CHAPTER 1

Introduction

1.1 Problem statement

Many children suffer from different types of physical impairments, which significantly lowers their quality of everyday life. Cerebral palsy is most common children movement disorder, affecting on average 1.5 to 4 per 1000 infants [10].

Cerebral palsy (CP) is a name used to describe a group of neurological disorders that affects children and has negative impact on muscle coordination and body movement [6]. It may cause symptoms like an ataxia [1], limb weakness, difficulties swallowing, speaking, making precise movements and much more. Those symptoms may vary in type and severity among individuals, depending on which parts of brain have been affected by the disease.

CP is not curable, but rehabilitation, medication and surgeries can greatly improve both the quality of life and motor skills of the affected children. It is important to start the treatment as early as possible, so the children can enjoy nearly-normal life as adults.

The treatment, depending on symptoms and severity of the CP may consist of classic physical therapy (most important), occupational therapy, recreational therapy (improves physical and cognitive skills), speech and language therapy and more, depending on child needs. It may be combined with oral medication, used to relax stiff, contracted, or overactive muscles. Surgeries may be performed in order to help with orthopedic problems or to cut nerves to reduce chronic pain and severe spasticity.

1.2 Motivation

Different types of physical therapy are important part of supporting treatments. For some time already [36], modern healthcare started including *serious games*. *Serious game* is a name for a broad genre of video games that are designed for purpose other than pure entertainment, e.g. learning, rehabilitation, information spreading. In medicine, they are used as a part of educational process [13], mental therapies [1, 49], or rehabilitation [31, 50].

Results of such experiments are promising - subjects are more willing to participate in exercises and also learn faster when enjoying the game. Enjoyment is an important

[1] *ataxia* - the loss of full control of bodily movements.

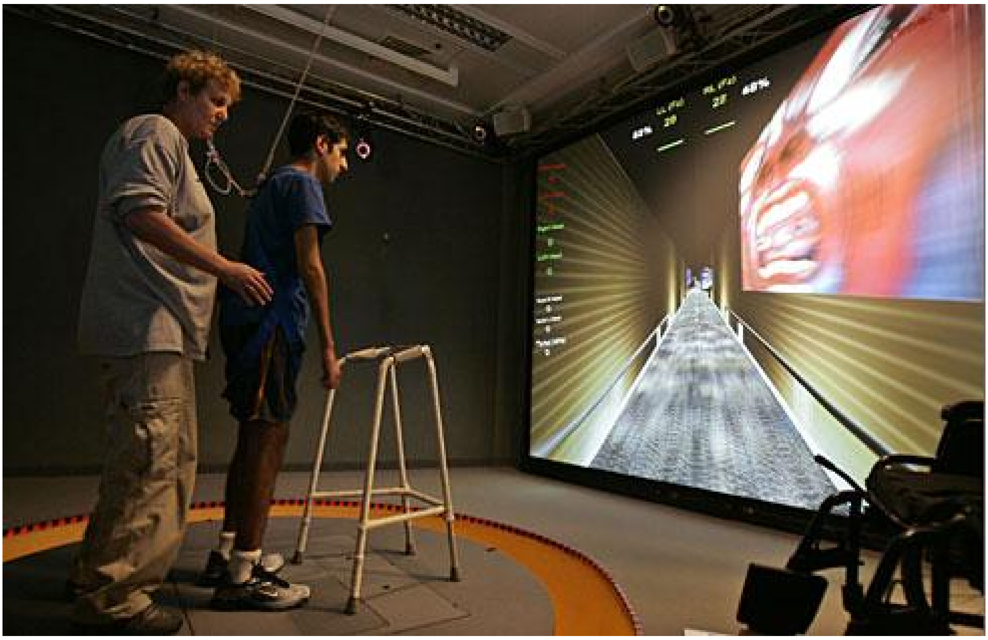

Figure 1.1: Shalev Malki - disabled patient in Israel, using a virtual reality system to control a video game, that forces him to use atrophied muscles. From Chaim Sheba Medical Center, Tel Hashomer, 2006.

factor in children rehabilitation, who often lack motivation or perseverance to perform exercise every day.

This seems to lead to the conclusion, that serious game can be a great solution for children with cerebral palsy, who require often repeated physical rehabilitation. Creating appropriate software is not an easy problem, but greater challenge is finding appropriate control mechanism. Unfortunately, casual computer controllers - mouse, keyboard, pad - are only useful when the game focus on training cognitive skills, not physical one. The controller used in physical rehabilitation should encourage and allow movements similar to natural and not require pushing any buttons. Expensive dedicated devices could be used (e.g. Geomagic Touch[12] - 1000$), but for a lot of parents that's a great expense, that cannot be utilized in any other way than rehabilitation. What is important, a lot of commercial, affordable motion trackers for games and everyday computer use has been introduced in last years. Although they usually show smaller precision then dedicated devices, their availability, price and possibility of using for different applications draws a strong attention to such solution.

Motion tracking is a hot topic in modern gaming. The world hype started with

Figure 1.2: Geomagic Touch - haptic device for dedicated use with modelling and medical software..

Microsoft Kinect [25] in 2010, which allowed to detected overall body movements with webcam-style technology, the industry presented more and more products with similar functionalities. Kinect was followed by PlayStation Move[40] and Wii[29], both using wand-shaped controllers for detailed motion tracking of arm movements.

Growing crowdfunding popularity allowed smaller developers to take part in a race - that's how Sixense TrueMotion(now Razer Hydra)[39] was funded. Other companies choose a startup path, with getting founding from large capitals, resulting in Thalmic Labs' Myo armband [43] or Leap Motion[20] from the company of the same name.

Using motion-tracking device could help in designing serious games for the rehabilitation, reducing the need for supervision from the therapists and also increasing the naturalness of the movements performed.

1.3 Related work

A number of similar studies has been already performed, testing the possibility to enrich children therapy with games using different type of motion controllers:

Li et al. in their article [22] describe in details a process and results of designing a tabletop game for physical rehabilitation of children with CP. Important part of their study is that they worked closely with both children and therapists. Firstly, together with the therapists they identified all movements used in the rehabilitation (e.g. wrist extension, finger abduction). Then an analogue prototype was built and presented to children. Based on received feedback, the final version was implemented and tested, yielding promising results, both in opinions of therapist and children.

During the design phase, an important problem was mentioned - compensation movements performed by child to avoid doing the desired (by therapist) ones. It is important to constrain (in hardware and software way) the possibility of such 'cheating'.

Peper et al. [33] presented an article about design and testing of a games for bimanual training, using new feedback method. All games were using a dedicated controller and visual (Lissajous) feedback. Three different tests were performed four times during training period, but no significant results on a group level were found.

Bryanton et al. [5] implemented and tested a VR game for ankle rehabilitation (for children with CP). The aim of this study was to check if it is possible to create a game that allows children to both train at home and strongly encourage them to do so. Only one training session took place, where both conventional and VR exercises were performed. Feedback was gathered from children, therapists and parents, who were observing the game. It was observed that children were much more excited and motivated to perform game-based exercise than normal one and seemed to be motivated to do this at home as well. Also, although number of repetition was greater in conventional exercises, range of the movement and a time of hold in maximal position was significantly larger in VR exercise, which is a encouraging result.

Luna-Olivia et al. [23] performed the study, where they tested influence of virtual reality games controlled by low cost console on children with cerebral palsy. They used already existing games to test the theory of positive impact of playing virtual reality games on children psychomotor status. The results showed statistically significant improvement after training period, that remain even after stopping this additional exercise.

1.4 Project outline

As mentioned, recently a lot of new motion-tracking devices entered the market. Not all of them are equally popular, but some of them may be actually more successful and cheaper solutions for creating eye-hand coordination games. First, a detailed CP study should be made, with focus on which age group and CP severity level can be the best recipient of the application. Then, using factors and parameters obtained from this part, the analysis of available hardware (controllers) and software (eye and hand movement detection from video stream) will be performed to find the optimal solution. Later, one or more prototype will be prepared, using this solutions and tested on children. The results will be evaluated to check if the analysis assumptions were correct or not.

CHAPTER 2

Requirements analysis

The first step of designing the game and picking the right controller is to establish what are the expected requirements and constrains. Part will be connected to the cerebral palsy and the rehabilitation process, part will focus on other projects' experience and general accessible games guidelines and finally some of them will be implementation-related requirements.

2.1 Cerebral Palsy (based on (6, 10, 46, 24, 7))

Important part of analysing the possible solutions is to have a well established understanding of the cerebral palsy disorder: what are the symptoms and different types, how to diagnose and treat it. The conclusions from this chapter will serve as a requirements and factors for further hardware analysis and design, therefore each section will be summed up with conclusions about the section's influence on these problems.

2.1.1 Diagnosing process

The diagnosis is based on observation of the child development in first years of its life. Growing infant has a lot of milestones connected to its development in different spheres: social communication, cognitive, physical. Checking if a child meets the milestones suitable for its age is the most important part of CP diagnosis and usually results in detecting the disorder in first 2 years of its life. However, if the CP is not severe, often the symptoms may not be properly classified until the age of 4,5, up to even 10, which is also caused by the fact, that CP is not progressive - which means it doesn't get worse with the time.

Once the particular child development has been classified as somehow delayed, further diagnostic, neuroimaging tools are used, i.e. ultrasounds, computed tomography, MRI or EEG. It helps to exclude other disorders, that gives symptoms similar to CP.

Conclude with

Children are diagnosed usually in first years of their lives, so it is possibles to start the therapy very fast. Therefore, diagnostic process has no significant influence on game requirements or target group.

2.1.2 Different forms and symptoms

The different forms depend of range, type and localisation of child's movements disorder:

- *spastic* - most common type, resulting in stiff muscles and awkward movement.
- *dyskinetic* - the symptoms of this type are slow and uncontrollable writhing or jerky movements of the limbs. It may also cause children grimace, drool, have troubles in straight sitting or walking, even physical ability to hear, speak or control the breathing may be damaged.
- *ataxic* - detrimental for balance and depth perception, influencing coordination and walking skills. Results in difficulties with precise or voluntary movements.
- *mixed* - when symptoms of the child comes from a different groups, e.g. both spastic and ataxic problems.

Depending on how much of the body is affected, also following subcategories can be distinguished for plegia (paralysis) and paresis (weakness of the muscles):

- *hemi* - when half of the body is affected, i.e. whole left side (arm, hand, leg).
- *di* - when disorder mostly influence leg muscles
- *quadri* - most severe form, when all four limbs are affected. Usually caused by widespread brain damage or malformation, typically results also in intellectual disability and seizures.

There are other conditions, that may be associated with CP, including:

- *mental impairment* - affects 30%-50%
- *seisures* - up to 50%
- *delayed growth and development* - affects children with moderate to severe CP
- *spinal deformities*

Concluded with

Although the game is not expected to be intellectually demanding, it should also not be dedicated to children with severe intellectual disability. Also, children with seizures should not be a part of the target group, as flashing game screens may cause a seizure attack. Because the game may be controlled with hand and eye movement tracking devices, some sight conditions like strabismus (crossed-eyes) or severe arm impairments are symptoms that exclude the child from the target group.

2.1.3 Treatment

As it was already described in chapter 1, CP is incurable, non progressive disease and all the treatment is focused on symptoms. Following type of therapies are applied:

- *physical therapy* - the most important kind of therapy, focusing on improving functional mobility, strengthen the muscles and preventing bent joints.
- *occupational therapy* - therapy that aims to help child live a normal life, aiming daily activities in home, school, out in public or at work. This therapy not only improves physical skills, strength or coordination, but also tries to help with difficulties with problem solving, decision making and similar.
- *recreational therapy* - by encouraging participation in recreational activities (e.g. art or cultural), this kind of therapy helps to expand physical and cognitive skills, resulting in raise in child's self-esteem, speech and emotional well-being.
- *speech and language therapy*
- *therapy with music, play, horses, massages*

Also, alternative medicine slowly becomes supportive part of treatment process with therapies like acupuncture or chiropractic care.

Medicines are usually used in order relax tight muscles and reduce muscle spasms. There may be additional drugs for treatments of seizures, if they appear. It is important to mention, that antispasmodics (muscle relaxants) are not good for still growing children and may result in child being lethargic, loosing concentration and having problems at school. It is only recommended to use them if the benefits can overcome side effects.

When CP is in a severe form, the surgery may be needed to correct various orthopedic (e.g. scoliosis, tendon disorders) and mobility (significant muscle tightness) problems. The physical therapy and medication are used in order to either postpone the surgery to older age or even totally avoid it.

Concluded with

It is important to include in a game not only the elements of physical, but also recreational therapy. Developing cognitive skills of child with CP may be as important as the physical part of rehabilitation.

2.1.4 Summary

To sum up the analysis performed in this section, following information were obtained during it:

Target group:

- *severity level* - light to mild, so that the person is physically able to control the device
- *disqualifying symptoms* - strabismus, mild and severe intellectual disability
- *expected age* - from 6 to 12 years old, because:
  - therapy should be started as early as possible, but also late enough so the child is properly diagnosed and able to control the game.
  - increasing the age range would cause problems with game design, because game expectations are different for small children and teens
  - the largest drop-out in the therapy is observed among 8-10 year old children

Game design:

- game should focus on both psychical and cognitive aspect
- game should be adjusted to age of participants
- game controllers reactivity should be adjusted to physical and mental abilities of the subjects

2.2 Similar projects and accessible games guidelines

This chapter is a review of projects and researches that has been focusing on creating and/or testing a games for children with motor disabilities. This review aims to find new hardware requirements, clues for game design or overall project guidelines, based on other solutions' experience and general guidelines for the accessible games development. The analysis will focus not only on the outcome of the project and the process of game design, but also on methodologies and tools used for everything that plays important role in developing meaningful results from such study (i.e. evaluating tools or testing session protocols).

2.2.1 Classification systems

One of the main problem in comparing different solutions implemented for rehabilitation purposes is the uses of various clinical scales and scores [4]. In literature, most often following systems are used:

- *GMFCS (Gross Motor Function Classification System) score* - very popular score used to evaluate gross motor skills, like sitting and walking. The system categorize the skills into 5 different levels. For example, level one is a person who can run, jamp, walk outside and climb the stairs without any help, but has decreased balance, speed and coordination. Level 3 usually requires a manual wheelchair or assistive mobility devices. Level 5 is an impairment in all areas of motor function and cannot sit, stand or walk independently - even with adaptive equipment[14].

- *GMFM* (Gross Motor Function Measure) - similar to GMFCS, but more complex, containing (depending on version) up to 83 individual tasks that have to be evaluated to get the final score. Also, this system assumes that the result may change with age and progress of therapy. It is rather not possible in GMFCS (for children with CP), which is much more coarse evaluation.

- *MACS score* (Manual Ability Classification System) - 5-level score similar to GMFCS, but dedicated to ability to handle objects. For example, level 4 means a child can handle easily only a few objects, and always requires help from others, e.g. with preparation.

- *AMPS* (Assessment of Motor and Process Skills) - AMPS is a popular score used to evaluate the quality of performance of personal or instrumental activities of daily living [2]. It consists of over 120 tasks, testing motor, process and social interaction skills[2].

- *10MWT* (10 Meter Walk Test) - simple test to assess the walking speed on a short distance, usually 6, 8, 10 or 12 meters. Used to track the progress of physical rehabilitation[37].

2.2.1.1 Concluded with

There is a variety of tests developed for people with cerebral palsy, and most of them is relevant for this project. The most interesting one is probably MACS, because of hand-focused nature of this project. The final choice will probably depend on therapists decisions, target tests groups and chosen test protocols.

2.2.2 Initial game requirements

Gathering game requirements is an important part of developing the medical game. Each game needs to have specified aim, i.e. what kind of outcome is expected from playing it. It should be clearly and unambiguously defined to guide during making design decisions.

In order to gather game requirements, knowledge of the standard therapy method is a key factor. In [13] and [22] researches spend a lot of time consulting the therapists to acquire knowledge about what movements should be translated into the game to increase the chance of therapeutic effect. Talks with the physicians and children were also important to discover and restrict number of compensation movements - game should not only support controlling with proper movements, but also refuse accepting the ’cheating’ moves (e.g. not accepting upper body movement when arm extension is expected).

2.2.2.1 Concluded with

Consulting physicians about details of the therapy that is about to be implemented in the game and observations of therapy examples and later trials with children are necessary in order to create game with truly therapeutic usage.

2.2.3 Accessible games guidelines

Different organizations developed guidelines for accessibility, usually similar, focusing on following areas of skill: motor, cognitive, vision, hearing and sometimes speech. Examples can be BBC guidelines [3] or widely used Game Accessibility Guidelines [11]. They contain many suggestions about controlling schemas, graphic interface structure and look, which are highly relevant also for developing games for children with CP.

Because the topic of serious games in CP rehabilitation exists in the literature for more than 10 years now, researches have developed specific guidelines for designing such games. In [16] Hernandez et al. gathered guidelines from many different studies, designed by experts in game design and accessibility standard in order to create a unified set of suggestions for creating games for people with motor disabilities. They are as follow:

- *avoid fast pace* - game shouldn't be too fast, so that player has appropriate time for reaction
- *do not require precise timing* - also mentioned in [3, 11]. Game should not require precise movement correlated with timing.
- *provide a simple control scheme* - also mentioned in [3, 11]. Number of controls can't be too large, up to the point to reducing controlling only to one key.
- *do not require multiple simultaneous actions* - it should not be required to use more than one control at a time or over the time
- *avoid repeated inputs (button mashing)* - Game should not require fast and consecutive pressing of control
- *automate the player's input* - this approach is helpful in reducing the number of buttons and simplifying the controlling by anticipating player's reactions, e.g. by using "walk" command for "jump" when it is required.

During their research, that was focus on creating action-based game for children with CP, Hernandez et al. discovered that although action-based games are in conflict with most of the rules described above it is still possible to create such game for motor impaired children by reformulating the guidelines and following these recommendations in design:

- *simplify level geometry* - reduces the need for careful timing

- *simplify level flow* - makes game more friendly to children with visual-spatial reasoning problems (around 83% of CP children [19])
- *reduce consequences of errors* - allows introducing some precise and rapid actions by not punishing the player hard for failing them
- *limit available actions* - reduces the control scheme and number of decisions player needs to make
- *remove the need for precise positioning and timing* - reduces the demands on manual ability and visual-motor integration
- *make the game state stable* - gameplay requires less attention and less visual-spatial reasoning skills
- *balance for effort* - game adjusts the rewards for player's gross motor skills based on effort and not absolute values

2.2.3.1 Concluded with

As it is described, guidelines for creating different kind of games for children with motor impairment is well-known topic in the literature and recommendation described in last section, together with input from therapist should be the main base for game development.

2.2.4 Development-related constains

Although some of the projects use games developed for healthy children [23], most of the researches aims to develop own games. There is a great variety of tools that can be used for developing and fast prototyping, depending on what platform the game is developed for. It is possible to implement the games from the scratch, using graphic libraries like OpenGL or DirectX, but for the purpose of research it's much better idea to use high-level frameworks, that although may trade in area of performance and customization, they also allow for much more rapid prototyping.

Unfortunately, most of the articles do not mention what kind of frameworks they used for developing the games. Those are some of the mentioned tools used in serious games developed for CP rehabilitation:

- *Unity3D [45]* - used in [16]. Unity3D is well-known development platform for creating games. It is also recognized for it's support for serious game developers [17].
- *Web-based solutions* - some of the projects (e.g. [35]) decide to implement their games as a websites. This cross-platform solutions highly increases the access to the application, but also requires some trade-offs, mostly optimazation-wise.

- *none game-related technologies*, e.g. d-flow ([33]). Some of the technologies used in the projects are not part of usual game development pipeline, but are easier to use with non-standard controllers.

- to be continued?

2.2.4.1 Concluded with

Unity3D seems to be the best solution for fast prototyping, because of low entry level and high possibility of customization.

2.2.5 Devices

The devices used for motion tracking in projects can be divided into three categories: custom camera-based technologies ([5]), custom motion tracking devices([5, 33, 16]) and commercial motion tracking devices ([15, 35, 23, 28]). It is important to mention, that ”motion tracking” not only applies to detecting based on the movement seen in video stream, but also on the input coming from physical machines, like bicycle or devices that you keep in your hand or on your body while moving.

2.2.5.1 Concluded with

Camera-based software is an interesting solution - unfortunately, to get promising results, it requires constant work on quality of the motion tracking. Custom devices have problems with gaining popularity, because there is no established manufacture process and each device is more or less hand-made for individual user requests. Using commercially available devices allows to move the problem of support to third parties and guarantees easy access to devices in most countries. That is why goal of this project is above all to find the best commercial device and not try to develop own solution.

2.2.6 Testing protocols

Depending of the time availability and aims of the research, some of the projects only perform one or two test sessions with children, while others have few weeks or months long testing periods, usually starting by measuring child progress during normal therapy, followed by normal therapy supported with playing game at home and ended with normal therapy again, to check if in the end of this period the results from playing the game persist.

2.2.6.1 Concluded with

Because of short project duration, the testing will probably only include one-time sessions. The game is expected to be enjoyable by child and considered to be good rehabilitation tool for therapist, which opinions can be obtained during single session.

CHAPTER 3

Analysis of the hardware

Based on the conclusions from the previous chapter, it is now possible to decide what features are expected from the controllers and what is their importance.

3.1 Prioritization of the features

The chosen device is expected to have a defined set of features - but not all of them have equal priority. MoSCoW analysis will be used to determine which features are most important[27]. It is usually used in deciding on priorities of requirements with stakeholders, but can be applied to any requirements-related problem. It segregates features in four different groups:

- *must have* - features, that are critical for success of the project
- *should have* - features, that are usually as important as critical, but not having them won't fail the project
- *could have* - features, that are desirable and usually can be easily obtained
- *would like, but won't get* - features that are least critical and not in any way decisive

Now it is possible to group the requirements acquired from previous chapter as following:

- Must have
  - detailed gesture recognition supported out-of-the-box
  - price not bigger than 300$
  - acceptable documentation and any kind of support for Unity
  - high comfort of usage in means of wearing/handling and range
  - be available for customer use

  - excellent precision
- Should have
  - excellent documentation
  - support for Unity provided by the manufacturer
  - worldwide availability
  - community significant in size
  - acceptable precision
- Could have
  - physical feedback
  - price lower than 200$
- Won't have

3.2 Devices

The devices for evaluation where picked based on their accessibility for testing. Devices listed above are all available for commercial use and have prices lower than 300$ per piece. Following devices will be evaluated:

3.2.1 Wii Remote - based on (29, 48, 30)

Figure 3.1: Wii Remote by Nintendo.

The Wii Remote (Wiimote) device is absolute pioneer in the motion tracking for gaming. It was released in 2006 by Nintendo for their new Wii Console, but the concept was invented as early as in 2001 by a company commissioned by Nintendo.

The important part of Wii Remote set in Sensor Bar, containing ten infrared LEDs, five next to each end, with the outermost lights pointing a little bit more to the outside, and the inner ones - to the inside. The Wiimote acts like a remote controller, as the motion detection requires the controller to point at Sensor Bar. The Wii Remote contains optical sensor, that using the position of two source of lights (left and right edge) is able to calculate the distance and position and send it to console via Bluetooth. The device optimal range is up to 5 meters from the Sensor Bar. It also includes accelerometer, as well as rumble and audio feedback. The later versions (Wii Remote Plus, to which Wii Remote can be upgraded) also contains gyroscope. The controller has eight buttons and control pad. Important part of the design is also a wrist strap, allowing to lock the device on a hand, stopping from accidental throwing during quick, energetic movements. Because of the design, it does not offer gesture recognition.

The documentation and SDK is available upon registration and acceptance from the Nintendo, so it was not possible to estimate the quality of it. There is no official plugin for Unity from Nintendo and those delivered by community are of poor quality.

The device is available worldwide by both online and stationary shops.

3.2.2 PlayStation Move - based on (40, 34)

PlayStation Move (with its important component, PlayStation Eye or PlayStation Camera) is a product of Sony Computer Entertainment and was designed for the PlayStation 3 as an answer to Nintendo Wii Remote in 2009. Similar in look, as can be seen in figure 3.2, PlayStation Move is a wand-like controller communicating through a Bluetooth 2.0, but the most important part of its design is an orb on the top of it, able to light up in different colors. The color is picked by the software to provide best distinction from the rest of scene. Known size of light allows the camera to precisely evaluate the distance and provide the position in all three dimensions. The simple sphere shape-based calculation allows high precision and accuracy.

Figure 3.2: Play Station Move (left) and Play Station Eye (right) by Sony Computer Entertainment.

PlayStation Move also contains accelerometer, gyroscope and even terrestrial magnetic field sensor to correct against drift caused by inertial sensors. Internal temperature sensor was also used in order to correct other sensor readings based on temperature effects. The sensors allows to estimate players position even if the orb is not visible to camera at the moment. The wand also has 8 buttons. It provides vibration feedback and visual one - from the orb.

Sony offers acceptable documentation and explicit support for Unity. However, obviously they do not provide any gesture recognition. The developer has access to buttons, position data and raw data.

The price is very low, while the product is available worldwide, also in stationary shops.

3.2.3 Microsoft Kinect - based on (25, 18, 26)

Figure 3.3: Microsoft Kinect for XBox One.

The Microsoft Kinect is a series of motion tracking products for Microsoft Xbox consoles. The first Kinect was released in 2010, and two years later its second version for Xbox One entered the market.

The device uses significantly different technology than its main competitors - Wii Remote and PlayStation Move. As shown in figure 3.3, Kinect do not have any controllers - it's camera based solution, where motion tracking is fully performed by only processing the image of a moving person, who does wear any type of calibration devices. The laters Kinect sensor contains 1080p camera, infrared emitter, infrared depth sensor, accelerometer and microphones array. Those features allows motion recognition in a range 0.5 to 4.5 meters from the Kinect with 4-centimetre cube precision and voice recognition. The sensor detects movement of the whole body with recognizing up to 20 joints.

Microsoft Kinect has an excellent documentation, explicit support for Unity and SDKs for C++, C# and Visual Basic .Net. It has an acceptable price and is available worldwide in both online and stationary shops.

As for now, Microsoft Kinect do not provide gesture recognition, but there are promising official demos showing the software upgrade providing such features. Unfortunately, it is not expected to enter the market for the next few years.

3.2.4 Creative Senz3D - based on (8, 9, 38)

Creative Senz3D is a product released by Creative Technologies Ltd. in 2013. It is the predecessor of Intel RealSense camera and as though, is not longer actively supported.

Senz3D contains laser for scene illumination, depth sensor for gesture recognition, HD camera for video capturing and dual array microphones. It allows detecting hand and head gestures as well as face recognition and to some extent

Figure 3.4: Creative Senz3D.

also voice recognition. The preferred range is 20 to 50 cm.

Because the project is discontinued, it is extremely hard to obtain the SDK via official ways. It means that there is also no actual documentation. There is no support for Unity, but the OpenCV library, popular solution for image recognitions, has a wrapper for it.

Device has an acceptable price and is available through few online sellers.

3.2.5 Myo - based on (43, 42, 44)

Myo is an armband, released by Thalmic Labs at the beginning of 2015, with developer access starting in 2014. It achieves detailed gesture recognition using unique technology in this industry, which is detecting the electrical impulses sent to the muscles (electromyography - EMG).

Figure 3.5: Myo armband by Thalmic Labs.

The device contains 8 EMG sensors, accelerometer, gyroscope, magnetometer and provides feedback with vibration. It communicates with computer through Bluetooth 4.0 LE.

It has excellent documentation and explicit Unity support. It offers not only raw data from the sensors, but is also able to detect five unique gestures, like fist, waving or tapping. It has a little higher than average price and is available worldwide by shimpent and in some shops in North America.

3.2.6 Leap Motion - based on (20, 47, 21)

Figure 3.6: Leap Motion by Leap Motion Inc.

Leap Motion is a camera-based device dedicated to hand, or rather palm movement tracking. Although the idea behind the technology was first developed in 2008, the product was released to developers in 2012 and entered the market in 2013. However, the device did not sell as well as expected. In 2014 the company released second version of software for developers and started combining its product with VR, which is the main commercial usage up to day.

The device is a small box, as shown in fig. 3.6. It contains two infrared cameras and three infrared LEDs. The field of view is a hemisphere, with range up to 1 m.

Leap Motion has an excellent documentation and a significant developers community, involved in many projects, also medical ones. It has an explicit support for Unity and SDK supporting most of popular modern languages (JS, C#, C++, Java, Python, Objective-C). The support for Unity also includes examples of how to connect it with Oculus Rift. The data send through SDK is the position of detected joints, but also detection of simple gestures like tapping, swiping.

The device has a low price and is available worldwide, not only with shipment from the producer, but also in stationary and online shops across four continents.

3.2.7 Sphero 2.0 - based on (41, 32)

The Sphero is a spherical robot toy, which prototype was first shown in 2010. The version 2.0 was released in 2013 by Orbotix (now Sphero). The device is a sealed ball, containing gyroscope, accelerometer, electric motor allowing speed to up 7.3 km/h, LEDs and and polycarbonate shell.

Figure 3.7: Sphero 2.0 by Sphero.

Sphero is controlled with app through Bluetooth. The App allows moving the ball around, changing its color and shaking it. Sphero can be used as a motion detector using the gyroscope and accelerometer.

It can be used with any device that can connect to it through Bluetooth. It has excellent documentation and support for Unity, however only for mobiles. It has an average price and is available worldwide through online shopping. It does not offer gesture recognition.

3.3 Evaluation

The evaluation will have following criteria, grouped from MoSCoW analysis:

- Critical requirements:
  - precision: high/average/bad
  - range: good/bad/not applicable
  - gesture recognition: have/do not have

- Important requirements:
  - price: low (<75$), average (75-150$), high (>150$)
  - documentation: good, average, bad, available upon registration
  - support for Unity: have, have partial, do not have
  - availability: great (both online and stationary shops around the world), good (worldwide shipment and some stationy shops), average (worldwide shipment), bad (shipment to only few countries).
  - community: good (>1000 question on Stack Overflow and own Dev Forum), average (1000-500 questions on Stack Overflow and own Dev Forum), bad (<500 questions on Stack Overflow or own Dev Forum).
- Useful features:
  - feedback: have/do not have

The summary of the analysis is described in tables 3.1 and 3.2.

3.3.1 Comments

Although most of the criteria has been explained in previous section, some of the experimentally evaluated ones needs further explanations.

3.3.1.1 Precision

Precision was evaluated by testing all of the devices and observing to factors - delay and accuracy of movement. The reason, why Senz3D, Leap Motion and Sphero 2.0 has average grade is that the former has too high detection rate and cannot always detect hands and the latter have low accuracy.

3.3.1.2 Range

The Leap Motion is the only device who received "bad" range evaluation. It is caused by the fact, that while playing with the device it is easy to, instead of reaching for an object, remove the hand from the device's field of view. The FOV is small and except for small gestures, no broader movements cannot be made.

3.4 Conclusions

The devices PS Move and Myo have similar, very high number of positively evaluated factors. The final choice for the device will be Myo, because built-in gesture recognition have higher priority than price lower than 200$.

Table 3.1: The summary of analysis of the devices, part 1.

Criterion:	Wii Remote	PS Move	Microsoft Kinect
precision	✓high	✓high	✓high
range	✓good	✓good	✓good
gesture recognition	×don't have	×don't have	×don't have
price	✓low	✓low	◇average
documentation	◇after registration	◇average	✓good
support for Unity	×don't have	✓have	✓have
availability	✓great	✓great	✓great
community	◇average	✓good	✓good
feedback	✓vibration & audio	✓vibration	×none

Table 3.2: The summary of analysis of the devices, part 2.

Criterion:	Senz3D	Myo	Leap Motion	Sphero 2.0
precision	◇average	✓high	◇average	◇average
range	✓good	N/A	×bad	✓good
gesture recognition	×don't have	✓have	✓have	×don't have
price	×high	×high	◇average	◇average
documentation	×bad	✓good	✓good	✓good
support for Unity	×don't have	✓have	✓have	◇have partial
availability	◇average	✓good	✓great	✓good
community	×bad	◇average	◇average	×bad
feedback	×none	✓vibration	×none	✓vibration & light

CHAPTER 4

Design and implementation

4.1 Initial design

The initial design for the game was an outcome of a few suggestions:

- the armband can best track the movement similar to natural movement of a forearm and do not translate so well to 2D movement (e.g. mouse control).
- it is important to have cognitive elements that can translate to everyday life, like color recognition, using familiar objects.
- the game focus should be on hand-eye coordination, so as a natural consequence, the idea of something appearing and the need to catch it/shoot it emerged.

Based on that, I came up with an idea of *The Battle of Rainbow Bridge*, shown in figure 4.1. In the game, the player is a wizard, that has a magical wand. A lot of monsters appear in the sky and try to fly next to him to attack the city behind and he needs to stop them all. There are different type of monster and he need to use different spells to be able to destroy them. In a game, the player gradually learn new spells, one per each level. The movement of a wand is similar to movement of an forearm with elbow resting on the desk.

The initial design is simple and not too detailed, because I have chosen to use Agile development method. I quickly built a prototype based on described design and tested it with children and adults. It allowed to receive continuous feedback and made game more entertaining and playable.

4.1.1 Dictionary and mechanics

- *Asteroid* - check: *Monster*
- *Failures* - counter for failed attempts in destroying *Monsters*. Do not impact the game.

Figure 4.1: The early concept of a game view. Number one is the wand, number two - the laser, number three - the monsters..

- *Gate* - an object from which the *Monsters* come from. It has a circle shape and is rotating counter-clockwise. There are 15 gates in the game, three rows with 5 each.
- *Laser* - a long object shot from *Wand* using gesture, able to destroy the *Monster* if has the same colour as it.
- *Level* - the game contains 5 levels, each one unlocking new gesture, so in first level player can only use one of them and on last one - all five. Each level is started with zero *Successes* and *Failures*.
- *Monster* - a rock-like, rotating object that is created in one of the *Gates* and will stay, slowly growing. It will be destroyed if shot by a player with *Laser* or after certain amount of time passes. If former, it counts as *Success*, if latter, counts as *Failure*.
- *Successes* - counter for successfully destroyed *Monsters*. If reaches appropriate number, player advance to next *Level*

- *Wand* - an object, that can be wave around by the player. When player uses different gestures, *Wand* can shoot with different coloured *Lasers*.

4.2 Iterative testing

4.2.1 Testing of alpha version

State of the game: The game supports controlling with one Myo device. It allows to shoot different colours lasers with different gestures. All asteroids are the same and they response to any kind of color. Backgrounds is an image. Basic UI counts successes and informs about Myo status (synchronized, connected etc.). Game is buggy, has stack overflow problems and allows accumulating not-destroyed asteroids in player's scene view.
Testing group: three male adults, under 30 yo, with supervision of author
Testing feedback:

- background and ground should be 3D structures to allow better depth recognition
- the scene should have better lights
- making the controls more advanced may result in more interesting game
- missiles should be faster
- using two hands for controlling seems to be interesting idea

Design decisions:

- background should be substituted with a skybox and a terrain with proper lightening
- the velocity of missiles should be increased
- one hand should be now responsible for gestures and one for steering

4.2.2 Testing of beta version(children)

State of the game: The game support controlling with two Myo devices - one for waving the wand and one for casting the spells with gestures. Lasers have better contrast. Asteroids have different colors and reacts only to lasers of appropriate colors. Background is now 3D terrain with skybox. The aim device has been introduced (green sight that gets red if on line with any target). The UI shows available gestures and their colors. Not destroyed asteroids now explode in front of the player. Objects

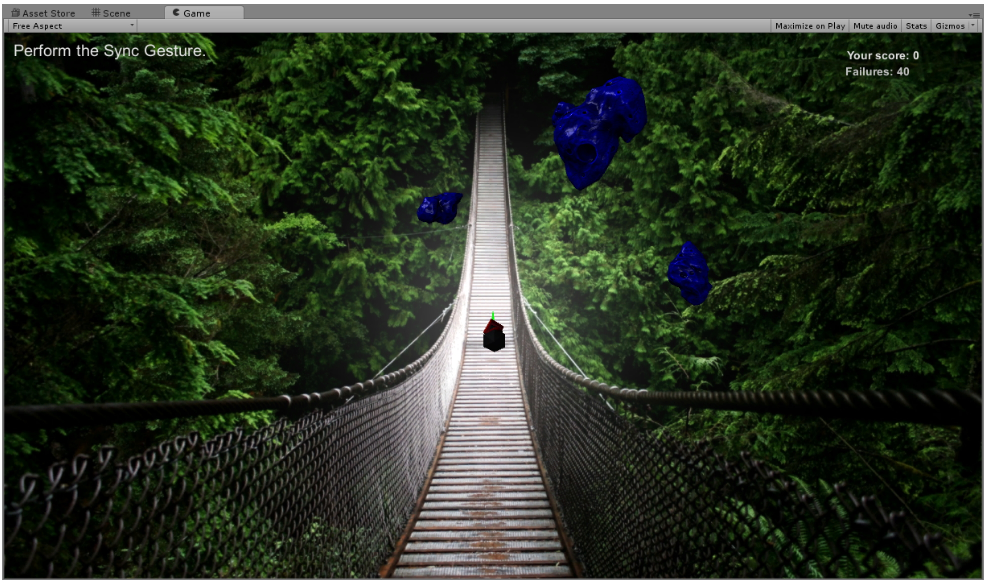

Figure 4.2: The alpha version of the game..

like lasers and asteroids have time-based destructors to avoid the stack overflow. Levelling up mechanism has been implemented.
Testing group: two girls, 9 years old and one adult, without supervision
Testing feedback:

- aiming mechanism still too hard
- two hands-based control works fine and even allows cooperative play
- there are problem with calibrating the device and detecting the gestures

Design decisions:

- the aiming mechanism should be changed to whack-a-mole - monsters should appeared at predefines places on the 2D plane and do not move.

4.2.3 Testing of beta version(adults)

State of the game: Same as in version for children.
Testing group: 2 males, under 30 yo, with supervision of author
Testing feedback:

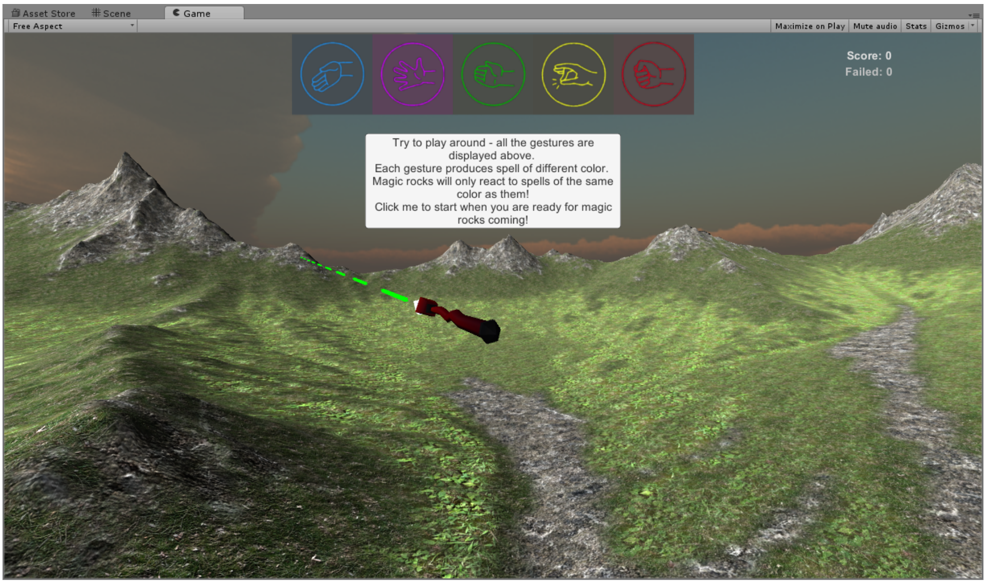

Figure 4.3: The beta version of the game - training screen..

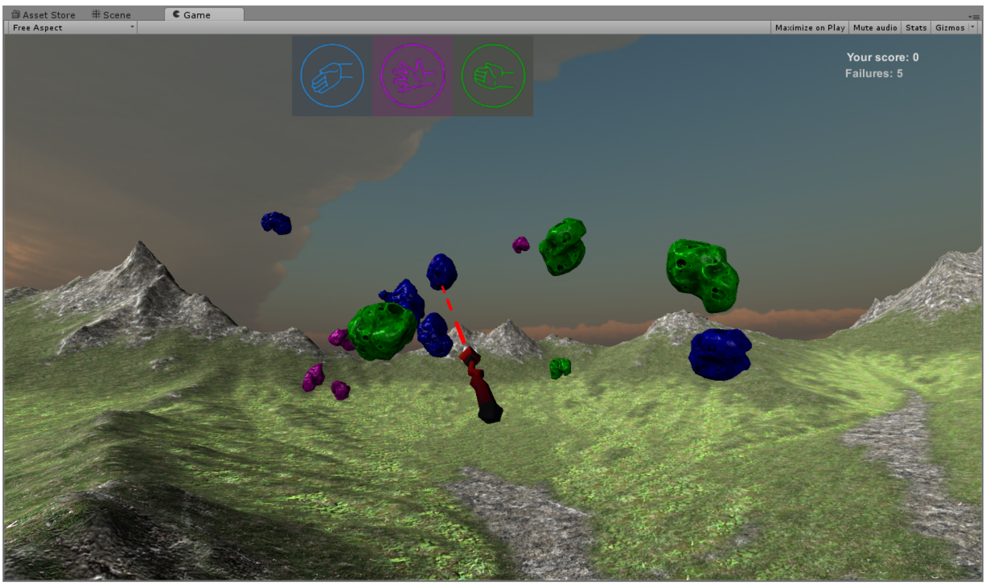

Figure 4.4: The beta version of the game - casual screen view on third level..

- aiming problem persists
- some gestures are not recognized as easily as the others
- game was easily completed in a few minutes

Design decisions:

- same as in children testing

4.2.4 Testing of version 1.0 (in debug mode [1])

State of the game: The ”gate” concept was invent - now the screen contains 15 gates, that are spawning monsters. Monsters are spawned in the center of the gate and grow in size for some amount of time and disappear, if not destroyed. Single monster is never bigger than a gate. The statistic tool was added, counting how many and of what kind monsters were killed on each level. At the beginning of the game, game requires name, age and trial number, which it uses for creating a file with statistics. Number of spawned minions per level and time differences in spawning had been individualized per level. This version works by default with 2 Myos. This version includes sounds and music.
Testing group: 1 boy (9yo), 1 male adult
Testing feedback:

- there is problem with centering the wand
- too many asteroids appear on the screen
- second hand (steering hand) does not require to be synchronized
- asteroids live too short

Design decisions:

- adjust number of asteroids appearing in final levels

4.2.5 Testing of version 1.0.1 (in debug mode [1])

State of the game: The number of asteroids for all levels has been adjusted (lowered).
Testing group: 4 girls (6,8,10,11 yo), 1 male adult
Testing feedback:

- the armband may require additional support (a band) for better fitting smaller arms

[1] Debug mode is run inside Unity instance and is slower then Release Mode

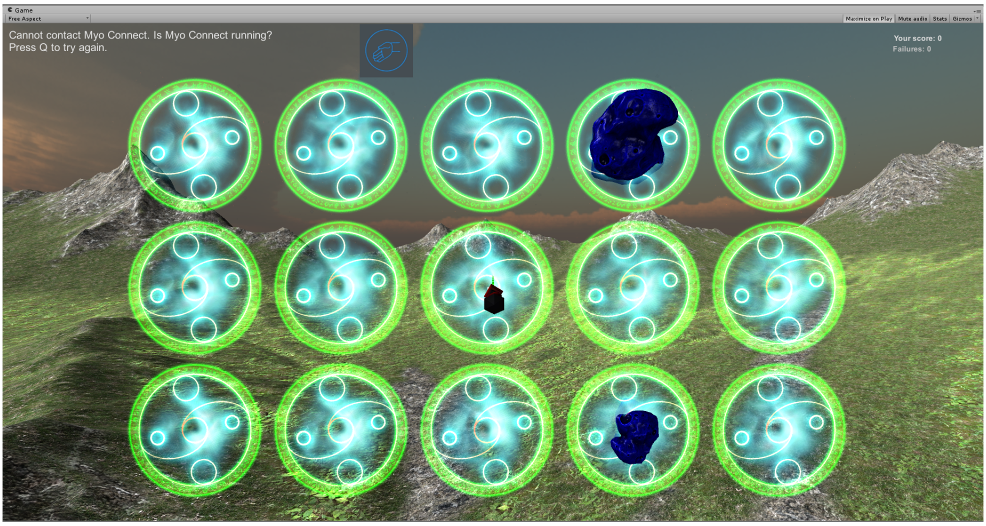

Figure 4.5: Version 1.0. The gates are spawning monsters, that are staying at the same place and only growing in size for defined amount of time before disappearing..

- asteroids seems to have appropriate or too short, depending on subject, length of life
- sometimes it is not easy to remember appropriate gesture for appropriate color
- the keyboard-based recentering does not seem to be natural
- some subject has perceived wand movements not natural
- the 6 yo was the only one whom hand was too small to detect the gestures

Design decisions:

- put recentering mechanism as a gesture of steering hand
- display small information on asteroid about which gesture to use

4.3 Design process

4.4 Implementation details

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