Playful Stimulation against Parkinson
a Tentative Exploration

Masters dissertation in Design and Multimedia
Faculty of Sciences and Technology
University of Coimbra

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Abstract

Virtual rehabilitation through the games is an emerging and promising treatment for patients suffering from Parkinson's disease (PD), which combines exercise with gaming to provide playful and enjoyable physio-therapeutic sessions even at home. In this way, exercises can be performed more frequently and effectively, as the player would be best engaged with the game. In this thesis we intend to design and develop an exergame using current interface technologies to encourage PD patients for sticking to the therapeutic sessions. The design part of the game is enriched from the old Persian and Portuguese geometrical design. The game is using the MYO armband gesture recognition system for user's interaction with the game environment. The developed game was tested with volunteer participants to evaluate the extent of effects and possible improvements on the mental and physical aspects of patients suffering from PD.

Keywords

Virtual rehabilitation, Parkinson's disease, Multimodal interface, Gesture recognition, Exergaming, Geometric design.

Acknowledgements

I wish to dedicate this thesis to my parents.

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Although being several thousand kilometers away from my family, yet I have always felt their love and mental supports throuhjut these years, especially my mom and dad who I owe so much to.

Last but not least, I wish to thank my beloved husband Mojtaba, for his unceasing understanding and perpetual love right from the beginning. I could not finish this work without your unconditional support.

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Chapter 1 Introduction

1.1 Motivation

With current advances in technology, people's lifestyles have completely changed compared to several decades ago. Recent changes in the eating habits, working conditions, activities, and in personal and social communication schemes have created new physical and mental disease among all age groups. These include going through high levels of stress, obesity, and anxiety, becoming isolated within homes, and getting more attracted to and imprisoned within the easy-to-reach virtual environments. In line with this revolutionary change of lives, the requirement was quite felt for building new tools for replacing and filing of this everyday gap in the lives of people. These requirements are now answered by using emerging technologies to a large extent.

Virtual reality (VR) is one of such new technologies, already introduced and being continuously developed. VR is a multimedia environment, which can simulate real or imaginary objects, environments and spaces, to create a sense of reality to the participant through a human-machine interface (Holden 2005). Simulation may also involve deeper sensory experiences such as taste, smell, sound, touch, and heat. The ultimate goal perceived for VR is to build a virtual world in which real people can interact with the virtual environment, people, objects, entities and applications, giving them a sense of real or close-to-real experiences. VR has found many applications in medicine, gaming, industry and military.

Virtual rehabilitation (VRH) as one of the medical and healthcare applications of VR has recently attracted overwhelming interests from rehabilitation society. VRH refers to a collection of software and hardware tools, which act together as a therapeutic solution, to increase the daily mental and physical ability of the patients through their interactive participation. In these patients improvement are required in sensory, motor, or cognitive functions, through specific exercises, aiming to restore patients' abilities to normal conditions.

VRH bears the advantage of inducing excitement and joy among participants, so that they are willing to carry out the boring repetitive tasks prescribed by a rehabilitation specialist. VRH generates such fancy and pleasurable environment providing the user with an opportunity to forget about his/her surrounding, and motivating him/her to follow until the end. It has been shown that VRH users tend to have fun and are therefore more motivated to stick to the therapy schedule (Halton 2008). Furthermore, VRH can provide a controlled virtual framework for the individuals, so that it would be much easier to apply relevant therapies and obtain valid assessments of the results (Rizzo 2002). The results of the VRH can be assessed using various factors such as movement range and speed, non-effective moves, and overall scores. Furthermore, as usually patients have transportation problems, taking an extra time from them, imposing costs and making more dependent on help from relatives, the at home VRH will be more favorable for these patients. Although having many advantages, VRH is a relatively new technology with relatively high costs on one hand, and requiring experts to use it on the other hand (Burdea 2003).

Developing exergames for health care is currently a hot topic in the field of VRH. An exergame, which refers to the combination of "exercise" and "game", is a video game using an action-controlling interface, which requires body movements and involvement of the users to interact with the game. These body movements can be tracked using different interface technologies, providing both joyful moments and exercises for the participants.

1.2 Objective

In this thesis, we develop an exergame for playful virtual rehabilitation of patients diagnosed with Parkinson's disease. The game is controlled by the user's hand movements, which are defined according to the suggestions achieved from Parkinson expert physiotherapists, in order to improve the overall sensory motor abilities, and if possible to prevent from the further progress of the disease. From the design point of view, the game uses a combination of ancient Persian and Portuguese geometric arts. On the technology side, we utilized the MYO armband for the interaction of users with the exergame.

This thesis is organized in seven chapters. Chapter 2 deals with the Parkinson's disease, its definition, types and treatments. Then we proceed to the concept of virtual rehabilitation and exergaming, and comprehensive review of the exergaming studies in Parkinson's disease is presented. Finally, some of the interface technologies for VRH are introduced, and a brief comparison between them is provided. Chapter 3 covers the game design proposal involving storyline and multimodal interface technologies used for game controlling. Chapter 4, which is devoted to the graphic design considerations of the game, we first present the historical background of the design with reference to the old Persian geometric architecture. Afterwards, the various approaches of developing such geometrical shapes are presented. In chapter 5, prototyping of the game is discussed and a number of screenshots from the application are illustrated. Chapter 6 presents evaluation results of the designed game. Conclusion remarks are discussed in chapter 7.

Chapter 2
State of the art

In this chapter, first an overview on Parkinson's disease (PD), its progress states, and current therapeutic interventions to fight this disease are summarized. Afterwards, we review the current multimodal interface technologies and available studies on VRH to treat physical and cognitive disorders in general, and PD patients in particular. Furthermore, several studies on the usefulness of exergames for virtual rehabilitation in patients is reviewed.

2.1 Parkinson's disease

Although Parkinson's disease (PD) has been mentioned in the earliest available documents, however the first known medical explanation goes back to the scripts of James Parkinson in 1817. Around 6.3 million people are suffering from PD worldwide (Yao et al. 2013). It is a progressive neurological disorder, which develops gradually, targets dopamine-producing brain cells in the substantia nigra, located within the basal ganglia, and on either side of the brainstem, which are in charge of body movements (Obeso et al. 2008, Yao et al. 2013). In fact, clinical signs of PD may not become evident until about 80% of these neurons are lost.

Sometimes in its early stages, PD can be distinguished by hardly noticeable tremors in one hand. In fact this disease happens when neural transmitter cells are wasted. As a result, such symptoms as shaking, stiffness of muscles, slow movements and tough walking start to appear, while speech may become soft or unclear. Over time and as patient moves towards developed stages, his condition deteriorates and symptoms worsen. In final stages of disease however, other symptoms are noticeable such as thinking and behavioral problems. In the advance stage of the disease, depression is also a most common psychiatric symptom.

Normally we encounter this disease in elderly people, but although rarely young people may be also diagnosed with this disease. Specifically, PD in patients under age of 18 is known as juvenile Parkinson's. Also the PD affects all races and cultures, and is more widespread among men than women, who are mostly affected when they are 40-60 years of age. Moreover, PD is not contagious, that is non-spreadable from one person to another. Currently PD cannot be cured, but medications only try to reduce the related symptoms. In limited number of cases, a surgery is suggested and carried out trying to regulate specific parts of brain through deep brain stimulation, to suppress the related symptoms.

2.1.1 Symptoms of PD

Signs of PD can change from one patient to another, often begin unilateral and remain dominant on that primary side even after developing enough to affect both sides. The most primary sign of PD is tremor (Jankovic 2008). It usually appears in one limb, which is most probably the hand or fingers. PD related tremor in hand occurs even during resting hours. Frequeny of PD tremor is around 5 Hz. As PD develops to its last stages, movements become harder, slower and more time-consuming. Shorter steps, difficulty to get out of one's seat and dragging of the feet during walking makes it difficult for PD patients to move around. Stiffness of muscles is the other known sign of PD. This symptom may occur anywhere in the body, which in turn can limit movements in PD patients and cause them pain when trying to move.

Moreover, PD causes posture and absence of balance control (Yao et al. 2013). PD patients may develop stooped posture, or find themselves faced with balance problems. Another Problem caused by PD is related to the automatic movements. PD patients' ability may be decreased or lost to take unconscious actions such as blinking, smiling, swinging of arms while walking, or even not gesturing during the talks. Speaking ability is also affected by PD. Speech problems may develop, causing them to speak softly, quickly, unclearly, or to pause before pronouncing sentences. Speaking may become monotone and lose usual inflections. In such cases a speech pathologist may be required to help these patients. Writing also becomes difficult, while the letters written by PD patients become smaller in size. As PD patients suffer from low levels of dopamine in their brain, medications are prescribed trying to reduce most of these symptoms by adding to or substituting for this chemical.

2.1.2 Causes of PD

Parkinson's is linked to the gradual death or breakdown of particular type of neurons in the brain. In fact, most PD symptoms are caused by the lack or reduced levels of a special chemical called dopamine, which is in charge of regulating brain activities (Noyce et al. 2012, Van Maele-Fabry et al. 2012). While the exact cause of PD is not yet known, few factors are thought to have potential role in the development of this disease; (1) Inheritance and gone-wrong mutations: This rarely occurs however (estimated as 5%), despite those cases in which family members are also affected. Specific variations in one's Genome although bear relatively small risks of PD, but tend to increase as their number increases. Up to now, nine genes have been found to cause PD or add to the risk. (2) Exposure to some specific toxins such as the chemical MPTP or hazardous environments may trigger PD or turn into a future cause of PD. This Factor has also a relatively limited risk. In overall, further research is required to distinguish true causes of PD.

In the brains of patients diagnosed with PD, various changes take place. Lewy bodies, which are lumps of specific chemicals found within the brain cells of PD patients, are considered as important markers and represent a clue to the cause of this disease (Davie 2008). Lewy bodies involve specific types of protein categorized under A-synuclein, among which Alpha-synuclein is considered the most important and wide spread. In fact, this protein is found in a clumped form in all Lewy bodies, in such a way that cannot be cracked down by the cells.

The following factors are known to increase the risk of PD. Age is one of the major factors affecting the risk of PD. In fact as becomes older, he/she will be more easily affected by this disease. By contrast, younger adults are seldom affected by PD. Heritance and bad genetic record although increase the risk of PD, but should not be considered very important unless many close relatives are diagnosed with PD. Sex is another factor. Interestingly, men are at risk of PD more than women. Furthermore, being continuously exposed to the toxins such as herbicides or pesticides will increase the risk.

2.1.3 Related complications

Apart from PD itself, patients usually face some additional problems related to this disease. Problems that sometimes can be treated. Patients experience cognitive and thinking issues especially in the later stages of PD. Unfortunately medications are nearly helpless in treating such conditions. PD patients may also experience depression, anxiety and other emotional changes. Prescribing medical treatment in such cases can be quite relieving, and helpful for these patients in facing other problems of PD. Another problem, which may accompany Parkinson's disease, is difficulty with swallowing. Although this is not categorized under severe issues, yet it can make saliva to accumulate in patient's mouth or at worst may cause drooling.

Additionally, PD often causes sleeping problems (Jankovic 2008). Patients wake up frequently during the nights or wake up early in the mornings. On the other side, they tend to fall asleep throughout day times. Patients may also experience rapid eye movement disorder during sleep, for which medications may be helpful. PD patients may develop bladder problems and lose the ability of controlling urination. Slowness in digestive tract of in these patients may cause constipation as well. The long list of problems caused by Parkinson's disease also includes blood pressure issues, smell dysfunction, fatigue, pain and sexual dysfunction.

2.1.4 Diagnosis of PD

There is no specific rule for diagnosing of PD. Doctors usually review medical history, and test patient's physical and neurological signs and symptoms (Jankovic 2008). As some conditions exhibit symptoms similar to PD, sometime additional tests are necessary to rule out conditions with similar symptoms. These conditions include essential (familial) tremor, post-encephalic Parkinsonism, cerebrovascular Parkinsonism, progressive supranuclear palsy (PSP), multiple system atrophy (MSA), corticobasal degeneration and Wilson's disease. As the final stage of diagnosis doctors may ask pertinent to take Carbidopa-levodopa, which is a known medication for PD. If their condition is improved significantly, PD is confirmed. In taking this medication however, patients need to follow few rules to achieve the optimum results. Enough dosages should be consumed for several days in a row, each time after at least an hour of keeping the stomach empty. Finally, diagnosis of PD may sometimes turn to be a long process. If so, regular appointments with a neurologist to monitor and evaluate the possible movement disorders in long run may be recommended, to either confirm or rule out PD.

2.1.5 Current threatments and medications for PD

Currently, PD cannot be cured, and there is no proven way of preventing Parkinson's disease. The reason is simple: the disease itself is yet a mystery. Yet its progress can be decelerated and its symptoms can be controlled or reduced. In worst scenario in in the latest stages of the disease, surgery may be suggested and carried out as an option. Anyhow, changes in lifestyle are always helping. Doctors would suggest physical therapy and aerobic exercises, which in particular focus on balance and stretching issues.

As low dopamine levels are responsible for PD related symptoms such as tremor, balance and movement issues, medications try to fix it by adding to the dopamine supply in the brain. However, this substance should be consumed as a compound, otherwise if taken directly it will not reach brain tissues. Once the treatment begins, patients notice significant improvements. However these initial benefits fade away, and the drugs become less effective over the time.

Various forms of prescribed medications are available for PD. Carbidopa-levodopa as the most effective medication involves Levodopa, which is a natural substance that once passed into the brain will convert in to the much needed dopamine. Carbidopa helps to protect Levodopa from conversion before entering brain. The possible side effects are nausea or lightheadedness. Consumption of higher doses of Carbidopa-levodopa may cause involuntary movements. In these cases, doctors try to decrease the overall drug intake by reducing each dose as well as the frequency of doses.

Dopamine agonists are another medication prescribed for patients suffering from PD. The major difference with Carbidopa-levodopa is that, once in the brain this drug will not convert in to dopamine, but will mimic its effects. Although it is not as effective as levodopa, however its effects can last longer. Therefore, by using these drugs in combination, one can achieve more consistent results from levodopa. Apart from the mostly similar side effects of Carbidopa-levodopa and dopamine agonists, the latter also includes sleep issues, hallucinations, swelling, and showing compulsive behaviors such as eating. Patients need to see their doctors, if they find them extraordinary.

MAO-B inhibitors are also used to treat PD. As MAO-B is the dopamine-metabolizing enzyme in the brain, these drugs are produced to prevent from the decline of the dopamine levels by stopping MAO-B from functioning. Again, these medications also cause nausea or headaches. Using in combination with Carbidopa-levodopa increases hallucination risks. Furthermore, they are not prescribed in combination with most anti-depression drugs or certain narcotics for rare dangerous reactions that may possibly arise.

Catechol O-methyltransferase (COMT) inhibitors are also used to stop the breakdown of dopamine. Entacapone is the most known from this group. In contrast, Tolcapone is another seldom prescribed member, for its increased risk of liver damages. General side effects of this class of PD drugs involve increased risk of involuntary movements, diarrhea or other issues related to enhanced levodopa. Another group of medications include anticholinergics, mainly used over the years to control tremor in PD patients. Side effects of COMT include confusion, hallucinations, impaired memory, irregularity, difficulty with urination, and dry mouth, which often spoil the limited benefits achieved from taking these drugs. Furthermore, Amantadine may be prescribed during early stages of PD, which provides short-term effects, or may be given in combination with Carbidopa-levodopa during later stages to compensate the levodopa-related involuntary movements. Side effects of Amantadine may be manifested as purple mottling of the skin, and swelling of ankles.

Apart from the above mentioned methods, there also exist some alternative ways that PD patients can benefit from. These include Coenzyme Q10 in high doses, which is not proved for medical society to be really effective, massage therapy, speech and language therapist, acupuncture, Tai chi, Yoga, meditation, Alexander technique, music therapy, art therapy and finally pet therapy. All of these methods try to improve patient's fine motor skills, muscle strength and balance. Normal living activities throughout the day that can be very difficult for these patients are considered much important in fighting PD. To have an easier and more fruitful daily life, these activities should be carried out by learning helpful techniques and receiving advices from some occupational therapist. Furthermore, some researchers believe that doing regular aerobics, as well as drinking coffee, tea and consuming cola which all contain the well-known caffeine substance, may reduce the risk of PD. More specifically, green tea is mostly suggested.

As with many other well-known chronic illnesses, PD patients too may sometimes find it difficult to cope with intolerable situations caused by this disease. Simple tasks of walking, talking and eating can become very frustrating or even impossible. Moreover, issues such as depression and anxiety may emerge from taking medications and the mental pressure arising when they find themselves incapacitated. Support from close friends, from family, and also from specific PD support groups can be very helpful in coping with and resolving these issues.

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2.1.6 Physiotherapy for PD

Changes in lifestyle provide the most natural way with the least effects for treating of PD patients. A combination of right medications and lifestyle changes can improve living conditions of these patients, while keeping the side effects at minimum. A balance diet of high in fiber foods, vegetables, fruits and drinking that provides much required nutrition such as Omega-3 may be helpful and relieving for PD patients.

Physical exercises can help PD patients by increasing the power, flexibility and balance of their muscles, and reducing from their depression (Goodwin et al. 2008). These exercises may include aerobics, walking, swimming, dancing, and stretching. In doing the exercises, it is suggested not to move quickly, to first put the heels on the ground look to the front but not down while walking. Sanding correctly, holding right posture and walking without shuffling are very important to achieve the best results.

PD Patients especially during the later stages of disease can easily lose control of their body balance and fall to the ground. As a safeguard for these patients, it is suggest to slowly follow a U-turn while making 180 degree turns, which would take longer but helps to better keep the body balanced. Also patients are advised not to walk backwards, not to carry weights and not to go leaning much for reaching things.

By the availability of new technologies especially from the electronics industry, unprecedented opportunities are now opened for new forms of rehabilitation. Technology serves to attract the interests of patients specifically among children and elderlies by adding such elements convenience, accessibility, joy and competence to the traditional exercises, which otherwise may appear boring to many of us. The next section deals with virtual rehabilitation as a physiotherapeutic approach, playing an effective tool in the rehabilitation of PD patients.

2.2 Virtual rehabilitation and exergaming

The main goals followed in VRH of the patients include elevation of the physical fitness levels and normalization of the everyday activities (Schonauer et al. 2011). Various issues need to be carefully considered for the proper and effective application of VR in VRH. VRH is designed based on standard rehabilitation exercises, which are scheduled and taught to the patient and supervised by an expert physiotherapist.

Several aspects naturally come along with physical therapy at rehabilitation centers that make the patients to follow the regular exercises, such as confidence in supervising physiotherapist, bashfulness to rehabilitator, realness of exercise environment, and the accompanying of the patients by his/her relatives. Therefore to motivate patients to use VRH at home regularly, VRH should also borrow the above mentioned parameters for the real rehabilitation practices. For instance, a standard VRH system, which would be supported and advised by expert clinicians and rehabilitation centers, could eradicate patients' worries on the VRH system being effective and to gain their trusts. Also tele-rehabilitation technology, which provides online access to the results and information of VRH system for clinicians, will both motivate patients and induce the sense of being continuously monitored for failures and progresses, thus making them responsible to fulfilling their exercise routines.

2.2.1 Exergaming for virtual rehabilitation in PD

Computer games specifically designed to be controlled by body limbs, provide invaluable potentials for treatment of patients with PD. Interestingly they have most recently emerged as a new, yet effective weapon against this paralyzing disease (Barry, Galna, and Rochester 2014, Zettergren et al. 2011, Esculier et al. 2012, Pompeu et al. 2012, Dowling et al. 2013, Herz et al. 2013, Mhatre et al. 2013, Gonçalves et al. 2014, Paraskevopoulos et al. 2014, Pompeu et al. 2014, Sharp and Hewitt 2014). Such games can act as a simple exercise, which shall not become boring for these players, as usually happens with other known physical exercises. Although all kinds of games seem to have curing effects on PD, however the full benefits will be limited as these games do not completely match the requirements and abilities of these patients.

A good aspect of the movement-based games for treating PD is that other family members as well as caregivers are also invited; hence, improving patients' lives both physically and mentally. In this section we review some of the important studies reported on using exergaming systems for VRH in PD patients.

In a joint study by University of California - San Francisco and Red Hill Studios (a California serious games developer), therapeutic improvements were observed in the movements, balance and stride of more than 50% of the patents (Dowling et al. 2013). In this study, 20 patients had gone through a 3 month computer-based physical therapy game, playing the game three times per week.

In a systematic review on the potentials of exergaming in PD rehabilitation (Barry, Galna, and Rochester 2014), the three parameters of safety, feasibility, and effectiveness of exergaming were investigated from the available literature. Although the safety of exergaming has not been considered yet in the most of the studies, the feasibility and rehabilitative advantages of playing has been proved on PD patients. However, for some PD patients it may be difficult to use the commercial games that are usually controlled using complex and quick movements. For these patients, exergames should be specifically redesigned, so as to adequately answer the rehabilitation requirements and limitations. In particular, the issues of optimal efficacy, adherence and safety need to better be taken into perspective (Barry, Galna, and Rochester 2014).

Bateni (Bateni 2012) compared the effectiveness of physical therapy and VRH through Wii-based exergaming on 17 elderly PD patients in terms of changes in the balance. He concluded that physical therapy achieved better results during balance rehabilitation. However since the exergaming is more attractive, and can be done at home, therefore by the long-term and continuous exergaming at home, the outcome would be comparable to the physical therapy.

In a pilot study (Esculier et al. 2012), the usefulness of using the Nintendo Wii Fit and balance board was examined on 10 PD patients and compared with the results obtained from 8 healthy participants. After six weeks of rehabilitation program, they concluded that this exergaming could enhance both static and dynamic balances, while improving the mobility and functional abilities of the PD patients.

In a case study on a 69 years old male PD patient (Zettergren et al. 2011), the effects of Wii Fit gaming system on four parameters of gait speed, balance, functional mobility, and depression were assessed using different criteria, and compared with the same parameters measured before engaging with the game. The results indicated that after sixteen one-hour training sessions performed during 8 weeks, an overall improvement around 35-40% was observed for the studied patient.

Herz et al. (Herz et al. 2013) also studied the usefulness of Nintendo Wii for rehabilitation and in improving the motor and non-motor aspects of PD on 20 patients. After four weeks of Wii therapy sessions three times per week, the results indicated significant improvements in the investigated evaluation metrics, and showed enhancements in the quality of life for PD patients.

In a controlled clinical study on sixteen PD patients and eleven healthy subjects (Mendes et al. 2012), ten Wii-based exergames were investigated to understand their influences on VRH of the PD patients, with respect to the motor and cognitive demands. According to this study, PD patients were able to transfer the learned motor ability during these exergames to the real world similar, yet unspecified task. However, their ability to learn, retain, and transfer the achieved improvements after the training highly depended on the demands required by the game, especially the cognitive demands. These findings suggest that the game should be selected according to the rehabilitation goals.

The VRH efficiency of Wii Fit exergame in PD patients was also evaluated in (Mhatre et al. 2013) on 10 PD subjects. After 8 weeks of training, although improvements in the balance and gait abilities of the patients were observed by the clinicians, however the patients themselves did not feel mentally improved nor believed they had grown further balance abilities.

In this section we have reviewed some of the important studies carried out on the VRH of PD patients through exergaming. In the next section, three multimodal interface technologies with VRH potentials, namely Kinect, Wii balance board/remote, and MYO armband, which can be employed in exergaming for VRH, is introduced. We also compare their advantages and drawbacks for VRH in PD.

2.3 Current interface technologies for virtual rehabilitation

Several commercial game control technologies are currently available for VRH, among which Nintendo Wii balance board/remote, Microsoft Kinect motion sensor, and recently MYO armband are most popular. Here we briefly introduce them and compare their effectiveness for VRH.

2.3.1 Wii balance board and remote

The Wii balance board from Japanese Corp. Nintendo is built using four 16-bit pressure sensors embedded in four corners of this board; by analyzing the four pressure displacement measurements of the overall pressure center is estimated and relayed to the game console or computer using a Bluetooth connection. Obviously, balance related exercises could straightforwardly be planned and carried using this technology. Such exercises involve standing, sitting, kneeling, etc.

Apart from the board, Nintendo also includes the Wii remote to provide information on player's displacement and acceleration. Such information is obtained using two accelerometers built into this remote. By attaching Wii remote to patient's body, location information can also be extracted, which again is transmitted over a wireless link. As an example, if the remote can be attached to patient's head, so as he/she can answer yes/no questions by turning his head up or down only. Several software development kits (SDK) for Wii are made available for programming society to connect and code Wii, and to develop applications. WiimoteLib is one of the SDKs used with Nintendo Wii remote.

Figure 2.1 – Wii remote and balance board

2.3.2 Kinect motion sensor

The Kinect motion sensor developed by Microsoft Co., during its initial release on 2010 was primarily announced for exergaming purposes. However later it very quickly emerged as the essential tool for most research centers and groups because of its high potentials specially for video processing and motion tracking projects. Kinect is designed to track almost all body movements without the help of a wearing tool, which is a low-cost gaming solution and is therefore ideal for home-based physical therapy and exergaming purposes (Galna et al. 2014).

The Kinect works based on a fusion of four different technologies namely a monochrome depth camera, a RGB camera, an infrared laser projector of speckle pattern, and a multi-array microphone. The depth camera in combination with infrared laser projector can provide a depth map of the RGB camera view, and hence facilitates the tracking of location, movement, speed and orientation of players in 3-dimensional space. Kinect also has the capability of speech recognition to receive and process specific voice commands.

The Kinect sensor has the capability of recognizing all objects made visible to its cameras, and therefore can detect multiple objects within a scene, or capture the movements of different users simultaneously. This characteristic enables the building of an augmented reality environment, letting users to interact with virtual objects. For instance, a virtual basket can be mounted on a real wall upon its detection to let the player throw an imaginary ball also placed in his/her hand.

Interestingly, there are several open source frameworks, enabling researchers and software developers to connect and interact with Kinect device. Open Natural Interaction (OpenNI) is the most famous available resource among these, which is able to read sensor data and includes various functions for specific tasks such as body motion tracking, hand gesture recognition, and voice command recognition.

Figure 2.2 – Kinect device and its sensors

2.3.3 MYO armband

The MYO gesture armband developed by Thalmic Labs introduces a new way of interacting with our everyday computing environment by fitting around the upper part of forearm and detecting slight muscle movements through capturing electromyography (EMG) data, acceleration as well as rotations. MYO armband consists of eight EMG-sensing modules, and is strapped onto the widest part of forearm. It senses the electrical impulses as ones moves his/her hand, and translates the captured EMG signals to a predefined set of hand gestures, to enable users to interact with a wide range of electronic devices or software applications in real time (Thalmic Labs website).

MYO provides two different types of data streams. Spatial data indicates how the armband moves in 3D in terms of roll, pitch, and yaw. Gestural data is the second type of information generated by this armband and tells us what the user is doing with his/her hand. Spatial data encompasses angular velocity from gyroscope and acceleration data from accelerometer. Gestural data on the other hand is provided by the proprietary EMG muscle activity sensors. Currently, the MYO armband is designed to detect 7 unique poses, but its future versions as promised may detect extra hand poses as well. The supported gestures are shown in Figure 2.4.

Further, it provides accelerometer data in vectors of units of g, gyroscope data in vectors of degrees per sec, as well as orientation data of the current roll, pitch and yaw values provided as quaternion. Quaternions are members of a non-commutative division algebra that can represent orientation or rotation. In order to communicate with the MYO device, the MYO Connect application must be installed on the operating system. This application acts as link between the MYO device connected by a proprietary Bluetooth 4.0 Low Energy adapter and the applications that use it.

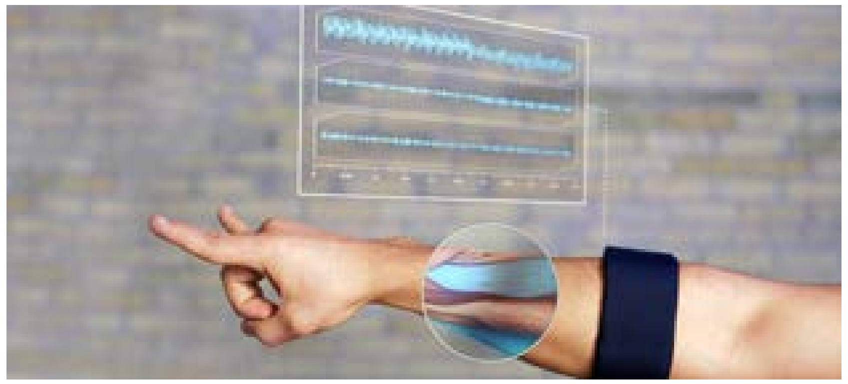


Figure 2.3 – MYO armband detects some gestures using electromyography signals (Picture credit: Thalmic Labs)

2.3.4 Technology comparison

Galna et al. (Galna et al. 2014) evaluated the sensitivity of the Kinect sensor for capturing the movements in PD patients. According to the results of their study, although the accurate measurement was possible for capturing of gross movements and their relevant timings such as sit-to-stand, but was of very poor accuracy for finer movements such as hand clasping. In contrast, both Wii remote and MYO armband can easily capture the fine movements using their embedded accelerometers.

Apart from the precise capturing requirement of the desired motions, an important issue in exergaming is the response latency of their interfaces to user movements. The latency is the time interval between the movement from player and the detection time by the platform. In Wii, data is transmitted at 100 Hz (10 millisecond intervals) using Bluetooth technology, providing a comparably high temporal resolution. However, despite this high-speed transmission rate of Wii device, a set of consecutive information needs to be transmitted to generate a meaningful instruction code to the machine. In overall, the measurements on Wii have revealed an average detection latency of around 0.14 second from an action by user and the time of detecting a movement by the system. In the case of Kinect, the capturing rate of camera is 30 Hz, about three times slower than Wii. Since Kinect-based applications make decisions using high computational cost video and image processing techniques, therefore they usually provide higher detection latencies. Moreover, compared to Kinect the MYO armband can recognize gestures by analyzing one-dimensional EMG signals in combination with some spatial sensors, something apparently faster than analyzing two-dimensional images captured by Kinect.

Due to the above mentioned reasons, the MYO armband device is investigated for developing of this game. The small movements are very important to be measured precisely in PD patient, which cannot be captured accurately using Kinect. Furthermore the detection latency of MYO is comparable to Wii system and less than Kinect, and is therefore preferred for VRH. Apart from these, EMG signal recorded by MYO armband can be useful for further analysis as a biosignal marker of muscle activities usually affected in PD patients. In the next chapter, the storyboard and investigated methodologies for controlling the exergame is presented.

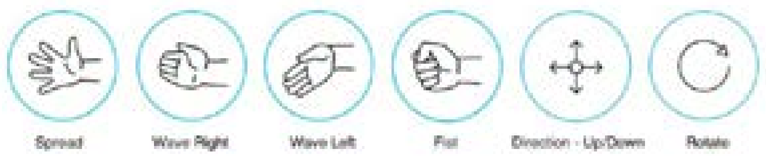


Figure 2.4 – Recognized gestures using MYO armband
(Picture credit: Thalmic Labs)

Chapter 3
Game design proposal

In this chapter we present the storyline of the game and the multimodal interfaces used to capture users' movements/inputs.

3.1 Story of the game

This game is proposed to be a prototype of an exergame aimed for people suffering from Parkinson's disease. Our main character is this *dandelion* who is hovering through the space, just to send her good news to the people around. On her voyage, she loses her hair on different happenings, and since she needs her hair back to become able to fly more across the space, she goes searching for them to bind to. Meanwhile, there are some thorn flowers who try to prevent her from having her hair back. They use their thorns to hurt our *dandelion*.

Sadly though, the little *dandelion* does not have any thorn and the only thing she can do is to fly away and escape thorns. Contrary to the thorn flowers, there are also some nice characters that helps her on her way, to escape or to eliminate the thorn flowers.

These include bubbles for example, who are also hovering in the space, and when our dandelion attaches to them, these bubbles transform to an electrical halo covering in and protecting her inside temporarily for a few second. They are really kind with our little dandelion, sometimes helping her to fly faster so that the angry thorns could not do harm. These bubbles also help the tired players to have some rest by keeping the dandelion to stay a little more above the ground.

3.1.1 Game interaction & control

The player's goal in this game is to catch the hairs by moving his/her arms and guiding Dandy on its way through the game. Dandy should be moving all the time, off course by the user's hand movements captured using MYO armband. She should watch out not to touch or hit the thorn flowers, otherwise she loses extra hair, and her appearance degrades. The exergame is controlled by user's hand movements. The player can select and click on the designated buttons from the game inventory. Meanwhile, MYO can be configured to pause or play the exergame, check the score levels or even restart the game, when user moves his/her hands in a predefined fashion. Furthermore, as some fine movements should also be controlled using the MYO, users need to try and focus to improve their fine motive controls, helping them to grow abilities of overcoming tremors. A visual guide (using pictograms) also designed to help users to find the right movements while playing the game.

The sound parameter also plays an important role in the design of this exergame. The sound parameter refers to the sounds and musics used for different actions in the game. In most games, this parameter is simply utilized to increase the attractiveness and pleasure of exergaming. However, in our game, the sound and music is doing much more. This is accomplished in several sections of the game design, from clicking on the icons by user to start, to setting up of some parameters throughout the game. Every action and contact (either allowed or forbidden) has its own specific sound, so that the player is easily notified. The background sound is also very important in this game, as it should be inducing a kind of mystery and secrecy to the game atmosphere. This background sound can also be changed according to the situation, which the dandelion has just faced, or is going to encounter. In the design of this exergame we have tried to use abstract sounds such as that of a horn, to keep the overall game as minimal as possible.

3.1.2 Rewarding&penalties

The particular goal of the game is to collect blue flowers in a two-dimensional game space to increase the score. Meanwhile it should avoid the so-called harmful thorn flowers designed in yellow color. A yellow progress bar on the top left corner indicates the remaining time. A single-round play time is set to 60 seconds. Collecting of one flower adds 10 points to the player's overall score and increases the play time by 2 seconds. An additional bonus score is increased each time by 1 point. Moreover, collision with a thorn flower subtracts 10 points from the score, while decreasing 5 seconds from the play time. In case of such collision, the additional bonus score is also resets to 0. Each time our Dandy finds and attaches to a hair, and further develops towards his final form, 12 seconds is added to the remaining play time and the score is increased by one point. At any occasion though, hitting by a thorn flower, will decrease both from time and score of the game.

3.2 Multimodal interface

Multimodal systems rely on multimodal interfaces to collect and present information from and to the users. Such interfaces include speech, handwriting, touch, gesture, and other natural forms of communicative movements like shrugging of the one's shoulders. In any case, input and output modalities should be generated in coordination, when using a common multimodal interfacing backbone. This class of interfaces are built around the new concept of recognizing and synthesizing natural human language, and behavior to create a high level of user friendly natural interaction between humans and machines. The Dandelion exergame uses gesture and voice inputs for remote control.

Table 3.1 Game scoring rules

Task	Descriptions
Goal	Collecting dandelion parts as long as possible, while escaping torns
Initial play time	60 sec
Initial play score	10 points
Time reward on each successful move	+2 sec
Time penalty on each failure to escape torns	-5 sec
Point Reward on each successful move	+10 points
Point penalty on each failure to escape torns	-10 points

3.2.1 Gesture modality

Gesture is a naturally used modality. A basic version of gesture modality is used in computer mouse and trackpads. In fact, the more advanced gesture modalities are the natural expansion of such gestures. While pointing gestures are directed and reliable, sign gestures are synthetic, more complex and harder to be recognized by a machine. In this thesis, we employed MYO gesture armband to capture users' control gestures.

3.2.2 Speech modality

Although speech is considered the primary input/output modality in human-to-human communication, yet it may not be the default option in human-to-machine communication schemes. It is usually helpful when the user's hands and/or eyes are totally busy with competing tasks, or when only a limited area is available on the keyboard and/or screen, for users with physical disability, and when the voice is the subject matter being used (e.g. reading, foreign language training, ...). Additionally, some users may prefer voice input for a variety of reasons such as its easy and straightforward interaction.

In our implementation, speech has a supportive role for those with excessive disability preventing from smooth exergaming. In such cases, some of the harder to perform gesture controls can be replaced by speech orders to enable them engage with the game. On the other hand, the use of gestures intends to animate patients suffering Parkinson disease to perform training movements.

Speech is the modality with some specifications and constraints that should be taken into account when used as an interface modality. Although the users can easily adapt, learn and enjoy voice controls, yet they should obey some guidelines for best performance. They should follow good spoken language using short sentences with a prosody clearly indicating end of words, to make it clear enough for machine to confidentially understand. Other technical limitations include ambient noise, disturbance, and others. Voice modality is usually helpful when the user's hands and/or eyes are busy with competing tasks, or when only a limited area is available on the keyboard and/or screen, for users with physical disability, and when the voice is the subject matter being used (e.g. reading, foreign language training, and more). Additionally, some users may prefer voice input for a variety of reasons such as its easy and straightforward interaction.

3.2.3 Types of interfaces

There are two types of multimodal interfaces implemented for the game. The first one uses MYO gesture to trigger the player's movement in the game and voice input to set the level of speed for the character, the Dandelion. It is referred as interface A. The second interface termed B do the opposite using gesture to set the level of speed and voice for the movements. Both interfaces use voice and/or electromyographic gestures for the game's menu interaction. Table 3.2 presents the supported commands for each type of interface.

Table 3.2 Supported commands for each type of interface

Type	**Interface**	**Application state(s)**	**Input**	**Consequence**
Speech	A, B	Menu screen	Start	Starts a new round oft he game
Speech	A, B	Menu screen	Help	Open the Help screen
Speech	A, B	Menu screen	Score	Open the Score screen
Speech	A, B	Menu screen	Exit	Terminates the application
Speech	A	Game screen	Faster	Increases the speed oft he player
Speech	A	Game screen	Slower	Decrease the speed oft he player
Speech	B	Game screen	Up/Down/Left/Right	Sets the moving direction of the player
Speech	A	Game screen	Speed <Level>	Enables to set a speed level directly
Speech	A	Game screen	<Speed> Fast	Sets the speed level to level Fast
Speech	A	Game screen	<Speed> Medium	Sets the speed level to level Medium
Speech	A	Game screen	<Speed> Slow	Sets the speed level to level Slow
Speech	A, B	Startup, score, help, and game over screens	Next	Forwards to the next screen
Gesture	A, B	All screens	Double Tap <Pose>	Unlocks the MYO for further EMG gestures
Gesture	A, B	Menu screen	<Double Tap> Wave In	Moves selection to the left
Gesture	A, B	Menu screen	<Double Tap> Wave Out	Moves selection to the right
Gesture	A, B	Menu screen	<Double Tap> Fist	Select the menu element
Gesture	A, B	Game screen	<Double Tap> Finger Spread	Sets the current orientation as rest orientation
Gesture	A, B	Startup, score, help, and game over screens	<Double Tap> Fist	Forwards tot he next screen
Gesture	A	Game screen	Move arm to right/left/up/down	Sets the moving direction oft he player
Gesture	B	Game screen	Move arm up/down	Increases/Decreases speed level

Chapter 4
Graphic design proposal

In this chapter the graphic design parts of the proposed game are discussed. First, a historical background of the proposed designs is provided with regard to the old Persian and Portuguese arts. Several approaches for building such geometrical architectural shapes from those years are then presented. In the last section of this chapter, our preliminary and final designs for the character of the proposed game are illustrated.

4.1 Historical background of the graphic design

Social life related requirements in the ancient east played a huge role in the development and evolution of the mathematics and geometry. First the Sumerians and later Babelians, as well as other nations such as Indians and Egyptians became the birthplace of most rules governing mathematics. Tablets recovered from historic remains indicate that around 2000 BC, the mathematicians of Susa were aware of the characteristics of the circle, regular polygons contained in the circles, and from methods of drawing them. Apart from the practical applications, geometry carried divine basis. It was the embodiment of celestial secrets, and a means of reaching the meanings of creation, as apparent in the arts and buildings.

This continued not only in the ancient Persia, but also further developed and excelled during the Islamic ages of Iran. Bearing in mind the extension of these forms in the Iranian arts, here we consider the role of geometry on the design of geometric forms used in the pre- Islamic architecture decorations, and then study the trends of continuity of using geometric forms in the decorative arts of the ancient Persia and its following ages, through a historic- descriptive methodology based on the matching of forms as well as their mutual effects used in different courses of history. Although the forms of these periods focus on decorative designs inspired by natural structures, we investigated them in three levels of motif, composition and their expansion, and changes.

It can be concluded that, geometry is primarily hidden inside the architectural decoration of Achaemenids, through simple repetition of natural and abstract motifs according to axial symmetries, as well as the placement and distances of these shapes across known geometric structures. Within the arts of Parthians, taking effects from Greek arts, motifs have more geometrics and more complex structures, and with Sasanians advanced geometry manifests in the architectural decorations. Among the most important changes in the arts of Sasanians, are the use of hidden stage geometry towards the more complex geometric structures, increase in the rhythms from an state of alternative repetitions to complex rhythms with diverse motifs, and the employing of central symmetry, which in turn became the underlying factor for the biggest changes in the decorative architectures in later periods, more specifically in the geometric motifs of Islamic architecture.

In this thesis, to understand the extent of knowledge that ancient artists of Persia possessed from geometry, and in particular from the geometry applied in the arts, as well as to study the geometric advances employed in the pre-Islamic decorations of Iran, we investigate the three periods of Achaemenids, Parthians, and Sassanians through a historical descriptive method. Efforts are made, so that the samples represent the common methods of the studied period, and in some cases to show the achievements corresponding to the architecture resulting from the advances in the applied geometrics, and to best reveal the artist's' knowledge on geometry and its reflection on the architectural art of these ages.

Decoration is a inseparable part of the ancient worlds' art of architecture, where the decorative elements convey meanings. Belief in this issue is so strong that Vitruvius (Vitruvius 2005) in the first chapter of his dissertation on architecture within the context of decorative themes of Greek civilization, advises architects to increase their knowledge of history to understand the motif hidden with arrays, the primary carriers of meaning in the architecture. Quite similarly, in Persia the motifs carried meanings and concepts, and were remarkably present in the structure of applied arts. The dominance of this decorative aspect is a major and all-time property of Persian art, which has lived from pre-historic ages until the present time, and represents specific decorative ideals. Clarity, precision, ordered arrangement, balanced design, use of illustrative designs, and professional attention in exploiting these principles -which appear as a gift throughout every stage of the Persian culture- is reborn by the endless innovative talent. It seems that, this power for innovating impressive and genuine shapes continuously renews itself.

Playful Stimulation against Parkinson

Different opinions exist about Persian designs. From Pope's point of view, Persians had a mathematical thinking, and for sure specific forms of mathematics are noticeable in some design principles (Pope, Daneshvari, and Gluck 2005). According to Pirnia, comparing some topics with the method of design implementation it is found that Persians had great interest in abstract forms. Ancient Iranians, considered the imitation of nature as unpleasant. Therefore, they implemented their designs in "a freeway", known as mental or abstract deduction (Pirnia 2005). Naming of the free-woven carpets originates from this same method of mental deduction.

Many researches are made on the application of geometry in the Persian architecture, and therefore our knowledge about the use of advanced geometry in the design of the building plans during pre-Islamic ages, can be guidance for understanding applied geometry in the design and decoration tasks related to the architecture of that period. It appears that, in some branches of the art, especially architecture, some kind of geometric rules are followed to achieve more harmony among the shapes of decorations.

4.1.1 Geometry in the Persian art and architecture

Geometry is defined as the order of placement, by measuring relations among shapes, geometry, math and astronomy which is the science of timing order through the observation of distant movements, as the major sciences of ancient times. The goal was to teach geometry, and to prepare the human mind as a channel through which he could percept the abstract, the life of cosmic heavens. Application of geometry was then in finding a method, by which cosmos was being ordered, and conserved. In the context of still and constant moments, geometric designs may be considered as always-revealing the current universal moment for eternity, something far beyond the reach of our perceptions. Hence, the common mathematical activity can be a journey towards intellectual and spiritual understanding.

No architecture related decoration exists from the prehistoric ages of Iran, and it is only through the architectural shapes sketched on some ancient dishes that one can find out the application of shapes in the design of architectural decoration. Despite the shortage of references, what remains from the times of Medians, from archaeological excavations in Ecbatana hills, as well as from the rocky architectures, reveals huge advances in the fields of architecture and related decorations. Art of the age which followed was that of Achaemenids, the art of kingdom. They ruled for 200 years the civilized world of their age, and created an art worthy of their mythiness and dignity. Throughout this period, many kings ruled various nations, some of which possessed particular art traditions, and this created a combination of arts during Achaemenids.

After the Alexander's invasion of Persia, Seleucids as his successors introduced many visual traditions into the Persian art, which also affected the forms and application of geometry in their design. In the age that followed, Parthians made some innovations in the field of art and more particularly in architecture. By mixing Persian and Greek elements, they tried to revive Persian art and the symbolic specifications of Persian design (Pope, Daneshvari, and Gluck 2005). By the rise of Sasanians, the last pre-Islamic national government was established which relied on national religion and Persian civilization. Linking themselves to and following the arts of Achaemenids, the kings of Sasanians exploited from the experiences obtained from the Greek and Roman civilizations' effects, and prepared the grounds for huge artistic developments (Ghirshman 1962).

4.1.2 Applied geometry in decorative architecture

The emphasis of Persian art has been on beauty, and for the Persian artist geometry acted as a powerful tool, which enabled him/her to quantify space proportionalities to create balance, order and beauty across the earth. Geometry was both art and science. Extreme goal of the Persian traditional art was to achieve the absolute perfection. Architecture was considered as a symbolic language, which could present the eternal ideas in such a way that humans could understand. Geometry transformed into a means used by Persian architects, for developing shapes of plants and animals, which by themselves were regarded as sacred. Traditional architecture attempts to represent the order embedded within the creation, as in earthy scales. In the ancient construction of architecture, all sizes (length, width, height) as well as all of their synthesized forms (including geometric surface patterns) were interrelated, and were never independent from the geometry. Hence, the art of geometry encapsulates the necessary key for creating relations among buildings and patterns, which the creator has in mind (Hejazi 2005).

In the view of Pope, although Persians (unlike the Greek) apparently didn't have any accomplished exploration of the "compiling ratios", yet they always well comprehended the scales and used then professionally (Pope, Daneshvari, and Gluck 2005). Based on the surveys of Ferrie about Achaemenids (Ferrier 1989), every building plan was precisely designed, and the floor plan was possibly sketched with dimensions marked using common legends in those days. From the legends discovered on the platforms of the two palaces of Darius and Xerxes kings, and according to the measurements of other buildings, it is found that the employed units were as: Cubit with an approximate length of 52 cm, foot sole (about 34.8 cm), and hand palm of about 8.7 cm length, which in turn were themselves proportional as (1:4:6), and probably were borrowed from Mesopotamians (Ferrier 1989).

Pirnia (Pirnia 2005) believes that Achaemenids' architecture was based on the repetition of square cells, something that has a long record in the ancient history. These cells are essentially built upon bases of simple square forms, and indeed provide fresh revelation by their extrusion into the third (vertical) dimension (Pirnia 2005). The architects of Persepolis, further to using the layout lines and geometric proportions in their designs of statues, have also developed, expanded and overlapped basis design modules for controlling of their architecture arrangement. Rules were pursued in the architecture works of Achaemenids, which later became common with the traditional Persian architecture.

By mixing of Persian and Greek elements, the architecture of Parthians achieved a style, which again flourished the symbolic characteristics of Iranian design. Parthians used stucco, plastering and painting widely in their works, the method which later during Sasanian dynasty and then in the Islamic Iran became quite developed (Pope, Daneshvari, and Gluck 2005). In this period, decorative plastering became highly popular, for the easy accessibility of mineral stucco, and easy formability and finishing of the stucco grout (Pope, Daneshvari, and Gluck 2005). Since plaster was easily sprayed and quickly fixed on the wall, it created some kind of enthusiasm for wallpapering; making the artist to cover all over the wall by a unified chain of shapes (Ferrier 1989).

Sasanians built most of their buildings using bricks, and uneven clay method, and this way they tried to rival the glory and mythiness of Achaemenids buildings. As a result, the architectural method practiced by Sasanians in which the ceremonial palaces and chambers were designed and constructed using diverse forms to achieve luxury and magnificence, provided an adequate working ground for extension of arrays. Decorative plastering became highly important during Sasanians, and despite the weakness and fragility of plaster, even the palace facades are finished by plastering as noticed in Bishapur and Tisfoon (Ghirshman 1962). In this period, in the view if Ghirshman, once a portion of plastering was finished, it was molded and copied to as many numbers as required for covering of the whole surface with endless patterns extendable in every direction. In the art of this age, square blocks in which circles are sketched in the form of pearls are very common (Ghirshman 1962).

4.2 Geometric design

An artist at any time or any place is bound with his/her national arts and ethics, and learning of these arts is much essential in sustaining the cultural originality and independence of that nation and those people. Something that is considered here is the context of geometric forms of in the Persian traditional art and how they can be utilized in the design of our intended game. Here we pointed out these forms. It should be noted that geometric forms are usually sketched on top of specific substrates (backgrounds) to minimize the drawing errors as much as possible. Such substrates include patterns and backgrounds, where we extend their forms through various methods.

Some of the geometric forms are built upon network structure, an arrangement in which geometric networks are divided into specific partitions (such as square, triangle, and diamond forms), which can be regularly repeated. In this methodology, dimensions of the intended are divided in particular orderly units of squares, triangles or diamonds. Each of these units, then act as the basis according to which, the sketch of geometric design is expanded. At the end, these units connect to one another from all sides to generate the overall design. Another important aspect of this type structure is that, units can be sketched either larger or smaller based on the design requirements.

It should be noted that geometric networks are mainly utilized for sketching of simple geometries. To this end, it is first required to draw a lattice of squares, diagonal squares, diamonds and triangles with 30, 45 or 60-degree angles. Whenever the sides of a square or rectangle are divided into equal sections, and then these sections are precisely connected with each other, a network of smaller squares is formed within the original rectangle, which is called square lattice. Various methods exist for creating sketches inside square lattices. If the smaller squares inside a bigger square or rectangle are arranged diagonally and oriented 45 degrees to the large sides, the lattice is called "diagonal (oblique) square lattice".

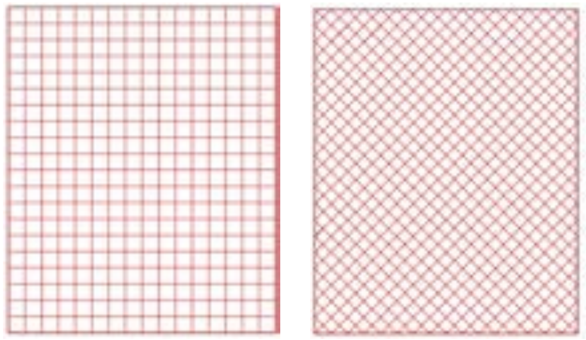


Figure 4.1 – Square lattice (left) and diagonal square lattice (right)

Playful Stimulation against Parkinson

Among these methods, one uses the sides of squares within a lattice of squares or diagonal squares for the construction of forms. In the second method, the design is created using the sides of diagonals of oblique squares. In the third method, design is formed inside the lattice of squares and diagonal squares, by connecting the corners of the squares with lines through specific angles.

4.2.1 Expansion approaches

In the creation and implementation of the geometric designs, apart from having the much required knowledge on the appropriate substrates, techniques for the expansion of forms is also important. Geometric designs are expanded through various methods of symmetry at different levels. The tendency towards using these forms through repeated and ordered symmetries has always been attractive to the human race, across the history. Many such examples are noticeable in the artistic and historical remains.

To achieve beauty, harmony and coordination, the artist starts from creating a simple or complex form, and then proceeds to decorating a large area by expanding and repeating this form. In this method, sometimes symmetry and coordination is achieved by the replication of a form. A basic unit shape is sketched, which in turn creates the main design by repeating itself, something deployable on any surface.

Therefore in order to symmetrically expand and replicate, a unit shape is moved to other locations according to some specific rules. This replacement is done through transfer, axial movement, and rotation or sometimes by a simultaneous combination of these methods. Transferring of the symmetry is one of the oldest methods of expansion for symmetrical generation, examples of which are noticeable in the historical remains. In this method, the size and orientation of the unit shape is not changed, and only its location is replicated in different directions. In geometry this is represented by a vector, which is a directional piece of line with specified length and direction.

Figure 4.2 – Painted pottery using expansion approaches

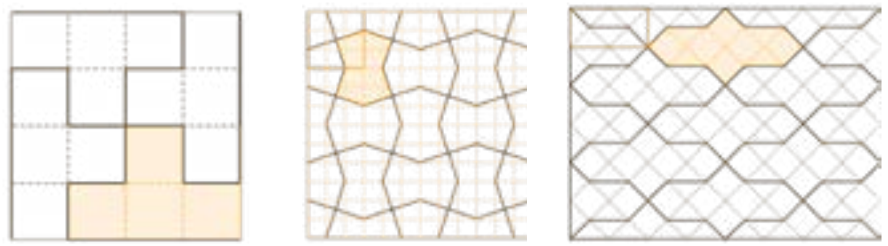


Figure 4.3 – Creating shapes using square lattice nad diogonal square lattice

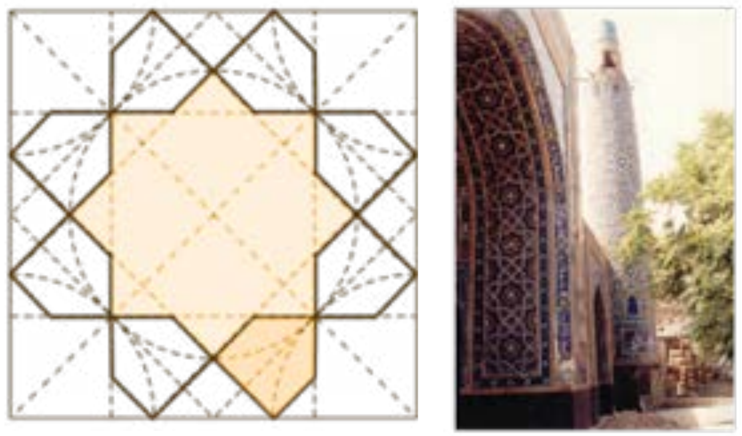


Figure 4.4 – Expansion of geometric designs

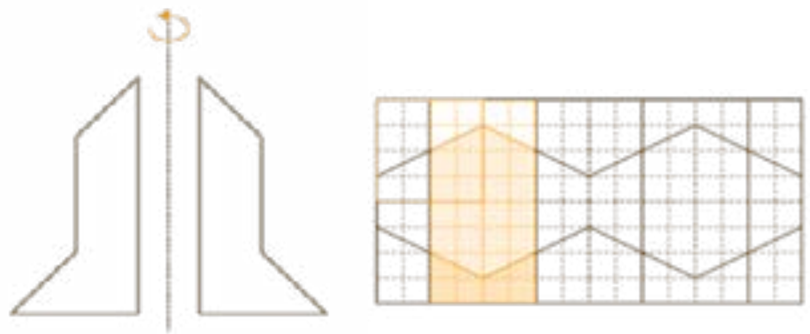


Figure 4.5 – Expansion using reflected symmetry

Axial or reflected symmetry, as another approach of expansion, is more complex than the transferred symmetry. Traditional artists call it pivot transfer. In this method of replacement, both designs are equal but not exactly matchable, and are inversely replicated around an axis. Just like an image in the mirror. It should be noted that, in the transformation of some forms it is possible to use both methods of transferred and axial symmetries to achieve a same result.

Rotated Symmetry is also another method for creating symmetry, which in this method the intended shape is rotated around some specific point or about one of its corners as much as the angle of the same corner. This process can be repeated so many times until enough to cover the surface of a circle. It is notable that, the rotated symmetry can be used in combination with transferred or axial symmetry. However, in both methods the unit shape should be so as to cover the whole area of a circle.

4.3 Preliminary designs

Throughout this thesis, we tried to design the main character according to the Persian architectural geometry. The details of this method and the related character-building procedure are explained in this section. In the first place, a pattern is designed based on square lattice methodology. Whenever the sides of a square or rectangle are divided into equal sections, and then these sections are precisely connected with each other, a network of smaller squares is formed within the original rectangle, which is called square lattice. Various methods exist for creating sketches inside square lattices. Once the pattern is ready, the main character is sketched by highlighting some of the squares. Here we have tried to preserve symmetry as one feature of the Islamic geometry. Rhythm is also taken into account and is quite evident from the design.

Here are some of our preliminary designs according to the mentioned approaches for making geometrical shapes. Since, our primary goal was to design the dandelion based on geometrical shapes, We had to create its patterns according to the traditional schemes.

Moreover, the design had to be made minimal as much as possible. Figure below illustrates the evolution of these designs from most the complex towards the most minimal.

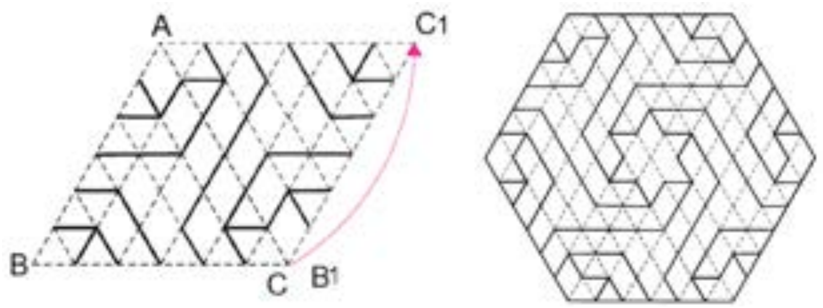


Figure 4.6 – Expansion using rotated symmetry and transferring of the symmetry

Figure 4.7 – Evolution of preliminary designs from complex to minimal

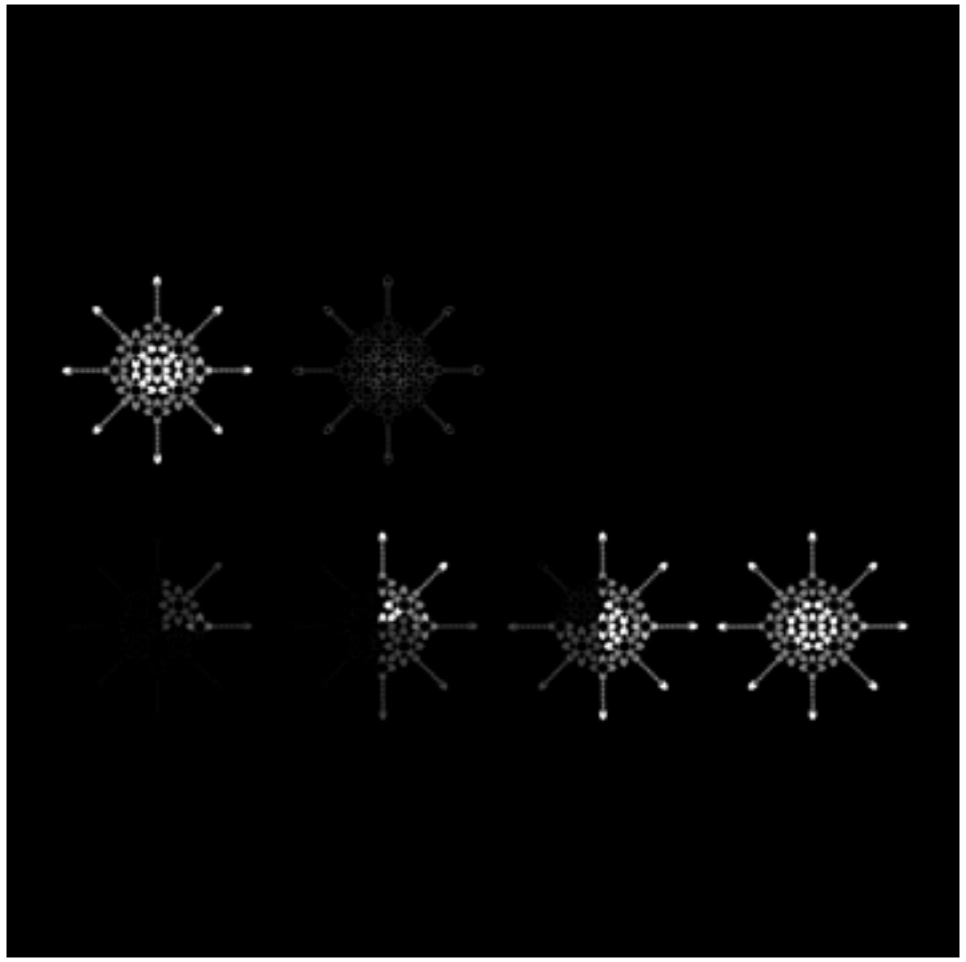


Figure 4.8 – Preliminary designs using repetition

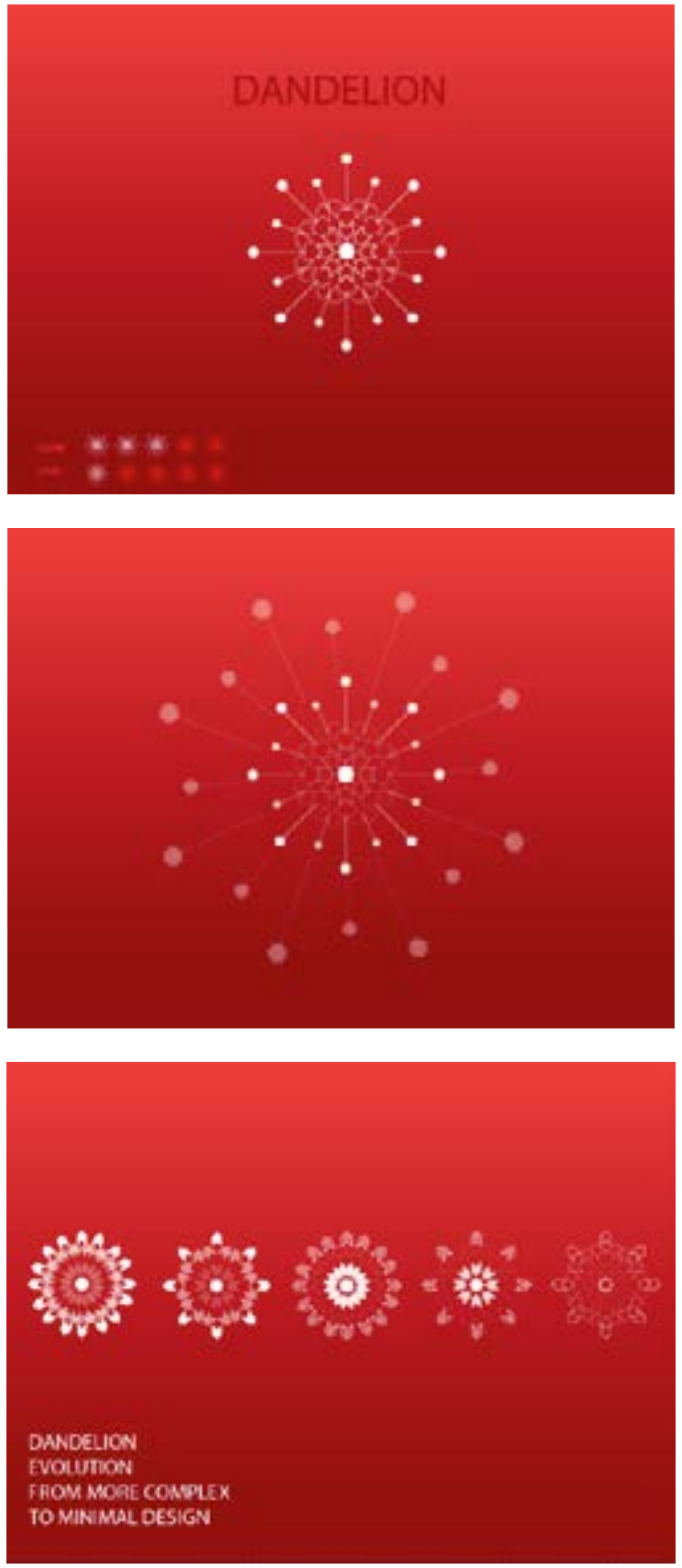


Figure 4.9 – Preliminary designs (1)

Then we began to create a single pattern to be used for building of the main character of the game. Starting from a square lattice, we sketched our own pattern as seen from figure yy. From this figure, it is clear how we draw the lines and connect the corners to inside the lattice. Here, I'm using symmetry to repeat, geometry to create the symmetry and rhythm, and try to sustain a good overall harmony across the design. Finally, selected parts of the lattice are highlighted to find various characters within.

In fact different versions of this dandelion are required to reflect the sense of movement and progress throughout the game. During of the game then, our gamer will also become curious to see what shape the dandelion will transfer to, if he/she further succeeds to the next levels. And this is one way of keeping him/her surprised. For me though, this provides a good means for attracting gamers' attention and making them more acquainted with these traditional forms and designs.

Interestingly, one can notice much similar geometry in the traditional architecture of Spain and Portugal. This taste of Portuguese geometry and colors, we loved to add to our designs. Once we were finished with sketching, it was the time to color. We look around us, and see lots of beautiful color combinations. That's it! Why not to use this rainbow from Portugal. Hence, we took the geometry from Persian architecture, and colors from Portugal and you know? It looks and feels amazing! Design should be from Persia, and colors would be from Portugal, a fantastic combination.

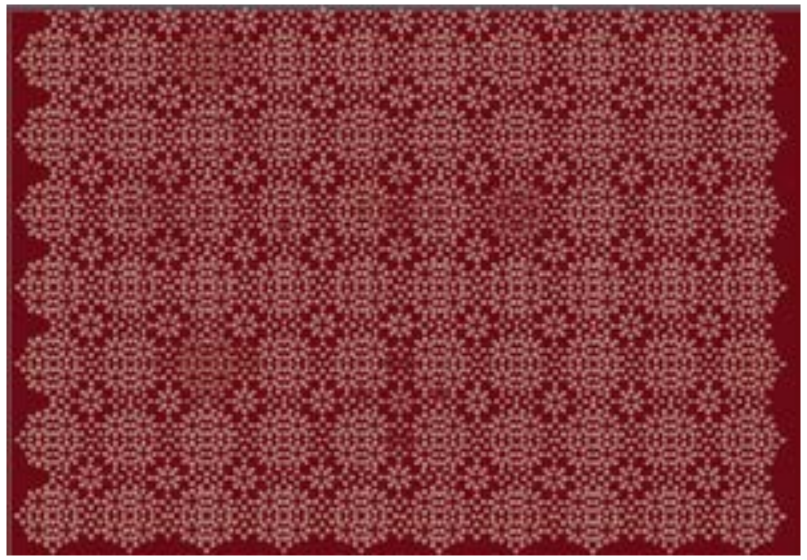


Figure 4.9 – Preliminary designs (2)

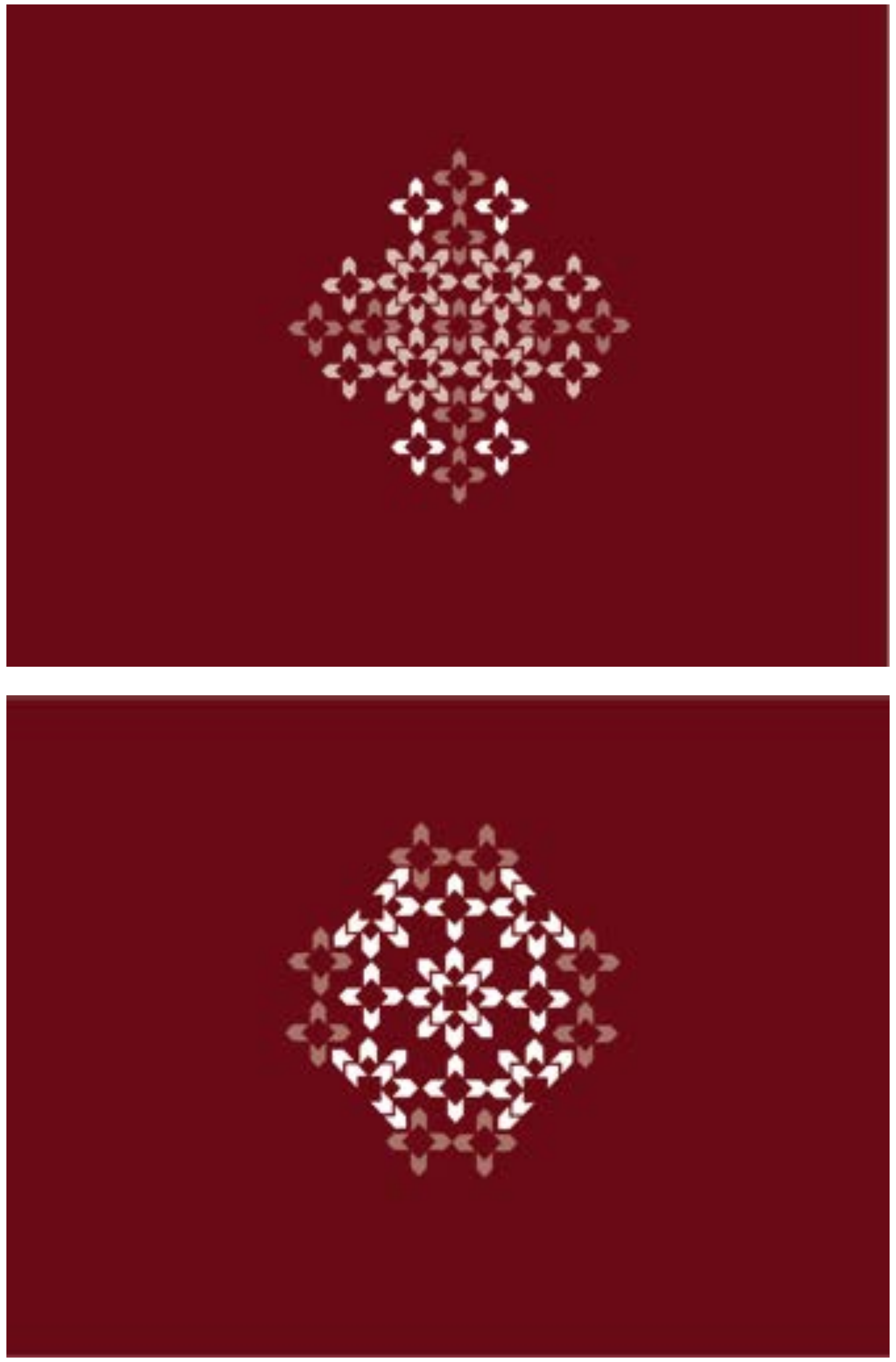
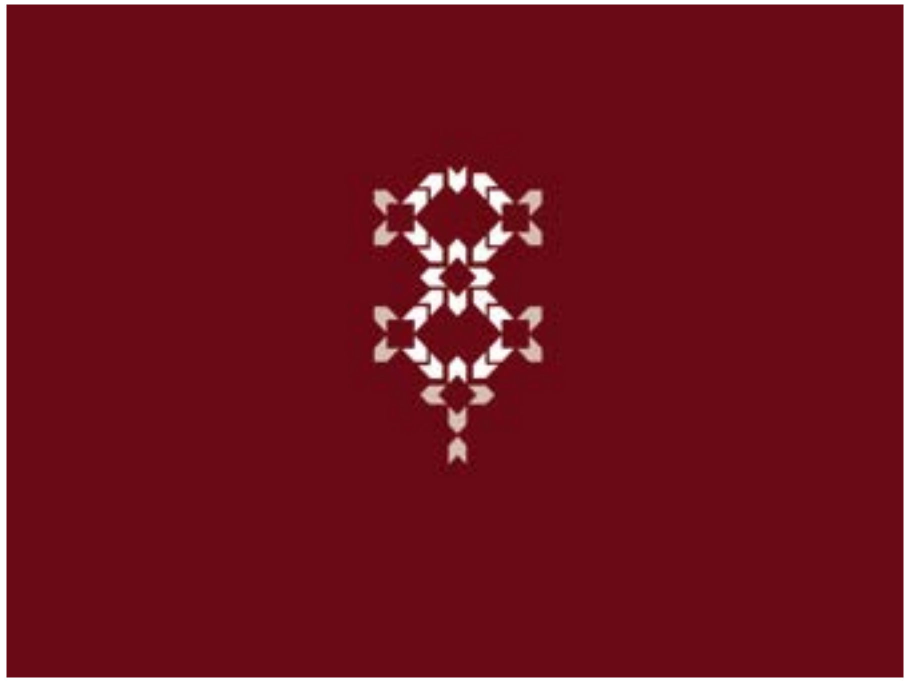


Figure 4.9 – Preliminary designs (3)



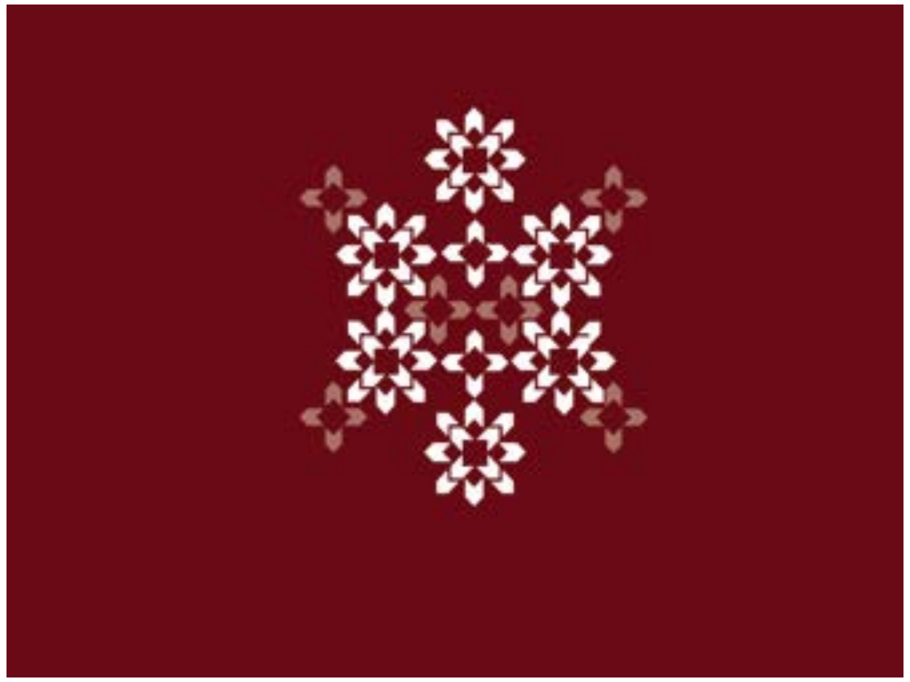


Figure 4.9 – Preliminary designs (4)

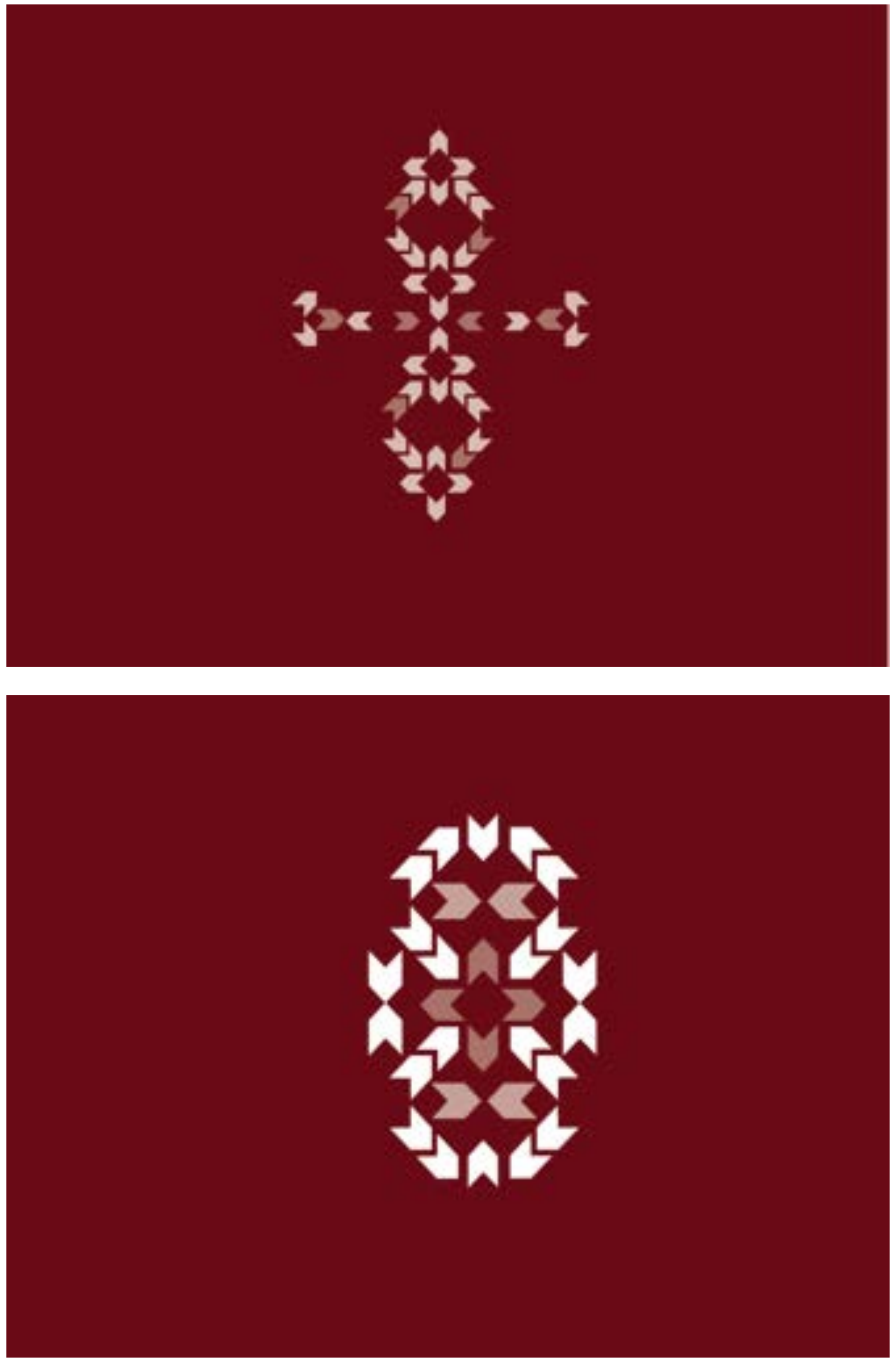
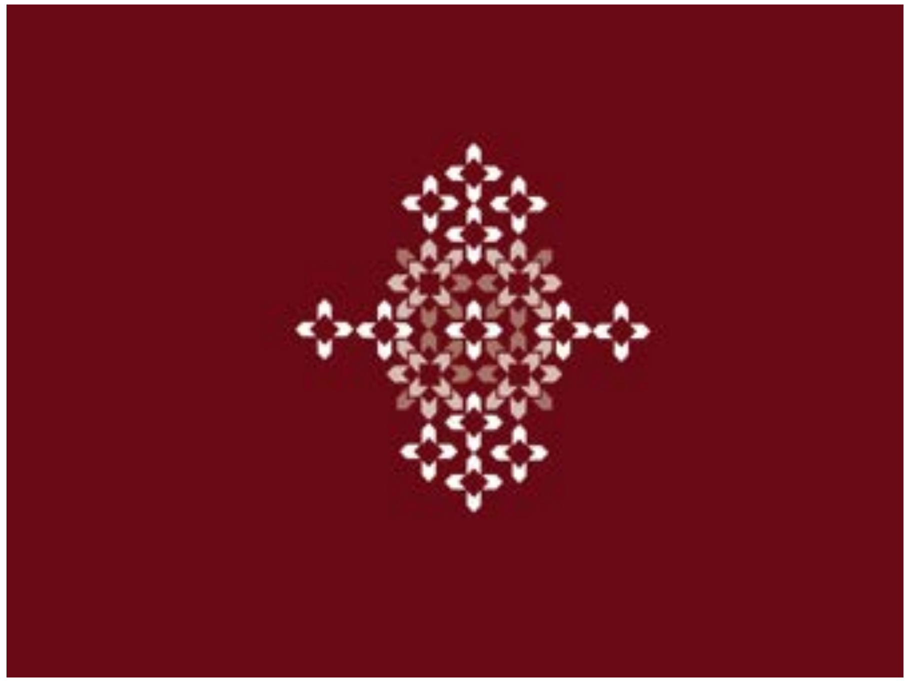


Figure 4.9 – Preliminary designs (5)



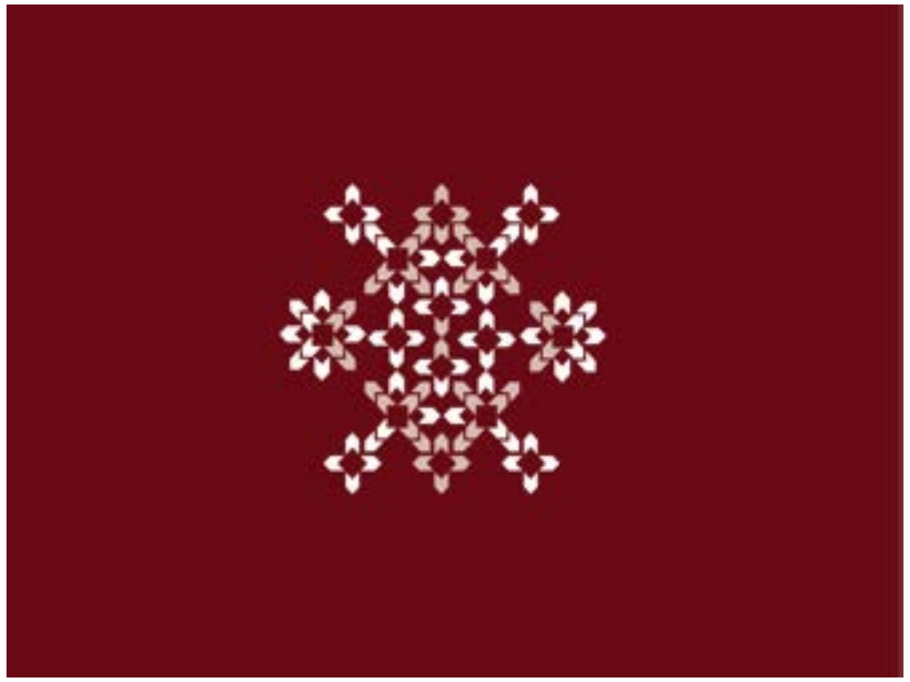


Figure 4.9 – Preliminary designs (6)

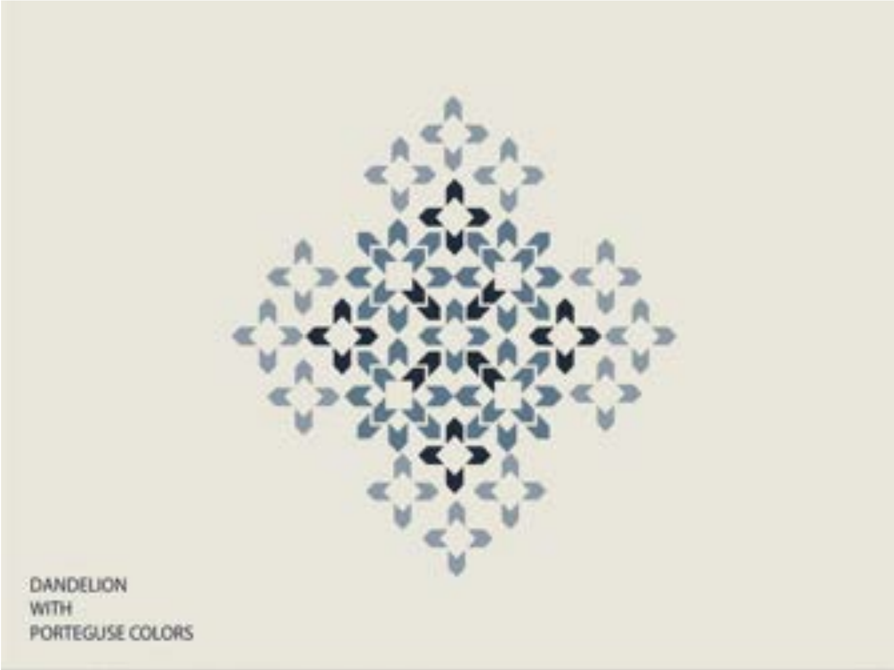


Figure 4.10 – Combining the color of Portuguese geometrical architecture with designs (1)

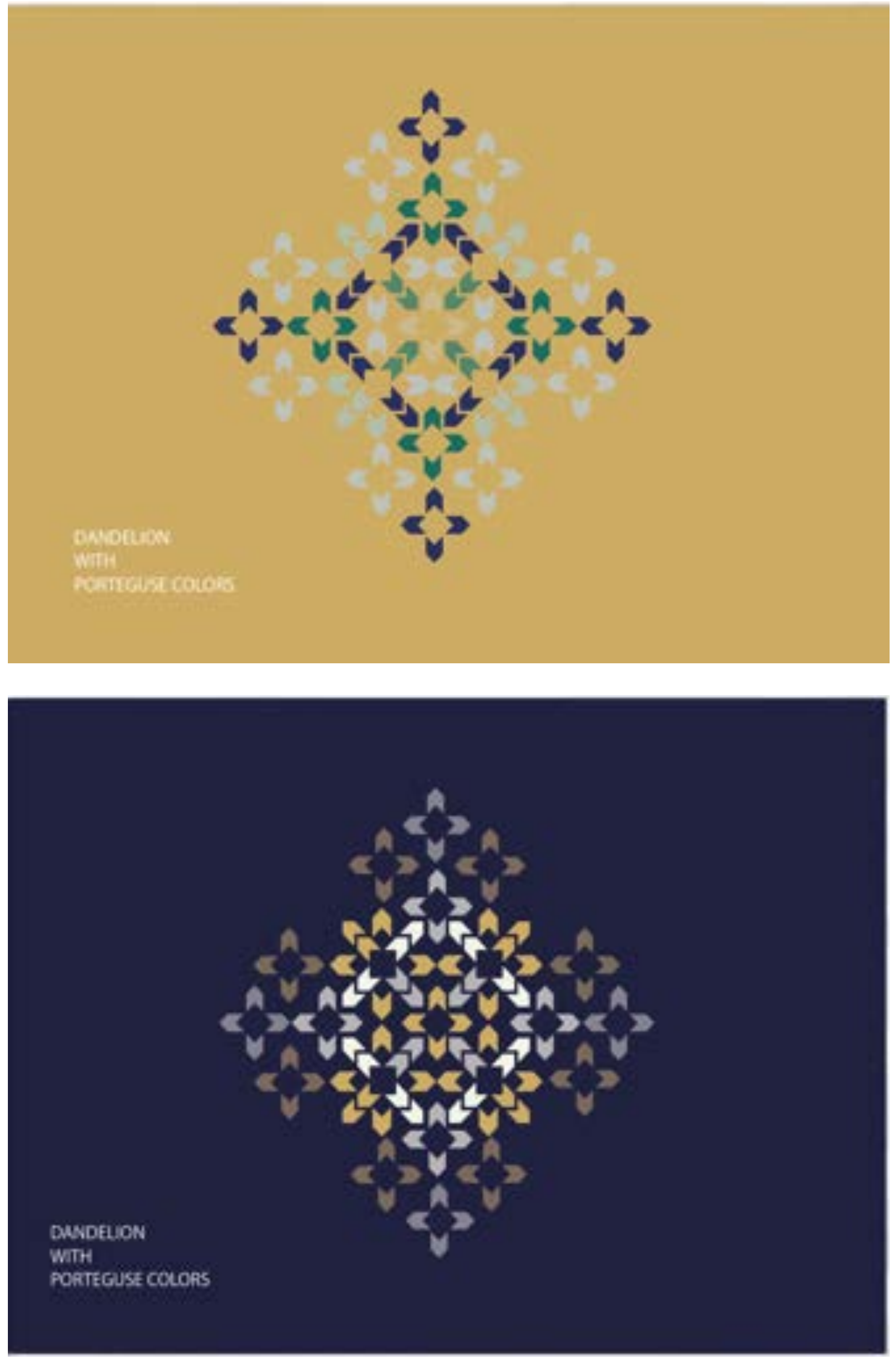


Figure 4.10 – Combining the color of Portuguese geometrical architecture with designs (2)

4.4 Preliminary designs for the game screen

Figure 4.11 – The first screen of the game

Figure 4.12 – The main menu of the game

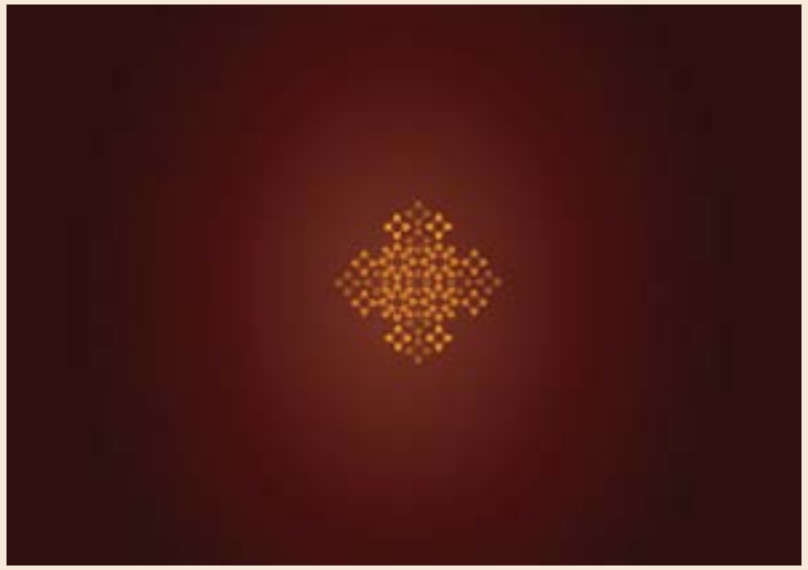


Figure 4.13 – One of the preliminary designs for the dandelion

Figure 4.14 – Two of the designed barriers to hurt dandelion!

Chapter 5
Prototyping

This chapter presents the detailed description for implementation of the multimodal interfaces. Also the final designs of Dandy character as well as some screenshots from prototype of the game is illustrated.

5.1 Multimodal interface implementation

5.1.1 Gesture modality implementation

This application uses the Java language binding library for the MYO Developer Kit originally created by Nicolas Stuart. The Java Native Interface (JNI) libraries are provided for OSX as well as Windows 32/64-Bit systems. Java SimpleEventBus is a library that provides subscribe and publish type architecture. The event bus helps to simplify event communication between multiple software components such as threads and promotes a more stable and simplistic decoupled interface between them. In general, an event bus is and software architecture, where objects can subscribe to receive certain events from the bus. When an event is published to the event bus, it will be propagated to any subscriber of this event bus. In consequence, each component is able to couple solely to the event bus itself and not directly with each other.

5.1.2 Speech modality implementation

For implementing the speech modality, we used Sphinx4 library. Sphinx4 is a speech recognition library using Hidden Markov Model (HMM) written in JAVA. It provides an API to convert the speech recordings into text using acoustic models. Beside speech recognition Sphinx4 is able to identify speakers, adapt models, and perform transcription. For hardware, a simple microphone that supports PCM_SIGNED 16000.0 Hz, 16 bit, mono, single channel input is used.

Sphinx requires in its configuration a dictionary containing grapheme to phoneme (G2P) conversions of words that should be recognized. G2P uses rules to generate a pronunciation for a word in a textual description. The resulting dictionary can therefore be considered as a pronunciation dictionary.

Standard acoustic models are provided by the Sphinx data package but can also be manually created. An acoustic model helps to adapt to a particular recording environment, audio transmission channel and accent of users. Dandelion uses "en-us" acoustic model, as it provides good recognition accuracy.

To describe the language that should be recognized, a grammar has to be provided. In Sphinx, grammars are created with JSpeech Grammar Format (JSGF) format. While the dictionary provides the phoneme descriptions, the grammar contains the set of words that actually can be recognized.

5.1.3 Application stack

Dandelion makes use of multiple threads. The main threat, executing the game logic in a PApplet, a Java Applet providing the functionalities of Processing programming language, the MYO Listener thread and Sphinx Listener thread are marked in blue color in the next figure. MYO Connect is a stand-alone application, which must be installed on the operating system that executes Dandelion, is marked in green color.

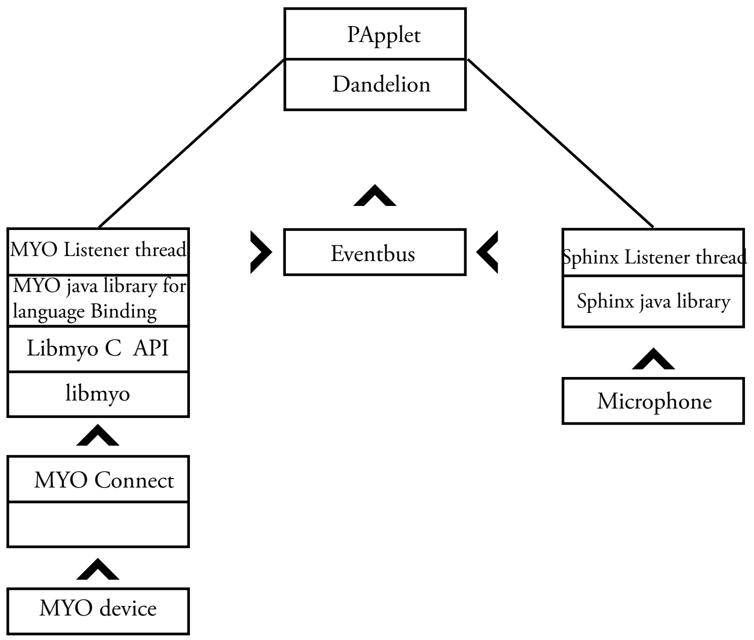


Figure 5.1 – Application stack

Once the MYO Listener thread is started, it will include the JNI library for the MYO device. This library is a programming framework that enables Java code running in a Java Virtual Machine (JVM) to call and be called by the MYO Connect application. The libmyo library is the core of the MYO Software Development Kit (SDK). The functionality of libmyo is exposed trough a plain C API. Applications normally do not interact directly with the C API but use language binding techniques corresponding to the programming language used by the application. This enables a wide variety of software written in different programming languages to interact with the MYO device.

The Sphinx Listener thread is responsible to gather voice input and to provide a hypothesis of recognized words. Both, the MYO and Sphinx Listener threads, constantly sense information provided by MYO device or, respectively, microphone. If Sphinx recognizes words contained in the grammar it will trigger an interface event over the event bus. If a defined gesture is provided by the MYO device, it will also trigger an interface event. On the other hand, the main thread is a subscriber of the event bus and will therefore be notified about the event. Depending on the application state it will translate the event into an action in the game.

5.2 Prototype of the game

Here are the screenshots from the final version of the game.

Figure 5.2 – Final application (1)

Figure 5.2 – Final application (2)

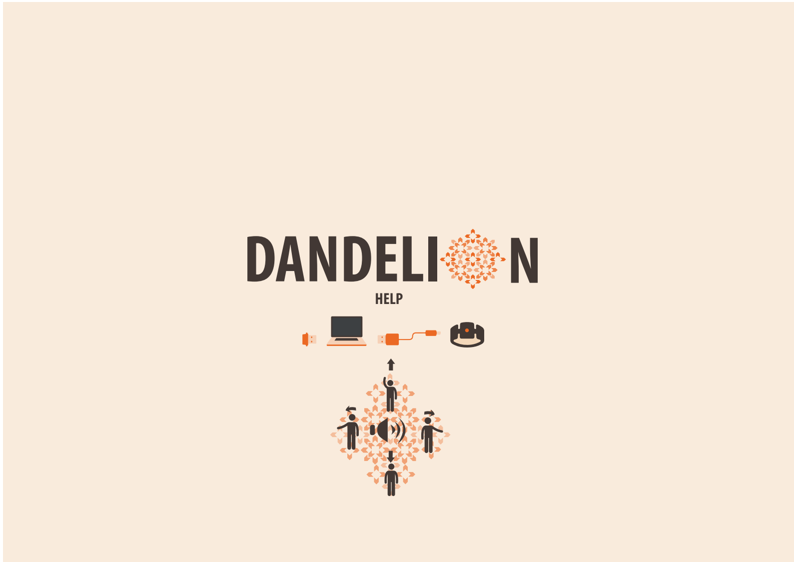


Figure 5.2 – Final application (3)

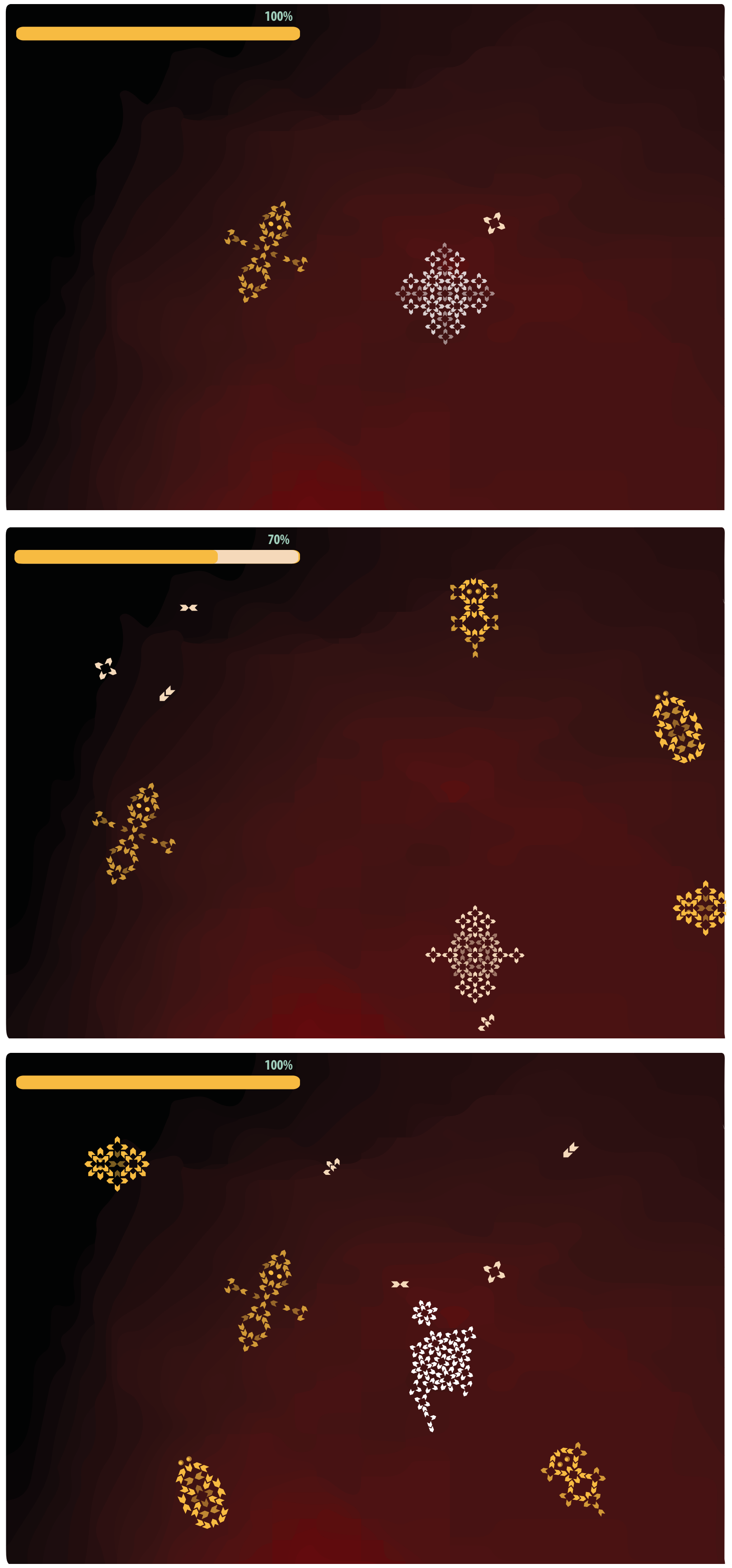


Figure 5.3 – Final designed game

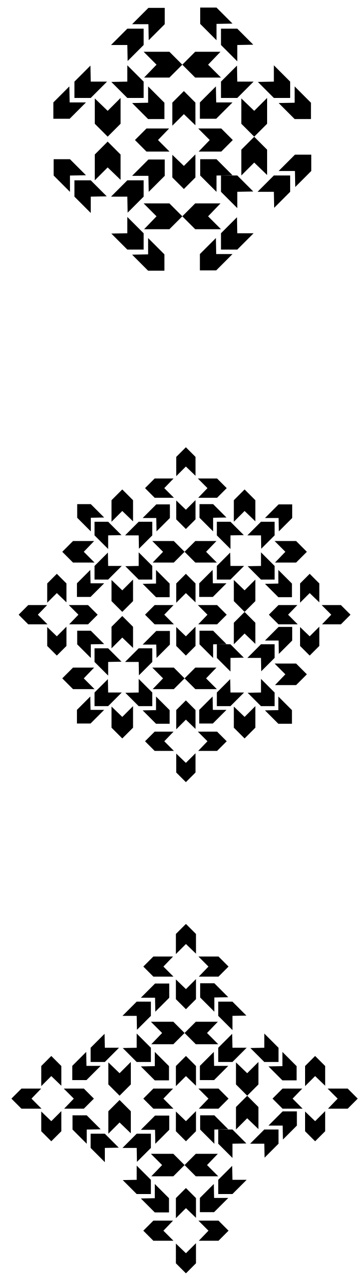


Figure 5.4 – Final Dandelion designs (1)

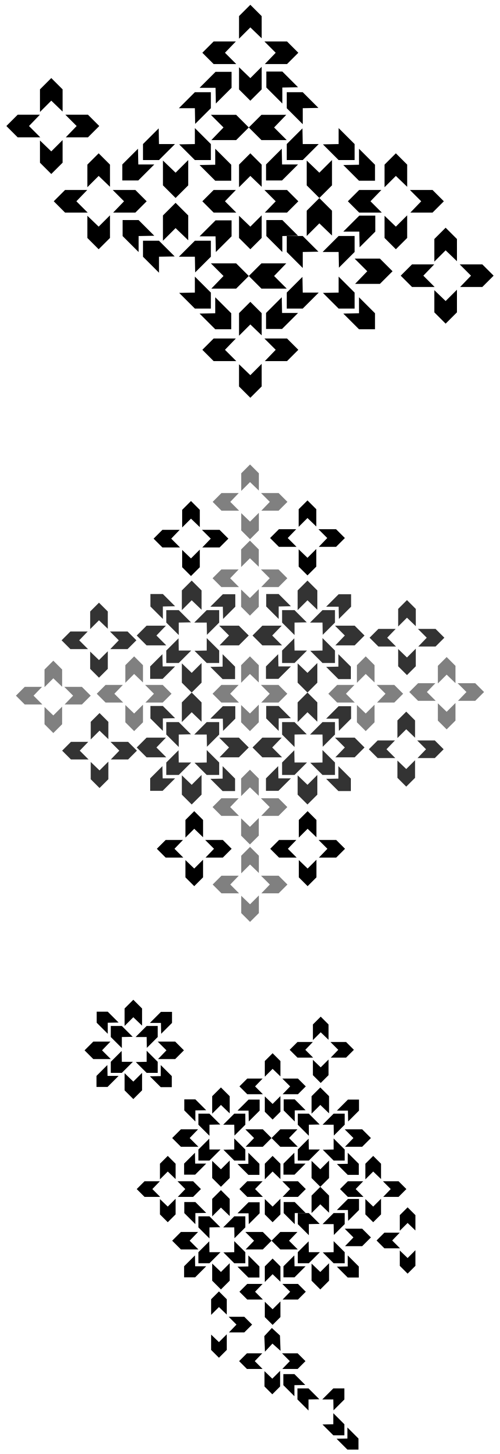


Figure 5.4 – Final Dandelion designs (2)

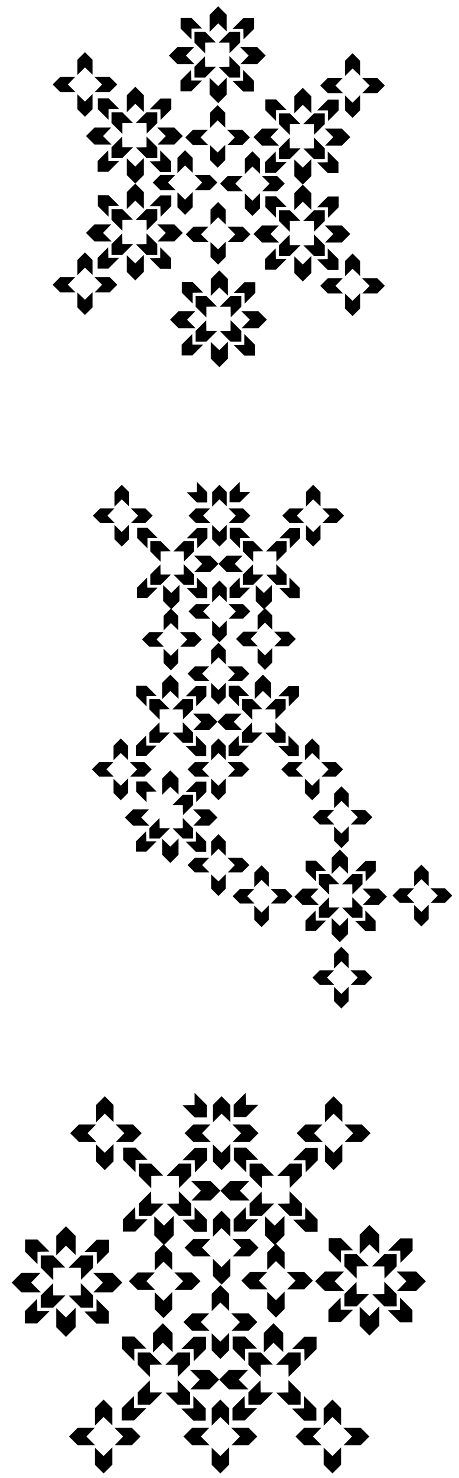


Figure 5.4 – Final Dandelion designs (3)

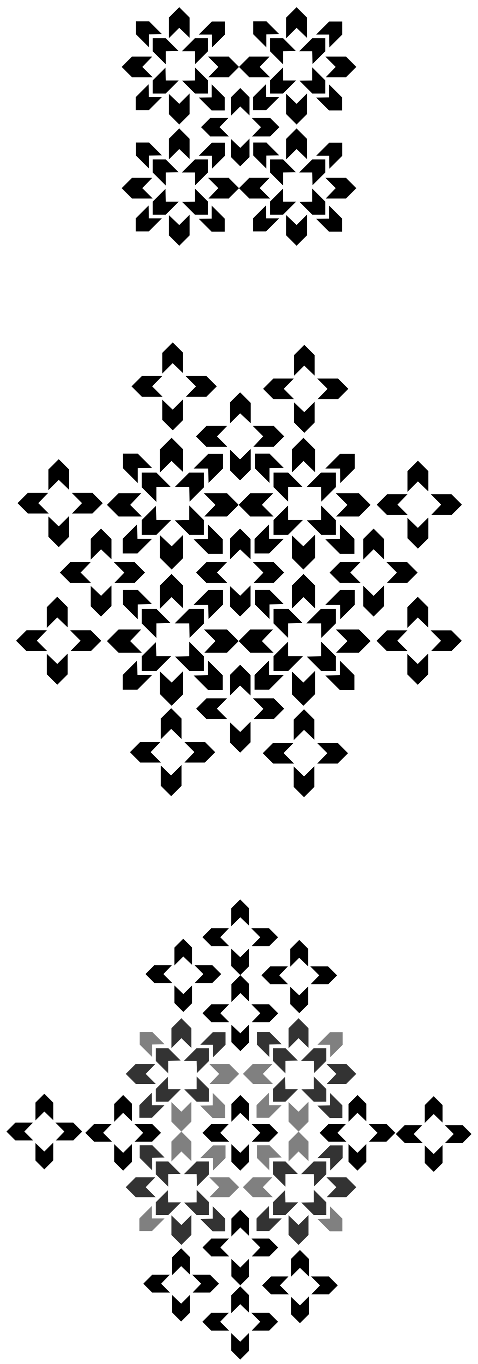


Figure 5.4 – Final Dandelion designs (4)

Chapter 6
Evaluation of the game

6.1 Usability

Research on user experience (UX) and usability (Nielsen 1994) is currently attracting increasing attention from game developers, and more game publishers are now starting to realize the importance of UX evaluation before releasing their final product to the fiercely competitive gaming market. Big names are either outsourcing this evaluation or beginning to establish their own during design process of games, various Human-Computer Interfaces (HCI) and psychological methods are usually employed to evaluate user experience.

Although the usability of software products has always been an inseparable part of development process throughout the past two decades, however it has not received satisfactory attention from game developers for some reasons. Recently though, this trend has been changing and more and more game producers find it important to incorporate easier and more improved gaming experience into their products.

Usability is an important issue in game design. Players, who mostly take time to have fun and maybe enjoy their spare time, merely seek good moments and satisfaction. Any difficulty, ineffectiveness, inconvenience and reduced gaming pleasure will hinder this goal and exhaust them physically or mentally, something in contrast with perceived goals of an ideal game. Definition of usability goes back to early software development years, but today is readily borrowed by game design experts. A game with higher usability would be capable of delivering a better and more vivid experience to the players, while at the same time keeping them away from annoying moments, unnecessary interruptions, or unmanaged game story and challenges.

One obvious reason enforces game developers to improve usability is the strong competition from gaming market. Sometimes players can easily switch from one game title to another or from one game console to another. Usability if not considered effectively, can essentially turn a game into a catastrophe.

Furthermore, for the new generation of gamers the simplicity and easy interaction with software in general and games in particular seems a natural concept, whereas for earlier generations who tolerated many technical issues, software shortcomings and frequent pitfalls with patience and accepted them as a must-be-there realty. In fact, world of game owes a lot to these gaming pioneers who enthusiastically enjoyed, praised and lived any piece of what they got, even if it was the long maintenance hours. Sadly though, the new generations have bypassed those "Golden Age of Wild West" of gaming by the mere magic of time, and developers should take care of now-fragile gamers who are only desperate to win and never tolerate even a freeze, miscontrol or wrong address.

From technical point of view, usability involves consideration of three independent measures of efficiency, effectiveness, and satisfaction. But, apparently games are quite different from other software products when it comes to usability. Specifically, here the measure of satisfaction for games is more important compared to the other two.

Unlike other software products, games are not purchased for increasing productivity and performing automated tasks only, instead they are paid for by volunteer gamers demanding entertainment and pleasure. That is how the measure of satisfaction finds such an importance among the three. More precisely, in the context of games and based on the same 9241-11 standard, usability is defined according to the same parameters. Here, effectiveness is the accuracy and completeness of perceived targets to achieve within that game, efficiency is how well all resources are managed to cover all of the goals, and satisfaction reflects user's attitude towards the game they are playing.

However, there are two important aspects to consider when studying and implementing these parameters. Firstly, they do not bear the same importance, and secondly they share dependencies among these importances. For example, although the efficiency requires developers to use the least possible resources to complete a game level or goal, yet if resources are so much underused that significantly reduce from game challenges and entertainment, satisfaction parameter will be highly affected or even lost.

6.2 Case and care

In this project we didn't use fusion of modalities. The main reason behind this is that we didn't see a benefit in terms of usability for users. As this prototype game is aimed to be used by patients suffering Parkinson's disease, a requirement to use speech as well as gesture to trigger one action may decrease user experience depending on the health condition. Because Parkinson is a degenerative disorder of the central nervous system mainly affecting the motor system some patients may not be able to perform certain gestures. The focus on providing alternatives, respectively equivalent inputs of different modalities, as provided by the interfaces can be considered to be beneficial to such users. In respect to the case and care models, the modalities can be classified as follows; (1) case: all commands triggered by modalities are exclusive and happen one after another in the order they were performed, (2) care: only FINGER SPREAD pose can set the MYO rest position that is needed to calculate the relative orientation drift from it in order to determine where the users arm is pointing to. Speed and direction for the players' character control can be performed only by one modality depending on the interface currently used. The user has the choice to use either speech and/or gesture in the Menu screens.

6.3 Evaluation of the game

To verify the efficiency of the developed exergame for VRH in PD patients, we asked 10 voluntary participants to play with the designed game, to have their feedback about the game and also assess the resulting physical and mental improvements. The game was evaluated with users that do not suffer Parkinson disease, as we were not allowed to test the game on PD patients.

Most users were first uncomfortable with the MYO device. Main reasons are that it sits tight on the forearm and they are unfamiliar with it. We observed in general that users could control the direction of the player character better with the MYO, but they tend to move the body too instead of only the arm. For all users the MYO hand gestures were difficult to perform and they tend to exaggerate the hand gesture using too much force. From our own experience, we witnessed the same at the beginning. The usage of hand gestures requires training. One has to condition himself to relax the muscles when wearing the MYO and only use a certain amount of force when performing a hand gesture.

In order to evaluate our game qualitatively, 10 healthy individuals were asked to fill out a questionnaire after playing with it. Questions were designed to assess various aspects from game playability, attractiveness to what they liked/disliked about the game, and how well they liked the interaction with the different modalities. This questionnaire is provided in Appendix 1 as reference.

In general, they preferred the voice for the menu screen interaction but the MYO for controlling the direction of the player character. Voice has a too large delay to quickly react on the game screen, forcing the user to give the command before he actually wants to turn. For some users voice recognition performed poorly, so that they had to give the same voice command several times.

60% of the users said it was easy to play. 20% of the players though had some difficulties playing with the game and felt more needed to be done regarding game directions. 70% said they liked designs of the game environment and its elements. 50% found storyboard of the game acceptable and attractive. Some users suggested that incorporating additional gestures could increase the game usability specifically for players with motor disabilities. As an example of such movements, is the sitting/standing moves, which was also suggested by our PD expert. Moreover, 80% of the players argued that a 3D version of the game could be more challenging and joyful.

6.4 Comparing multimodal interfaces

In order to compare the two different interfaces quantitatively, we let the users play two rounds on each multimodal interface. Then we took the average of the game score to figure out which interface performs better in terms of usability. Indeed there is a certain variation as the game's collectibles and thorn flowers are randomly generated in the playing area. On average, the users could obtain 250.4 points using Interface A, whereas they achieved 144.6 points using Interface B.

From the average score results we can see that with Interface A more points were collected. But we have to pay attention to the game mechanics. As the objects on the playing area are randomly set, some users found an area with a high amount of collectibles that give points, which they could harvest, and some did not. In consequence, luck is also a playing factor. The higher overall score using Interface A, can be traced back to the more responsive recognition when using MYO for the direction in contrast to the voice.

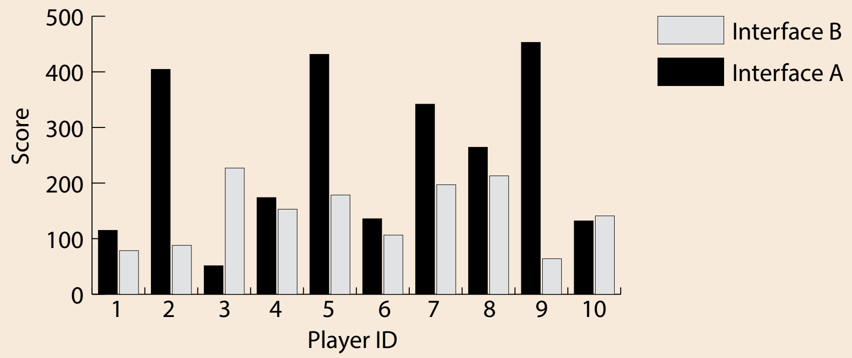


Figure 6.1 – Average scores obtained by each type of interface

Chapter 7

Concluding remarks and future directions

In this thesis, the design procedure, specifications and results of creating an exergame for patients suffering from Parkinson's disease was presented. Our goal has been to design a motivative game for PD patients as well as those patients who are in need for therapeutic movements. Game design also tried to incorporate those patients who quickly exhaust either physically or mentally, and for which particular attractive motivations such as a game can be helpful. For patients with severe movement problems, a second multimodal control input of speech is utilized, facilitating game play and aid them to longer engage with the game to accomplish its predefined goals. The preliminary results of testing on healthy candidates indicated that the game was quite successful in inducing such a motivation.

With respect to the designs of game elements, we utilized ancient Persian architecture, which is based on strong rules of symmetry, and this symmetric nature of shapes and forms induces a sense of peace and tranquility.

As another result of this study, it is found that the new game controllers such as MYO armband represent huge possibilities for treating many common diseases noticed among elderly. In fact, improvements in the game interfaces which facilitate engaging with the game on one side and bind the actual physical movements to the artificial game character maneuvers on the other side, can induce the much needed motivations for these patients to think, act and move in the right place and within the right timing.

Among the basic limitations of this game, was how to enlighten the elderly patients about the time required to wait until the MYO armband is completely synced and ready to use. In fact, the MYO armband as the rest of new technologies, although would seem straightforward for the young, can become a formidable challenge for elderly. Therefore, it is necessary to notify and educate these patients about the waiting time to warm up and the movement required for MYO to start syncing.

7.1 Future directions

The current game is based on a two dimensional scenario. Since MYO armband is by design a 3D controller, one natural development path for Dandy could be to utilize this capability for 3D character movements. Such expansion of the game can be useful for supporting more advanced and finer physiotherapeutic exercises, and be used by wider audience from patients with simple movement disorders to those suffering from more complicated sensory motor disease.

Last to say, the use of exergames for virtual rehabilitation is an interesting area on the rise. Physical exercise is a very important subject, which can be beneficial for a wide range of patients suffering from movement disorders. It is more specifically attractive in the case of elderly patients, which quickly become exhausted and lose interest in the physiotherapy plans.

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Appendix

User number:

Name:
Surname:
Field of study:
Age:

1. What did you think of the game overall in terms of playability?
   I could not play at all
   It was hard to play
   So so
   It is easy to play

2. What parts of the game did you like?
   Myo interface
   Speech interface
   Game story
   Game design

3. What parts of the game did you dislike?
   Game story
   Game design
   Interface
   Other (please mention)

4. What would you change?
   Game interface
   Game speed
   Rewarding and penalty system
   Pretty everything

5. What was the message of the game?
   Peace and friendship
   Try and you'll succeed
   Game and technology can be useful for all ages
   None of above (please mention)

6. What problems did you run into?

7. Were the directions clear?
   Excellent
   Good
   Weak
   Useless

8. How did the controls feel? Did they make sense?
   Very convenient
   Had little problem
   Could use with many difficulties
   Useless

9. Did the game feel too long, short, or just right?
   Long
   Right length
   long
   Short
   Very short

10. Are there any controls or interface features you would like to see added?

11. What elements of the game attracted you?

12. What was missing from the game?

13. If you could change just one thing, what would it be?

14. What was the most exciting moment of the game?

15. Did anything feel awkward, clunky, or confusing?

16. Did you had fun?

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Professor Artur Rabelo

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