2017

MASTER'S THESIS

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UNIVERZA NA PRIMORSKEM
FAKULTETA ZA MATEMATIKO, NARAVOSLOVJE IN INFORMACIJSKE TEHNOLOGIJE

MASTER'S THESIS
(MAGISTRSKO DELO)

STREETGAMEZ, A MOVING PROJECTOR PLATFORM FOR GAMES
(STREETGAMEZ, MOBILNA PLATFORMA ZA PROJECIRANJE IGER)

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StreetGamez, a moving projector platform for games

(StreetGamez, mobilna platforma za projeciranje iger)

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Koper, september 2017

Ključna dokumentacijska informacija

Ime in PRIIMEK: Peter ŠKRLJ

Naslov magistrskega dela:

StreetGamez, mobilna platforma za projeciranje iger

Kraj: Koper

Leto: 2017

Število listov: 53 Število slik: 32 Število referenc: 31

Mentor: doc. dr. Klen Čopič Pucihar

Somentor: doc. dr. Matjaž Kljun

UDK: 004.4’23(043.2)

Ključne besede: exergaming, projekcija, platforma, droni, art, mobilna, robotika, grafika, igre, ulične igre, leteči prikazovalniki, dostavljanje vsebine, interaktivne kontekstne projekcije, interakcija človek-računalnik, interakcija človek-dron

Izvleček:

Implementirali smo programsko rešitev idejne zasnove sistema za igranje video iger v prostoru s pomočjo zaznave gibanja v prostoru. Pri tem smo kot platformo za nosilnost opreme uporabili brezpilotnega drona. Sam sistem je sestavljen iz treh elementov, drona, mini projektorja z vgrajeno baterijo in Google Tango tablice. S pomočjo te tablice in tehnologije ki jo ponuja, lahko zaznavamo 3D oblike v prostoru in pridobivamo informacije o relativni lokaciji same tablice (oddaljenost od tal, kot pod katerim je tablica rotirana).

V iskanju podobnih rešitev nismo naleteli na noben obstoječi sistem, ki bi pokrival vse tri aspekte interakcije igralca z napravo.

V tej nalogi sem podrobneje opisal kateri so bili koraki pri izdelavi prototipne programske rešitve za detekcijo igralcev v prostoru. Sistem je bil implementiran do te mere, kjer poteka zaznava igralca v prostoru, transformacija teh detekcij na igralno površino ter projekcija igralne površine na tla in mesto kjer igralec stoji.

Key words documentation

Name and SURNAME: Peter ŠKRLJ

Title of the master thesis:

StreetGamez, a moving projector platform for games

Place: Koper

Year: 2017

Number of pages: 53 Number of figures: 32 Number of references: 31

Mentor: doc. dr. Klen Čopič Pucihar

Co-Mentor: doc. dr. Matjaž Kljun

UDK: 004.4’23(043.2)

Keywords: exergaming, projection, platform, drones, art, pervasive computing, mobile, robotics, graphics, gaming, street games, flying displays, drone-assisted art making, content delivery, interactive context-aware projections, user interaction tracking, human-drone interaction

Abstract:

We implemented a software solution for a video game platform that is capable of detecting player movement. At this we plan on using a drone as a platform that could carry the setup. The system is composed from three elements: Drone. A mini LED projector with integrated battery and Google Tango supported device. With this tablet we will be able to run spatial recognition and detect 3D shapes in space and also obtain the device orientation in space. While searching for similar solutions, we have not encountered any similar systems that would cover all three aspects of interaction of the player with the device.

In this thesis we provide a detailed description of steps that were necessary to develop a prototype software solution to detect player movement on game floor. The system was implemented to the point where it can detect the player, transform these detections to a gaming surface and correct the projection distortion.

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LIST OF ACRONYMS

AR	Augmented Reality
DDR	Dance Dance Revolution
FOV	Field Of View
FPS	Frames Per Second
GPS	Global Positioning System
IR	InfraRed
NFC	Near Field Communication
PC	Personal computer
RFID	Radio Frequency IDentification
RGB	Red Green Blue (color format)
SUS	System Usability Scale
VR	Virtual Reality

ACKNOWLEDGEMENTS

Conducting master thesis research and prototype implementation can be quite demanding at times. This becomes even more challenging if you are a full time employee whilst having other commitments and even other side projects to focus on.

I am very grateful to University of Primorska and especially Faculty of Mathematics, Natural Sciences and Information Technologies for giving me the opportunity to enroll and finish my master studies in the environment where one is able to expand his knowledge on theoretical and practical research areas.

I would like to thank dr. doc. Klen Čopič Pucihar for mentoring, assisting and challenging me in the process of writing this thesis, giving me ideas and encouraging me to think outside the box. Without his help, the results presented in this thesis would not be achieved.

I also want to thank both dr. doc. Matjaž Kljun for co-supervising this thesis, dr. Mark Lochrie for his cooperation in the early stages of the project in the system design. During my research and prototype phase I had a chance to talk and meet some extraordinary people, to whom I wish to express my sincere gratitude.

Special thanks also goes to my Mother, Father, both sisters Katarina and Pavlina for encouraging me in being persistent and raising me into the person I am today.

Lastly and above all, I would like to thank Asja for supporting me in all these years of studying and giving me the greatest joy in my life.

1 INTRODUCTION

Gaming industry is becoming more and more competitive with numerous game releases of high diversity. This has been fueled by recent rise in number of quality game engines, which are readily available and support deployment on multiple platforms. All these facts mean that companies find it more and more difficult to differentiate from other games on the market.

Games are most commonly developed for PCs' and dedicated consoles. However, in the last five years, mobile phones became a prominent gaming platform for distributing games. This new platform gained a significant share of the gaming market making $41 billion in revenue in 2016 which surpassed PC games for more than $7 billion. Together with PC and console games, these three platforms form a triangle of gaming platforms, that are most popular. [1]

Due to fast paced technology development in the field of computers and high level of competition in the gaming market companies have to continually find new ways to innovate. One way to do so is by employing new technologies, such as, motion tracking technology, Virtual Reality technology, Augmented Reality technology, etc. New technologies open new possibilities that enable companies to produce innovative gaming experiences with novel mechanics and player experiences. These new technologies commonly enable better gaming experiences with higher level of immersion when compared to traditional sedentary mouse and keyboard game setups. [2]

Nowadays computer games are commonly played whilst being sited down. This is a problem because our lives are already predominantly sedentary. We sit most of the time whilst at work or during other leisure activities such as watching television. Not being active may have many health risks, such as: back related problems, diabetes and cardiovascular problems. [3]

One possibility to encourage people to live more active lives is to create games that are played by physical moving in space. Such computer games can be divided into three categories, namely: location based games, games with motion tracking and projection based games.

Location based games require the user to navigate to a specific location in the world to be able to unlock the content that the game offers. Such games require the user to obtain the location information and then use some kind of GPS device, to find the target area. One such game is Geocache, where the players obtain the coordinates of a hidden treasure and once at the approximate location venture on a treasure hunt hidden in close proximity. Sometimes additional hints are provided, so that the players can solve puzzles and unlock the secret treasure box.

Location based games are usually implemented with the use of a mobile device with GPS location service, NFC technology or Bluetooth. An example of such a game is Pokémon Go a location based multiplayer mobile game, where the user needs to go to certain areas in the world to be able to catch more advanced types of Pokémon or battle in Gyms, where other virtual Pokémon trainers are located.

Another example of games that motivate users to engage in exercise are games with motion tracking. These games are based on motion tracking of players body which commonly requires special equipment such as Kinect, Nintendo Wii or PlayStation Move, hence are usually being played in living rooms. In case of PlayStation Move or Nintendo Wii, the player is required to hold the controllers in their hands. These controllers are then being tracked in 3D space and become game input devices. An example of such games are Wii Sports games (e.g. tennis, bowling, boxing, golf, baseball) or Tumble a PlayStation Move game that requires the player to stack different objects and reach the top.

Kinect on the other hand is a more advanced tracking system, that projects an infrared point cloud into the room, and then collects the data which is then processed to detect players and objects in the room. With this, a more accurate character rigging can be done and a number of different interaction systems become possible. Dance Central Spotlight[1] is a game that takes advantage of the full body outline of the player and transform is into a dancer movement in the game. The precision of the moves is then scored and on the end of the song, the final score is given.

The newest technology introduced to exergames involves a projector, which projects the graphical game elements onto a physical environment. These game elements become interactive through motion tracking of players to facilitate game play interaction. This implementation frees users from holding any device allowing gamers to focus on the game, its elements in the environment, and possibly other players. Use of projectors can enhance a workout experience, and can provide the users with a new, never tried before challenge. One such example is a climbing wall prototype where alongside with the challenge of climbing, the player must also avoid falling objects from the top, that are projected on the climbing wall. This way the climb itself is part of gamification of the task. [3]

[1] http://www.harmonixmusic.com/games/dance-central/

To sum up, even though current exergaming systems have seen large scale adoption they are faced with certain limitations. The problem with most location based games played on mobile devices is the dependence of games on what is shown on the screen, be it the object of play or the instructions of the game which may result in disconnecting the user from the environment and interrupt communication between players when playing multiplayer games as they are required to follow events on the screen in order to progress in the game. [4] In context of games with motion tracking and projection based games the main problem is the need for gaming infrastructure which limits their reach to indoor environments and static scenarios caused by the difficulty of moving and setting up the gaming system at new location.

In an attempt to solve the above problem this thesis proposes a new gaming concept that combines projection based games with drones creating a novel gaming platform that is:

(i) independent of location — tackling the problem of confining game play to closed environments and increasing mobility of the gaming platform,

(ii) offers a new gaming abilities that can facilitate various types of novel street and chalk games. We plan to design and build such a system that can track and react to user movements whilst also providing meaningful feedback that could be utilized by the game developers to create fun exergames.

1.1 MOTIVATION

Our motivation is to create an new type of exergaming platform, that will encourages people towards a more active lifestyle, whether this is in their free time, or when they are hanging outside with their friends and are willing to try a new form of outdoor activity.

This platform will attempt to overcome all the limitations of the existing exergaming platforms mentioned in the previous chapter by minimizing required and time of setup whilst providing a responsive gaming interface so that the players will be able to easily achieve an immersive gaming experience in the outdoors.

We strive to build a game platform we call StreetGamez that will be able to fly to the game location and perform three vital tasks such as: projecting game graphics onto arbitrary surfaces, enabling interaction within the projected surface through motion tracking of players, and enabling interaction through players' mobile devices (calling the platform to a desired location, selecting games, and so on).

Designing and building the StreetGamez prototype will serve as a feasibility study that will show if such a system is possible in the first place and explore ways in which the drones and advance spatial detection systems can be used to create a gaming platform. By implementing and researching the interaction, we will be able to get an insight into how players interact with such gaming systems.

We plan to evaluate the proposed design by creating a simple “whack the mall” game and conducting a small pilot user study.

2 SURVEY OF THE FIELD

2.1 EXERGAMING

In recent years there have been many popular games that promote active lifestyle. These games require that player exert some physical effort in order to succeed. Depending on the technology that is being used we group these games into location based games, exergames with motion tracking, VR exergames, and projector based games.

2.1.1 Location based games

Location based games are built by including the context of users location into the game hence they require the user to navigate to a specific location in the world to be able to unlock or interact with the content that the game offers. Most commonly such games require the user to obtain the location information and then use some kind of device to interact with the game content.

Figure 1: Screenshot of Pokémon Go game showing AR view of the game where the Pokémon is captured by throwing red balls at him/her.

One example of such popular game is Pokémon Go[2] where the player is on the quest to catch and train Pokémon, a virtual animal like creatures, that have special combat abilities. Pokémon can be found by actually walking around different neighborhoods in towns and cities. The game is played on mobile devices using GPS, phone camera and other movement sensors. Using a live GPS position and modified version of a map, a player is able to see nearby Pokémon and battle them. Once the battle begins, the player is able to observe the

[2] http://www.pokemongo.com/

battle through the phone camera and throw poke balls using a simple flick gesture (Figure 1). The goal is to strengthen your Pokémon and be able to defeat Gym leaders and earn the so called Gym badges, that prove the strength of the Pokémon trainer.

Figure 2: Screenshot of Pokemon Go game with map view, battle scene and points of interest. Blue marker presents a location where loot can be collected.

Pokémon Go was extremely successful and able to attract 65 million users in just a few months from its launch day. The game is probably the most successful location based game with elements of augmented reality that convincingly tie the real and digital worlds creating the impression of bird-watching, trophy-hunting and active treasure seeking activities.

Another driver of game popularity was the way in which the game was monetized by promoting real landmarks (Figure 2) or points of interests where player can find poke stops, that have free items such as poke balls and health items or the area is just a rare Pokémon hunting field. The owners of landmarks could purchase loot crates and rear Pokémon hunting fields in order to attract visitors to their location. Big companies like McDonalds grabbed this opportunity and established Pokémon gyms around its restaurants. [5]

Regardless of its success, Pokémon Go was faced with heavy criticism as people were getting injured playing the game because. The injuries were a result of game elements being placed at dangerous locations (e.g. near busy road intersection, at construction sites, etc.) or the game was being played in dangerous ways (e.g. catching Pokémon whilst driving a car, riding a bicycle, etc.). The former is a very new form of danger, especially problematic as the game guides the people into dangerous situations which are difficult to predict by the algorithm that places Pokémon. In addition to this, the player also has a difficulty detecting danger because he or she is immersed in the game and resides in the so called "playing bubble". This may be dangerous not only for the player but also for his or her surroundings.

Figure 3: Geocache is an treasure finding game where a person needs to navigate to the GPS coordinates published on the web. Treasures contain various objects such as pencils, notes etc.

Geocache[3] is another location based game that was created in 2000. This game is also based on GPS tracking technology and treasure hunting for geocaches which are small plastic container boxes, that contain various items that have some meaning to the person putting it there (Figure 3). The goal of the game is to find and exchange your personal belonging with other people playing this game. Since its beginnings, the game was adopted to mobile devices which opened up new possibilities for creating interesting game situations, so that by use of a compass, GPS systems and other phone peripherals you are able to find the spots, where geocaches are hidden.

Geocaches are placed by other users, hence this service is based on user generated model where the community takes care of safety in context of where geocaches are placed minimizing the aforementioned danger of guiding users into dangerous situations. In addition to this geocaches does not utilize AR approach, hence the instructions are provided in with higher level of abstraction making it easier for the user to detect dangerous situations when he attempts to map abstract instructions to the real world.

[3] https://www.geocaching.com/

Another type of location based games does not only rely on mobile devices but requires additional infrastructure that needs to be placed in the environment (e.g. RFID tags). One such example is PAC-LAN (Figure 4). [6]

This game is a mixed reality location based game that uses RFID enabled mobile devices to actively engage users in playing a Pacman-like game on university campus streets. The interface is build using yellow RFID enabled tags that are placed on the street and are collected when touched with RFID enabled mobile phone. Four additional players can participate in this game by acting as ghosts that try to catch the pacman. They kill the player if they successfully catch the player and read its RFID tag from his back. By picking up a power up pill, the player can also start to chase ghost players and by catching them, they are obliged to return to their central starting point. Points are collected by picking up yellow pills or killing ghosts.

Figure 4: PAC-LAN was a location based game where players navigated through a maze that was mapped over campus. [4]

Another example of location based games is Big Game Hunter, a mobile location based game which encourages emergent behaviour by allowing the general public to design their own games around any subject to be played in a place of their own choosing. Players are required to capture photos of specific locations and objects. Points are awarded depending on the location of the photo taken. Each created event contains clues on the areas that photos must be taken in. There are 3 areas, green (3 points), orange (5 points) and red (10 points). The game promotes discoverability and exploration of the nearby environment. [7]

[4] http://www.rfidbuzz.com/news/2006/paclan_rfidpowered_mobile_gaming.html

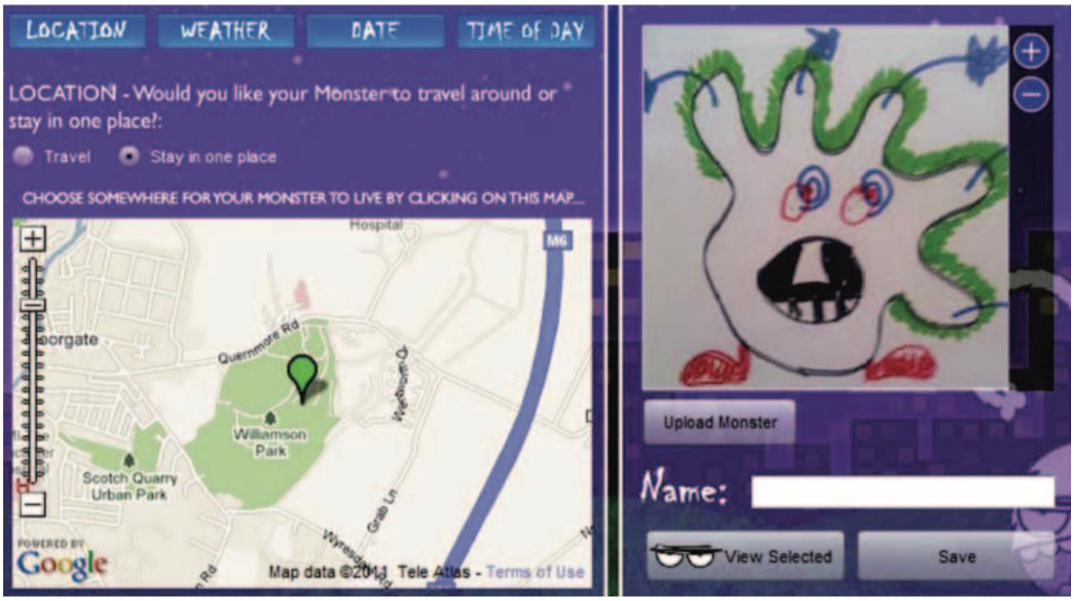

Figure 5: Free All Monsters iPhone game interface. The player can create custom monster, select its name and give it a special trait on appearing.

Similar to Pokémon Go, is game called Free All Monsters (Figure 5), which was presented on International Conference on Human Computer Interaction with Mobile Devices and Services. It uses user generated content in attempt to broaden its appeal by encouraging creativity. Players can create their own visual representation of the monsters. These images are then populated into local environment. The players then use a mobile device as a tracking device to find monsters hiding around the playing area. When he approaches the area where the monster is hiding, he can select on the device to free it. The monsters can have traits that they appear only in specific weather conditions, day times or act on different environmental events. [8]

PAC-LAN concept of gaming was introduced in the early 2006, but the concept was further enhanced and developed in 2015 when PAC-LAN: Zombie Apocalypse game was released on Android supported devices. This time, the communication between devices was faster and the improvements to the NFC reading were noticeable and allowed more fluid gameplay. Once the tag is scanned, the location of other tags that have been scanned is displayed on mobile device, this way the player can then navigate to try and capture other players. [9], [10]

To sum up, location based games have seen many successful examples and in some situations achieved wide scale adoption. Previous research also showed that location based games are exceptionally good for spatial knowledge acquisition as the users are always obliged to provide some location context in order to participate in this games [11]. However, as highlighted by authors of PAC-LAN: Zombie Apocalypse game, "emphasis on the digital over the physical means the opportunity for player immersion in mixed reality games is often limited to the single (digital) dimension" [9], [10]. Therefore, the main problem of location based games is the dependence of games on what is shown on the screen, be it the object of play or the instructions of the game.

2.1.2 Exergames with motion tracking

Another group of games that motivate users to engage in exercise are games with motion tracking. These games are based on motion tracking of players which is used to control the game.

One such early successful exergames is Dance Dance Revolution[5] (DDR) game. This game was introduced in Japan in year 1998 by Konami and quickly spread to other parts of the world as a fun, skill requiring arcade exer game, where the goal of the player is to survive as many rounds as possible. The game is played by watching the arrows appearing on the screen, and timing the press of foot pads to be in sync with the music and visual cues from the monitor. To increase the difficulty of the game for the expert players, the game offers a game mode where the player controls all 8 pads (4+4) and is required to display some of the more incredible agility and reflexes to stay in sync with the direction inputs.

The game is nowadays so popular, that tournaments are held worldwide. In 2004 Norway proclaimed DDR as a sport game and a good tool to help obese kids at staying healthy and in shape, later on US schools [9] commonly reported that by playing this game, they got in physical shape and lost weight as a result of physical exertion that has been done while playing the game [12]. For this reason and the popularity of the game, DDR was given much critical acclaim for its originality and stamina in the video game market.

In 2006 Nintendo company presented their next gaming console that introduced movement detection of the player through remote controls which are held in hand of users. The games with this kind of interaction brought another layer of excitement and enjoyment to the world of console games. When it was released, Wii[6] came with a list of 33 games that were all fully supporting the new interaction model. Some of games that are enjoyed by players playing on Wii are: Super Mario, Legend of Zelda, Pokémon, Wii Sports (Figure 6).

[5] https://en.wikipedia.org/wiki/Dance_Dance_Revolution
[6] http://www.wii.com/

Xbox Kinect[7] is a motion sensing device, that together with Xbox One or Xbox 360 enables the user to control the virtual environment of the games with the movement of their body or by performing various hand gestures to execute a certain action. It was released in 2010 and by providing the user with a hands free interaction platform it provided the gamers with new experience in console gaming. Popular games that embraced this device as their primary input were: Fruit Ninja, Forza Motosport, Dance central 3, Zumba fitness party (Figure 7) and other Sport games.

Figure 6: Wii was one of the first gaming stations, that introduced an active participation in interaction with console games. Its remote could be used a baseball bat, tennis racket or golf club.

[7] http://www.xbox.com/en-US/xbox-one/accessories/kinect/

Figure 7: Kinect motion sensor can easily track a position and pose of human body, this way it can be a great zumba trainer keeping track on correctly executed moves.

2.1.3 Virtual Reality Exergames

In recent years a big increase in the interest of virtual headsets was noticed. Devices such as OculusRift, HTC Vive or Playstation VR are just some of the most noticeable brands emerging in this market. By using VR headsets, players are able to start using their head movement as a controller input in the gaming environment. Combining these headsets with other peripheral devices may introduce some interesting results. [13]

An example of exergaming in the context of Virtual Reality (VR) is an omnidirectional treadmill. The original idea was to provide the player with a rigid platform, that would respond to players movement of the feet and by using a motorized treadmill the floors would move alongside the user. This way the player is always kept in the same physical location, whilst moving in the virtual world. To provide the player with as much of an immersion as possible, these systems are usually used in connection with VR headset. While this solution is possible, it leads to considerable complexity and high costs of purchase and operation. The costs are reduced by choosing an approach based on a low friction surface equipped with sensors that are able to detect direction of player’s movement.

The player’s movement is detected by a combination of different sensors, that are located in the ground floor, the ring construction and the pillars (Figure 8). The data of these sensors is sent to an integrated microcontroller which computes the orientation of the player’s body, the height of the player’s hips, the walking speed and the walking direction. Combining this information with virtualization utilizing VR headset creates highly immersive VR experience. [14]

Figure 8: Cyberith Virtualizer combines VR headsets, with player movement recognition and detection of vertical movement forces to create an virtual experience where full body presence is required to interact with game world.

While such system is actively promoting player's movement this is not their primary role. The main reason and application is in creating immersive VR experiences. In context of exergaming such systems are faced with a limitation of constrained movement space that is available to the player. Another issue is the bulkiness and the weight of the headset with all the wiring. Hence most players may feel discomfort when using such a system for longer periods of time, especially if performing fast movements and physically demanding tasks which are common in case of exergaming. Therefore, such systems are not seen as optimal for exergaming.

2.1.4 Projector based games

Another group of exergames utilize interactive projections. Such systems are built from a projector that projects graphical game elements onto the physical environment and a motion tracking system detecting player's movement and position. The later enables interactivity with the projected surface.

In the early 2010, US based company EyeClick launched their gaming platform called Beam[8]. Beam is an interactive video game which is projected onto the floor (Figure 9) and multi-player mode supporting simultaneous interaction of multiple players with the system. It promotes movement, social interaction and teamwork. Beam is designed to be all in one solution that consists of a motion detector, a light projector and a sound system.

Beam became very popular in the child care facilities, because of its simple setup which only requires the user to mount the projector on the ceiling and configure the software to load the desired game. Its gaming surface is 5.5x4.8 meters which provides the children with big enough playing surface so that the player needs to move extensively to reach all the corners of gaming surface. According to their specifications, the device is able to detect up to 15 different players, big team games are also possible, although 15 players on a surface of this size would probably mean overcrowding and lack of displayed possibilities.

[8] http://www.joinbeam.com/

Figure 9: Beam is an interactive projection gaming platform that is being used in hospitals, kindergartens and other public areas where the kids can play various multiplayer games.

Most popular games on the Beam platform are of various genres. One example is 2 player soccer game, where the game shows a ball and two goals. The players need to score by kicking the ball into the goal. The second most popular game is a variation of "whack the mall" type of game, where the enemies can vary from moles poking out of the holes, to ants trying to take steal piece of pizza from the middle of projected screen. Another fun game that they provide is piano playing game where children run across the piano keys producing a melody.

Another system similar to this has been presented by exertion games lab, where they put a projector on public transport vehicles (busses and trams) so that while commuting, passengers were able to interact with the system [15]. The responses from the public were positive, but the engagement was not as high as expected because there is a social barrier one needs to overcome in order to start engaging with games in public spaces (e.g. public transports). [16]

IllumiRoom[9] is a proof-of-concept system that augments the area surrounding a television with projected visualizations to enhance traditional gaming experiences. This system is using a calibrated projector with a Kinect sensor mounted on it to recognize the living room and

[9] https://www.microsoft.com/en-us/research/project/illumiroom-peripheral-projected-illusions-for-interactive-experiences/

project an expanded window of TV screen onto the furniture and wall rooms (Figure 10). [17]

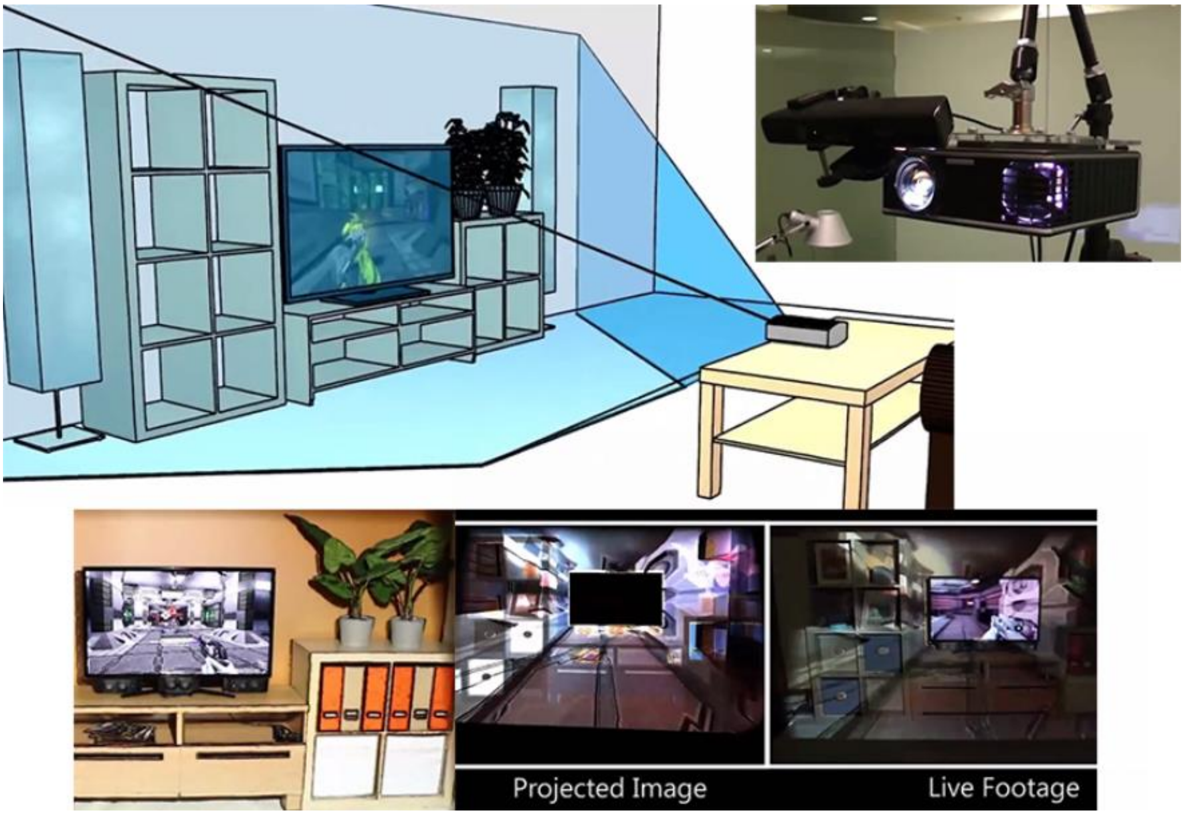

Figure 10: Expanding playing surface by recognizing the furniture shapes and using them to correctly map game image back the room was the problem that IlumniRoom tackled. This project served as a basis for much more promising gaming setup, RoomAlive.

Its successor, RoomAlive[10] builds on the familiar concepts of IllumiRoom, but pushes things further by extending an Xbox gaming environment to an entire living room. It aims to create an augmented reality experience inside your room. You can reach out and hit objects from the game, or interact with games through any surfaces in the room. RoomAlive tracks the position of a gamers head across all six Kinect sensors, to render content appropriately. The setup allows player to interact with the environment by touch feedbacks and by using a flashlight indicator. In this way the player is able to play games such as whack the mole in his living room by stepping on the mole or shooting the mall with a flashlight. The system currently uses 6 projectors and 6 kinect sensors with a price tag of over 5000 USD. This makes it too expensive for wide scale adoption, however, this system is very advance and is likely to have a long term contribution to future research in game development.

[10] http://projection-mapping.org/roomalive-uist/

2.2 DRONES

In recent years the technology of drones has seen many advances ranging from flying capabilities, to flight time, miniaturization and lift capacity. The volume of drones that are being sold also contributed to ever lower prices making them more accessible to the general public. Drones are nowadays predominantly used for taking pictures and recording videos because flying a drone with a camera up high is a great way to get high quality imagery at a budget price which was never before so accessible as it is today. However, flying drones in public has its own shortcomings and a set off legal issues that are in place to protect privacy and the safety of the general public. The main danger is the sensitivity of drones to critical errors or connectivity problems, which may cause a total failure of a drone and cause it to crash to the ground.

Drone legislation is still in progress whilst the programs on how to do it are still discussed and currently based on total weight of a drone. People have a wide range of opinions about drones, with privacy issues at the forefront. Nevertheless, drones are becoming the norm for many work and social environments. Nowadays we already start to see drones being used for more advanced purposes such as parcel delivery systems (Amazon[11]), find and rescue operations, marketing purposes or art projects.

In March 2017 Amazon made its first ever air parcel delivery in the United States. [18] This eCommerce giant aims to innovate the way of parcel delivery by using drones as a method of transportation. Amazon aims to use drones for delivery of small packages in the radius of 30 minutes from its dispatch centers. While the system is still in the development and testing phase, Amazon has already been running a service for a small number of customers in UK for over a year and is trying to obtain a license to expand their testing operations to US based locations.

Melbourne based company I-Drone has developed a drone that is capable of projecting news, games and advertisements on the walls of city buildings or city streets. Currently in its prototype stage, the drone is capable of 12 minutes of flight time and is fitted with 500 lumens projector. Live video streaming, manual projector controls and audio capabilities are still in development phase. [19]

Since this concept was shown live, companies like Disney jumped on board and obtained patent grants for use of such a technology in the United States. [20] Their aim is to use these drones in their amusement parks to enhance the experience of their visitors by offering them

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[11] https://www.amazon.com/Amazon-Prime-Air/b?node=8037720011

new ways of displaying various advertisements and movies projected on all kinds of surfaces. [21]

Drones present an interesting platform to develop new game designs, this is why the entertainment and gaming industry is already exploring the area of drone usage for gaming. One example is the Lumi quad-copter by WowWee[12], which offers a variety of games, including one where you use your mobile phone to control a drone's illumination. Another example is Parrot drones in combination with the AR.PURSUIT augmented reality game. Goal of the game is to shot down an enemy drone with virtual lasers while controlling the drone from first person perspective using the camera mounted on the drone. The Air Hogs Connect[13] game is another example, where player takes control of a real drone that is hovering over the magic carpet. This carpet acts as a marker for magic lense tablet that controls the drone and is displaying the player a virtual world where he must navigate the drone in order to achieve various goals. There is also an increase in popularity of drone racing events and even drone wars, where drones try to disable or destroy one another—and such events are drawing many spectators. [22]

To sum up, drones in the context of gaming present a technology already accepted by early adopters and provide an emerging and exciting research area for studying human-drone interaction in entertainment. However, current games require users to remotely control drone's movements in space using mobile devices or remote controls whereas what we seek to design and build in this thesis is a moving projection platform where drones are autonomous and provide a digitally augmented physical environment that provides the core interaction and gamification.

[12] http://wowwee.com/lumi

[13] www.connect.airhogs.com

3 EVALUATION METHODOLOGY

3.1 FEASIBILITY STUDY

The purpose of this study is to validate feasibility of building such a product using pre-existing components. Hence, we seek to answer: Can such a system actually be built? It is a simple question, but it requires a deep investigation into the existing technologies and possible interactions among different devices and platforms. In order to evaluate the system, we plan to build we need to define a set of minimal functional requirements we later use for evaluating the prototype. The minimal set of functional requirements, defined in section 4.1.

3.2 EVALUATION OF USABILITY AND USER EXPERIENCE

Besides evaluating the feasibility of the design or system one can also evaluate the quality of experience the user is perceiving when interacting with the system, better known as user experience, what user satisfaction does the system manage to achieve and the usability of the system which focuses on how easy the system can actually be used and commonly consists of: [23]

- **Learnability**: Is the system easy to learn and start using?
- **Efficiency**: How quickly can be the tasks performed once a proficiency is achieved?
- **Memorability**: How fast can the user memories the use of the system. Is he after a longer period of time still familiar with the controls?
- **Errors**: What is the frequency of errors? Are these errors minor or critical?
- **Satisfaction**: Is the user pleased using the system?

In order to get evaluate usability and user experience one needs to run user experiments through which qualitative and/or quantitative data is captured. Through various data analysis verification of hypothesis and various conclusions about usability and user experience can be made. In the following subsections we make an overview of different data capture techniques and experiment design types and propose how such as system should be evaluated.

3.2.1 Data capture techniques

Throughout the evaluation of usability and user experience many different approaches can be taken when considering data acquisition. These can range from task specific measurements, such as task time completion and task error rate, to more automated logged metrics, such as device location, number of detected players, player movement velocity, etc.

Another method of data capture is note taking whilst observing a person interacting with the system. Note taking can take place during the experiment or after the experiment if the experiment is video recorded. The main problem of this approach is that it is only possible to observe what is visible and is difficult to observe what people think throughout the interaction. To overcome this problem one can conducting interviews with participants or ask participants to fill questionnaires.

3.2.2 Data Types

Classification of research methods is commonly based on the data types that are being observed and analyzed. These types range from qualitative data types to quantitative. The main difference of the two is that quantitative approach focuses on trying to generalize user experiences and system usability feature, whereas qualitative approach focuses more into deepening the understanding of a single participant and its experiences while interacting with the system. This focus on a single participant usually means that the testing group can be smaller and still yield observational results that benefit the study. Every conclusion that is made from qualitative observations should in the end still be tested with quantitative approach so that the hypothesis can be validated on a broader audience. [24], [25]

3.2.2.1 Quantitative approach

Qualitative approaches are based on qualitative data types. In case of evaluating our system this could be done by designing a task where the user would have to step on 5 randomly lit grid elements as quickly and as accurately as possible. During each task we would measure different qualitative parameters such as task time completion, accuracy of action and error rate.

3.2.2.2 Qualitative approach

Qualitative approaches are based on qualitative data types. In context of our prototype we could record data by interviewing participants, and noting their comments. In addition to this participants could provide subjective user satisfaction scores and workload through questionnaires such as SUS [26], NASA TLX [24] or QUIS [27].

3.2.3 Experiment types

Part of every empirical research also incorporates some kind of an experimental stage. This stages can be separated into two experimental types. The first experiment type is within subject design which is a repeated measure system where the user performs every task under all possible conditions. This approach introduces a challenge on how to distribute the learning effect on the results of all conditions. This means that in the beginning the user is still learning the system and may accomplish the first few tasks with a lower success rate than the latter ones.

The second experimental approach is between subject design. Here, the users are separated into different groups, each group is then given the tasks, but under a different condition. This approach mitigates the learning effect, since all the groups are starting from the same point. Although this approach is better than within subject approach, it requires a bigger test audience and the variations of the groups may cause the results to be negated. [25]

Due to the fact that in this thesis we do not plan to conduct a comparative study of two different systems or interfaces it is not possible to choose any of the two experiment types.

4 SYSTEM DESIGN

The StreetGamez moving projection platform is planned to be an open platform that can facilitate various types of street and chalk games using a drone to deliver the mounted game infrastructure to a requested location. It would fly to the game location and performs three vital tasks, projecting graphics onto arbitrary surfaces, enabling interaction within the projected surface through motion tracking of players, and enabling interaction through players' mobile devices (calling the platform to a desired location, selecting games, and so on). In the following sections we provide a more detailed view on the functional and system requirements.

4.1 FUNCTIONAL REQUIREMENTS

The minimal set of functional requirements that we imposed on ourselves was to design and built a system that will be able to:

1. Track player's feet on a detection grid where each grid unit measures 30x30 centimeters. There are many games of the type "whack the mall or "dance ritual" that could be built with such basic interactivity making such a system a viable platform for game development.
2. The system should achieve interactivity capable of providing quick feedback whilst maintaining correct detecting in case of fast movements. This is particularly important for us because our system is intended to become a platform for exergaming, hence enabling fast movement interaction is vital.
3. The projected surface should be always mapped as a rectangle, even in situations where the projecting platform is not orthogonal to the playing field. We do not want to fly the drone above the users', but in front of them in order to avoid any injury in case of drone failure.
4. The platform will be able of supporting multiplayer mode particularly important because playing games is fun, however, playing games with other players adds substantial excitement to the game play motivating players to more actively participate in the game, a very important element in context of exergaming.
5. Enable to hover at fix position in order to support player playing the game.
6. Fly to the location of the players enabling the users to call the game platform to the location where they wish to play the game.

4.2 SYSTEM REQUIREMENTS

The main goal is to try and fulfill functional requirements by building as system using preexisting components. There are two reasons for such decision, one is that building bespoke solution falls out of the scope of this thesis and that we would like to build a system that could be built by others with general ease once they have all the components. This idea is not only pursued in hardware design but also in software design because we would like other people to use our platform in order to develop their own set of games.

The system itself should be self-controlled with an option of a manual override by using a third device in the hands of drone controller. The main reason for this is safety as we would like to avoid any injuries caused by drone failure. The system is controlled by the game engine during the game play.

All the hardware components should be as light as possible in order to enable drone to maintain in operation for a minimum of 15 minutes. Minimizing weight is very important as increase in weight reduces drone flight time and/or introduces the need for a bigger drone. The bigger the drone the more dangerous it becomes to the general public.

In context of projection, the system should be able of project sufficiently bright images in evening lighting conditions with a minimal refresh rate of 20 Hz.

4.3 PROPOSED SOLUTION

We propose a system which consists of a Tango device which we plan to use as a game engine for detecting player's movement and generating computer graphics. For projection we plan to use Asus S3 mini projector (measuring 15x15x3 cm) which is capable of producing brightness of 200 lumens. In order to provide stable projection, we plan to mount both devices onto a gimbal. Tango and projector will have to be mounted at an angle (45-70 degrees) as displayed in Figure 11. We estimate the total weight of our projector system to 1kg (weight of first generation Tango tablet is 360g, Asus S3 projector (measuring 10x11x3 cm) is weighing 340g, cables and gimbal ~300g).

Having the Tango tablet attached to a drone might present several problems so for the testing of the software solution we planned to use the device in a static environment, placed 2m high of the floor facing the playing field under an angle of 45-70 degrees. In addition to this, mounting and flying the system on a drone falls out of the scope of this thesis.

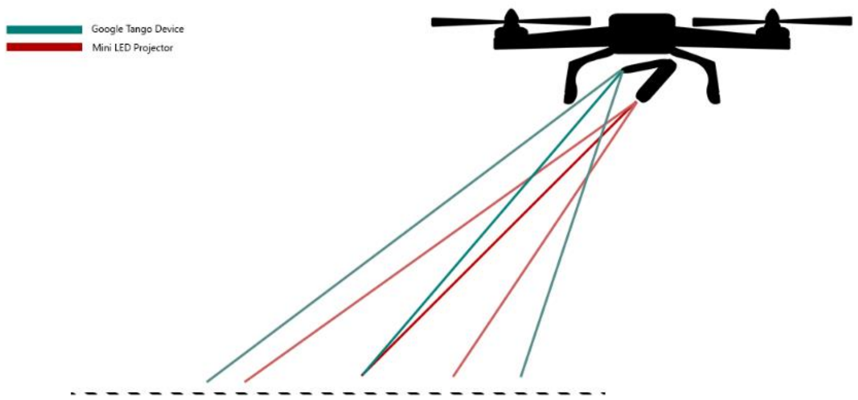


Figure 11: Drone platform with projector and the tablet attached with a special frame.

In the following sections we take a closer look at the proposed solution for each functional requirement.

4.3.1 Tracking players

For detecting player movements with a lightweight device, we selected Google Tango[14] tablet. The second option was to use a mobile phone in combination with an external depth sensor (Structure IO[15]), however using Structure IO would considerably increase the weight of the device, hence Tango was chosen.

Tango, formerly known as Project Tango, is augmented reality computing platform developed by Google. Its core concept is to use the devices peripheral hardware to orient and recognize its environment. This allows its developers to create user experiences that include 3D mapping, indoor navigation, physical space measurement, environmental recognition, augmented reality and an interface which can act as a window into a virtual world.

There are currently 3 devices (Figure 12) that support Google Tango platform, namely: Google Tango Tablet, Lenovo Phab 2 Pro and Asus Zenfone AR. In the early days, another device was used, The Peanut phone, that has been deprecated because of the advancement made in the software stack.

[14] https://get.google.com/tango

[15] https://structure.io

Figure 12: Tango Supported devices (Tango tablet, Lenovo Phab 2 Pro, Asus Zenfone AR)

The platform integrates three main functionalities: Motion tracking of the device by using visual features of its surroundings in combination with the accelerometer and gyroscope. Area learning, by recording the visual features and the distance measured it can store the area data that can be reused by another tango device or it can leave notes or other visual marks. The third feature is depth perception. The device can scan the room and build a point cloud image of the room. From this point cloud, a room meshes can be made and used as a 3D models for further processing. This feature is of particular interest to us, as we plan to utilize depth cloud in order to detect players movement over the ground plane.

However, there are certain limitations to the depth cloud functionality. Current devices are designed to work best indoors at moderate distances between 0.5 and 4 meters. The device consist from RGB camera, fisheye camera, IR projector and LED Flash (Figure 13). If the object is too close to the device, the binocular vision is limited, because the projected IR matrix from cannot be correctly identified by the IR camera. The 4-meter distance is an approximate distance where the structured light pattern that is projected with IR starts to lose its visibility and the cameras cannot get sufficient light feedback. This distance is further reduced if the area is light by a strong light sources that are high in IR wavelength (e.g. sunlight, incandescent bulbs). Another problem presents the objects that do not reflect IR light, preventing the system from obtaining a sufficient light reflection. This limits the use of the system in case of outdoor environment to low lighting conditions and to surfaces (e.g. ground) that reflect light well. The latter is also a requirement for the clothes being worn by the players.

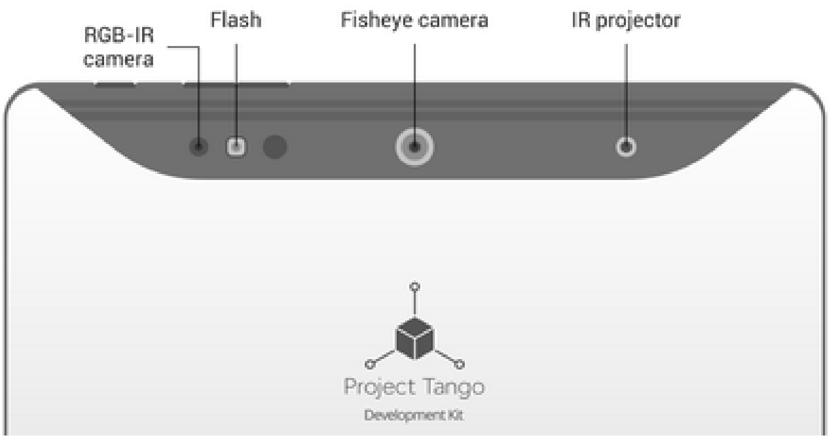


Figure 13: Tango peripherals layout

4.3.2 Game engine and graphics

Trying to appeal to a wider community of game developers, we decided to create our prototype on Unity game development platform. We hope this would increase the number of people that would be interested in trying to build various games for our platform.

Figure 14: Unity Logo

Unity[16] (Figure 14) is a commercial game development product, which in 2017 was quoted saying that "34% of top 1000 free mobile games are made with Unity". Such a popularity means that the engine developed could receive a broader specter of developers outside of the academic world and as such receive a bigger community support in developing, bug fixing and introducing new concepts that would benefit all the parties involved.

Google Tango provides the developers with an SDK that can be used in unity, to obtain the callback calls and events from the C library used for processing signals in the Tango device itself. It also provides a debug development mode, where the point cloud detection and

[16] https://unity3d.com/

device orientation is simulated, so that the device is not needed to develop in some scenarios, example of this may be that the graphics development team is not required to have the device on site and that they can replicate the basic interactions on their PC-s.

4.3.3 Projection

For projection we plan to use ASUS S3. The device itself is very compact and light (0.35 kg), but with 22Wh battery, provides up to 3 hours of projection time and with USB port, it can serve as a battery bank for Tango device. It provides 200 lumens of illumination and with its wide projection angle is able to project a large playing area from relatively short distance.

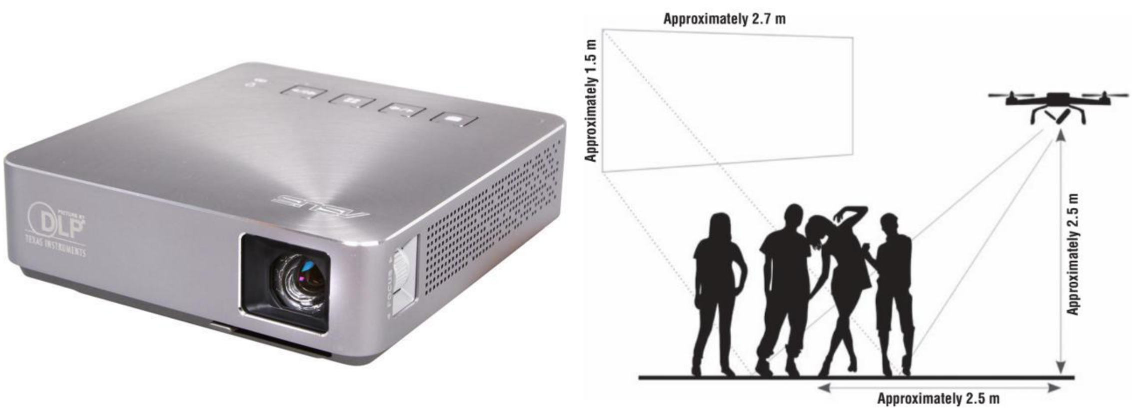


Figure 15: Asus Projector and Sketch of it being mounted onto a drone that is hovering above people using its projection as a playing field of dimensions 2.7x1.5 m.

While the projector is mounted on the rig, and projecting to the floor, the image that is projected is distorted. Instead of projecting a true square or rectangular image to the floor, the image projected has a trapezoidal distortion. This distortion is called keystone distortion and it is caused because the surface we are projecting on is angled. This distortion can be approximated by equation (1).

$$\frac{\cos(\varepsilon - \frac{\alpha}{2})}{\cos(\varepsilon + \frac{\alpha}{2})} \quad (1)$$

Where ε is the angle of the surface being projected on, and α is the width of the focus. Because the projector is mounted in the same space as the Tango device, and the device is spatially aware of its orientation in respect to the ground plane, we can calculate the required adjustments to the projected image and project the proper square to the floor.

5 PROTOTYPE IMPLEMENTATION

Our goal is to build a prototype that will fulfil as many functional and system requirements as possible. In pursuit of this goal we plan to implement a system that will project an interactive playing field to the floor surface using a small projector that is connected to Tango tablet via mini HDMI port. The projection is built from tiles, that are activated once the user steps on one them.

To enable easy integration with new and existing games, we made our system compatible with the Unity game engine. This will enable us to offer our player tracking and game projection solution as a Unity prefab (which acts as a template for creating GameObject instances in the scene). We decided on this to enable easy integration when modifying existing games or when creating new games that are compatible with our platform.

As part of the prototype we propose an algorithm built of 4 components (Figure 16): floor plane detection — where the algorithm detects the ground plane and initializes; *point cloud processing and player detection* — where the algorithm searches for players feet position using information from depth camera; *RGB optimization* — where the system performs player identification and optimizes tracking performance; *rendering* — *projector alignment correction* — where the algorithm removes perspective distortions from the projection which is caused by the fact that the projector is at an angle in relation to the projection surface; Each step will be presented in more detail in the following sections.

It is important to note that the system is currently limited to projections on horizontal planar surfaces, where the system tracks only the players' feet. The system should refine player tracking and distinguishes between players in RGB optimization utilizing color tracking of players feet, hence unique footwear color is required to play a multiplayer game. However, due to problems with obtaining RGB camera image, we did not succeed in implementing RGB optimization of proposed algorithm, nevertheless we decided to include detailed description of the algorithm within the thesis.

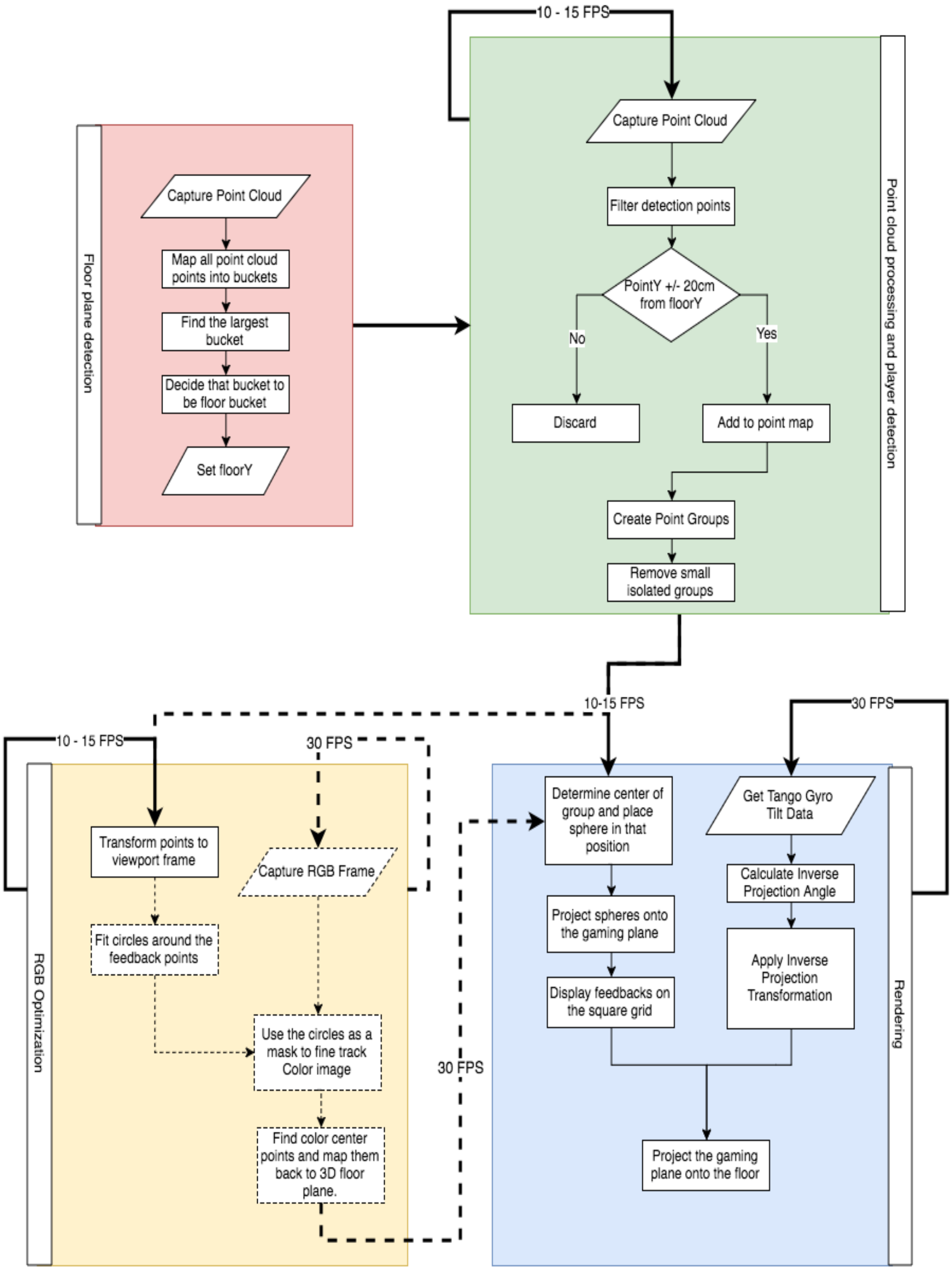


Figure 16: Algorithm used to create interaction system based on Tango tablet detection and projection on the floor.

Algorithm is built from 4 parts:

(i) floor plane detection, marked in red;

(ii) point cloud processing, marked as green;

(iii) RGB optimization that speeds up and refines player tracking, and performs player identification marked as yellow.

(iv) rendering where perspective distortions are removed and computer graphics are generated.

5.1 TRACKING PLAYERS

The tracking system is mainly based on information from depth camera. In order to improve performance of tracking system we planned to also include color based tracking. Player tracking is based on three main segments: floor plane detection and point cloud processing and RGB optimization. Each of them is explained in more detail in the following subsections, however we start by presenting different systems for point cloud detection whilst highlighting the chosen system.

5.1.1 Point cloud detection

There are three common methods for generating depth information, namely: Stereo, Structured Light and Time of Flight. In case of stereo two observations of a single point are required. This can be achieved by using two cameras filming the scene. Each camera records the point under a different angle. Using simple trigonometry one can calculate the distance between the object and the camera. This is true if both cameras know which is their reference point F. In real scenarios, objects can be of a similar color, and shape, so we are unable to determine which are the exact points the cameras are seeing. This is why our Tango devices and other point cloud detection devices use Structured light of Time of Flight method Figure 17

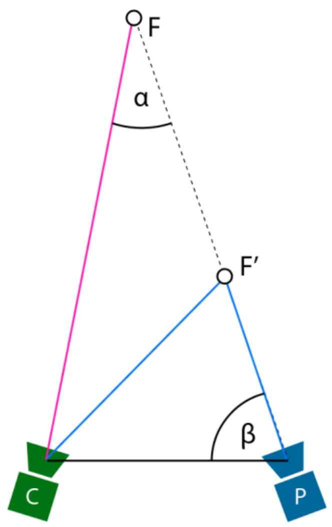


Figure 17: Calculation of point is done by calculating expected point position (F) an angle α and its detected position (F') and angle β. This process is repeated for every marker point projected from Tango.

Structured light uses IR projector which beams a grid pattern of dots so that each sample group of the dots is uniquely identified. This way the IR projector and IR camera are able to determine the exact position of the detected point group. Example of projected beam can be seen on Figure 18.

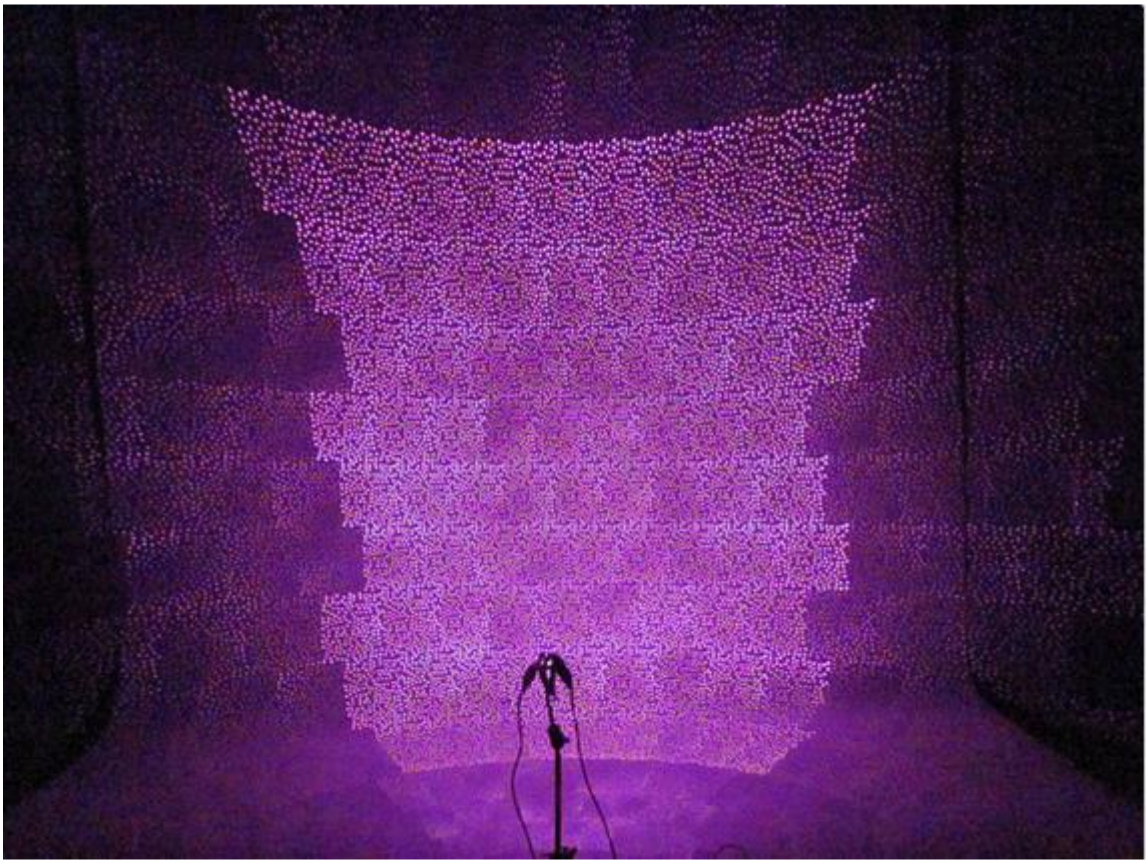


Figure 18: Projecting IR grid onto a wall with disassembled tango IR projector.

The newer devices use time of flight sensors which castes small rays into the room and times the time for the waves to bounce back. This technology provides us with a more precise measurement system, but such devices were not available to us, hence we used structured light approach which is integrated into our Google Tango Tablet (Figure 19).

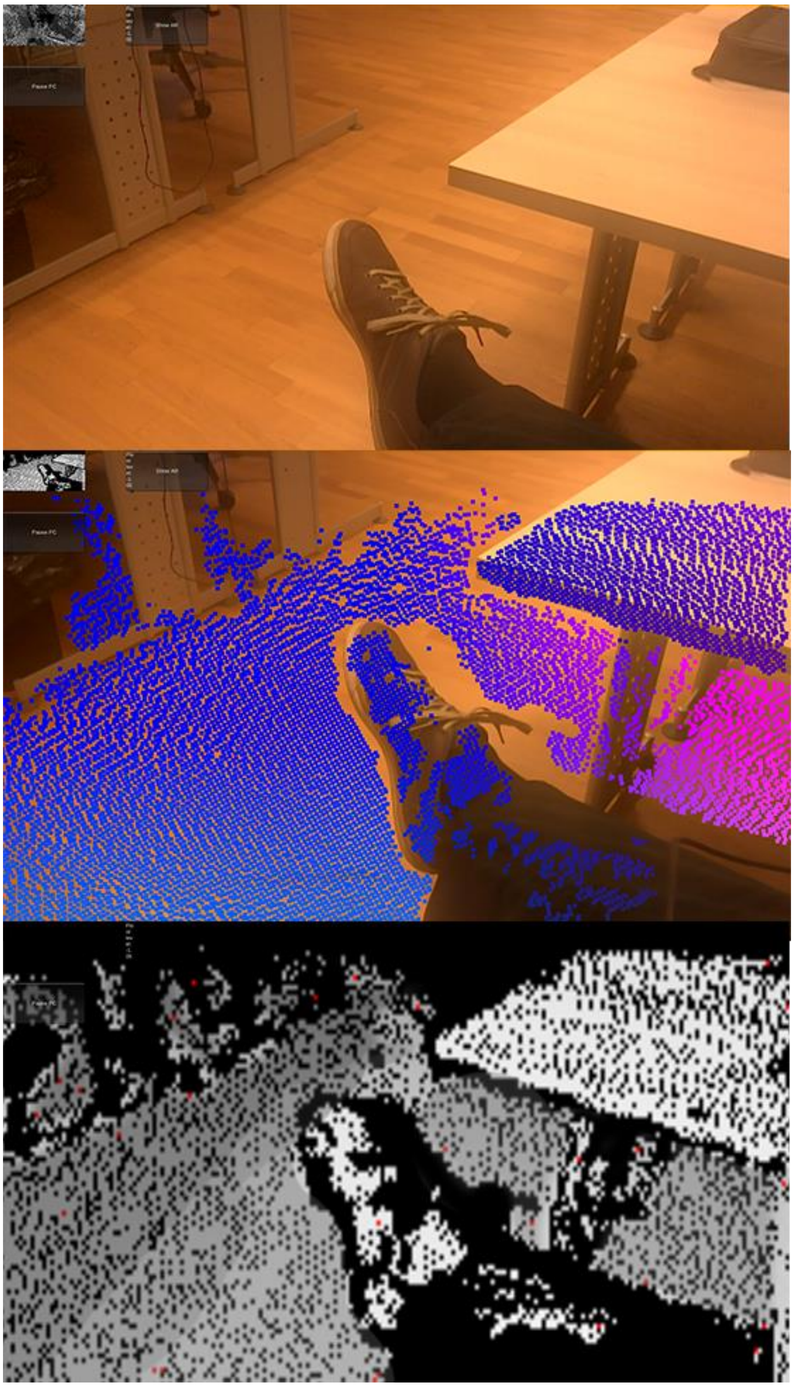


Figure 19: Images of depth clouds produced by Google Tango device. Lighter points represent feedbacks closer to the camera, whereas darker dots are representing faraway signals.

5.1.2 Player tracking with point cloud data

The tracking systems is mainly based on information from depth camera obtained by Tango device (Figure 19). The algorithm is represented on Figure 16 and is trying to detect player feedback at the ground level.

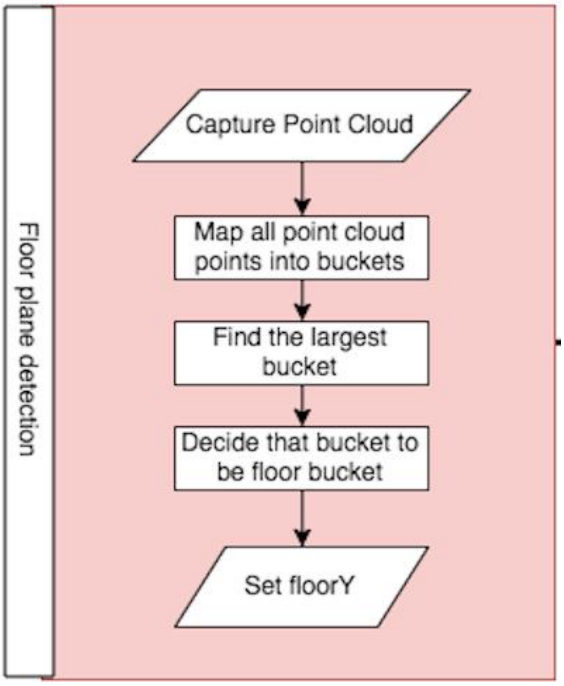


Figure 20: Floor plane detection algorithm

The first step of tracking players at the floor level is to estimate where ground plane lies. This is done by Floor plane detection algorithm (Figure 20) which is only run at the initialization stage of our system. After obtaining point cloud data, we start by mapping points into buckets where the Y axis is kept in small deviation groups. At each new point cloud frame the points are added into group and once the threshold is reached, the algorithm marks that Y coordinate as a ground plane. Based on the assumption that Tango device can localize itself in the area, the ground plane needs to be detection only once at the initialization stage.

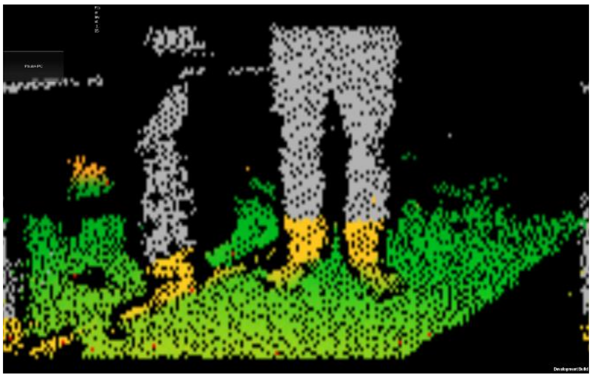
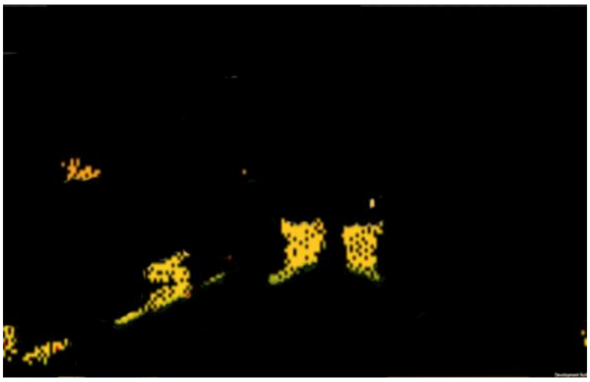


Figure 21: Left — green colored points are on the floor level, orange points are objects that are within the 20 cm threshold; Right — filtered image after min max filtering



Once we know the position of the ground plane, we move to *Point cloud processing* step of our algorithm (Figure 22) which starts by obtaining point cloud data. After obtaining point cloud data on can perform simple min max filter on the Y axis to isolate 3D points that are likely to be feet of our players. We set this filtering threshold to 20 cm distance from ground plane. Points that fall out of this threshold are discarded. The results of the filtering can be sen in Figure 21. We can use the centimeters to define this range, because Tango platform offers us a map function from global coordinate measurement to a real world dimensions.

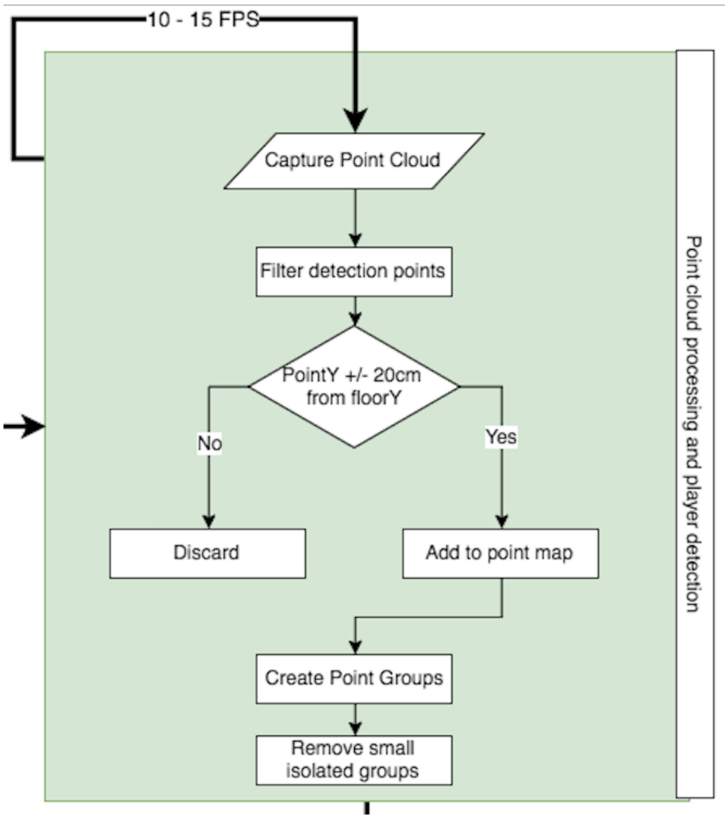


Figure 22: Point cloud processing — we try to obtain player feet position in virtual world

After filtering, remaining points are grouped into spherical geometric shapes. This is done by processing every point and trying to fit it into a nearby sphere. The radius of the sphere can be manually configured and was set to default diameter of 30 cm. To simplify this grouping process we ignore the Y coordinate of the feedback mapping placing all feedback points to a single plane. Using a 2D image, we can generate distinct groups by using a simple grouping algorithm.

Our algorithm starts grouping process by randomly selecting a feedback point. Then we check if there is any group defined within threshold proximity of this point. If no, we create new point group, set its rank to 1 and set the location of the group to this point. If the point is found in the diameter of an existing group, it is added to the nearest group. The group location is then updated by weighted average (see Equation 2).

$$GroupPosition = \frac{N_{items} \times GroupPosition + FeedbackPosition}{N_{items} + 1} \quad (2)$$

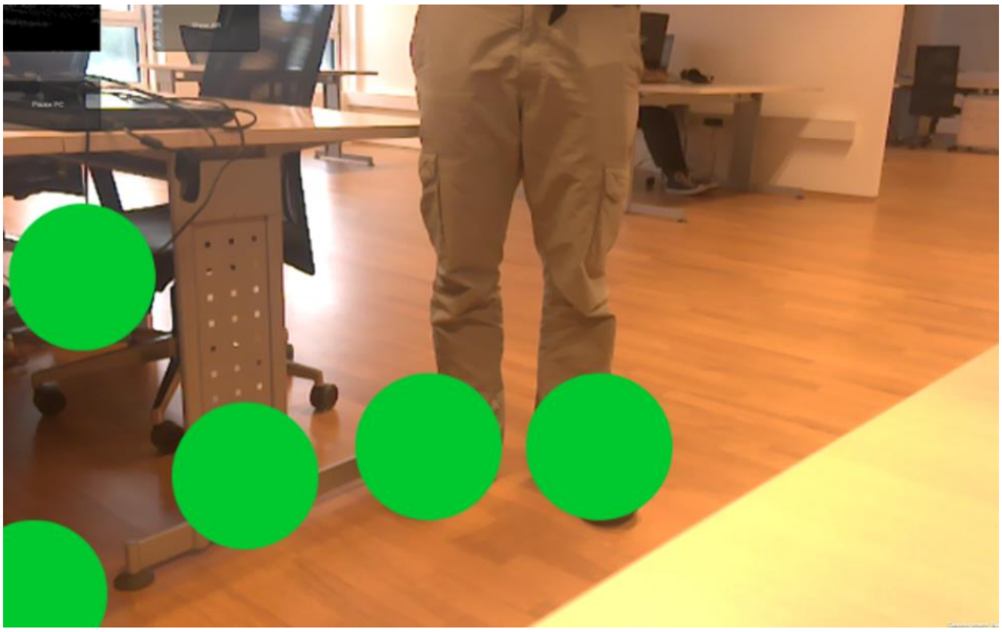


Figure 23: Groups are being rendered back to the scene in form of spheres that cover a certain area in the virtual world.

After processing all the points, the transformation from 2D group coordinates back to 3D coordinates occurs by averaging the Y coordinate of group points. At this stage we remove groups which consist of insufficient number of detected points. This value can be changed though game engine configuration. The result of this step is an averaged group of strong feedbacks (Figure 23).

5.1.3 RGB optimization

The main limitation of player tracking is low refresh rate which is mainly caused by low refresh rate of depth camera. One option to improve detection rate is to utilize information from RGB camera. Even though we explain the way to do this in this segment, we unfortunately did not manage to fully implement this stage. Segments of the algorithm in dashed lines were not implemented.

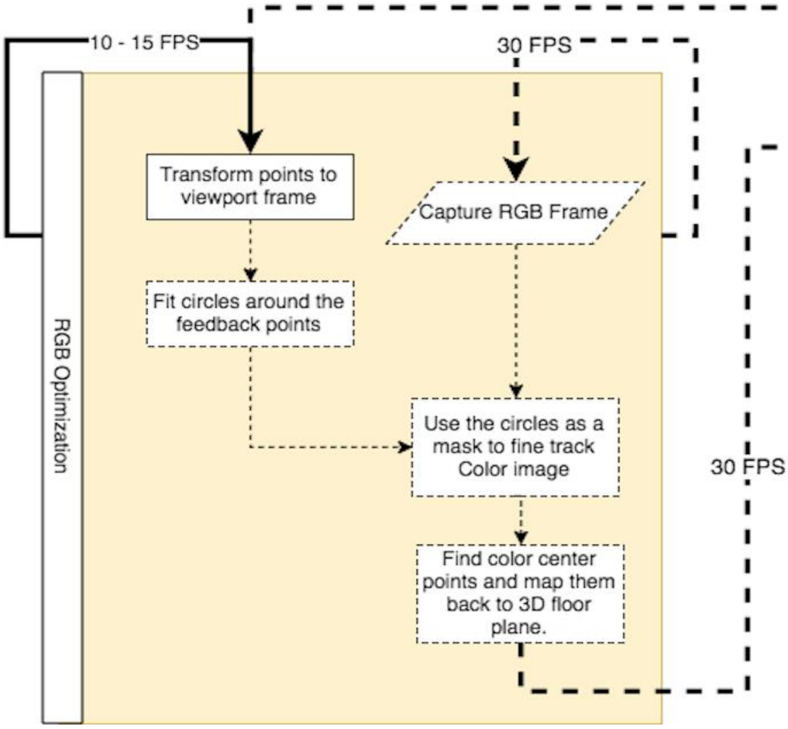


Figure 24: Optimization of player tracking by use of high refresh rate RGB camera

5.1.3.1 Capturing RGB information

To obtain data from the camera the SDK callbacks varied across different versions of Tango Core. In the latest version Ikariotikos (Version 1.54, June 2017), one needs to register an event that signals when a new camera image has been rendered to the buffer and is available for reading. Unfortunately, we were not able to obtain RGB stream whilst depth camera was in operation. The reason for this problem is still not fully understood and the lack of documentation made it impossible to find the solution within the timeframe of this thesis. Nevertheless, the next section presents a theoretical approach for optimizing player tracking using color detection.

5.1.3.2 Color based tracking with high refresh rate and precise detection

Although the primary feedback is detected with Tango depth camera, we planned a fine grained tracking by analyzing captured images from RGB camera (Figure 24). This requirement emerged during the development of the tracking system using depth camera which only managed to perform at relatively low refresh rate of 10Hz. The performance was mainly affected by low refresh rate of depth camera.

To improve tracking performance, we planned to perform color based tracking whilst waiting for the next depth camera frame. We planned to perform color based tracking within the regions detected by Tango depth camera, hence the first step was to perform transform of detected 3D points from depth cloud to the screen coordinate system in the step we call "Transformation of points to viewport frame". This allows us to create a mask with regions of interest. Such transformation can be done using pinhole camera model (Figure 25) [28].

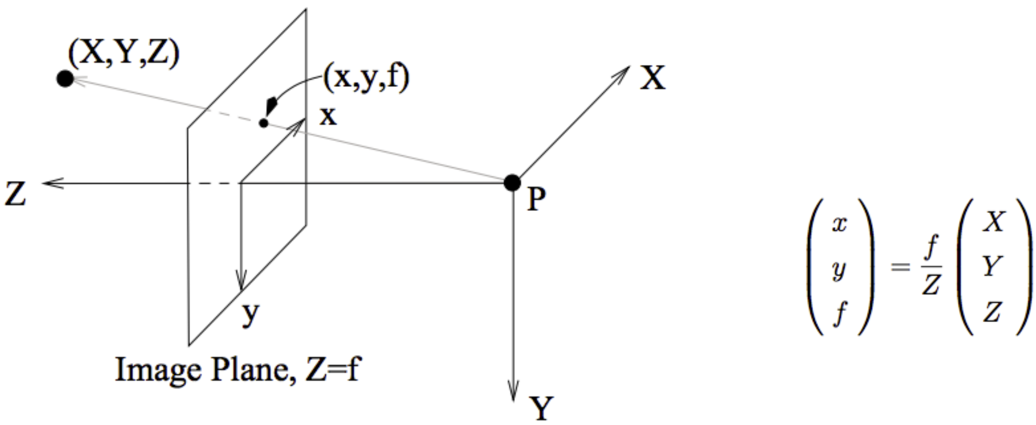


Figure 25: Pinhole camera model showing how 3D pint is transformed to 2D image.

The projection of 3D point cloud to the screen can be therfore formulated as:

x, y - location of point in image coordinate system
X, Y, Z - location of points in world coordinate system in which the data is provided (see Figure 21)
K - intrinsic camera parameters

$$[\, x\ y\ z\,]_{pixel} = K \times [\, X\ Y\ Z\,]_{3dPoint} \qquad (3)$$

Where the K matrix is constructed by:

$$\begin{bmatrix} F_x & 0 & F_x \\ 0 & F_y & F_y \\ 0 & 0 & 1 \end{bmatrix}$$

Hence, to obtain the pixel coordinates within the viewport frame, we need to multiply the 3D point with intrinsics matrix of the camera. The intrinsic camera parameters are defined through camera calibration process which has already been done by the provider of the Google Tango device.

We can ignore extrinsic camera parameters, due to the fact that the coordinate system in which the depth camera information is provided is almost perfectly aligned with the device screen (see Figure 26), hence the extrinsic camera parameters that specify the transformation from world to camera coordinates can be ignored.

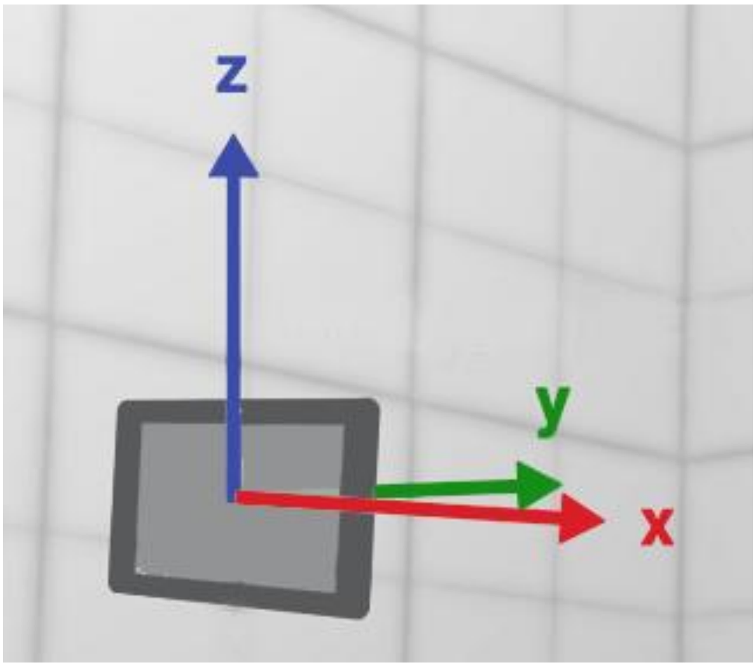


Figure 26: Alignment of the virtual camera with the depth camera is in almost identical orientation.

After we receive 2D points, we clip these point groups into detection masks for the next step of processing we call "Use the circles as masks to fine track Color image". In practice this is easily done by because we only need to do is to map a 3D vector to camera view port which is done by using Unity WorldToViewPortPoint method call.

Figure 27: Concept sketch of detecting player feets in RGB image with higher refresh rate.

Color based tracking

First we need to map color image to the mask. In order to do so we scale the 2D point so that it corresponds with the captured image. After mapping all the detected groups this way, we are able to cut the detection area from color image. To enable adjusting the performance of the detection, the size of the detection square is possible to be manipulated via GUI control.

Using mask the segments of detection image are cropped out (Figure 27) and the color group detection is ran over them using OpenCV contours finding method which allows us to filter the color groups and detect center and radius [29]. After detecting 2D point groups, we can start using Unity methods to transform 2D location on image to world coordinates. Because our 3D point detection is also working on detecting the playing plane, it is possible to calculate the correct point of contact. We call this step "Find color center points and map them back to 3D floor plane" in our algorithm.

Mapping the detected centers of the feedback back to the detected floor is an easy task. The points are transformed with an inverse of the mapping of 3D point to the 2D screen space. We simply raycast the screen coordinate of the point to the floor and obtain the group position.

5.2 RENDERING

In first part of this subsection we will tackle projection alignment correction which is caused by the fact that the projector is not aligned perpendicularly to the projected surface. In the second part we plan to explain how we generate computer graphics where players position is correctly rendered in the scene.

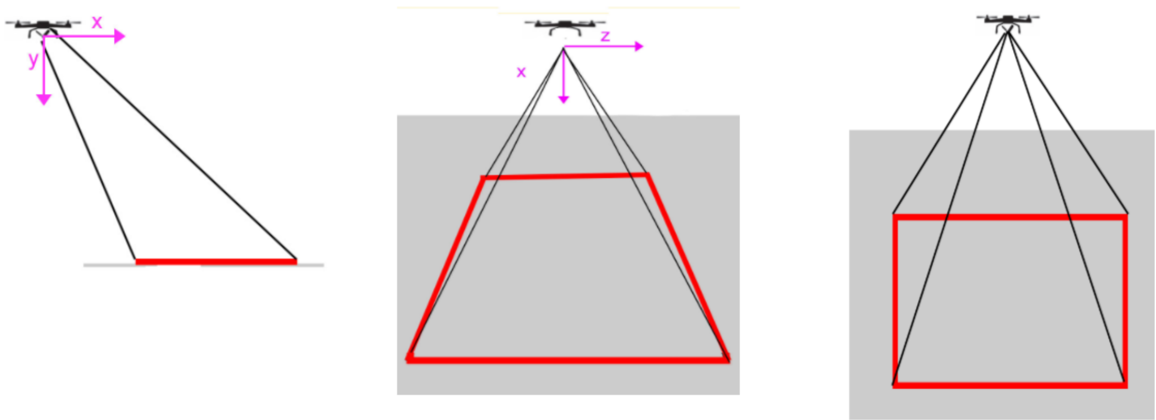


Figure 28: Rotations around x and z cause perspective distortion. Middle figure shows perspective distortion of rotation around z-axis on geometry of a rectangle. The projection needs to be corrected to maintain geometry (left image).

5.2.1 Projector alignment correction

Projecting an image at the surface which is not perpendicular in respect to the light source will produce distorted image as is shown in middle picture on Figure 28. This problem is caused by perspective distortions and is commonly called a keystone effect. Two rotations that cause such distortion are rotation Rz and Rx. Due to the fact that depth camera need to point at the player, the drone will need to be equipped with a gimbal maintaining the rotation Rx.

To successfully correct for this distortion caused by Rz we need to know the parameters of the projector FOV, lense parameters and Rz in relation to the ground surface. Using this knowledge, we can generate a transformation which will correct the above mentioned distortion.

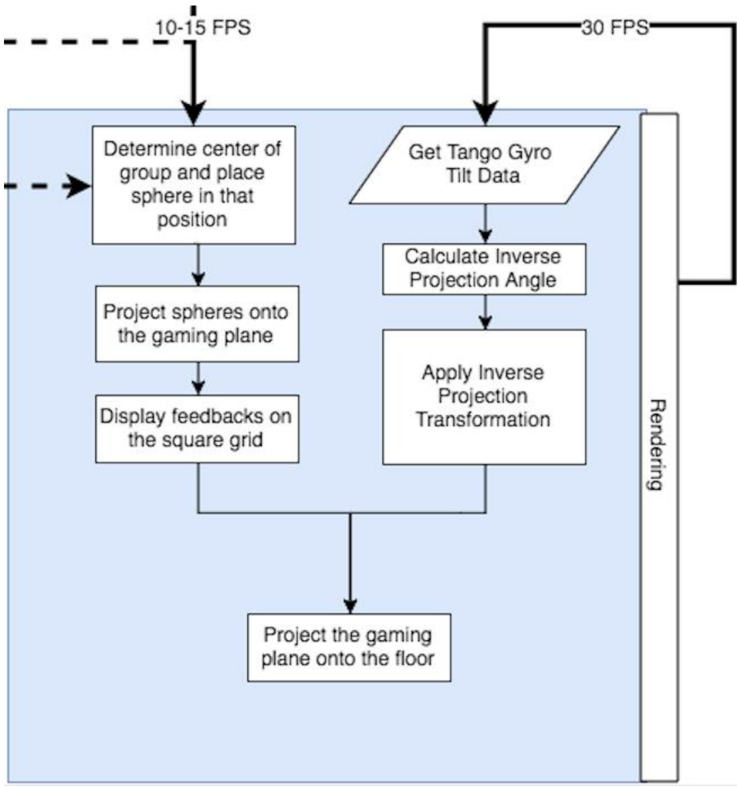


Figure 29: Rendering part of the solution, consisted from two threads, one for Tilt correction and the second for display points mapping.

The implementation of the above was done by algorithm presented in Figure 29. To summarize we created a virtual scene with a single texture we call Render Texture and a virtual camera to which we assign field of view and aspect ratio that matches our projector. We place the virtual camera at a fixed distance and rotate the plane around z-axis in the opposite direction of tilt detected by Tango tracking system. In this way we render graphics where perspective distortions from rotation around the z-axis are removed seen on Figure 30.

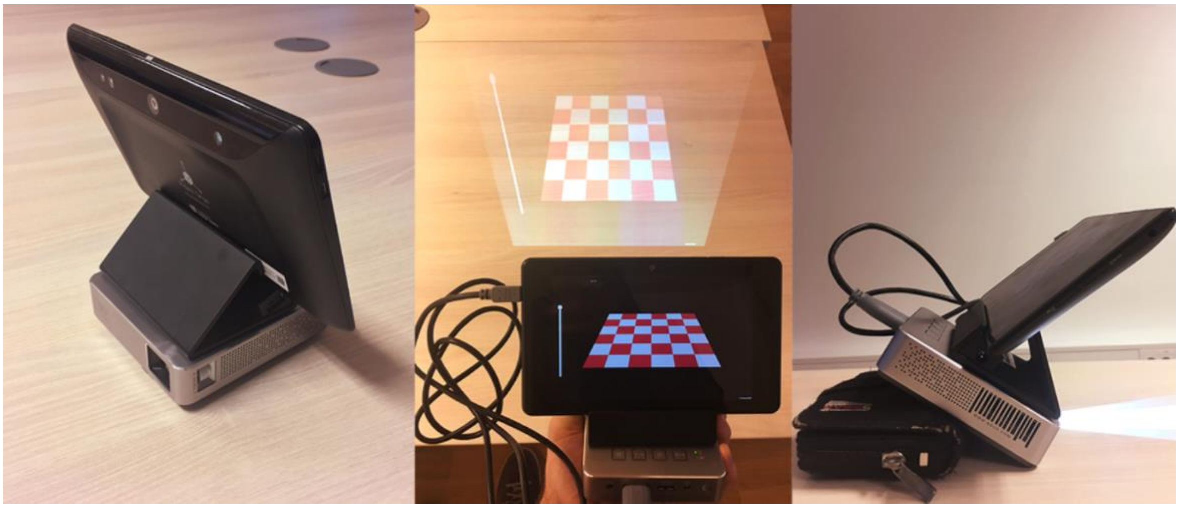
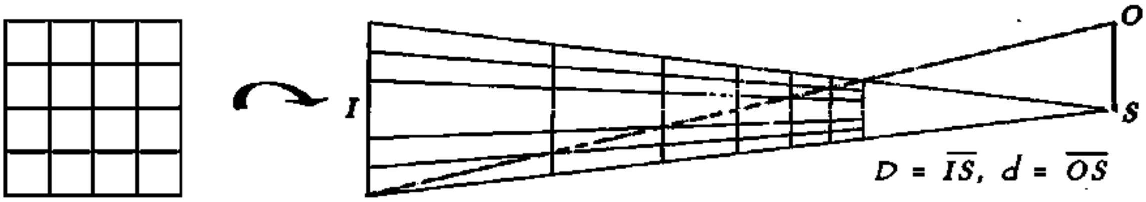


Figure 30: Example of perspective mapping of square onto a flat surface. The internal camera mimics projectors field of view and inverts the projection angle.

This solution only corrects for one rotation, but as Tango device is capable of 6 DOF camera pose tracking rotation around x - could be accounted for. We could also use the tracking information to fix the playing field onto a position in real world. In this way the playing field would stay at the same place regardless of the position and orientation of the drone.

A more advanced solution is to use inverse transformation using game shaders or other transformations that is possible to be done in the Unity game engine. A possible approach would be to apply the correct inverse trapezoid transformation to the image received from unity engine Figure 31.



$$x_2 = \frac{D \cdot x_1}{d + x_1} \quad , \quad y_2 = \frac{d \cdot y_1}{d + x_1}$$

Figure 31: Forward trapezoid transformation maps a square image into a trapezoidal distorted image that can be then projected onto a flat surface and by mitigating projector distortion project a square to the surface.

5.2.1 Rendering: Mapping feedbacks to a 6x6 playing plane

In the initialization step, a ray is casted from the center of the camera to the detected floor plane. The intersection of this ray and the plane represents the center of the detection matrix. The center point of the detection matrix is used for syncing the display grid with the detection grid.

This detection grid is defined in the engine with the default values of 6 columns and 6 rows. This setting can be additionally adjusted to allow more precise feedbacks, however, this may cause performance issues. After the grid is initialized, its fields are updated according to the sphere positions that are being calculated by point cloud detection algorithms. When a square is overlapped with the sphere it becomes active.

5.3 PROTOTYPE GAME

Following the previous noted steps, a simple game was created. The detection runs at 10-15 FPS with some lag spikes that additionally occur because of point cloud detection instability. Once the system is initialized (the ground plane was recognizing) the system starts to track feet of the player. At the position where he stands a green sphere is rendered and segments of the checker box pattern that intersect with the spare get colored in green color. (Figure 32)

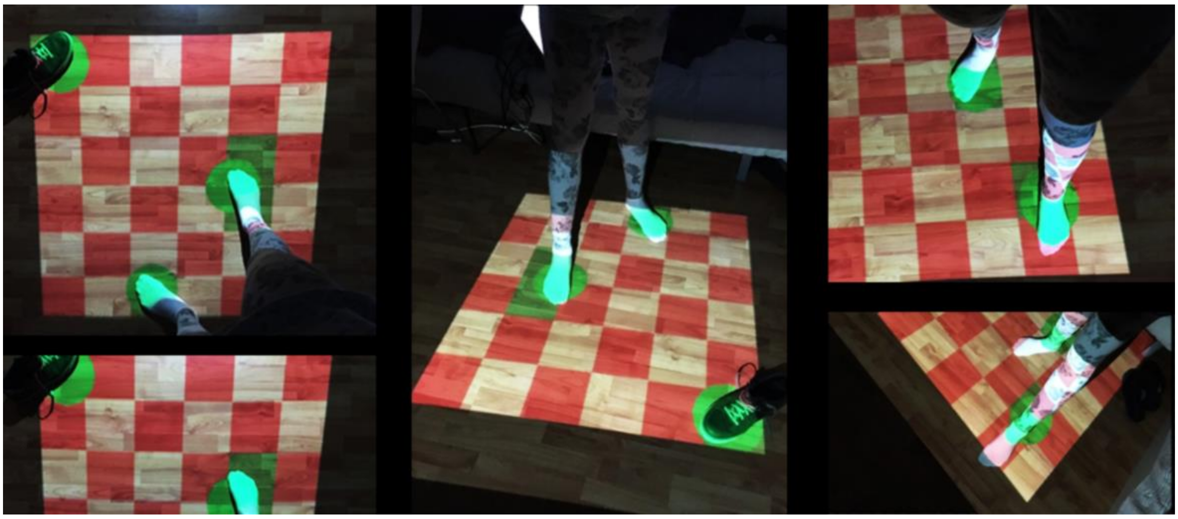


Figure 32: Complete detection system with projection

The playing area in the figure is of size 1,7x1,7m, meaning that the projected squares were of approximate dimensions of 27x27cm. But this area could be increased by putting the projector and tango device on a fixed mount point on the ceiling or mounting it on the drone.

Because the playing field was relatively small, only 2 players could be on the playing field at the same time. The player tracking would fail if there would be more players because of the excessive density of the detected points.

6 PROTOTYPE EVALUATION AND DISCUSSION

This section will focus on evaluating functional and system requirements that were specified in the chapter 4 of this thesis. After the system was built, we ran several performance tests that would measure the responsiveness of the detection. Furthermore, we analyzed the display of tilt correction and the problems that are not covered with our implementation.

6.1 TRACKING OF PLAYER'S FEET ON A GRID WITH 30X30 CELLS

Software tracks player feets with accuracy of 5-15cm, which is enough to fit the feedbacks in the correct position of the grid with 30x30 cm cells. An interaction with games of type whack the mall or dance ritual is possible, but the games may be shown as laggy because of the low refresh rate of player feedbacks.

6.2 PROVIDING QUICK FEEDBACK

The tests showed that further color image processing would be needed to obtain a stable 30 FPS input detection. The reason for this is that the point cloud detection sometimes drops the frames and the tracking of unique feedbacks is lost. By using the color tracking, we would have an additional information that the system could use to find the original state that was lost due to the noise of the feedback or a small delay in processing the point cloud. In the implementation section we already proposed the color tracking solution, however due to problems in obtaining RGB camera frame whilst depth camera was running proved to be a problem beyond our reach because it was linked to the way API is implemented.

In order to perform color tracking one would need to integrate OpenCV into Unity. This would drastically enhance our ability to perform image processing on RGB camera images. By having this available to us, we could use multiple tracking algorithms as well as facial recognition and other OpenCV features that would enable us to enhance gaming experience.

Besides introducing RGB tracking, optimization of proposed algorithm of detection is also another step one could take to improve the system. In pursuit of this goal one would first need to benchmark current algorithm in order to see where are the bottlenecks.

Detecting a player from the sides creates another problem, that cannot be solved using only one device. This problem is a shadow of detection behind the player. The system as it is currently cannot track the events that are happening behind the obstacle. To solve this, issue another depth camera would need to be introduced into the scene, so that it could register the events happening behind player backs. This could be solved by flying the drone above the players and making the top-down projection. This way a player would be identified as only 1 object on the playing field and not as two.

6.3 PROJECTION CORRECTION

The inverse trapezoidal projection correction, that responds to the device orientation is currently working only in its basic setup. The projection distortion still occurs at an extreme angles or when the projector is above the players. This is caused because of the error in the calculations or sometimes because of the gimbal lock. A more precise model of this transformation angle mapping needs to be added. Another step, that was not taken in the consideration is that the cameras on the Tango tablet are at a different angle than the Tango itself. This can also cause misalignments when using other Tango supported devices, that have its cameras mounted in the same plane as the device.

6.4 MULTIPLAYER PLATFORM

The platform detects multiple players in a single scene. But to add a support system for player feets recognition, a RGB filtering should be implemented. The players could then be tracked by identifying the color of their socks or shoes. But even this theory causes a new problem, because the player feets are being illuminated with projection of the game itself. In this case, a player with white socks can be shown as a player with yellow socks in case that projector projects a yellow object onto his feet. This is an area that would need a further research and solutions that would not be based on a color (but perhaps on pattern recognition instead).

6.5 API CALLBACKS AND VERSIONING

During the development time we continuously faces various problems with API that ranged from frequent changes to poor documentation. Because no such system exists and the Tango framework and device we used is in early stage of its development there is very little online support and limited robustness of system operation. For example, in the early stages of the prototyping we encountered a lot of problems with the random tango core crashes caused by sudden movements of the device. This issues were fixed in the later update to the Tango SDK, but that meant that a lot of the initialization code had to be rewritten to accommodate the new API calls and solve the use of deprecated methods.

6.7 OTHER NOTICEABLE ISSUES

Implementing such system showed as a difficult task with multiple unforeseen obstacles were encountered. The detection of the players is currently very sensitive to various influences from the environment and this is why the testing and the development needs to be done in the controlled environment. Here are some other issues that were observed while evaluating the system.

Hardware

While testing we noticed that the older Tango device had a lot of problems with overheating and high power consumption, meaning that the device could be used for 20 minutes before a recharge was required. However, the device that we used to develop the prototype is already 2 years old and since then, Google launched new tango devices, that are made from newer and faster processors and contain better detection cameras.

Drone platform

While developing and debugging the prototype, a fixed setup was used. The use of such a system together with a drone platform still needs to be researched and developed. Furthermore, an controller that would be able to autonomously interact with the game and keep the drone in the correct position needs to be developed and tested.

Cost of hardware

Another field that need further research and investigation is the reduction of cost of such a system. Current value of such prototype can reach up to 1000€ and to make such a device more appealing to a broader public, this price would need to drop for at least a half.

Users point of view

System as is, is currently not giving the user a fun experience because the detection itself is too slow. As mentioned before, there might be a way to increase this speed. But the game designers would still need to make sure to create games that are not too fast paced to uncover the limitations of the system.

Drift correction

In some cases, the tango localization model loses track of its position in space and in this case the floor Y coordinate that was calculated in the beginning, no longer matches the correct world model. In this case we should implement a floor detection algorithm to be run every so often. At this moment this feature is disabled because of performance hit that occurs when manipulating with point cloud buckets.

Projection shadows and inability to detect overlapped players

Because the projection is done from the side, a part of the playing field is always obscured by player. This is the reason that Tango Point cloud cannot detect overlapping players. In the same way the light cannot reach the shaded area and this causes that the playing field is not always displaying full information. This can cause that while playing, a player can miss an object, just because it was projected to appear in the spot where the shadow is casted. A solution this could be in use of 2 projectors, but creating a setup this way may show as a problem with costs and feasibility of such solution.

7 CONCLUSION AND FUTURE WORK

We designed a prototype for spatial detection of user movements in a way that it could be mounted onto a flying projecting platform so that it can be used as an outdoor exergaming platform. The selected technology being used was displayed as a good choice, but because of its novelty on the market it is being developed and updated regularly so that the game engine went through several different rewrites, because the underlying API call have been changing and to receive the best possible experience with the usage of the tablet. Doing so several different solutions were tested to detect and map the user feedbacks to the global coordinate systems.

A small prototype game was developed to showcase the working internals of this coordinate system, but further games were not developed.
The prototype showed some problems while trying to scan the environment under the direct sunlight but for usage in indoors or places that are not exposed to sun the tablet is able to detect feedbacks with no problem.

To sum up, the developed system showed promise where it could be used to further research and develop a working prototype that could be carried by the drone. In the year 2017 Google released a phone version that supports the tango platform so the whole rig is possible to become even more lightweight. Since its release in 2014, the hardware also has been upgraded and by upgrading the hardware even better performance metrics are possible.

In the end the software engine was developed to the point, that the user movement with point cloud is possible.

To effectively finish the project and deliver the set goals of this platform, the project would need to be developed in a bigger team that would focus on delivering the points mentioned above. Furthermore, large gaming companies already developed interaction detection models that could be used in such prototype.

To conclude, the work done in this thesis already consumed a lot of time, but because the scope of the project is bigger than the time that we have remaining to invest in, we will try to develop and polish the prototype in the years to come.

8 SUMMARY (SLOVENIAN)

Igralna industrija postaja vedno bolj nasičena s številnimi zvrstmi iger. To je posledica nedavne rasti kakovostnih »Game Enginov«, ki so na voljo in podpirajo več platform. Igralniška podjetja zato vedno več svoje energije posvečajo k inovaciji novih pristopov k igranju iger.

Računalniške igre se dandanes večinoma igrajo sede. To predstavlja problem, saj v današnji družbi preživimo veliko časa v sedečem položaju (vožnja, delo, prosti čas, prehrana). Vse to lahko predstavlja grožnjo našemu zdravju, saj povečuje zdravstvena tveganja kot so težave s hrbtenico, diabetes ali kardiovaskularne težave.

Ena možnost za spodbujanje ljudi, da živijo bolj aktivno življenje je ustvarjanje igre, ki jih je moč igrati s premikanjem po prostoru. Takšne računalniške igre lahko razdelimo v tri kategorije, in sicer: lokacijske igre, igre s sledenjem gibanja in projekcijske igre.
Najnovejša tehnologija, ki je bila uvedena v periferne sisteme vključuje projektor, ki grafične elemente projecira v fizično okolje. Ti igralni elementi tako postanejo interaktivni, saj s sledenjem gibanja igralcev lahko reagirajo na njihove gibe.

Takšen pristop igralcem omogoča, da se osredotočijo na igro, elemente le-te v okolju in morda tudi druge igralce in ne potrebujejo toliko razmišljati o samem upravljanju iger. Uporaba projektorjev lahko služi tudi kot poživitev vadbe, saj lahko uporabnikom ponudi novo, nikoli prej izkušeno izkušnjo. Eden takšnih primerov je prototip za plezalne stene, kjer se mora igralec ob plezanju izogibati še padajočemu kamenju. S to gamifikacijo se sama težavnost plezanja poveča in tako prispeva k veliko večji nagradi zadovoljstva, kadar je vrh dosežen.

Problem lokacijskih iger je predvsem ta, da smo za pravilno izkušnjo same igre primorani uporabljati mobilne telefone, na katerih je prikazano veliko informacij o sami igri (navodila, namigi, slike, pozivi za akcije). To lahko povzroči, da se igralec preveč odtuji od realnega sveta in se lahko ob slepem sledenju navodil izpostavi nevarnosti. V kontekstu iger s programi za sledenje igralcu, pa je glavna težava potreba po infrastrukturi, ki omogoči igro na novih lokacijah.

V iskanju novih tehnologij in reševanja zgoraj omenjenih težav smo v okviru magistrskega dela predlagali rešitev o novi platformi, ki je neodvisna od lokacije – rešuje problem omejevanja in poveča mobilnost platforme. Ponuja znane igre, ki se lahko igrajo na ulicah z uporabo krede. V načrtu imamo sistem, ki bo lahko sledil igralcem in se odzival na njihove akcije, hkrati pa bo lahko zagotovil pomembne povratne informacije, ki bi bile uporabne pri nadaljnjem razvoju iger za igranje na ulicah.

Prizadevamo si za izgradnjo igralne platforme, ki jo imenujemo StreetGamez in bo lahko letela na lokacijo igre in opravila tri ključne naloge, kot so: projektiranje grafične igre na poljubne površine, omogočanje interakcije znotraj projicirane površine s sledenjem gibanja igralcev in omogočanje interakcije preko mobilnih naprav igralcev (klic platforme na želeno lokacijo, izbiro iger in tako naprej).

Oblikovanje in izdelava prototipa StreetGamez bo služila kot študija izvedljivosti, ki bo pokazala, ali je takšen sistem mogoče razviti in raziskati načine, kako se lahko prenosni projektorji in sistemi naprednega prostorskega zaznavanja uporabljajo za ustvarjanje igralne platforme. Z izvajanjem in raziskovanjem interakcije bomo lahko dobili vpogled v to, kako igralci komunicirajo s takšnimi igralnimi sistemi.
Minimalni niz funkcionalnih zahtev, ki smo jih postavili sami je bil zasnovati in zgraditi sistem, ki bo sposoben:

Sledenje poteka na prikazani detekcijski mreži, kjer vsaka mrežna enota meri 30x30 centimetrov. Taksna mreža omogoča veliko možnosti pri razvoju iger tipa "plesni koraki" ali pa "refleksni gibi" (Udari krta, izogibanje letečim delcem).

Sistem mora doseči interaktivnost, ki omogoča hitre povratne informacije hkrati pa ohranja pravilno odkritje v primeru hitrih premikov. To je še posebej pomembno za nas, ker naj bi naš sistem postal platforma za vadbene igre. Ključnega pomena je hitra interakcija z gibi.
Projecirano površino je potrebno vedno preslikati kot pravokotnik, tudi v primerih, ko projekcijska platforma ni pravokotna na igralno polje. S tem se želimo izogniti letenju nad igralci, saj se tako lahko izognemo poškodbam, ki lahko nastanejo ob nedelovanju sistema.
Platforma bo lahko podpirala način igranja več igralcev, saj ziva konkurenca motivira igralce, da aktivneje sodelujejo v igri, kar je zelo pomemben element v kontekstu vadbene igre.

Predlagamo sistem, ki je sestavljen iz naprave Tango, ki jo nameravamo uporabiti kot igralni mehanizem za odkrivanje gibanja igralca in ustvarjanje računalniške grafike. Za projekcijo načrtujemo uporabo mini projektorja Asus S3 (velikosti 15x15x3 cm), ki lahko proizvede svetlost 200 lumnov. Za zagotovitev stabilne projekcije nameravamo namestiti obe napravi na gimbalno konstrukcijo.

V okviru magistrskega dela je bila implementirana programska oprema, ki zajema signale iz Tango senzorjev, jih obdela in projecira na igralno površino. Samo razlago programske rešitve smo razdelili na dva dela, in sicer zaznava nog igralcev s pomočjo Tango točkovnega oblaka in transformacija zaznanih signalov na pravilno igralno površino ter projekcija te površine na tla pod pravilnim kotom in inverzno transformacijo projekcije za ohranitev pravokotnika igralne površine.

Končna rešitev omogoča zaznavo igralca s odzivnim časom 10-15 FPS, kar za namene aktivne interakcije ni dovolj. V nalogi predlagamo tudi način kako lahko ta algoritem performančno izboljšamo, saj za samo zaznavo poleg točkovnega oblaka lahko uporabljamo tudi sliko iz kamere, ki pa jo Tango naprava zajema s 60 FPS**.**

Za uspešno končanje projekta in dosežek zastavljenih ciljev te platforme smo ocenili, da bi bilo za potrebe razvoja minimalnega produkta potrebna večja razvojna ekipa, ki bi se lahko osredotočila na implementacijo in raziskovanje posameznega področja. Poleg tega so v času razvoja ostala večja podjetja že razvila svoje modele interakcije, ki bi jih lahko uporabili v našem prototipu.

Končna ugotovitev tega dela je, da je bilo v delo vloženo ogromno časa, ampak je obseg samega projekta veliko večji kot je količina preostalega časa ki ga imamo na razpolago. Zato smo se odločili da bomo prototip še naprej razvijali in dodelovali v prihodnjih letih.

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