. (b) Slow towers. (c) Range towers. (d) Damage towers.

Skippable Breaks If the player is ready, she can skip part of the break to earn additional gold. This is done by pressing the ‘Start Wave!’ button, indicating how much gold the player will earn by starting early (see Figure 26 above).

This mechanic is intended to help organically adjust the difficulty. By allowing the player to control the duration of each pause, the game can be adapted to their individual level of fitness. A shorter pause is still rewarded, motivating all players to start the next round as soon as they are ready.

The Goal of the Game If the players complete all ten waves, they have finshed the game and are presented with a victory screen (see Figure 29).

This clear, level-based goal acts as an overarching motivation for the players to complete the whole game.

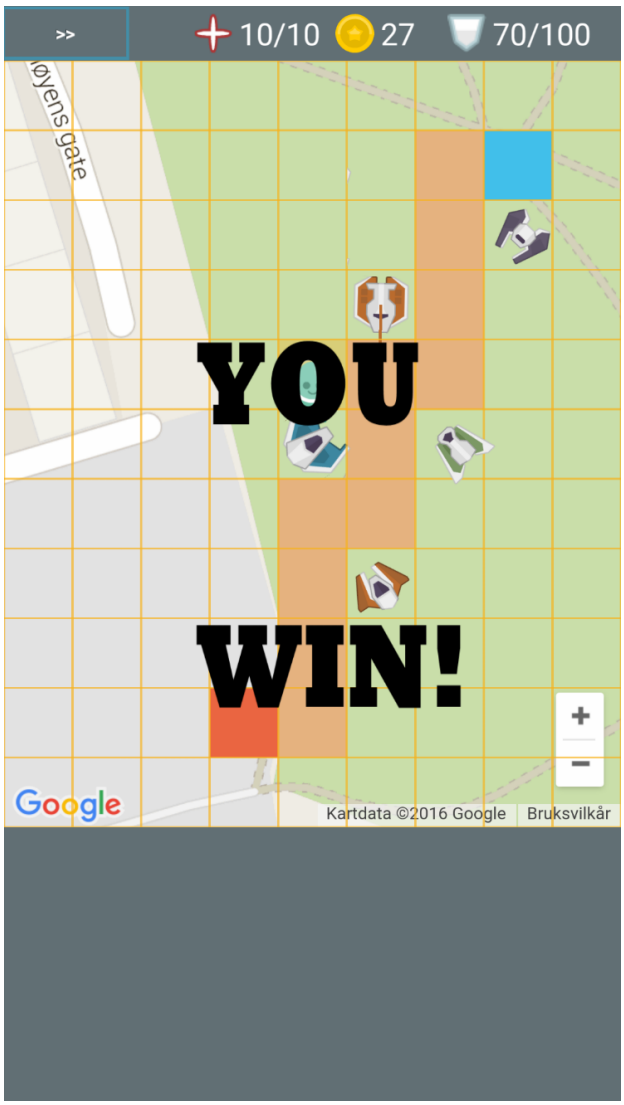


Figure 29. Victory screen.

The reason for making the game a single-player game as opposed to multiplayer wa exclusively a restriction on time. A few variations on multiplayer modes were considered. First, two players could play on the same field, racing to finish the game first. Second, the two players playing on the same field could act as direct enemies, adding the ability to send minions toward your opponent's base. A multiplayer mode would lead to several desirable outcomes, introducing social aspects such as competition and increased replay value.

11. Game Implementation

This chapter presents an overview of the implementation of the exergame prototype.

11.1 Development

The development of the prototype was based on an initial concept and design. This concept was a rough draft of the design described in the previous chapter. The implementation phase was a process of iterative development. The first version of the prototype was simply an application tracking the user's position on a custom made map. From there on, additional functionality was added in order of assumed importance. First, I implemented the customizable path, able to guide enemies along a set route. Next, the enemies were implemented. Further, basic tower functionality was added to the prototype, allowing the player to place them on the map. At this point, the prototype had the essential tower defense mechanisms. From there on, waves, breaks, and power-ups were implemented. Tower upgrades were added at a late stage, preceding the last part of the development, which was the balancing of the game.

11.2 Architecture

The game was implemented using Corona SDK. The framework encourages a certain project structure. This structure is built around the Composer library [56], Corona's scene manager. It allows the game to be broken down into separate scenes and controlling the transitions between them. Following is an overview of the main components in the project. As lua is not an object-oriented language, I will describe the role of the central modules in writing instead of a class diagram. The source code in its entirety is available at github.com/adabra/GeoTest.

The modules can be grouped accordingly: Corona project files, scenes, classes, libraries and asset handlers.

11.2.1 Corona Project Files

/main.lua When starting the application, the execution starts at the first line of this file. It defines a few platform specific properties, and transitions control to the menu scene.

/build.settings This file contains build-time properties, like application orientation or special permissions required by the game.

/config.lua This file contains the Corona application settings. This includes properties for scaling of the content and the intended frame rate of the game.

11.2.2 Scenes

Scenes are modules controlling the flow of the game. The scenes in the game are either menus or the actual game scene.

/scenes/mapSelectionMenu.lua This scene is a menu allowing players to choose between a series of maps, differing in location and size.

/scenes/game.lua This is the main component of the game. In this scene, the game is set up, and the main game loop runs during play. All the major components of the game are initialized, including the game map, the player, the minionMaster, and the towerMaster, as well as the controlPanel and statusBar. This is also where changes in location are registered and passed along to the player object.

11.2.3 Classes

Lua does not have a built-in class system. However, simple class structures are fairly easy to implement, which is what I did for the project. I tried making as much as possible of the code object-oriented, and following is a description of the relevant classes in the game.

/classes/gameMaster.lua The GameMaster class has the role of controlling the game and enforcing the rules. This class signals when a new wave should start, places new power-up items on the map, and checks whether the player can afford a new tower or upgrade. The game master also controls the speed of the game.

/classes/gameMap.lua The gameMap keeps track of the game grid, the location of the player, the location of towers, and the location of the path. The grid is calculated based on the size of the map, dividing the playing field into squares of either 5x5 or 10x10 meters. The class has multiple utility functions for translating between the pixel-based coordinate system and the custom grid system.

/classes/minion.lua This class represents an enemy minion. A minion can have one of a range of types, varying in appearance, hit points, speed, and damage. Functions for moving the minion along the path, taking fire, and attacking the base exist in this class.

/classes/minionMaster.lua The MinionMaster class is responsible for creating waves of minions, and sending them off towards the player’s base.

/classes/tower.lua This class represents a tower built by the player. The towers search for minions within range, and if found, fire at the ones with the lowest amount of hit points. Towers can have different types and levels, differing in range, damage and slowing effect.

/classes/towerMaster.lua The TowerMaster class keeps track of all towers on the map and can have them search for and fire at enemy minions.

/classes/path.lua This class includes functionality for creating a customizable game path for the minions to follow. Parts can be added to or removed from the path, according to some basic rules defined in this class.

/classes/pickupItem.lua The PickupItem class represents the three different kinds of power-ups found in the game. It contains timer-functionality, making the items disappear after a specified amount of time.

/classes/player.lua This class represents the player's in-game avatar. The position corresponds to the real world position of the player, updating on signals from the GPS.

/classes/visualObject.lua The VisualObject class represents the optional, purely graphical elements a player can add to the game map as landmarks.

/classes/controlPanel.lua This class represents the interface located below the map. It takes care of the in-game menus, in addition to the tower building interface.

/classes/statusBar.lua This class represents the interface located above the map. It contains a fast-forward button used for testing purposes, as well as information about the state of the game.

11.2.4 Libraries

Static code that was repeatedly used in different parts of the projects was placed in library-like modules.

/libs/colors.lua This module includes a series of color configurations used throughout the game.

/libs/eachframe.lua This library was borrowed from an official Corona sample app [57] and manages the core game loop.

/libs/layout.lua This module provides the game with several key pixel coordinates, like the min, max and center coordinates of the area of the screen dedicated to the map. These values are used to make the game playable on devices of different screen sizes and ratios.

/libs/set.lua This is an implementation of the set data structure, as Lua does not provide this.

/libs/utils.lua This module contains some static utility functions, like a method for calculating the distance between two latitude-longitude pairs.

11.2.5 Asset Modules

The /strings and /gameValues directories contain modules containing string and number values used throughout the game. These were put in separate files to make for easy modification of the game's visual content.

The /sounds directory contains code dealing with the loading of audio.

The /maps directory contains location data for the playing fields. These data were manually collected and entered because of technical limitations of the framework. The issue is discussed in the next section.

The /audio and /images directories contain the asset files used in the game. All graphical assets used in the game apart from the maps were free-to-use, obtained from Kenney.nl [58].

11.3 Challenges

Three elements of the implementation process are worth noting.

First, the implementation of location tracking. Unfamiliar with geographic coordinate systems, it was not obvious how to map GPS coordinates onto the two-dimensional screen area. The location data available from the phone's GPS chip is in the form of latitude and longitude, specifying a location on the surface of the earth. Researching the matter, I learned that when dealing with small areas, the curvature of the earth's surface can be ignored, and the latitude-longitude coordinate pair could simply be treated as x-y coordinates on a two-dimensional plane.

Next, the map support available in Corona SDKs free version proved to be lacking. Unable to interact with the native maps beyond zooming and scrolling, I had to implement a workaround. Map data had to be collected for each location that would serve as a playing field. The data required was latitude-longitude coordinates of the area, along with an image of the map. The data was manually collected using Google Maps [59].

Finally, the balancing of the gameplay required a significant amount of time and effort. Even though the rules and the scope of the game are simple, fine-tuning the numerous values involved turned out to be a complex task. The number of enemies, their hit points, movement speed, spawn rates, and attack damage; tower damage, range, build cost, upgrade costs, and upgrade effects; power-up effects, spawn rates and timers; everything had to come together to form a balanced game playable at different skill and physical levels. In contrast to sedentary video games, exergames need to take the physical aspect into consideration when balancing the game. As players' fitness can vary substantially, this complicates the task. I approached the task by initially balancing the numbers to make a single tower powerful enough to clear the first wave of minions. From there on, I wanted the player to have to build one or two towers per wave in order to keep progressing. When this was achieved, I increased the enemies hit points to take the effects of the power-up items into account. Continuous play testing was essential throughout the balancing process.

Part IV

Evaluation

In order to answer the research questions, my exergame was evaluated through user testing. This part of the report covers the chosen data generation methods, the test procedure, the recruitment of participants, and the resulting data.

12. Data Generation

To evaluate the effects of my exergame, I planned and conducted user tests. They consisted of observations of users playing the game followed by an interview. The research is explorative of nature, and so I prioritized having a small number of people experience the game thoroughly while having the opportunity to discuss their thoughts and feelings at length. The method of observations allowed me to see directly what the users were doing and how they were interacting with the game. The interview would let me ask questions related to the research, and getting a detailed account of the test participants thought and feelings on the matter. The combination of these methods allowed me to see the situation in more than one way. Method triangulation allows the different bodies of data to either corroborate or dispute each other.

The data gathered is qualitative. The research is of an explorative kind, focused on uncovering the potential of a new sort of exergame. It is preferable, then, to have flexibility in the data gathering process, making a qualitative approach suitable. For these same reasons, quantitative methods would not be appropriate in this setting.

The next subsections describe the execution of the methods in more detail.

12.1 Observations

The observations conducted were overt, as I introduced myself as the researcher and observer. The test participants were given a run-through of the game concept and rules (see Appendix A and Appendix B), and told to play the game for as long as they wanted or until they beat all ten levels. I let the participants know they could stop at any time to ask questions, and instructed them to start the game when ready. During the observations, I was looking for indicators of enjoyment and motivation, physical intensity, technological issues, gameplay issues, and anything else worth noting.

It is important to keep in mind that the play testers were fully aware of the research setting. While the observations took place in a natural environment, the presence of an observing researcher can change the behavior of the participants. This is known as the ‘Hawthorne Effect’ [10], and should be taken into consideration when analyzing the results.

12.2 Interviews

In addition to the observations, I conducted accompanying interviews. The interviews were semi-structured, covering a range of themes related to the research questions: background questions; motivation, engagement, and fun; physical aspects; gameplay; technological aspects; and improvements and potential.

At the beginning of the interviews, I let the participants deliver any immediate feedback on the experience. This semi-structured type of interview allowed me to focus on the thoughts and feelings of the users, rather than enforcing a strict scheme. This flexibility is useful when performing explorative research, which is unpredictable by nature. Audio

from the interviews was recorded using a smartphone, and the recordings were later transcribed. I then analyzed the transcriptions, extracting the essence of the various answers to each question.

13. Test Procedure

The testing was carried out over the course of a week during the spring. Before the official testing began, I carried out a pilot test to uncover any faults in the design or execution of the test plan. This lead to some minor rewording of the interview questions and some bug fixes.

The main test phase included five participants going through the procedure. Three participants were on their own, while two participants did the testing together. This was mainly out of convenience but turned out to display some of the differences between playing on your own and playing together. There were no differences in test procedure or gameplay, but the two playing alongside each other had the chance to communicate if they wished to do so. The interviews were all done individually.

The play testing and observations took place in a public park (see Figure 30 and Figure 31). To make the situation as realistic as possible, there were no indications of an ongoing research project, and the park was filled with passersby and people lounging on the grass. The space used for the test was hilly and covered an area of 96 x 119 meters. The weather conditions at the times of testing were sunny and cloudy, with temperatures ranging from 10 C to 20 C. The play testing and observations lasted from 10 to 24 minutes.

Figure 30. User testing and observations.

During the tests, I stayed in the background, observing and making notes. When the test participants had finished the play testing, we went inside and did the interview in a meeting room. In the case of the two participants playing alongside each other, one did the interview first, while the other had to wait. The interviews lasted from 18 to 41 minutes.

The devices used to run the games during the tests were three different Android smartphones, specifically of the models HTC One M7, Samsung Galaxy S4, and LG Nexus 5.

Figure 31. User testing and observations.

14. Participant Recruitment

Anyone able to walk or run with the ability to use a smartphone could be considered as potential users of my exergame. However, exergames have the chance of effectively reaching a particular demographic, namely people playing traditional video games. Time spent playing video games is negatively correlated with time spent exercising, putting this group of people in extra risk for health issues caused by inactivity [7].

The sampling technique used in this study is convenience sampling. This choice was made based on a few reasons. First, a restriction on time made convenience sampling a necessity. Second, the target population of people playing video games corresponds well with the computer science community at NTNU. As a result of using this sampling technique, no general conclusions can be drawn from the findings of the study. This is because the test participants are not likely to be representative of the sampling frame as a whole. However, the nature of the research is such that the results are still meaningful. The purpose of the study is to explore the possibilities of a playful, outdoor exergame, and the results can provide insight into this matter.

A total of five test participants were recruited to provide feedback on my exergame. They were all male students at the Department of Computer and Information Science at NTNU. The participants were the ages of 24 or 25 years old, and either currently or previously playing video games as a hobby.

To incentivize study participation, a gift card at a value of NOK 1000 was awarded to a randomly chosen participant at the end of the study.

15. Results

This chapter presents the results from the observations and interviews conducted to evaluate the exergame prototype.

15.1 Observations

All test participants were successfully able to play the game. The players followed some recurring patterns when playing the game. Most of the time was spent chasing down power-ups. This generally happened as follows. First, the players were alternating between standing still looking at the screen, and running in a straight line without looking to the device. This behavior corresponds to the player noticing a newly arrived power-up, determining its location, and running towards the destination. When close enough to a power-up, the players were running at a lower pace while simultaneously looking at the screen. At this stage, players would run in a more varied fashion, including one player running in circles. This behavior is related to the player trying to make the in-game avatar enter a specific cell to collect an item. In addition to collecting power-ups, the players spent some time stationary, placing towers, upgrading towers or catching their breath. The length of these pauses varied significantly from player to player.

The test participants expressed signs of enjoyment and motivation throughout the testing. Every player completed all ten waves, and throughout the game showed signs of excitement, cheering when reaching a power-up or completing a wave. One player exclaimed “I’m totally going to get that one!” as he ran off towards a power-up. After failing one of the later waves, another participant announced, “I can’t give up now, I have to complete the whole thing!”

During the play, all participants seemed to reach a certain level of exertion. The pace ranged from casual jogging to intense sprinting, varying from player to player and depending on the phase of the game. The physical intensity increased as the participants progressed throughout the session. All testers were perspiring and catching their breath at the end of the tests.

Regarding technological issues, none of the players seemed to have serious issues with the smartphones. The devices were handled with one hand when interacting with the screen and kept in the same hand when running. None of the participants dropped the phone. It was obvious, however, that the GPS location tracking was inaccurate, as the players expressed some frustration when missing power-ups they believed to have reached in time.

The test participants did not seem bothered by passersby or general activity in their environment. At one time, two girls passing through the playing field stopped and watched the two participants currently playing. The girls discussed what was going on, before continuing on their way. When asked after the test, neither participant had noticed what had happened. Several similar occurrences took place during the tests, but the participants showed no reactions.

As previously mentioned, three of the participants did the testing individually, while two did their tests in parallel. The gameplay was identical, but the two occupied the same playing field during the same time. This turned out to introduce a social aspect to the activity, as the two players kept each other updated on how they were doing, one player explaining, "At first I wanted to beat the game faster than him, but when I realized I couldn't, I just focused on my own game."

15.2 Interviews

Each interview consisted of a total of 35 questions covering a variation of themes and subjects: background; motivation, engagement, fun; physical aspects; gameplay; technological aspects; and improvements and potential. Following is a presentation of the questions and answers.

15.2.1 Background

The first part of the interview consisted of seven background questions, asking the participants about their habits concerning exercise, video games and exergames.

Question 1: Do you exercise? If yes, what do you do and how often?
Question 2: What motivates you to exercise?

All participants said they exercised regularly, ranging from three to six times a week. One participant was part of a football team, while the others did various forms of cardio and strength exercise individually.

The sources of motivation included wanting to look good, staying healthy, feelings of self-improvement, and progression. Only the football-playing participant responded that he exercised because it was fun.

Question 3: Do you play video games? If yes, what kind and how often?
Question 4: What motivated you to play video games?

The participants varied on the type and amount of video games they played, but everyone still played some games and had been doing so for many years. The main motivation for playing was the fact that it was fun, and two of the participants also mentioned the social aspect as an important factor.

Question 5: Do you play exergames? If yes, what kind and how often?
Question 6: What motivates you to play exergames?

None of the participants reported playing exergames on a regular basis, but everyone had tried it at least once. Movement-based games for the Nintendo Wii was the recurring type of game. Some of the participants had also tried other exergames developed at NTNU. The motivation for trying exergames was that it was a new and

different gaming experience, and they were curious to see what it was like.

Question 7: What do you think of the general idea of mixing video games and exercise?

The test participants were in unanimous agreement that the concept was interesting with a great deal of potential. Two participants said they were especially excited by VR exergames, and one of them pointed out the potential for players of traditional video games to get a workout.

15.2.2 Gameplay

The next group of questions was meant to uncover how the participants experienced the gameplay of the exergame.

Question 8: What did you think of the gameplay?
Question 9: Specifically, what did you like, what did you dislike?

The participants' all expressed that the game was fun. "It was really cool, lots of fun!" one player answered. A couple of participants went into detail on their thoughts on optimal strategy, explaining how they adjusted their play style and prioritization as they learned more about the game. Some misunderstandings were brought up, in particular, there was some confusion regarding at which times it was possible to build new towers and when these could be upgraded. Several responses emphasized that the session was a good workout and that they enjoyed getting exercise while playing a game.

A wide range of positive aspects were mentioned: feeling of progression, the game taking the focus away from the exertion, the adjustable difficulty, the high degree of movement, the audio cues, and the choice of genre.

The participants were unhappy with the accuracy of the GPS. One player explained that he had rotated the device while playing, in order to keep the map aligned with the real world. This had made it hard to interact with the rest of the interface. Another player said he would prefer to have to start over when the base was destroyed, instead of being able to restart the wave. "It should be strict and fair" he emphasized. Finally, one participant said he was confused by the grid layout of the game map. The coarseness of the path made him struggle to match the game map with the real world playing field.

Question 10: How would you compare a game like this to traditional, sedentary video games?

The participants commented that the exergame was similar to traditional video games in terms of gameplay. One playtester said, "This game brings about the same positive feelings as when I play other video games." The main difference, they all noted, was that this game included physical movement.

Question 11: How would you compare a game like this to other exergames you have tried?

Several differences were mentioned. One participant said that he had only tried indoor exergames in the past, and he enjoyed playing outside. Multiple testers expressed that the game had been more exhausting than other exergames. One participant explained, "The other exergames I have tried felt more like a way to track your exercise, this was an actual game."

Question 12: How was it like keeping track of both the physical world and the game world?

All participants mentioned the location tracking being inaccurate, making it harder to relate the game map to the physical surroundings. "I moved in real life, but not in the game. Suddenly my in-game character made a long jump," one participant said. Several testers also noted that the game map stayed fixed on the screen, as opposed to rotating with the orientation of the device. This made it harder to navigate the playing field, and the users rotated the whole device to compensate. This, in turn, led to problems interacting with the user interface, as noted earlier. Most of the participants agreed that the navigation got easier as the game progressed and they gained experience. This was due to the fact that they developed an understanding of the GPS inaccuracies and spatial layout of the playing field.

Question 13: What did you think of the choice of genre (tower defense)?

All participants were positive about the use of a well-known game genre. Four testers thought tower defense was an excellent genre for an exergame, "It leverages the positive feelings connected to other tower defense games," one participant said. The last participant said he would prefer that the tower element was removed from the game. "The time pressure made me place towers randomly, while I focused on the power-ups." He also noted that he did not like tower defense games in general.

15.2.3 Technological Aspects

Three questions investigated issues regarding the technology used and possible alternatives.

Question 14: What was it like interacting with a smartphone in a game like this? (Screen size, Sweat, Reduced motoric precision, Screen clarity)

In general, the test participants said the smartphone worked well as a game device in this setting. A couple of testers said they worried they would break the phone, but added that this could be fixed by using a protective case or a wrist strap. Two participants also said the icons used in the game were small and hard to make out when playing.

Question 15: How did you perceive the accuracy of the tracking of your location?

All participants noted that the GPS was inaccurate and performed unexpectedly. “There were some major errors, like when I ran all the way up the hill, only to see my avatar was still at the bottom!” one player said. However, they also agreed that it was not game breaking, and in general, it worked adequately. Some users noticed a difference in accuracy depending on their location on the playing field, saying it was more inaccurate when running close to trees. Another participant explained that he ran in circles around the power-ups, trying to get the GPS to place him in the correct cell.

Question 16: Do you have any suggestions as to what technology could be used for a game like this, other than a smartphone?

Two participants mentioned smartwatches, one mentioned Google Glass and augmented reality headsets. Another proposed using VR headsets but noted that they are too big and have to be connected by wire to a PC. One tester also mentioned using a WiFi-based positioning system instead of the GPS.

15.2.4 Physical Aspects

The following questions are concerned with the physical aspects of the user test.

Question 17: How would you describe the physical intensity of the game session?

The participants described the physical intensity as ranging from medium to high. They noted that the ability to adjust the difficulty meant you could control the intensity level. Everyone reported setting the level such that the game was challenging. “It becomes what you make of it. I was sprinting throughout the game; it was exhausting!” one participant said. Another explained that “I got a good run. The breaks arrived right before I got really tired; that kept the game playable.”

Question 18: Did you push your limits physically? If yes, why? If no, why not?

Three participants said they fully pushed their limits during the test. The reasons were related to the goals of the game. “I wanted to win!” one said, while another stated, “I was motivated by the game. I wanted to collect gold, protect my base.” The remaining two said they pushed themselves to some extent, stating concerns of stumbling or running into objects on the field as reasons for holding back. One of the participants also said he did not increase the game speed further because he thought the game would be too difficult, making him fail. Two testers explained that they pushed themselves further because they were taking part in a research observation.

Question 19: How would you compare this activity to 1) traditional sports activities like football or tennis, and 2) traditional forms of exercise like jogging or cycling?

When comparing the game to sports, the participants mentioned that this was a single-player game, while most sports require at least two people. This was seen as both strength and weakness, as it would make it easier to fit the game into your schedule, but lose out on any positive social effects. Three participants explained that fun was the main motivator behind both sports and the game: "Both involve exercise without focusing on the exertion. You don't pay attention to the exercise; you focus on the fun part."

Compared to exercise like jogging or cycling, the users pointed out the different sources of motivation. "When you're doing traditional exercise, you need to bring your own motivation. When playing this game, the gameplay is the motivator", one participant stated. Another tester said, "This is more goal-oriented, it has specific goals, problems you need to solve. Jogging and cycling are not challenging in the same way." One participant expressed doubt in the effectiveness of the exercise: "I don't feel like I've exercised unless I've done it properly."

Question 20: Can you see yourself including exergames like this in your exercise schedule?

Two participants said they would like to include an exergame like this if it was polished and worked well. The remaining three said they would be interested in playing such an exergame on a regular basis if it was a team based multiplayer game. "I wouldn't think of it as exercise. More as a social game", one of them said.

15.2.5 Motivation, Engagement, Fun

A series of questions covered the different aspects of gameflow, dual flow, and Malone's challenge-fantasy-curiosity framework.

Question 21: How did you experience the game's difficulty?
Question 22: Were you able to adjust the difficulty to a suitable level?

The answers to these two questions were interrelated. The participants all said that the initial difficulty was high, and they soon adjusted the difficulty using the slider. This worked as intended. Several participants explained that once they realized there was no penalty for failing a wave, they stopped adjusting the difficulty level. Instead, they kept attempting to beat the wave, restarting in the case of failure.

Question 23: To what degree did the game require your concentration?

All participants said the game required their full concentration. One tester suggested increasing the depth of the gameplay to prevent the player from losing focus as time went on.

Question 24: Did you feel in control of your game character?

The general consensus on this question was that the participants felt only partially in control of the character. “The GPS was inaccurate, but I was able to move the character roughly where I wanted,” one tester said.

Question 25: What do you think of the game interface?

The participants had differing views on the graphical interface. Two test users explained they were rotating the device for navigational purposes, making proper interaction with the interface hard. Another two participants noted that they were not able to pay proper attention to the status of the enemies moving towards their base. There was also some confusion regarding the tower-building interface. However, everyone reported understanding how it was used after a short period of time.

Question 26: Did it feel like you received sufficient feedback on what you were doing in the game?

The test users were happy with the feedback. “The audio was good, it worked well,” one participant said. Another explained, “The visual feedback from the screen was good. I didn’t pay much attention to the audio, except for the ‘new item-ding’.” Two users expressed a wish for more audio cues and making them more distinguishable.

Question 27: Were you aware of how you were progressing towards the goals of the game?

The participants explained that their focus was on the most immediate goal, reaching the next power-up. They were often unaware of how they were doing within the current wave, as they paid little attention to the state of the enemies. “I was too busy to keep track of the minions,” one participant explained. The testers said the progress towards the ultimate goal, beating all ten levels, was clearly indicated by the wave number.

Question 28: How did you perceive your surroundings while playing?
Question 29: Were you concerned with what passersby were thinking?

The participants varied somewhat on their answers to these questions but generally agreed on the fact that they paid little attention to the surroundings and passersby. One tester said “I was fully focused on the game, paid no attention to the surroundings. I didn’t care at all what passersby were thinking; I didn’t even notice them.” Another stated that he was made aware of the surroundings when coming close to other people. Two of the participants said they were worried about what onlookers were thinking when starting out. However, this feeling soon disappeared as they got immersed in the game.

Question 30: Did you experience time as passing slower or faster than normal?

All participants said they experienced the time passing faster than normal. Several also specified that time went by faster than when doing traditional exercise. “I completely lost track of time, didn’t know how much time had passed,” one tester said, while another stated, “I forgot all about the passing of time, I paid it no attention at all.”

Question 31: How did the game affect your experience of physical exertion?

The testers all responded saying the game took the focus away from the exertion. “I didn’t notice I was tired until the breaks,” one participant said. “I had no time to think about being tired,” another stated.

Question 32: What are your thoughts on playing this kind of game alone, compared to playing together with one or more people?

Three participants expressed they would prefer a multiplayer version of the game. This would add a social aspect, and competition would increase their motivation. “A multiplayer mode increases motivation to keep playing over time,” one tester said. The remaining two stated that they thought a single-player and multiplayer experience would be equally valuable. “I think it is an advantage to be able to exercise on your own, but I also see how playing with someone else can be fun and make me push even harder,” one tester said.

15.2.6 Improvements and Potential

Question 33: Do you have any thoughts on how to improve the game?

The responses to this question were varied, but all of them focused on elements of the gameplay. Adding more content and polish to the game was suggested. One tester proposed adding a competitive multiplayer mode. Another would like to remove the tower-building altogether, shifting the focus entirely to the power-ups.

Question 34: What do you think about the possibility of playing a game like this with AR headset technology?

All the test participants were excited about the idea and said they would want to try a game like this if it was available. “It sounds really cool! It needs to work perfectly, blending reality and game”, one tester explained.

Question 35: What would your ideal outdoor exergame look like?

All responses to this question involved transforming a traditional video game or video game genre into an augmented reality exergame. One participant wanted an AR role-playing game, another wanted a multiplayer-enabled AR tower defense, while a third

would like to see an AR first-person shooter. One participant simply responded that he would like to see “Some sort of team-based game.”

Part V

Discussion and Conclusion

This part of the report will discuss the results of the research and conclude on the answers to the research questions.

16. Discussion

In this chapter, I will discuss the findings from the user testing.

16.1 Background

The participants in the tests were very similar in terms of exercise and video game habits. The general pattern was that their exercise was motivated by external rewards, like staying healthy and looking good, and not because they considered it fun. On the other hand, they played video games purely because they enjoyed the activity. This emphasizes the potential of exergames, as they can combine the two activities, merging fun and health benefits. It is also worth noting that the only tester saying his exercise was motivated by enjoyment was the single person reporting participating in sports. This could indicate that sports are a good inspiration for exergame design.

The background questions showed that the users, although familiar with video games and physically active, had not spent much time playing exergames. At the same time, they displayed enthusiasm for the concept. From this, I conclude that the potential of the genre remains largely untapped.

16.2 Gameplay

Players said they enjoyed playing a video game outdoors, emphasizing that the gameplay felt like that of a traditional video game. This was in contrast to previous exergame experiences, which they characterized as exercise trackers. The ability of an exergame to produce the same positive emotions connected to traditional video games is essential to the genre's success.

Along with the answers in the interviews, cheering and positive body language corroborated that the players enjoyed the game. Everyone finished the game despite having to retry waves multiple times, a display of motivation and commitment. The players reported investigating and employing different strategies, a sign that the gameplay was deep enough to be interesting. These aspects - enjoyment, motivation, and strategy - are of vital importance for a video game to be effective. Positive responses to these factors can indicate a successful game design.

There was some minor confusion regarding aspects of the gameplay. I do not believe any of this to be critical, however, as they were mostly based on misunderstandings of the rules of the game. One issue that should be dealt with is the static orientation of the map. Fixed in a north-up view, this proved to complicate the navigation for some of the players. A map rotating along with the compass orientation would solve this issue.

Regarding the genre, almost all the participants were very positive, saying the familiar tower defense gameplay brought along positive feelings. One player, however, expressed his dislike towards the genre, proposing to remove the tower building element from the

game. This is a good example of how games should not try to cater to everyone but instead, focus on reaching an enthusiastic target audience.

16.3 Technological Aspects

As a device for physically intense exergames, the smartphone worked very well. No players dropped the phone, although two participants expressed concern over the risk of doing so. The screen was visible and clear even in sunlight, and sweaty hands did not prove to cause difficulties. Some participants noted the difficulty discerning the smaller icons on the screen while moving. This is partly related to the small screen size of the smartphone, but could easily be improved through a different graphical design.

The main problem with the game was the inaccuracy of the GPS. This was evident from the interview answers, along with the observations of players running around in circles and loudly expressing annoyance with a major mismatch between physical location and the avatar's placement on the map. The players reported the troubles not to be 'game breaking', but I believe they may have felt differently if the problem occurred in a finished game, outside of a research setting. Simply adjusting the size of the maps and the grid cells would reduce the issue of inaccuracy, but I do not believe this to be a satisfying solution. At the current scale, players alternate between short sprints and strategical activities on the device. Increasing the size of the map would replace the sprints with longer, less intense runs. This would decrease the game's ability to remove the focus from the exercise, and diminish the positive effect of the exergame. Some minor redesign of the gameplay might solve this issue. Another possible solution would be to keep the size of the map, but increase the size of the pick-up area around each item.

16.4 Physical Aspects

Most of the game time was spent sprinting for power-ups, implying a high level of physical activity. The players reported getting a good workout from the game session, matching the observation of perspiration and loss of breath at the end of all tests. The participants also said they enjoyed the experience of being physically active while playing a game and noted that the game took the focus away from the fact that they were doing exercise. Of vital importance to an exergame, these responses show the potential of the game to provide an enjoyable experience along with a decent amount of physical activity.

Some players reported not pushing their limits as far as the could have. One reason for this was not wanting to risk colliding with people or objects in the environment. This problem is inherent to location-based games, as they are not typically played on a dedicated field. Another reason for not pushing further was a feeling of imbalance between the difficulty of the gameplay and the physical requirements. One player stated that he was not at full intensity physically, but he feared that increasing the game speed further would render the game impossibly hard. This is one of the main design challenges of exergames, and the focus of the dual flow theory. Fine-tuning the balance of the game could hopefully solve the issue.

When asked to compare the game to sports and fitness exercise, the answers were encouraging. The participants noted that the game was similar to sports in that the main motivator is the enjoyment of doing the activity. This is contrasted by fitness activities, which the players saw as mainly motivated by external rewards. These results are encouraging, as they showcase the potential of video games to provide enjoyable exercise. However, comparing the game session to typical fitness activity, the participants said they were skeptical of the efficiency of the exercise resulting from playing the game. This could be a side effect of the game removing the focus from the exertion, making the players less aware of the physical effort. Alternatively, the game session might indeed be less efficient than traditional forms of exercise. Further testing monitoring physical effort would be needed to uncover these questions.

Despite the participants' positive attitudes towards the exergame experience, they were not unanimously ready to include an exergame in their exercise schedules. If they had the possibility to play on a regular basis with a group of friends, however, everyone would be willing to play regularly. Several of the participants pointed out that they would not view such a game as exercise, but rather as a fun activity.

16.5 Motivation, Engagement, Fun

The game fulfilled the requirements for gameflow to some degree. The game required the players' full concentration, it presented a suitable challenge, and provided clear feedback. The players reported substantial immersion, as they paid little attention to the surroundings and felt time passing at a fast pace. The short term and long term goals were clear, while the progress within a wave was not. Players reported only feeling partially in control of the character, caused by the inaccuracy of the GPS.

Several of the participants expressed their discontent with the lacking consequences following the failure of a wave. To allow testers to experience as much of the game as possible, failing a wave would allow you to restart the level. This did not line up with the players' view of how a game should work and decreased their motivation to push their limits.

The game did not provide social interaction, as there was no multiplayer mode available. This was requested by almost all testers, and would have been included if not for restrictions on time. The players expressed that this would add a social aspect and competition, increasing the replay value of the game. Some participants pointed out that they enjoyed the ability to play the game as a single player game, as this made it easier to fit a play session into one's schedule. The possibility of playing against a computer opponent is one of the advantages of exergames compared to traditional sports.

For practical reasons, two of the test participants played the game in parallel during the testing. This turned out to showcase the potential of adding a multiplayer mode. Without any direct connection between the two games, the players started competing, loudly announcing the completion of every wave.

16.6 Improvements and Potential

The changes proposed by the players mainly involved minor changes to the gameplay. As mentioned above, one player would prefer the whole element of tower building to be removed, as he felt the most interesting part of the game was chasing the power-up items.

All participants were very excited about the possibilities of augmented reality exergames. When asked about their ideal outdoor exergames, all the answers were inspired by traditional video games. This bodes well for the future of exergames and their ability to reach an audience of traditional gamers.

16.7 Limitation of Validity

There are questions regarding the validity of the test results. First, participants were recruited using convenience sampling. This means the results cannot be generalized to a wider population. Second, the participants could be adjusting their answers to fit what they believe to be the researcher's preferred results. When asked, two playtesters said they increased their effort as a result of being observed by a researcher.

17. Conclusion

The purpose of this thesis was to investigate the possibilities and challenges of creating an enjoyable, outdoor video game motivating physical exercise. In this chapter, I will consider the different aspects explored through the design, implementation and testing of the exergame prototype, and discuss the findings of the study and their implications. The following five research questions were addressed through the process:

RQ1: What genres of video games are well suited in this setting?

To answer this question, a review of the history and current state-of-the-art of exergames was carried out. Equipped with the necessary knowledge of the field of study, I reviewed the genres of traditional video games and assessed their suitability in the setting of active video games. The proposed design is based on the tower defense genre, possessing several traits advantageous for exergaming. This includes a top-down map view, a simple gameplay and the ability to induce a sense of urgency. Evaluation of the concept by user testing indicated that a tower defense gameplay worked well in an outdoor exergame.

RQ2: What kind of technology is fit to support the activity?

This question was addressed by reviewing existing exergames and the technology they use. For an outdoor exergame, the player must be able to move freely in the environment, implying a lightweight, battery-powered piece of technology with adequate computational power to run an actual game. The technological platform I found most fitting was the smartphone. Smartphones are equipped with motion-tracking sensors, have an easy-to-use touchscreen, and the capability to track the user's location. User testing proved the smartphone to work very well for this purpose.

RQ3: What new challenges arise from this combination of video games and outdoor physical activity?

User testing of the exergame prototype revealed challenges not usually found in traditional video games. First, the inaccuracy of the GPS chips found in smartphones turned out to represent a substantial restriction on fast-paced, location-based exergames. Game designers must have this in mind when deciding on the physical dimensions of the playing field. Next, navigating using a digital map while running and frequently changing directions is challenging. In addition, when playing in a varied, outdoor environment, players worry about the risk of causing injury to themselves or their device. Social stigma could keep potential players from trying an outdoor exergame in public. This will change if this type of video game gains popularity.

RQ4: How does an exergame like this affect the motivation and engagement of the users?

The feedback from the observations and interviews clearly indicated the potential of an outdoor exergame to motivate and engage. The players displayed joy and thrill, and their

statements indicated an experience of flow during the game. The participants described concentrating fully on the gameplay, losing track of time, and a reduced focus on the physical exertion. They expressed a wish to progress and complete the game, motivated by the goals of the game.

RQ5: To what extent are players willing to exert themselves physically during the activity?

The players participating in the evaluation of my game showed no reluctance of physical exertion while playing. The only limiting factor was a slight imbalance in the gameplay, and all the participants put in the effort necessary to beat the game. To make players expend their full effort, exergames need to decouple the difficulty of the game mechanisms and the intensity of the workout.

The work done in this project has shown the potential of playful, outdoor video games to motivate and encourage physical exercise. Wisely designed and implemented games of this kind could prove to be key in activating a new generation of technology natives.

18. Future Work

There are numerous interesting opportunities for further study related to the game presented in this report, and within the field of outdoor exergames:

- More extensive testing should be done on a larger and more representative sample of users.
- Experiments should take place over a longer period of time, exploring ability of the exergame to engage players beyond the first session.
- The physical effect of playing the game needs to be measured.
- Exergames based on other traditional game genres should be explored.
- More work is needed to determine how to best deal with GPS location data inaccuracies. This could include a study of the optimal size of playing fields.
- Future work should explore the possibilities of an outdoor exergame with gameplay based around multiplayer. This has the potential to further improve the experience, increasing enjoyment, intensity, and replay value. The result could be a digitally enhanced sport of the future.
- Another exciting area of study is the application of augmented reality technology in the setting of outdoor exergames. While the technology might need more time to mature, there are solutions allowing smartphones to be used to create AR experiences.

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Appendices

Appendix A
User Test Instructions

- Exergame: video game with an element of physical movement
- Tower defense: game where you build towers to prevent enemies from reaching your base
- Location based game: Your real-world location is tracked and used to move your in-game character
- The game: The game consists of 10 waves. Each wave has a group of minions spawn and move towards your base. If they reach your base, it takes damage until its hit points reach zero and you lose the game. To stop the minions, you will build towers along their path, upgrade these towers, and last but not least, you will collect power-ups.
    - Towers: You build towers during the waves. This is done by pressing one of the nine buttons below the game map. The buttons indicate the desired location of the tower, relative to your character. By pressing once, you get a preview of the tower placement. At this point, you can 1) confirm the location by pressing the same button again, or 2) cancel the build by pressing any other button. The towers fire automatically at the minion within its range with the least hit points. You must have enough gold to build a tower.
    - Upgrades: Towers can be upgraded to increase either their 1) damage, 2) slow effect or 3) range. This can only be done between waves. Press the tower and follow the instructions. Every tower can be upgraded four times. You must have enough gold to upgrade a tower.
    - There are three different types of power-ups: gold coins, zappers and shields. Gold is the currency used to build and upgrade towers, and you have to collect these throughout the game to keep up with the increasing health of the minions. Zappers damage all minions on the game map when picked up. Shields add extra hit points to your base.
    - If you defeat a wave, there is a 30 second break before the next wave spawns. You can use this time to upgrade your towers, plan ahead and catch your breath. If you feel like starting the game before the 30 seconds have passed, you can do so and earn extra gold.
    - In the between-wave breaks, you can also adjust the difficulty using a slider. This slider will adjust the speed of the game, making it either easier or harder. Use this to adjust the game to your level of skill and fitness.
    - If your base’s hit points reach zero, you can restart the current wave and try again.
    - The game map is grid based. To collect a power-up, simply move your in-game character to the grid cell containing the power-up.
    - You should try to build at least one tower every wave to keep the minions from reaching your base.

- Audio cues tell you what is going on: ‘ding’ means new power-ups have spawned. ‘Punch’ means a minion attacked your base. ‘Laser’ means your towers are attacking the minions. ‘Three notes’ means you have picked up a power-up. ‘Bam’ means you used the zapper.

Appendix B
Test Participant Agreement

Purpose of Study

The purpose of this research is to investigate how to design a playful, outdoor activity that utilizes video games to motivate physical activity. The research is being conducted as part of a master's thesis at the Department of Computer and Information Science at NTNU.

Test Process

The study will consist of a playthrough of an exergame, during which test participants will be observes by a researcher. Next, there will be an interview about the experience. The complete process will last about 30 minutes.

Test Data

The data collected in the study will be anonymous, with no possible ways of tracing the data back to the test participant. A summary of the data will be presented in a master's thesis.

Voluntary Participation

It is completely voluntary to participate in the study. You can choose to withdraw from the study at any time without a need to provide a reason for doing so.

I have read the information contained in this document, and I agree to participate in the study.

Signature, Location, Date