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ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

Φυσικοθεραπεία με Kinect

ΙΩΑΝΝΗΣ ΣΥΜΕΩΝΙΔΗΣ

ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΡΙΑ:

ΕΡΓΙΝΑ ΚΑΒΑΛΛΙΕΡΑΤΟΥ

ΣΕΠΤΕΜΒΡΙΟΣ 2014

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ABSTRACT

Physiotherapy is a multistage process that includes diagnosis, planning and performing the treatment; traditionally physiotherapy is performed from trained professionals and requires time consuming, one on one personal care and individual attention of the patient, especially at the treatment stage. These demands increase the requirements in personnel with impact to the cost of therapy, while in the present days the demand for physiotherapy increases with the growing and ageing population, which has better health awareness.

The subject of this thesis is to develop an integrated physiotherapy system for unsupervised treatment performance from the user.

The system uses the functionality of the multi- sensor device Kinect™ (Microsoft™, Redmond WA, USA) for motion capture and natural user interface as the input channels to a controller that supervises the performance of the exercise and the interaction of the user.

Four exercise games were developed for user engagement (a 2D first person game, a 3D stereoscopic first person game, a 3D third person game with the avatar of the user, and a 2D platform game with the user avatar as a sprite). The interface and data structures for the user and exercise, creation, management and storage were implemented. Tele- medicine functionality that allows data transfer through internet, as well as, distant exercise supervision from medical professionals was also implemented.

For the evaluation of the system two studies were performed. An experiment with eight volunteers took place in order to assess the accuracy of the Kinect input channels (face expression recognition, kinematics and voice recognition). While a system assessment with questioners and a focus group followed with

seven volunteers concerning the functionality of the system, the use of personal data and the preference of the exercise game from the users.

ΠΕΡΙΛΗΨΗ

Η Φυσιοθεραπεία είναι μια διαδικασία πολλών σταδίων που περιλαμβάνει διάγνωση, σχεδιασμό και πραγματοποίηση της θεραπείας. Παραδοσιακά η φυσιοθεραπεία πραγματοποιείται από εκπαιδευμένους επαγγελματίες και απαιτεί χρόνο, προσωπική ενασχόληση και φροντίδα του ασθενή κυρίως στο στάδιο της θεραπείας. Οι παραπάνω ανάγκες αυξάνουν τις απαιτήσεις σε προσωπικό με αποτέλεσμα την αύξηση του κόστους θεραπείας, ενώ στην εποχή μας οι ανάγκες φυσικοθεραπείας μεγεθύνονται με την αύξηση και την γήρανση του πληθυσμού καθώς και με την καλύτερη ενημέρωση του σχετικά με την υγεία.

Το θέμα αυτής της διατριβής είναι η ανάπτυξη ενός ολοκληρωμένου συστήματος για φυσικοθεραπεία που πραγματοποιείται από το χρήστη χωρίς επίβλεψη.

Το σύστημα χρησιμοποιεί τις λειτουργίες της συσκευής πολλών αισθητήρων Kinect^{TM} (Microsoft^{TM}, Redmond WA, USA) για την καταγραφή της κίνησης και την φυσική διεπιφάνεια χρήσης, σαν τα κανάλια εισόδου σε ένα ελεγκτή που επιβλέπει την άσκηση και τη αλληλεπίδραση του χρήστη.

Τέσσερεις ασκήσεις- παιχνίδια αναπτύχθηκαν για την ενασχόληση του χρήστη (ένα 2Δ παιχνίδι πρώτου προσώπου, ένα 3Δ στερεοσκοπικό παιχνίδι πρώτου προσώπου, ένα 3Δ παιχνίδι τρίτου προσώπου με ένα avatar του χρήστη και ένα 2Δ παιχνίδι πλατφόρμας με τον χρήστη σαν sprite). Η διεπιφάνεια και οι δομές δεδομένων για τον χρήστη, την άσκηση, καθώς και τη δημιουργία, διαχείριση και αποθήκευση των δεδομένων υλοποιήθηκαν. Τηλε- ιατρικές λειτουργίες που επιτρέπουν την μεταφορά δεδομένων μέσω Internet, καθώς και την απομακρυσμένη επίβλεψη της άσκησης από ιατρικούς επαγγελματίες επίσης πραγματοποιήθηκαν.

Για την αξιολόγηση του συστήματος δύο μελέτες ολοκληρώθηκαν. Ένα πείραμα με 8 εθελοντές πραγματοποιήθηκε με σκοπό την μελέτη της ακρίβειας των καναλιών εισόδου του Kinect (αναγνώριση εκφράσεων προσώπου, κινηματική και αναγνώριση φωνής). Επίσης μια αξιολόγηση του συστήματος με ερωτηματολόγια και focus- group ακολούθησε όσον αφορά την λειτουργία του συστήματος, τη χρήση προσωπικών δεδομένων και τις προτιμήσεις των χρηστών σχετικά με τα παιχνίδια- ασκήσεις.

1. INTRODUCTION

Kinect is a multi sensor device, which among other functions; it is a 3D motion capture tool. Kinect is a system developed from Microsoft in collaboration with Primesense^{TM} (Tel Aviv, Israel). During this project, Kinect is used in a system for physical rehabilitation at home taking into advantage its motion capture capabilities. Physical therapy tends to be very costly but also very common to people of all ages either for young athletes or elderly patients. An important reason for the costs is the demands for personalized treatment and supervision needed from the therapist during the exercises. With the creation of a rehabilitation system proposed in this project the exercise costs can be minimized while the need of supervision from the physiotherapist can be reduced since the user can perform the prescribed exercises with the feedback support of the system at his house. This project focuses in two points

- The development of an integrated rehabilitation system of the upper limb.

- The creation of a controller of the performance of the user during the exercise, using as feedback channels the motion capture capabilities and the natural user interface of Kinect.

This thesis is structured on the following seven chapters. The first chapter is the introduction. The second chapter is the literature research. The third chapter is the project plan and the forth the development of the system. The fifth chapter describes the implementation of the system. The sixth chapter includes the experiment for the feedback accuracy and the assessment of the system. The last chapter is the conclusion and future work.

2. LITERATURE RESEARCH

In the literature research several aspects of the use of Kinect for physiotherapy are examined. A small introduction to physiotherapy and its purposes is followed from the presentation of technical aspects of Kinect concerning its hardware, software and accuracy. The use of Kinect is evaluated for various physiotherapy application areas and is separated in the different human body parts. Most popular commercial implementations of Kinect are presented and compared. The advantages of the use of Virtual Reality, exer- games and tele-medicine in rehabilitation are also presented while the influence of psychological factors in rehabilitation is discussed. Guidelines found in literature for home rehabilitation systems are summarized. At the end of the chapter a resume of the major findings is presented, and finally the development of a system for physical therapy based on Kinect is proposed. The literature research was performed always relative to the use of Kinect for physiotherapy.

2.1. Physiotherapy

According to (The World Confederation for Physical Therapy (WCPT), 2007). Physical therapy involves the interaction between therapist, patients or clients, other health care professionals, families, care givers, and communities in a process where movement potential is assessed and diagnosed and goals are agreed upon.

The procedure for therapy performed from trained professionals has as follows (WCPT, 2007):

1. The physical therapist examines the patient and his medical record and formulates a diagnosis.
2. The therapist discusses with the patient about his condition and sets goals for the therapy.
3. The therapist creates a management plan for the treatment.

4. Treatment is performed from the therapist while exercises are prescribed to the patient to be performed at home.
5. Assessment of the patient's progress is performed from the therapist.
6. Recommendations are made to the patient for self management.

The American Board of Physical Therapy Specialties(ABPTS,2013) lists eight specialist certifications.

1. Cardiovascular & pulmonary including respiratory problems
2. Clinical electrophysiology related to the use of electromyography
3. Geriatric concerned with the health of the elderly
4. Neurological related to neurological disorders and disease
5. Orthopaedic related to rehabilitation of the musculoskeletal system
6. Paediatric related to children's health
7. Sports for the fitness of the athletes
8. Women's health therapy for women's health issues

In this thesis we are going to focus to orthopaedic physical therapy which is also the most common specialty according to ABPTS.

2.2. Kinect Hardware

Kinect (“Kinect for Windows", 2012) is a multi sensor device originally developed for the Microsoft XBOX 360 gaming platform and later released as a developer tool for PCs with various applications as "Kinect for Windows".

Figure 1Kinect for Windows Sensor(“Kinect for Windows", 2012)

The device connects to a PC through a USB 2.0 port and consists of the following sensors and actuators:

An RGB-D sensor with a field of view 57° horizontally and 43° vertically. The RGB-D sensor consists of

- a **Depth Sensor** that combines an infrared emitter and an infrared sensor, the depth sensor allows the extraction of depth information from the captured scene.
- an **RGB camera** with a resolution of 1280 x 960 resolution at 12 frames per second and 640 x 480 resolution at 30 frames per second.

A multi-array microphone with four microphone sensors that allows sound source localization and noise reduction.

A three-axis accelerometer and **a tilt motor** (“Kinect SDK Readme | Microsoft Kinect for Windows,” 2012) that allows the vertical tilt of the field of view the device at a range of +/-27°. The tilt motion is performed based on the accelerometer information of the gravity direction.

2.3. Kinect Software

There are several software development tools available for Kinect with the most complete being the **Microsoft® Kinect SDK** and the **OpenNI framework**. Other Software Development Kits SDKs include the libfreenect**,** CL NUI Platform, ROS Kinect, these SDKs are less complete or have specific focus that is out of this work interest. Apart from the SDKs there are various middleware as SensorKinect, NITE, NI mate and FAAST.

Microsoft Kinect SDK

The Microsoft Kinect for Windows SDK (“Kinect for Windows", 2012) contains drivers, and APIs, development tools and software libraries for processing of the captured data, that add several functionalities to the device. The SDK also has programming examples in C++ Basic and C# languages.

The SDK supports the following functionalities:

- Voice recognition
- Skeletal tracking for standing and sited mode
- Tracking of two skeletons
- Facial tracking
- Gesture recognition
- Near Mode function of the RGB-D camera at a distance of 40 cm
- A background removal API that allows the easy implementation of a green-screen effect

- Adaptive user interface based on user's height that allows the adaptation of the GUI touch points to the appropriate positions
- A record and playback tool of captured datasets
- A 3D model creation tool called "Kinect Fusion" that allows to 3D scan and create the mesh and textures of objects and scenes
- Kinect fusion also allows the simultaneous functionality of two Kinect sensors.
- Support for HTML5 and Javascript interaction
- MATLAB and OpenCV integration

Concerning the skeletal tracking, the SDK can distinguish 6 people and track two people bodies simultaneously. The SDK can track the full body, representing it with a skeleton of 20 links and 19 joints(“Skeletal Tracking,” 2012) (Figure 2 Microsoft Kinect SDK skeleton (“Skeletal Tracking,” n.d.) however the joints can represent only 2 Degrees of Freedom of body motion since all the body parts are represented with links and not with bodies (roll motion is not supported (Figure 3)). The actual joint state is not provided directly from the SDK but it can be calculated with the links three-dimensional positions that the SDK provides(“Tracking Users with Kinect Skeletal Tracking,” 2012).

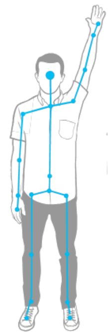


Figure 2 Microsoft Kinect SDK skeleton (“Skeletal Tracking,” n.d.)

Figure 3 3 DoF representation of body motion (adapted from wikipedia article "Degrees Of Freedom (mechanics)," 2013)

MICROSOFT KINECT SDK SKELETON TRACKING ALGORITHM

The skeleton tracking algorithm of Microsoft Kinect SDK is discussed in a published paper from Microsoft Research, Cambridge & Xbox Incubation(Shotton et al., n.d.). The target of the research was to create a computational efficient and robust human body tracking system. The materials used was the, then, recently introduced real time depth cameras, the methodology was an object recognition approach based on trained classifiers of the depth-image's pixels to body parts. The result was a system that is able to run at 200 fps on commercial hardware and produce state of the art accuracy.

The tracking process is separated in three steps:

1. Depth image capture
2. Pixel classification
3. Joint identification

At the first step the depth image is captured with the electronic CMOS sensor, at the second step each pixel is classified to a body part according to trained decision trees, at the third step a density estimator of pixels is calculated for each body part and used to identify joint positions based on (D. Comaniciu et al., 2002).

For the training of the decision trees, 500.000 key frames with humans were used with anthropometry variations, in different poses of various activities as driving, dancing, kicking, running, navigating menus, etc. Randomized decision trees and forests (a forest being a group of trees) were trained based on depth classification and position of pixels (V. Lepetit et al., 2005). The training of the trees was done on different image sets.

The accuracy of the approach was evaluated with two tests a synthetic data set with 5000 depth images with known labels and joints position and a test with manually labelled depth images of 15 subjects with 7 upper joint positions. The accuracy and the precision of identification relative to (V. Ganapathi et al., 2010) is presented below.

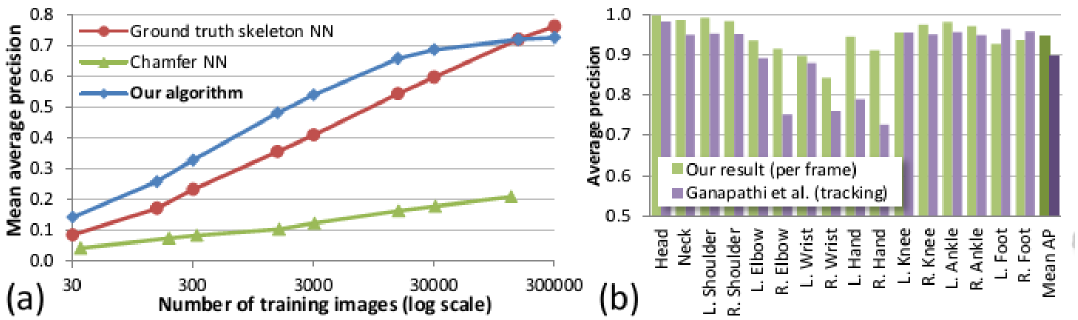


Figure 4 (a) Comparison with ground truth and Champfer Nearest Neighbour algorithm, (b) Comparison with Ganapathi et al.. Adapted from (Shotton et al., n.d.)

OpenNI/NiTE Framework

Open Natural Interaction Framework or OpenNI (OpenNI, 2011) is an open source SDK for development of 3D sensing applications. OpenNI is compatible with Kinect but also with other sensors such as Xtion available from ASUS ® and PrimeSense ® Sensors. Open NI supports multiple platforms and programming languages with the use of middleware software.

The skeleton tracking algorithm allows the tracking of 3D bodies and not only links as the MS Kinect SDK thus allowing also roll motion of the body parts ("NiTE 2.2.0.11 | OpenNI," 2013) (Figure 4), however less bodies are tracked. Before tracking starts OpenNI requires the user to perform a calibration "psi-pose" for 3 seconds (Figure 5).

Figure 5 Skeleton tracking with OpenNI and NITE middleware ("NiTE 2.2.0.11 | OpenNI," 2013)

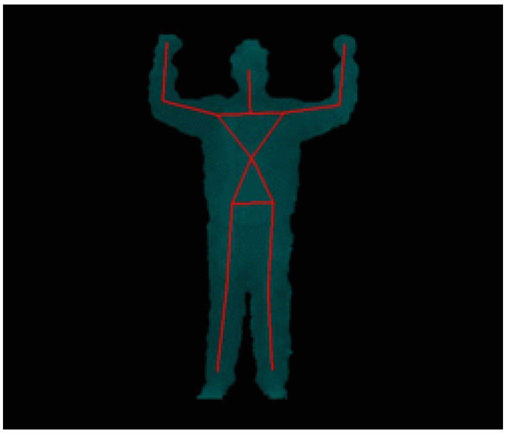


Figure 6 "Psi-pose calibration" (image adapted from Dassult 3DVIA website)

OpenNI has a variety of supported middleware that allows hand tracking and gesture recognition("Open-source SDK for 3D sensors - OpenNI," 2013). A Comparison of the two SDKs is presented below.

Table 1 Functionality support of Microsoft Kinect SDK and OpenNI/NITE

Functionality	Microsoft Kinect SDK	OpenNI/ NITE
Body parts representation	2D Links	3D Bodies
Number of Body parts	20	15
Occluded joints estimation	Yes	No
No need for calibration pose	Yes	No
Hand tracking framework	No	Yes
Gesture recognition framework	No	Yes
RGB stream registration to Depth stream	Yes	Yes
CPU intensive	Average	Low
Multiple sensors support	Yes	Yes
Other sensor support	Kinect only	Yes
Speech recognition	Yes	No
Audio support	Yes	No
Colour video stream	1024x768	800x600
Raw Infrared stream	No	Yes
Record Playback support	Yes	Yes
Programming language support	C#, C++	C++, Java, Python …
One step installation	Yes	No
OS support	MS Windows only	Linux, Mac OSX, MS Windows
Tilt motor support	Yes	No
Commercial use license	Yes	Yes

2.4. Accuracy of Kinect

The accuracy of the Kinect motion capture can be discussed in two different levels based on:

- the sensor accuracy
- the skeleton tracking accuracy

Sensor accuracy

The sensor accuracy in the literature is studied relative to professional motion capture systems or laser scanners with sub-millimetre accuracy. The sensor accuracy is not so relevant for rehabilitation since the skeleton tracking is the input that is useful for the user's motion; however two articles are presented for completeness.

In (Dutta, 2012) the Kinect sensor was able to capture the relative 3-D coordinates of markers with RMS errors near to 1 cm in all directions relative to a VICON (VICON, Oxford, UK) motion capture system. In (Rafibakhsh et al., 2012) Kinect's accuracy is compared with a laser scanner (Faro Focus3D). Kinect's sensor is calibrated from the researchers and its spatial resolution is calculated in points/cm^2. The resolution is found to decrease from 4.5 points at 1.7m distance from the sensor to 1.8 points at 3.4m distance.

Skeleton tracking

Skeleton tracking is a difficult task even for professional grade motion capture systems. Different protocols exist in biomechanics for compensation of skin artefact error and calculation of functional joint centres(Benoit et al., 2006). It is evident that similar level of accuracy cannot be expected from a marker-less, lower resolution, single camera sensor relative to multi-camera, high resolution systems, which use markers placed by professionals on anatomical landmarks of the subjects. However since also the professional systems face challenges to estimate the bone motion(Campbell et al., 2009) sometimes even with errors of a couple centimetres the skeletal tracking marker-less approach of the Kinect sensor becomes relevant. In (Cosgun, A., et al., 2013) the Microsoft Kinect SDK and the OpenNI framework were compared with a VICON optoelectronic multi-camera motion capture system VICON. Various motions were studied as walking, 360° turning around one self, sitting, picking up a box and occlusion of arms and full body. The error of the measurements relative to the VICON system and the frames where body parts were not tracked was studied. The two SDKs performed similarly in most cases all the body parts were tracked except in the full body occlusion motion and for some body parts in the 360° turning which is something to be expected since Kinect is not a multi camera system as VICON. The average error was found to be around 5cm while the maximum error was during fully body occlusion and it was very high. Skeleton tracking accuracy in various rehabilitation scenarios is studied in the next chapter.

2.5. Evaluation of the use of Kinect in physiotherapy

The Kinect sensor is widely used for development of rehabilitation applications, its applications are categorized in the following main physical rehabilitation areas:

Balance

In (Clark et al., 2012) the use of Kinect for assessment of postural control relative to commercial motion capture system was studied. Front, lateral reach and single stand with eyes closed were the tests performed from 20 healthy subjects. Kinect found to have similar intra subject repeatability and concurrent validity to the professional system however its inability to reconstruct limbs' orientation was noted.

In (Gonzalez et al., 2012) the centre of mass is estimated with Kinect by applying the statically equivalent serial chain method and it is evaluated relative to the accuracy of a balance board which was found to be very close to the accuracy of a force plate which is taken as the absolute measurement(Clark et al., 2010). Five healthy subjects participated in the research and the average Root Mean Square Error from all the subjects was less than 15mm with the maximum being 37 mm. Further in (González et al., 2013) the combination of Kinect and Wii-board is compared relative to a VICON motion capture system and an AMTI force plate with two subjects in this experiment the maximum RMSE was 37mm relative to 15mm of the professional equipment. Based on these findings the researcher proposes that Kinect has several advantages for balance rehabilitation while it is also a portable system.

In (Funaya et al., 2013) the accuracy of Kinect was studied relative to a commercial optoelectronic motion capture system for a instant posturography test. Six healthy adult subjects participated in the study, the comparison of the measurement results from the two showed that Kinect has adequate accuracy for balance measurement tests.

Vestibular system rehabilitation with Kinect as the motion tracking device and a Virtual Reality setup was performed in (Yeh et al., 2012). The Cawthorne-Cooksey rehabilitation exercise was practised from 17 subjects with chronic vestibular dysfunction. The subjects' performance in the tests, as the time histories from the deviation of their centre of gravity to the target, but also their subjective feeling were recorded. The findings of the study were that the practise of the exercise with the proposed system not only had medical benefits to the subjects but also increased their willingness and motivation for rehabilitation.

Balance disorder rehabilitation with Kinect is proposed also in (Garrido et al., 2013) where Kinect is used with a special framework to analyze the movement of the patients and to correct them. The system functions as a complement to professionals of physiotherapy. The use of the system was described from the medical professional as “a useful tool for home rehabilitation”.

In (Wade and Porter, 2012) the researchers studied the use of Kinect and exercise games to improve the sitting ability of children with cerebral palsy by leaning their upper body in different directions. Statistically significant improvements were found, but further research is needed to understand the effects of these types of activities.

In (Vernadakis et al., 2013) the use of Kinect for improvement of balance ability was studied relative to physical therapy. Sixty three young male previously injured athletes participated in the study. Both physical therapy and Kinect had improvements on the balance metrics of the athletes while the overall enjoyment was higher in the athletes that used the Kinect sensor.

Virtual reality in combination with Kinect was used in (S.-C. Yeh et al., 2013) for Ménière’s Disease-induced Chronic imbalance Problem rehabilitation. Fifty MD patients participated in the study all the patients showed statistically significant improvement, while age and number of practise sessions was found to influence the range of this improvement.

Upper limbs

A low cost arm rehabilitation system is proposed in (Pastor et al., 2012) were the user is practising with an exercise game moving his arm over virtual obstacles presented on screen. One stroke survivor with arm disabilities tested the system with encouraging results of enjoyment and willingness to use the system in the future.

The feasibility of using the Kinect system for arm rehabilitation for children with Cerebral Palsy in public schools was studied in (Chang et al., 2013). A simple 3 Degrees of Freedom model was used to represent the arm. An experiment was conducted with two CP children. During the experiment two types of interventions were used, one with a physical therapist only orally instructing the subject to perform a certain motion and one with the Kinect system giving visual feedback to the children for the correct performance of motion. Two special education graduate students were observing the experiment and were noting the number of correct motions during each intervention. The intra-observer agreement was above 97% of cases while the interventions with Kinect were found to have statistically significantly more correct motions.

In(Fernandez-Baena et al., 2012) the Kinect sensor's accuracy for the lower and upper limb was studied. For the upper limb various motions of the arm were performed. Kinect was evaluated relative to a VICON motion capture system. The accuracy of Kinect was found to be near to 13° for the shoulder motions.

In (Bonnechère et al.,2013) the accuracy and repeatability of Kinect was studied relative to a professional motion capture system. Forty eight healthy adults participated in the study. Kinect was found to be equally repeatable for Range Of Motion studies with the professional system. The calculation of shoulder abduction ROM was excellent while the elbow flexion was not stable in the two sessions of the measurement. A reason for these inaccuracies was the variability on the measurement of the limb lengths during the trials, something that is also reported in (Mavriki et al., 2013)

Lower limbs

In(Fernandez-Baena et al., 2012) (was mentioned above also for the upper limb) the lower limb the motion of knee flexion extension, hip flexion, extension on the sagittal plane and hip abduction adduction on the coronal plane were studied. The accuracy of Kinect was found to be less than 9° for the knee motions and less than 10° for the hip motions while when many repetitions were used to calculate the range of motion and incorporate it in the calculation the error was further reduced.

In (Bonnechère et al., 2013) (was mentioned above also for the upper limb) The accuracy of the ROM of hip abduction and knee flexion was not satisfactory.

In (Clark et al., 2013) the accuracy of Kinect was studied relative to a professional motion capture system. Twenty one healthy subjects participated in the study. Several spatio- temporal parameters were investigated. Gait speed, step length, step time and stride length from the two devices possessed excellent agreement. Foot swing velocity, step time and stride time were not accurate. The researcher proposes that Kinect can provide clinicians with a very useful tool but caution should be taken in the interpretation of the results.

In (Stone et al., 2013) Kinect is evaluated relative to a VICON system for the diagnosis of Anterior Cruciate Ligament injury. The "Drop vertical jump" test is used for the diagnosis. Thirteen healthy subjects participated in the study. The intra correlation coefficient between the Kinect and the VICON system was used for accuracy assessment of Kinect and was found to be sufficient accurate for this type of diagnosis.

2.6. Commercial applications

Implementations of Kinect for rehabilitation that are currently in development or commercially available are presented below. Some of them found in (Health start-up Europe, 2013) where several start-ups using the Kinect are presented, while others by searching the web. Many of these implementations were spin-offs from Universities or research centres and were founded through accelerator programs. A comparison of these systems is presented on the table below.

Table 2 Comparison of commercially available rehabilitation systems that use Kinect

Feature	MotionCare360	MIRA	Reflexion	Home Team	Doctor Kinetic	DevMotion	Voracy Fish	Meine-Reha	Jintronix	SeeMe	VirtualRehab
Web interface	YES					YES			YES		YES
Tele progress assessment	YES	YES	YES			YES			YES		YES
Tele prescription		YES	YES			YES			YES		YES
Multi patient		YES								YES	YES
Game				YES	YES		YES		YES	YES	YES
Approved from a Country Medical Organisation			In progress		YES						

2.7. Virtual reality

Virtual reality is a wide area in computer science that refers to simulated environments that are presented to the observer with a certain degree of immersion. Virtual reality usually refers to visual immersion but also other senses are involved most commonly hearing and touch with auditory and haptic or tactile stimuli. For visual immersion devices from simple displays to stereoscopic video glasses and VR CAVES are involved. Some applications of virtual reality towards the improvement of the rehabilitation systems are presented in the articles below.

In (Goffredo et al., 2013) the use of a Kinect and a projection screen is used. The subject sees himself mirrored inside the projection screen immersed in a virtual world. The task of the rehabilitation is the subject to perform certain reaching motions to virtual objects. Six right handed subjects participated in the study and performed successfully the task. The results of the study showed that the object representation influenced the learning curve and the velocity of the motion.

In (Hayes et al., n.d.) the development of a system for post stroke patients is presented. The system focuses on rehabilitation training of the paretic arm of the patients. The patient sees himself mirrored in a screen and he tries to control his virtual arm with his paretic arm.

In the literature meta analysis (Saposnik and Levin, 2011) concerning the benefits of the Virtual Reality in stroke rehabilitation. Twelve studies were included with 195 subjects. In the studies there was a 4.9 higher chance in improvement of motor strength, a 20% improvement in motor function outcomes and a 15% improvement in motor impairment. It is noted that Virtual reality can be helpful to increase the intensity and duration of the exercises, while the rehabilitation process is enhanced thanks to the multi-stimuli feedback.

In the editorial of the Journal of Neuro Engineering and Rehabilitation (Keshner, 2004) the editor discusses the advantages of using Virtual reality for rehabilitation. He describes the Virtual reality as able to create environments reach as in the physical world while controlled without the need of the reductionism of science. Some of the advantages of virtual reality he mentions are real time parameter measurement of the rehabilitation process, stimulus control, safe testing environment, repeatability, gradual increase to difficulty of the exercise or the stimulus, but most importantly increased motivation for the patient.

2.8. Tele-rehabilitation

Tele-rehabilitation is the employment of the electronic communication networks for rehabilitation purposes (Russell T. et al., 2009). Tele-rehabilitation can be used for distant home rehabilitation, study of the patient's progress and prescription of future treatment without the patient leaving his home. There are several technologies of tele-rehabilitation but in this research the most important are the communication of electronic medical records, the use of motion capture systems as it is the Kinect, the virtual reality for home rehabilitation.

A cloud based rehabilitation system for the gleno-humeral joint is proposed from (S. C. Yeh et al., 2013) that supports analysis of the patient's motion on the cloud where the medical professional can also find the progress of the patients and issue prescriptions for rehabilitation.

In (Golby et al., 2011) a low cost system is proposed for assessment of the patient's "Activities of Daily Living". The therapist while being in the clinic can measure quantitatively (Range of Motion) the patient's improvement in daily life activities between therapy sessions. A similar approach is presented also in (Hondori et al., 2012).

In (Tacconi et al., 2013) the patient can exercise at home while the therapist, being in the clinic. is able to asynchronously observe the patient's progress and adjust the therapy.

(Callejas Cuervo et al., 2013) notes the importance of tele-rehabilitation for countries were patients have difficulty to access rehabilitation centres, as the countries of Latin America.

In (Wood et al., 2012) and (Finkelstein et al., 2013) a tele- rehabilitaiton system for elderly is proposed entitled Home Automated Telemanagement. The system allows home rehabilitation of walking for the elderly and monitoring of their progress and prescription for the clinicians. Statistical significant improvement was found for the elderly while there was high acceptance of the system.

Commercially available motion tracking devices are studied for use with a web based application in (Dhillon et al., 2012). Kinect is found to be useful for rehabilitation, diagnosis and for social aspects or emergency situations with video calling.

2.9. Exer -games

Exer- games is a term used for games that the player involvement includes forms of physical exercise. Exer- games can be used for fitness or for therapy. In this project we focus on the exer- games used for rehabilitation of the motor system.

In (Taylor et al., 2011) a literature review was performed on activity promoting gaming systems used for rehabilitation. In the literature several case studies were found supporting encouraging results in rehabilitations settings. A limitation was found on existing exer- games system that were used in rehabilitation, that even-though they enhance balance and fitness they were not specifically designed for rehabilitation and they propose that future work should focus on the specific needs of rehabilitation.

Game design principles for rehabilitation games for stroke patients are discussed in (Wang, 2012). The author distinguished in the literature that two important aspects of game design for rehabilitation are feedback and adjustability of the challenge. While she noted that games targeted at upper limb rehabilitation have shown potential in terms of both therapeutic value and patient enjoyment.

In (Dukes et al., 2013) 6 stroke patients used a Kinect based upper limb rehabilitation exer- game and positive feedback about it to the supervising physiotherapist.

In (Borghese et al. 2013) an intelligent game engine for rehabilitation is presented. This game engine supports personalized feedback and adjustability of the game challenge while a multi layer abstraction approach for designing highly adjustable and configurable games is presented in (Omelina et al., 2012).

2.10. Psychological factors

The following psychological factors related to home rehabilitation with motion capture systems as Kinect were noted from researchers in literature.

Shared decision making

Shared decision making and set of goals is very important for the patient treatment while the satisfaction of the user setting and succeeding a goal that he agreed upon is evident, the education of the patient in decision making and planning about his treatment will have a greater impact in the success of the treatment (Moore, 2012).

Motion compensation

Motion compensation is the act of the patient to avoid performing the treatment motion and instead to perform a motion that is not relevant with the treatment but tricks the rehabilitation system to register it as the correct motion. Researchers are developing rehabilitation system's that detect and alert the user if he is trying to compensate motions (Da Gama et al., 2012)

Challenge

The physiotherapy exercise need to be interesting and not boring for the patient. The variability on the difficulty level and complexity of the exercise according to the patient's performance is important to keep the patient interested. (Weiss et 2004)

Engagement and positive feedback

Positive feedback is included in most rehabilitation systems to keep the user motivated and interested. In (Swann-Sternberg et al., 2012) a rehabilitation system was evaluated from physiotherapists and patients and it was noted the importance of positive feedback. In (Ganesan and Anthony, 2012) a score board is proposed to motivate the patients to set and achieve targets. While in (Lamoth et al., 2012) different types of feedback were used and found that when the feedback is competitive it does not have any improvement to the results of balance rehabilitation.

Social aspects

The rehabilitation exercise is a chance for the patient to socialize either at home with friends and family either at the clinic with other patients or the therapist(Kolbjornsen, 2012). While the use of social networks can be beneficial for the patients either to exchange and discuss their progress or to feel empathy (Anacleto et al., 2012). Another aspect is that the patients by collaborating together or with the therapist in a rehabilitation game they become motivated to continue their treatment. Finally the social aspect of rehabilitation is important for the patients not only for their treatment but also in their everyday life (Weyer et al., 2012).

2.11. System design

In (Kolbjørnsen, 2012) the researcher used the Research Through Design methodology. The researcher built three prototypes for rehabilitation systems based on motion sensing game technologies with one of them being the Kinect, the other two were the Nintendo Wii remote and the Playstation Move. After building these prototypes he presented them on a board of experts including medical and physiotherapy professionals. Technical evaluation of the systems followed while questioners were filled from the expert's board with a focus group discussion at the end. Kinect was found to be the most technically adequate system for home rehabilitation. The outcome of questioners and focus group can be summarized in the following guidelines for the development of home rehabilitation systems:

1. It is not possible to have one system fits all rehabilitation demands. The experts found that each system had respective advantages for certain rehabilitation exercises.
2. All the systems motivated the user to perform physiotherapy exercise.
3. For specific physiotherapy targets more focalised games are needed.
4. The games must have very flexible adjustment of difficulty in order to be always challenging but not too hard for the users.
5. The rehabilitation games should be more social allowing family members or friends to participate.
6. The system should be easy to setup and start using it at home.
7. The system should encourage the user to not compensate motions.
8. The progress of the user should be tracked and be available both to the medical professional and the user.
9. The system noise and obstructions should be minimal.

In (Swann-Sternberg et al., 2012) the researchers interviewed physiotherapists and patients with chronic musculoskeletal pain to find out their user requirements from an interactive physiotherapy system. The requirements were grouped in for before the exercise session during and after. A resume of these requirements is presented below:

Before the exercise

1. User selection of exercise goals
2. Sessions to adjust the difficulty of the exercise
3. Encouragement for the user to start and continue the exercise

During exercise

1. Exercise specific to the therapy
2. Exercise presentation before the its performance from the user
3. Different avatar's for the user and the coach that can be selected according to the user's preferences.

4. User's movements are presented with an avatar as captured from the system
5. Feedback for the user's motion performance can be enabled and disabled.
6. Positive feedback for the user during the exercise for encouragement

After exercise

1. Presentation of all data captured
2. The user can selected what type of data is captured
3. Options for different presentation of the results

2.12. Summary

Some of the key findings of the literature research are the following:

Kinect is a motion tracking tool that is widely used in rehabilitation research and it is agreed that has great potential. Kinect rehabilitation application research includes cognitive, balance, upper- lower limb, hand finger spine and neck rehabilitation. The system is sufficiently accurate for rehabilitation in several application areas in comparison to commercial motion capture systems.

The use of virtual reality provide personalized rehabilitation that can be easily parameterized to the patient's needs from the clinician and can track the patient's rehabilitation progress quantitatively with high accuracy. The virtual environments help in the immersion, the easy task learning and the motivation of the patient to the subject of the exercise.

Tele medicine applications can be used from the clinician to study the patient's progress and to modify the patient's rehabilitation plan as needed without the need of the patient to make an appointment or having the discomfort of visiting a doctor.

2.13. Proposed system

Based on the literature research and the limited time span of a master thesis the following project was proposed and implemented as the subject of the thesis.

A prototype system for rehabilitation was developed based on Kinect, for motion capture, with a game centric idea. The rehabilitation of the upper limbs was the target of the project. The upper limb was selected since, according to the literature the accuracy of Kinect is higher there, than on the lower limbs.

The prototype has:

1. a parametric virtual environment,
2. a natural user interface (gesture or voice control),
3. it is be able to analyze the user's progress and give feedback
4. basic online functionality for tele- medicine purposes

The system acts as a controller for the performance of the exercise. It adjusts the difficulty of the exercise in order the user to don’t feel discomfort and to complete the exercise.

An experiment was performed in order to assess the feedback channels of the system. The motion capture accuracy, the face expression recognition and the voice recognition were studied. While at the end of the development the system was assessed by volunteers with questionnaires.

3. PROJECT MANAGEMENT

3.1. System requirements

The high level requirements specifications found in the literature review are the followings grouped in functional and non functional requirements

Functional requirements

1. System for arm physiotherapy
2. User's movements are presented with an avatar as captured from the system
3. Motion compensation control
4. Sessions to adjust the difficulty of the exercise
5. Encouragement for the user to start and continue the exercise
6. Progress tracking and analysis
7. Feedback for the user's motion performance
8. Presentation of all data captured
9. A parametric virtual environment
10. Basic online functionality for tele -medicine purposes
11. Multiplayer support for social games

Non-functional requirements

1. Easy to start using the system at home (hardware software compatibility, setup)
2. Use a natural user interface (gesture and/ or voice control)
3. User selection of exercise goals
4. Exercise presentation before its performance from the user
5. Different avatar's for the user and the coach that can be selected according to the user's preferences
6. Options for different presentation of the results
7. Feedback can be enabled and disabled
8. Keep system noise and obstructions minimal
9. The user can selected what type of data is captured

3.2. Resources

The system was developed using the Kinect sensor, and is functional on a PC. The system was developed in Visual Studio using C#.

The software that was used include

- the Kinect SDK for the extraction of the user's skeleton.
- the WPF Framework for the exercise games applications and GUI
- the Helix toolkit for the stereoscopic effect
- Web sockets for telemedicine functionality

The hardware of the system included the Kinect for Windows sensor and a PC. The characteristics of the PC were similar to the system requirements of Kinect:

Processor: Intel Core i5 2430M, dual core, 2.4GHz-3.0GHz

Memory: 4GB RAM

OS: Windows 7

3.3. Development model

For the development of the system the **incremental** development model was used. At the beginning a system prototype with the core functionality, as a proof of concept and at the following iterations functionality was increased with additional software units. In the proposed system we can identify the following software units as presented in the figure below

The use of an incremental approach is important for the design of a system that it's focused in a specific task from a specialized discipline as the physiotherapy. The first system iteration includes only one game based on its simplicity.

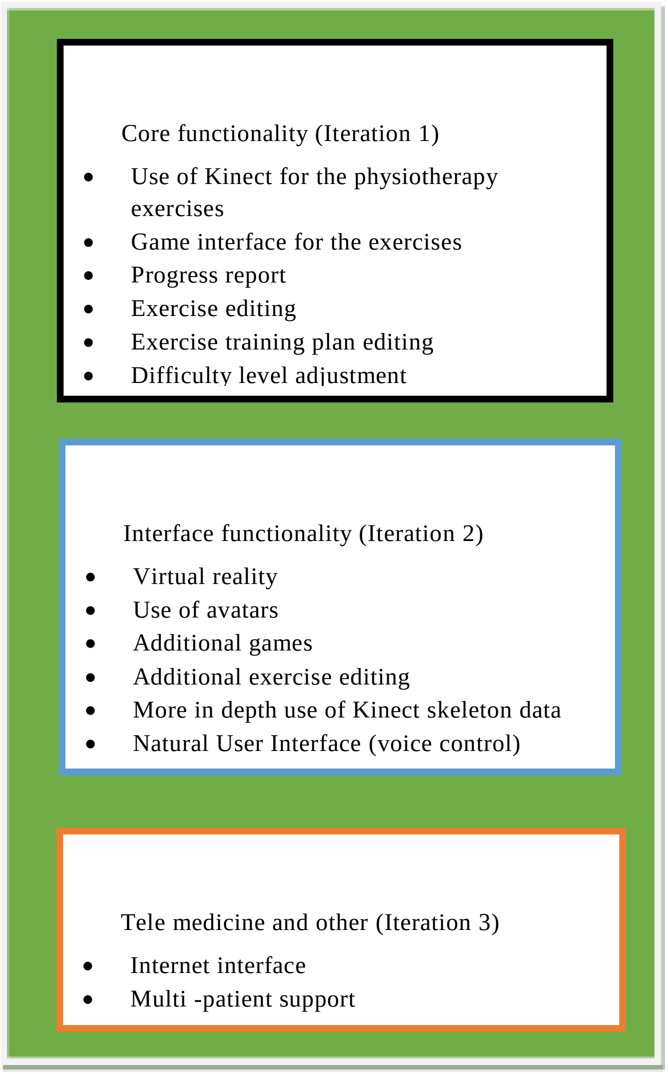
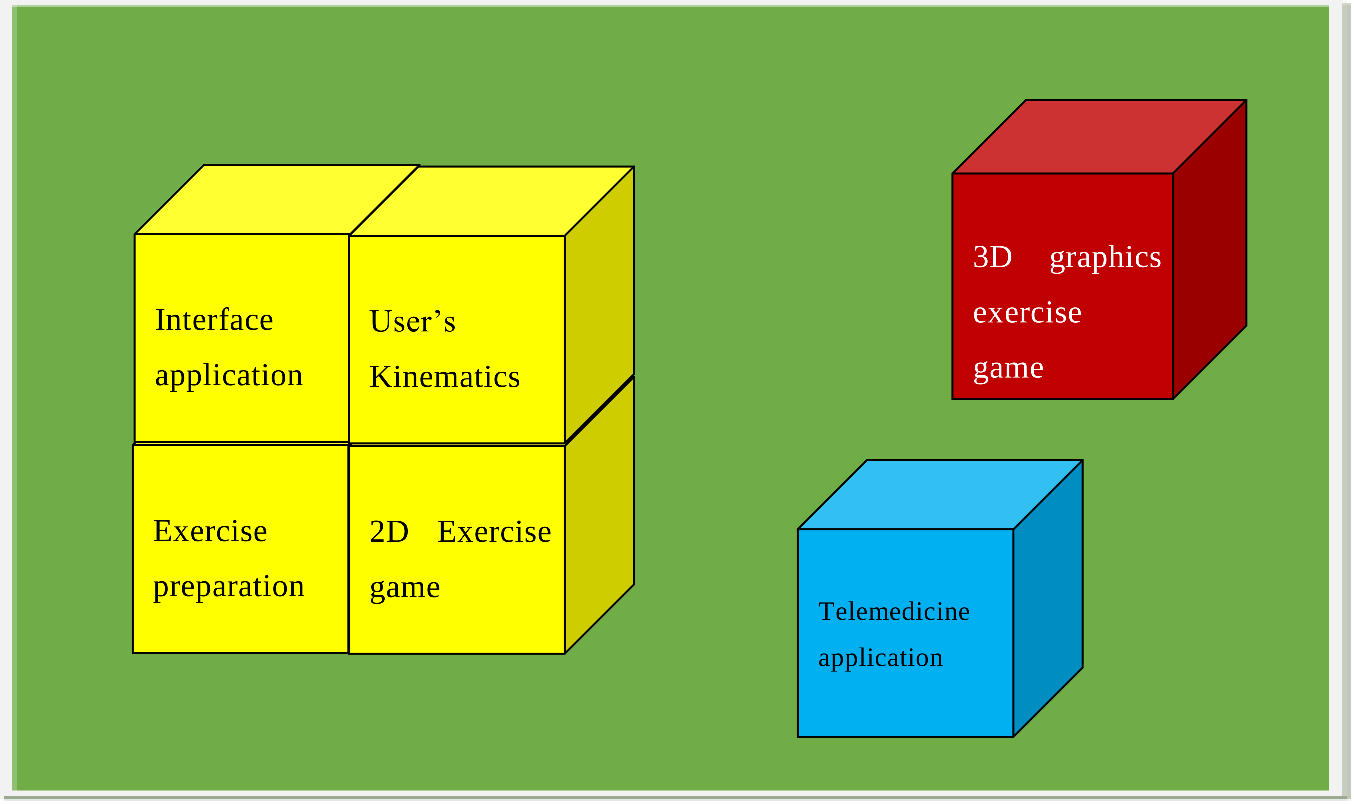


Figure 7 System Iterations

In the figure below the project is separated in packages and their detailed functionality is described.



- 3D graphics
- Stereoscopic effect with head tracking
- Target for next motion based on exercise and kinematics
- Natural User Interface (voice control)
- Avatar presentation

- Interface for the application
- Progress report
- Difficulty level adjustment
- Selection of tracked information

- User's position relative to Kinect
- Joint angle calculation

- Exercise editing
- Exercise training plan editing

- Game algorithm
- Game content
- Target for next motion based on exercise and kinematics

- Internet connectivity
- Upload and download of patient data
- Upload and download of exercises

Figure 9 Packages and their Detailed functionality of the packages

3.4. Work plan

For the work plan the initial Gantt chart and the project Milestones were defined as presented in the tables below.

Table 3 Gantt chart

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Literature									
Iteration 1									
Milestone 1									
Iteration 2									
Milestone 2									
Iteration 3									
Milestone 3									

Table 4 List of Milestones

Milestone 1	The discussion of the system with a board of experts as medical doctors, physiotherapists
Milestone 2	The use of the system with a Virtual Reality system as a Power Wall
Milestone 3	Thesis report

Due to a successful ERASMUS application and observations on the work plan from the supervising Professor the work was modified. An experiment was added for the evaluation of the Kinect natural user interface signals. While at the end of the project an evaluation of the system was performed from volunteers.

3.5. Erasmus Secondment

The subject of the secondment was facial expression recognition with Kinect. This functionality is used from the system as bio feedback in order the system to understand when the patient is feeling discomfort.

During the secondment also the Internet connectivity of the system was developed in order the doctor to be able to see the progress of the patient and provide him with new exercises.

4. DEVELOPMENT

For the development of the system the ICONIX process was used. The ICONIX process is a well defined methodology for the design of object oriented software. The ICONIX process can be separated in four steps

Step 1: Requirements analysis

The requirements review is used to produce cases model, the analysis of which will produce a problem domain model and prototype GUIs.

Step 2: Preliminary Design

The use cases are described in detailed text analyzing the user system interaction.

The robustness analysis follows that is helps to apply the text description to the domain model.

Step 3: Detailed Design

The use case detailed is used to create the sequence diagrams.

The domain model is transformed to a class diagram with addition of the method that were identified.

Step 4: Implementation

The programming phase follows.

The implementation of the ICONIX method for the proposed system is presented below.

4.1. Requirements analysis

Use case model

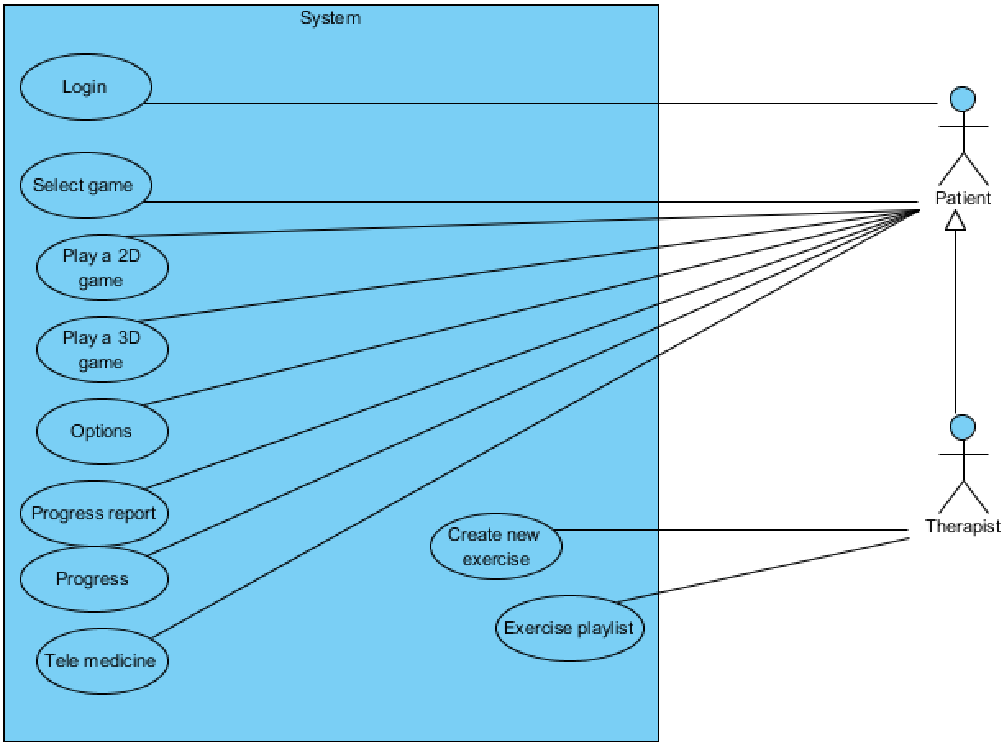


Figure 10 Use Case model

Table 5 Use cases

Use Case	**Name**	Main User	Secondary User	Use Case Description
UC01	Login	Patient	Therapist	The user logins and the system identifies him either as Patient or as Therapist
UC02	Select game	Patient	Therapist	The user selects type of game to play
UC03	Play game 2D and 3D	Patient	Therapist	The user plays the game in 2D and in 3D
UC04	Progress	Patient	Therapist	The system presents the game's progress
UC05	Difficulty level	Patient	Therapist	The user can change the game difficulty
UC06	Track data	Patient	Therapist	The user can change the type of data to be tracked
UC07	Progress report	Patient	Therapist	The system present a detailed progress report for the user
UC08	Create new exercise	Therapist		The Therapist creates a new exercise
UC09	Exercise playlist	Therapist		The Therapist changes the exercise playlist
UC10	Telemedicine*	Patient	Therapist	The user uploads downloads progress report, user data and exercises from a server

* The telemedicine use case is not presented since it concerns only transfer of files.

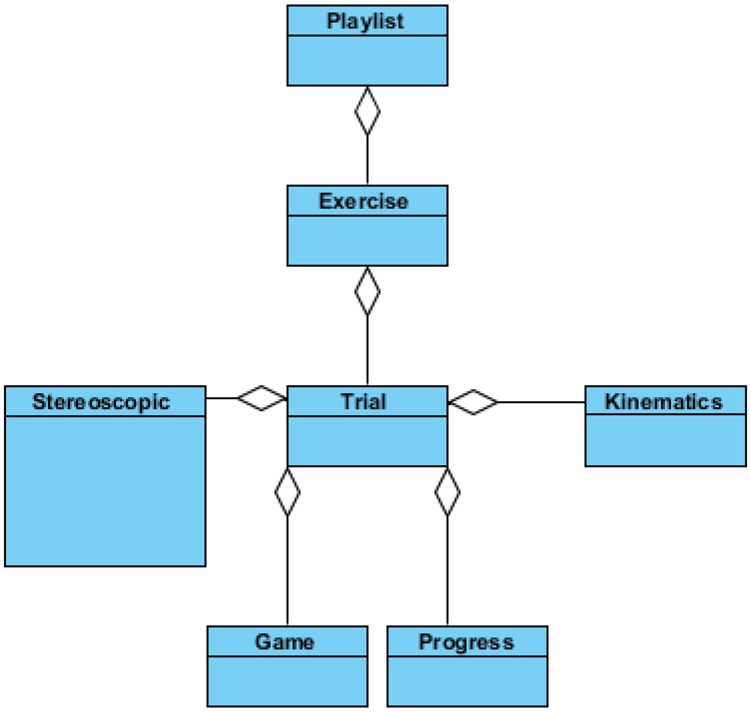


Figure 11 Problem domain

GUI prototypes and implementation

The GUI prototypes and their actual implementation follows

- The following GUI prototypes were created
- Login
- Main menu (Patient- Therapist)
- Options (Patient- Therapist)
- Select Game
- Post Office Game
- Progress
- Progress Report
- Edit Exercise
- Exercise Playlist
- Telemedicine menu

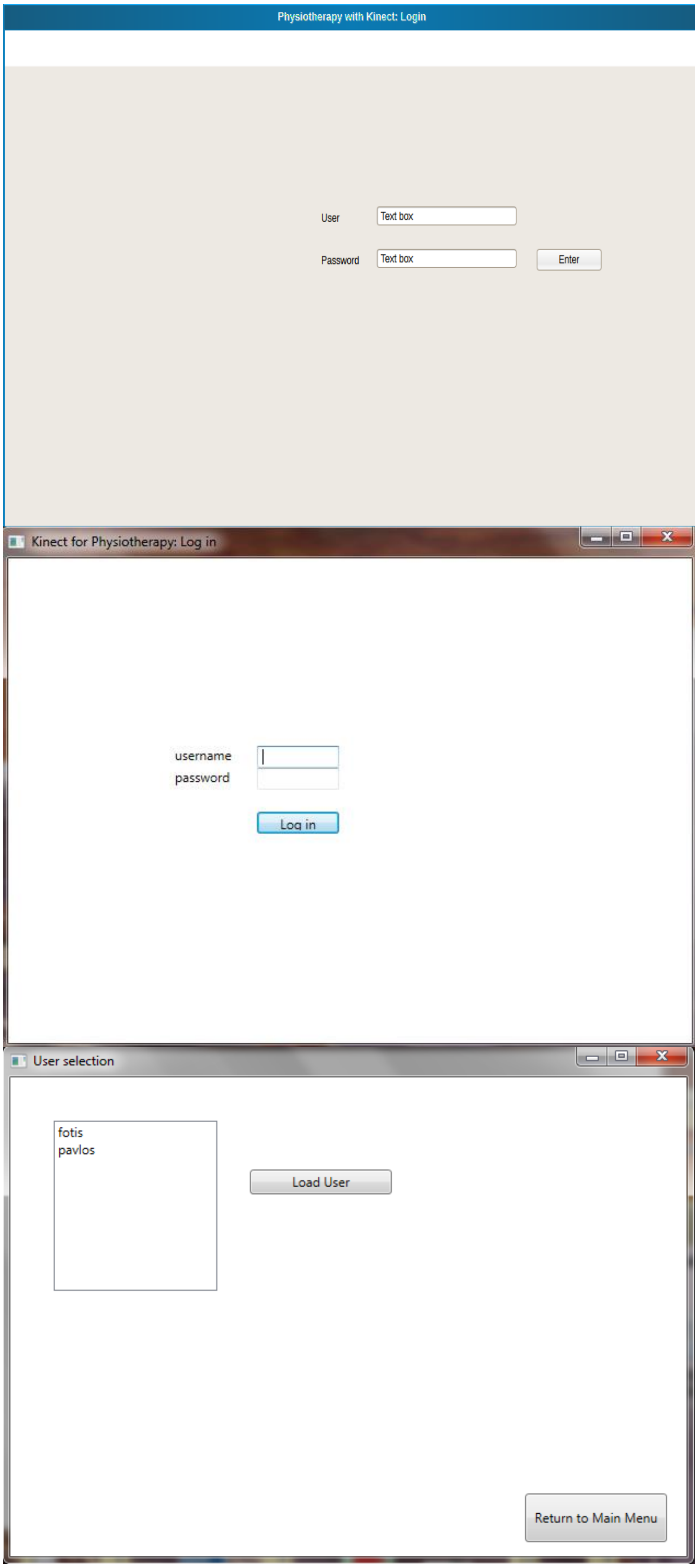


Figure 12 Login screen for normal user design and implementation and an additional screen for the professional user to select patient.

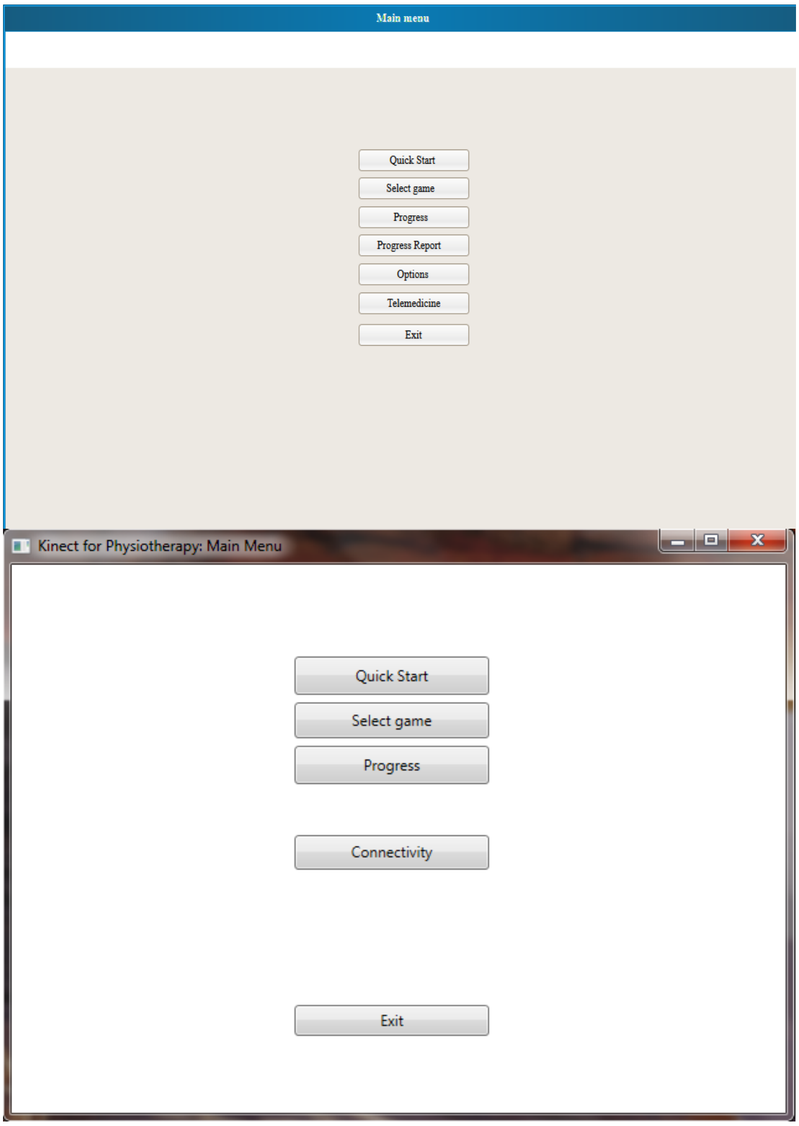


Figure 13 Main menu Design-Implementation (Patient)

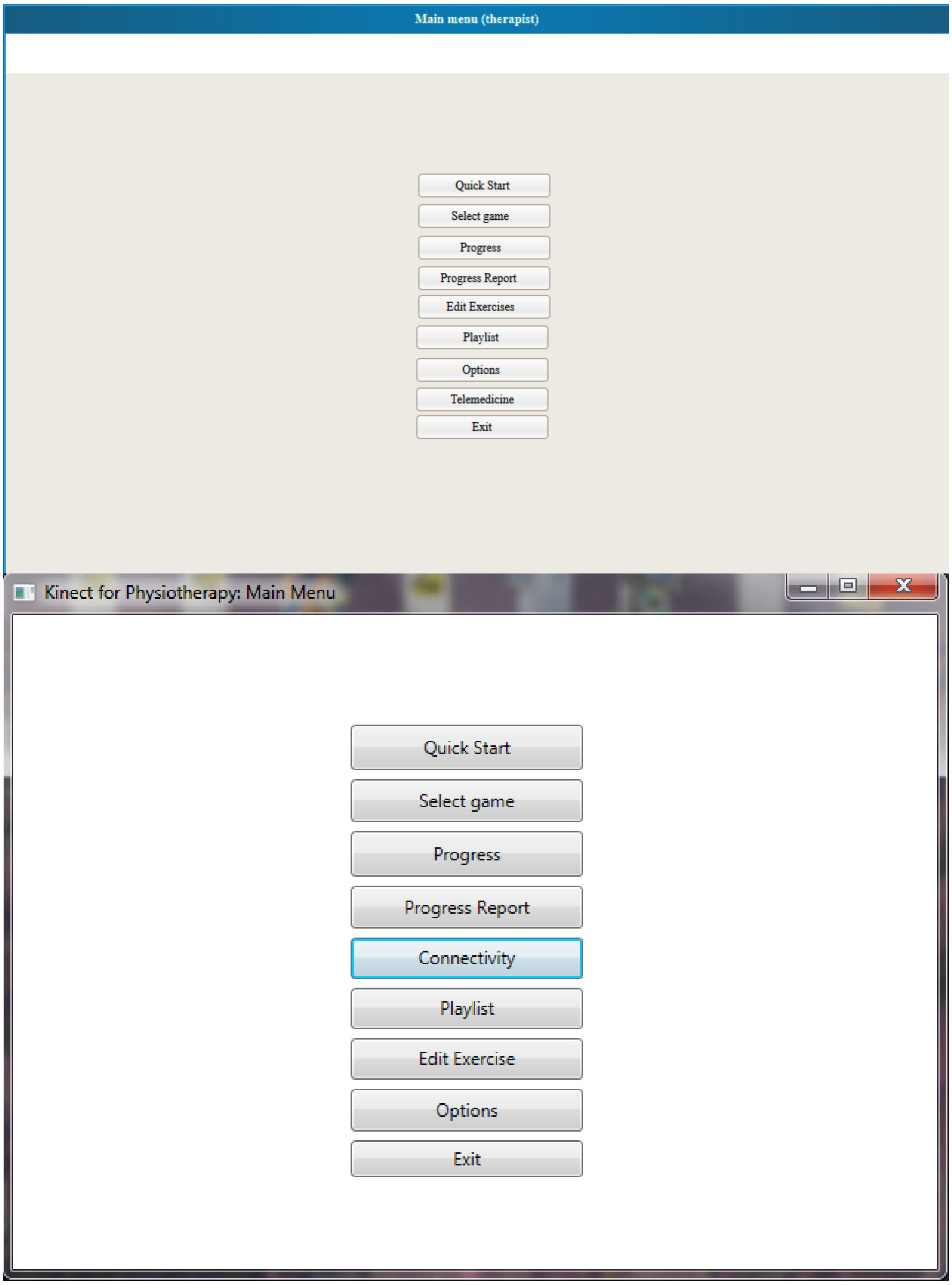


Figure 14 Main menu (Professional User)

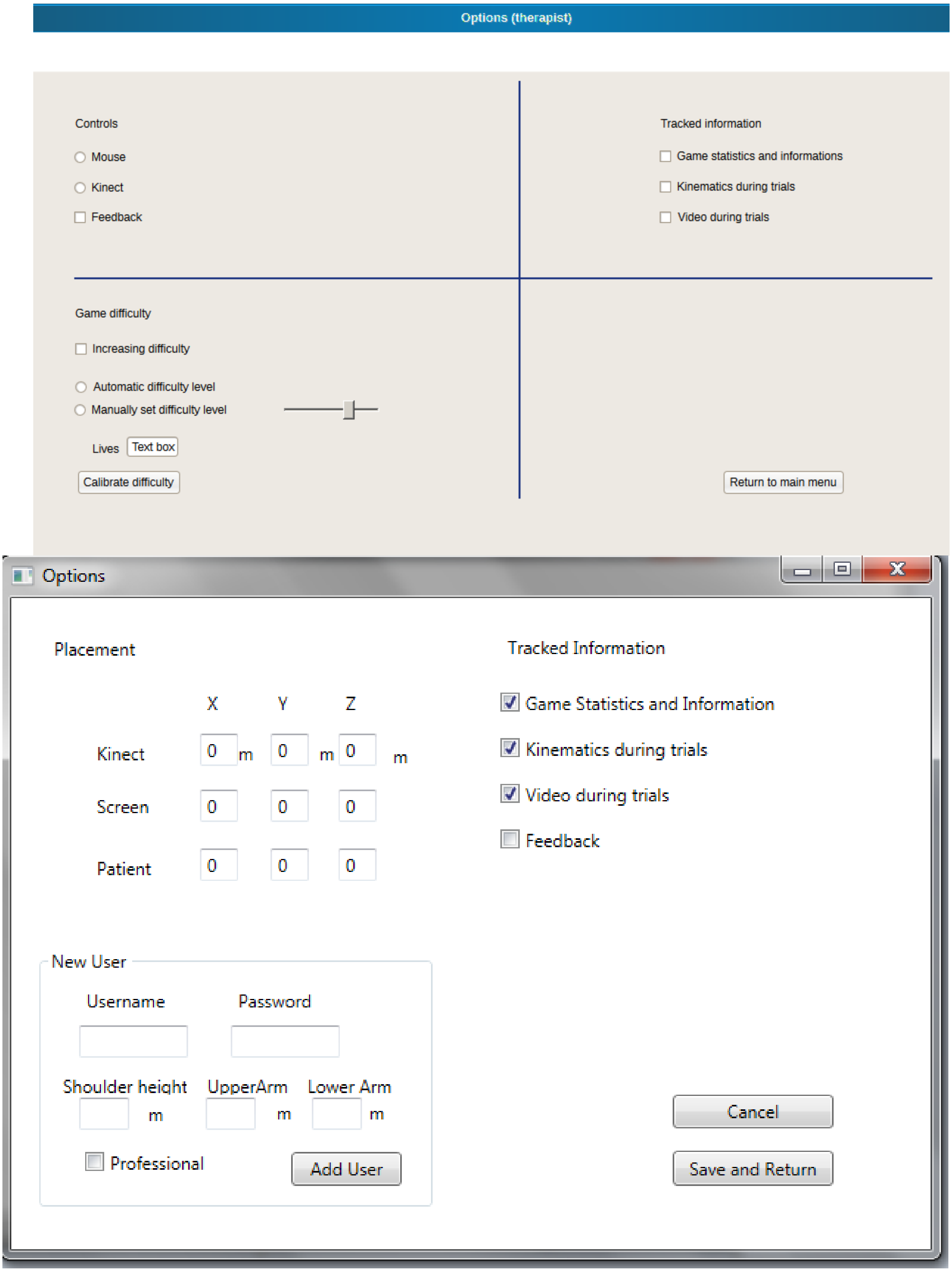


Figure 15 Options

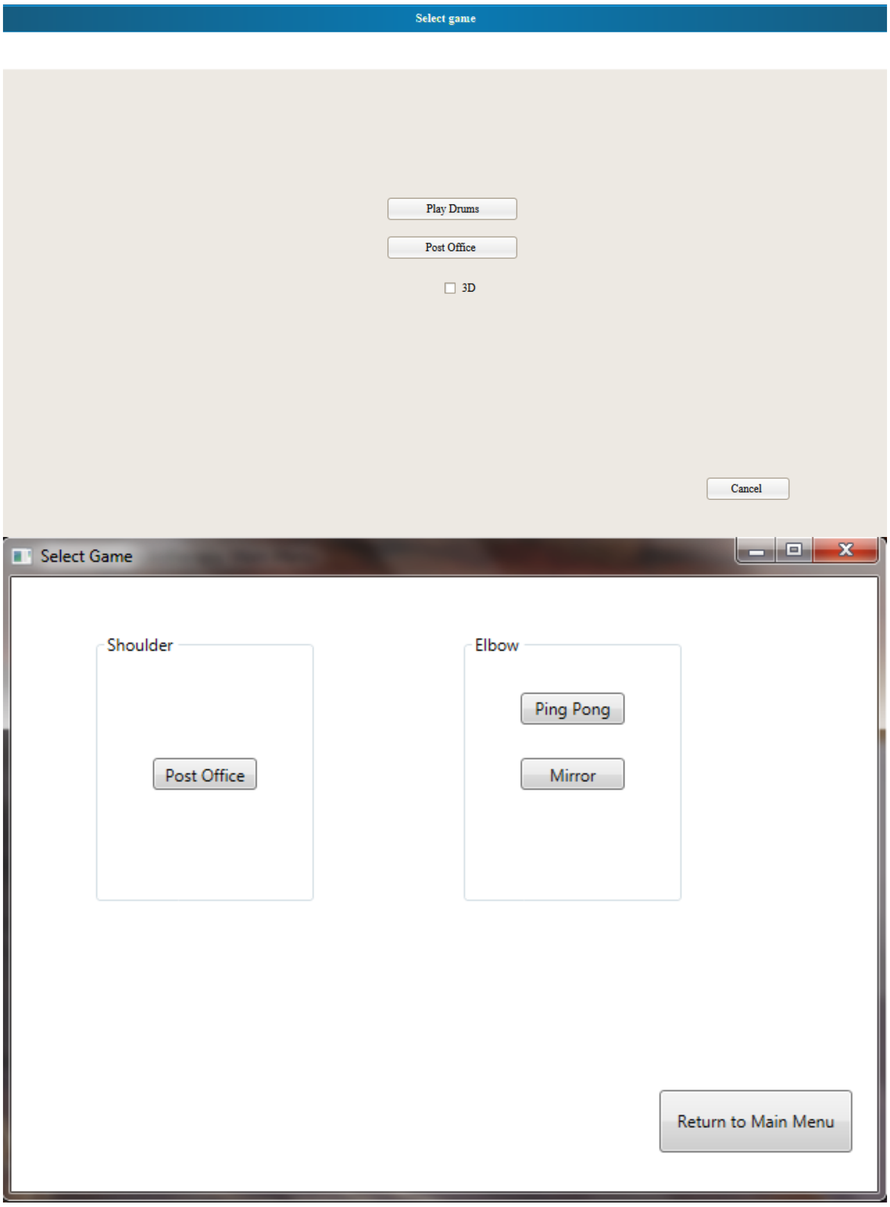


Figure 16 Select game

Figure 17 Post office game

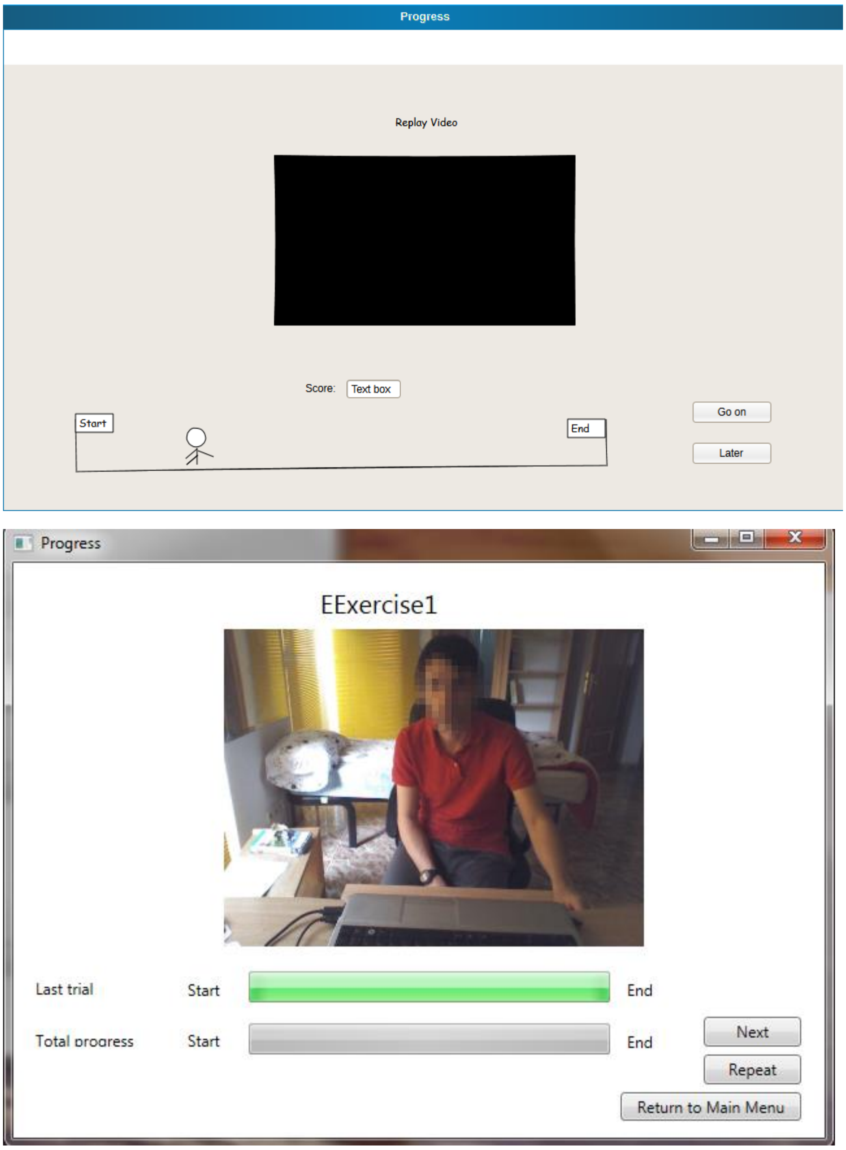


Figure 18 Progress

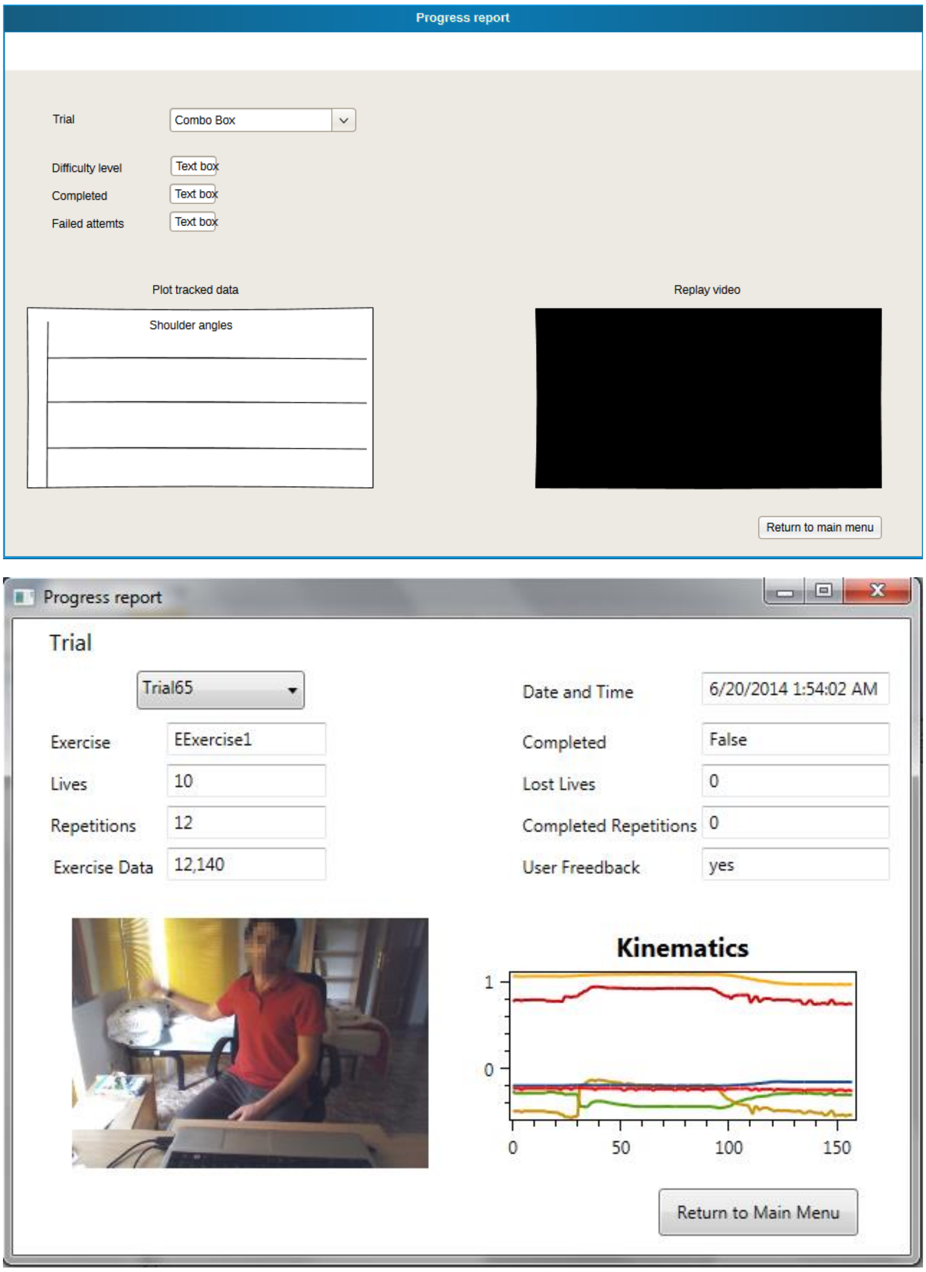
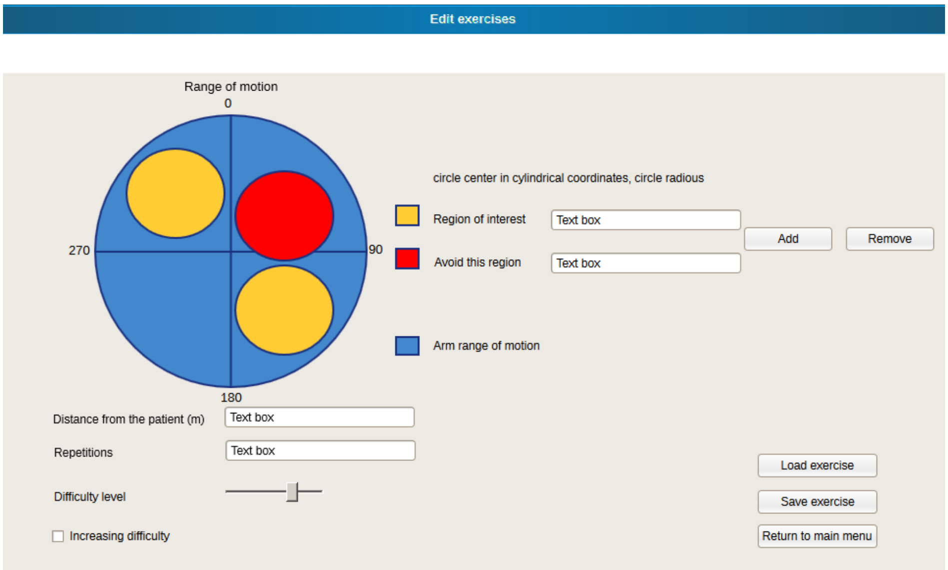
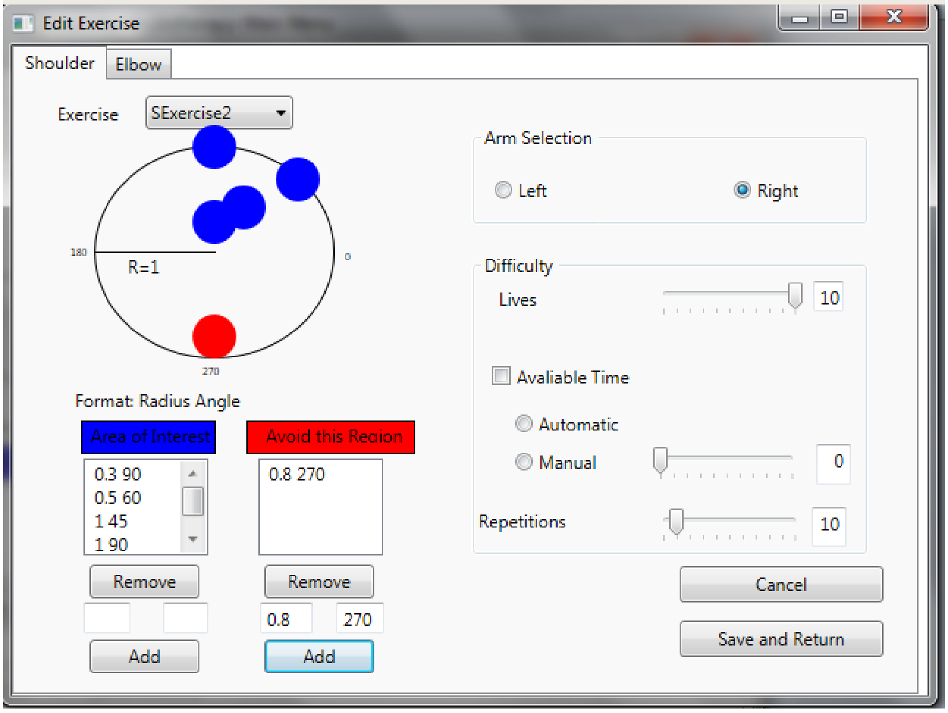


Figure 19 Progress report


Edit exercises
Range of motion
0
270
90
180
circle center in cylindrical coordinates, circle radious
Region of interest
Text box
Add
Remove
Avoid this region
Text box
Arm range of motion
Distance from the patient (m)
Text box
Repetitions
Text box
Difficulty level
Increasing difficulty
Load exercise
Save exercise
Return to main menu


Edit Exercise
Shoulder
Elbow
Exercise
SExercise2
180
R=1
0
270
Format: Radius Angle
Area of Interest
Avoid this Region
0.3 90
0.5 60
1 45
1 90
0.8 270
Remove
Remove
0.8
270
Add
Add
Arm Selection
Left
Right
Difficulty
Lives
10
Avaliable Time
Automatic
Manual
0
Repetitions
10
Cancel
Save and Return

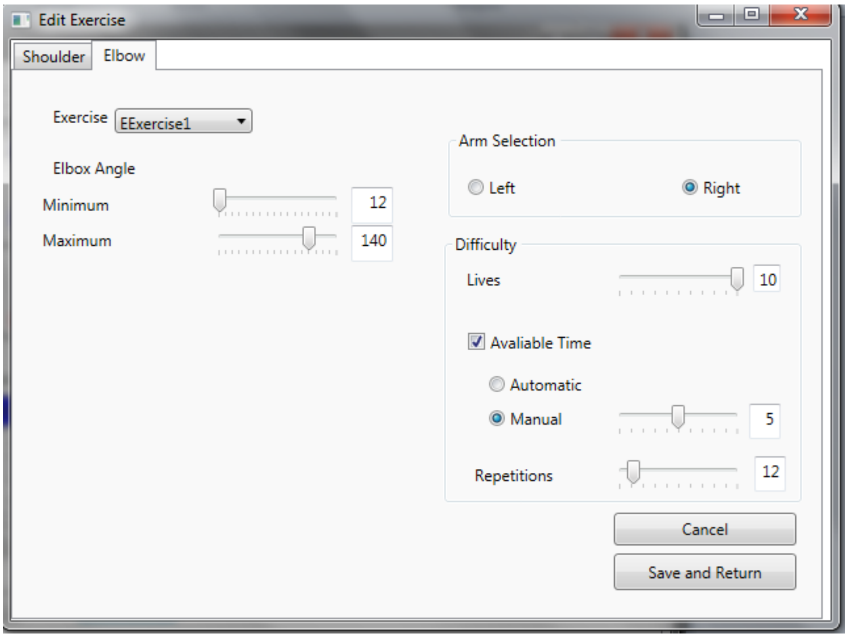


Figure 20 Edit exercise Design and Implementation and additional exercise editor for the elbow joint

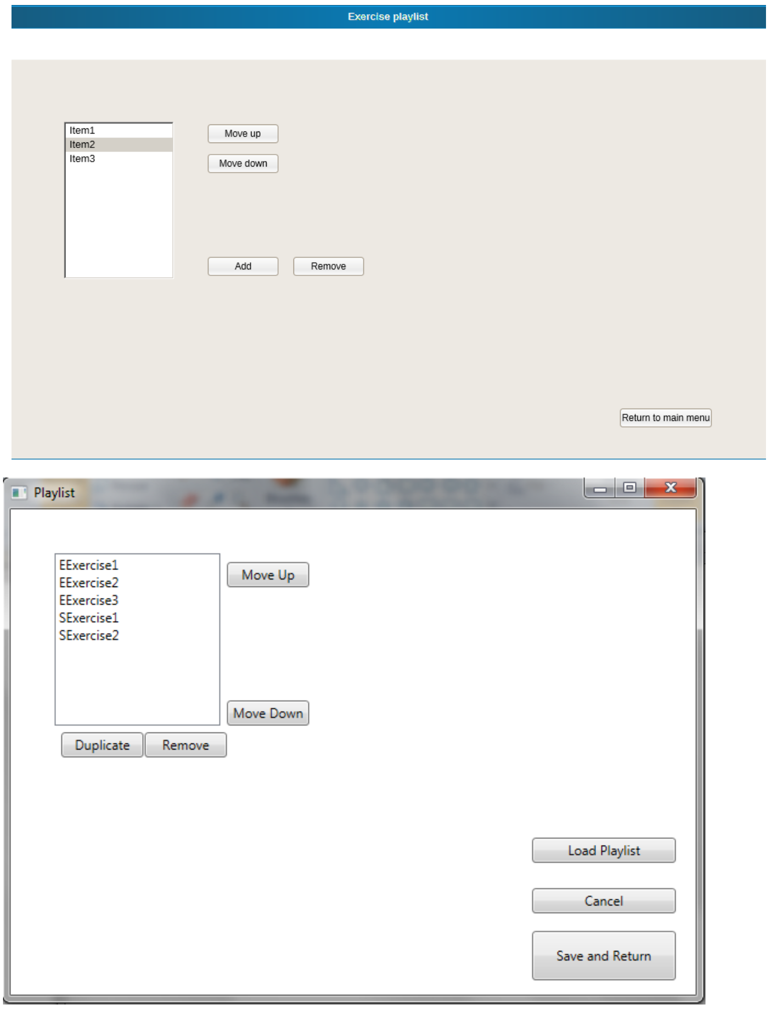


Figure 21 Exercise playlist

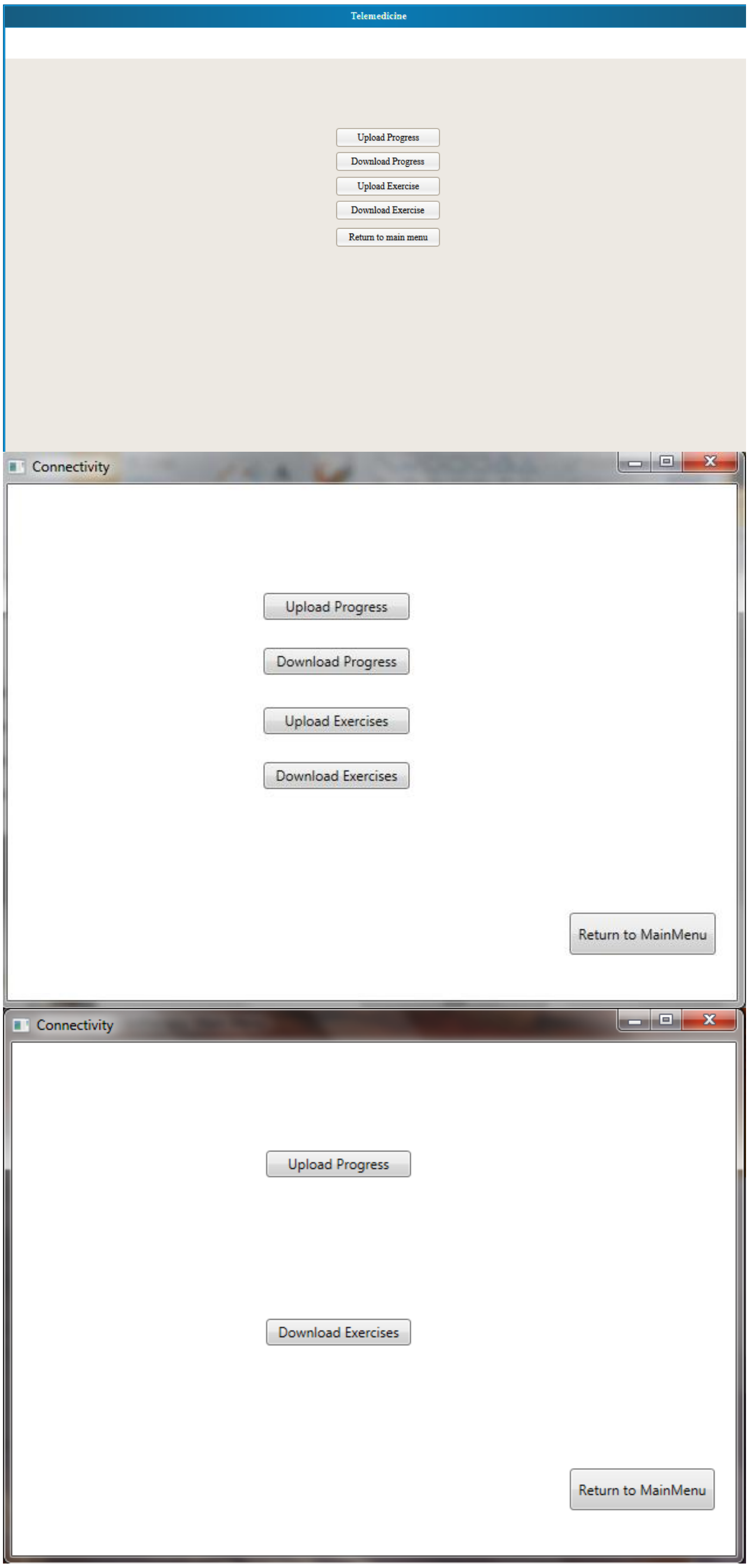


Figure 22 Telemedicine menu for professional user and patient

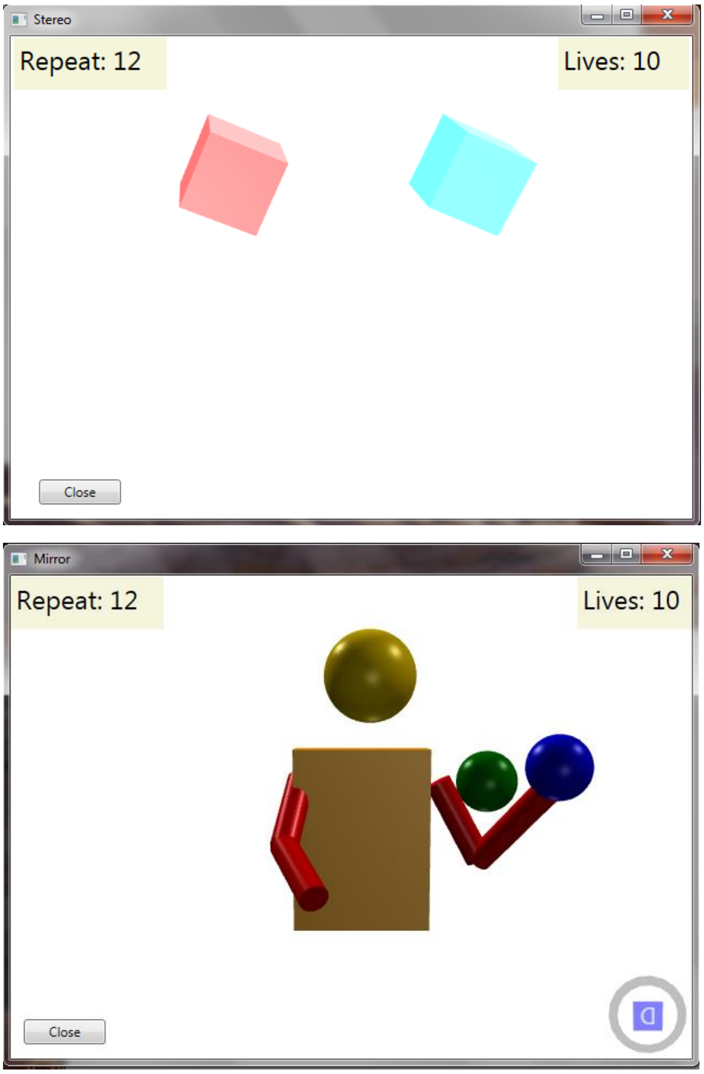


Figure 23 The two games for the elbow joint exercise

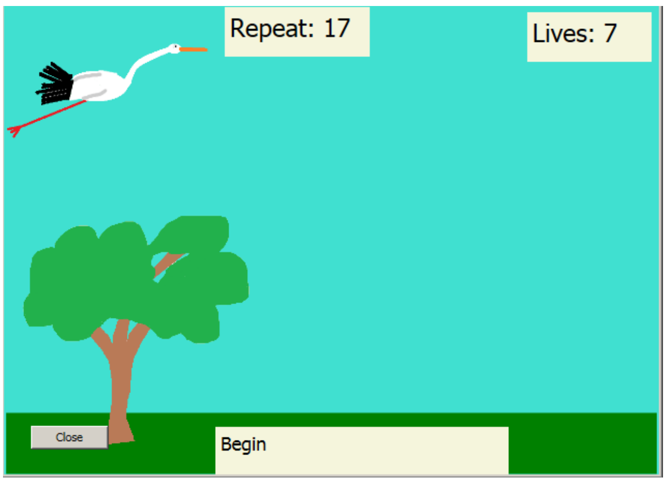


Figure 24 The game for the shoulder abduction

4.2. Design

Login use case

1. The user enters his user name and password and presses enter
2. The system opens and loads the user file
3. If the combination user name and password, exist and are correct, the system opens the patient progress file (PPF) (only one patient per system for now)
4. If the user is the therapist the system sets the therapist flag to true
5. The main menu screen according to the therapist flag is displayed

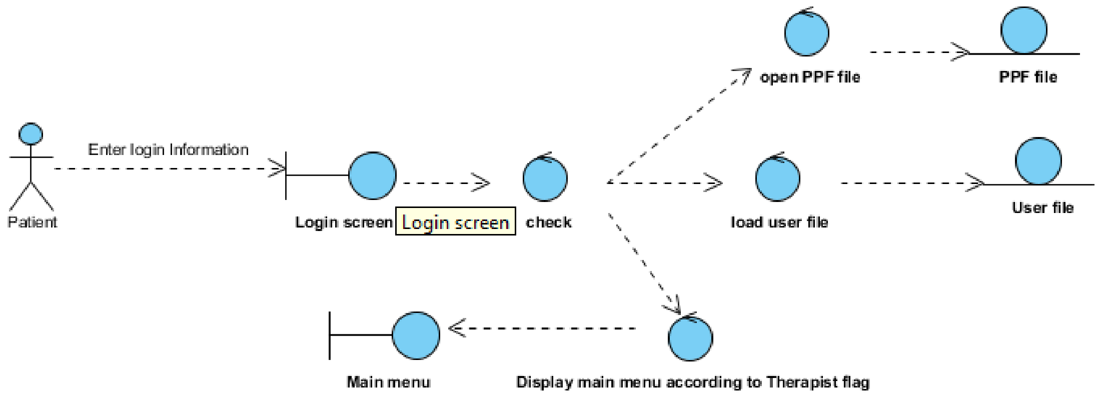


Figure 25 Login Use Case

Select game

1. The user selects Select Game from Main menu
2. The Select game screen is displayed
3. The user selects a game
4. The last played game (LPG) variable changes to the selected game
5. The last practiced exercise(LPE) is loaded from the PPF

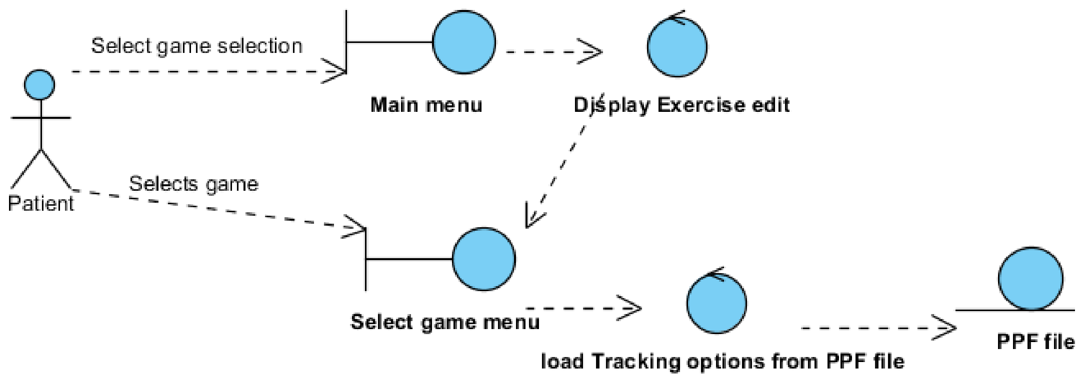


Figure 26 Select game Use case

Alternative flow

1. a The user selects from main menu quick start
2. a The LPE loads from the PPF
3. a LPG variable loads from the PPF

Play game

For presentation simplicity this use case is broken in two parts Play game and progress

1. The LPG game file loads
2. The game screen is displayed
3. The Exercise Playlist (EPL) file loads
4. The exercise difficulty loads (countdown time)
5. The tracking option loads from the PPF
6. The increasing difficulty loads from the PPF
7. If the manual difficulty is exists in PPF loads and replaces exercise difficulty
8. The controls loads from the PPF
9. The exercise repetitions loads
10. The exercise lives loads (available failures)
11. The video starts recording if set in the tracking options
12. The kinematics are saved in a matrix if set in the tracking options
13. The exercise file based on the LPE from the EPL loads
14. The repetition counter decreases by one
15. A position is selected randomly from the Range Of Interest (ROI) matrix (This matrix is included in the exercise file)
16. The position is found in the game file's Position matrix (PT)
17. The object described in the PT matrix is highlighted on the display
18. Countdown timer starts

19. The user moves the mouse at the highlighted point before time Is over
20. The reaction time is measured
21. The score counter increases by one
22. The repetition counter decreases by one
23. A position is selected randomly from the Permit This Area (PTA) matrix (This matrix is included in the exercise file)
24. The position is found in the game file's Position matrix (PT)
25. The object described in the PT matrix is highlighted on the display.
26. Countdown timer starts
27. The user moves the mouse at the highlighted point before time Is over
28. The reaction time is measured
29. The score counter increases by one
30. Go To 14
31. After 3 repetitions compare reaction time to difficulty if very near display on screen "Faster" else display "You are doing well"
32. If increase difficulty is true after 10 repetitions decrease countdown time by 1 sec
33. When the repetition is 0 display on screen "Success"
34. If set in the tracking options save LFE and LGP and game statistics as score, difficulty, lost lives are save in the trial file TRI, reaction times, recorded kinematics and video are saved in the corresponding RT and KIN file and AVI files, save LFE and LGP in the PPF file
35. increase LFE by one
36. Go To 11

Alternative flow

12 a The user fails to move his hand at the position if lives>0 one life is removed

13 a Goto 7

12 b The user fails to move his hand at the position if lives=0 the game ends

13 b If set in the tracking options save LFE and LGP and game statistics as score, difficulty, lost lives are saved in the trial file TRI, reaction times and recorded kinematics are saved in the corresponding RT and KIN file and AVI files, save LFE and LGP in the PPF file.

14 Progress is displayed

12 c User selects stop

13 c Progress is displayed

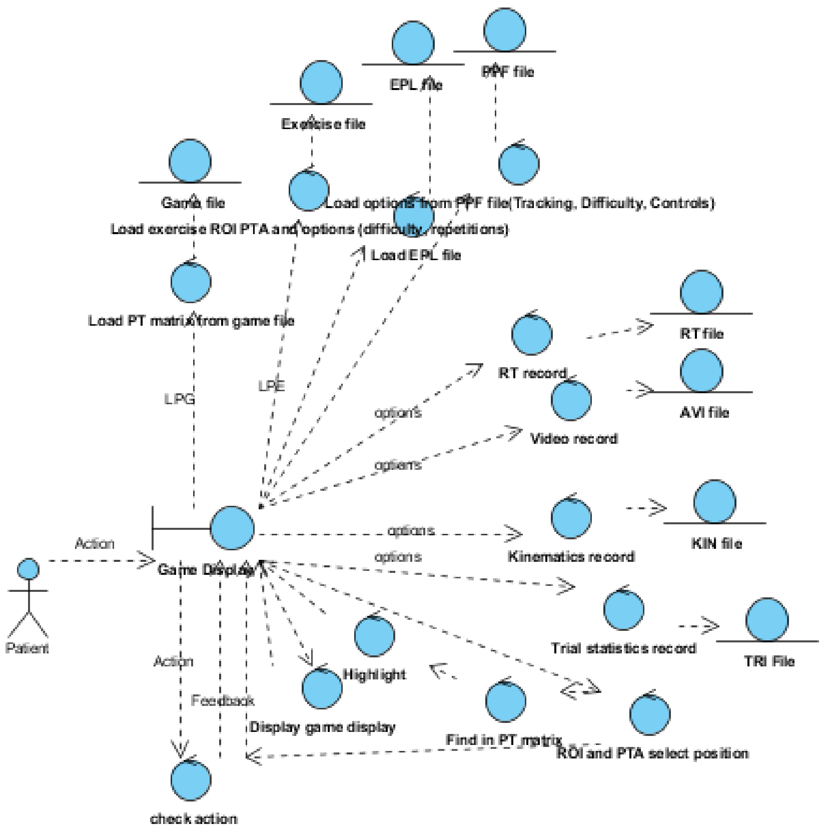


Figure 27 Play game 2D Use case

Figure 28 Play game 3D Use case

Progress

1. The progress screen is displayed
2. If set in the tracking options the video starts replay
3. The score is displayed
4. The stick figure is moved from the start to the end relative to the repetitions completed.
5. The user selects return to main menu

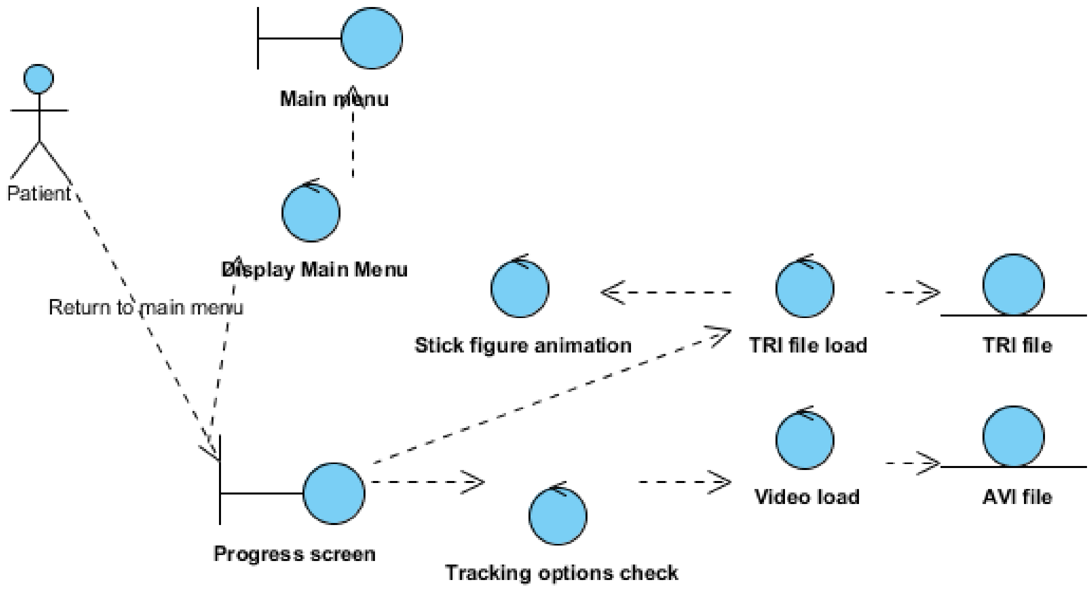


Figure 29 Progress Use Case

Progress Report

1. The user selects progress report
2. The progress report screen is displayed
3. The user selects trial
4. The trial file is loaded and the parameters are displayed
5. The video if exists is loaded and starts to play
6. The tracking data if exists is loaded and ploted
7. The users selects return to main menu.

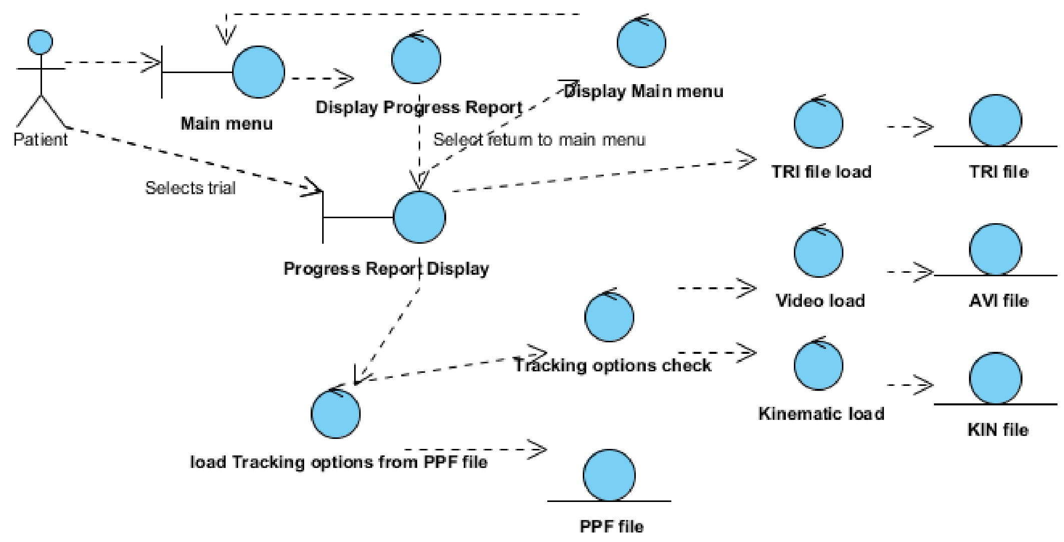


Figure 30 Progress report Use Case

Create new Exercise

1. The user enters distance from the patient
2. The user enters repetitions
3. The user sets difficulty level
4. The user sets the checkbox increase difficulty
5. The user sets ROI circle in cylindrical coordinates
6. The user selects add
7. ROI circle is drawn
8. ROI matrix adds box points in approximate Cartesian coordinates for the circle
9. The user sets ATR circle in cylindrical coordinates
10. The user selects add
11. ATR circle is drawn
12. ATR matrix adds box points in approximate Cartesian coordinates for the circle
13. The user selects save exercise
14. The ATR matrix is subtracted from the Range of motion matrix to create the PTA matrix
15. A save file dialog appears
16. The exercise options (distance, difficulty) and the ROI and PTA matrix and coordinates are saved in the exercise file.
17. The EPL file open the exercise is added at the end of queue

Alternative

6. a The users sets a point in cylindrical coordinates
7. a The user selects remove
8. a If the point is inside a ROI or ATR circle, a circle in the colors of range of motion is drawn over it and the circle is deleted from them ROI or ATR matrix else nothing happens

1. b The user selects load exercise
2. b The load file dialog opens
3. b The user select exercise to load
4. b The exercise file loads
5. b The ATR and ROI circles according to the exercise file
6. b The exercise parameters are loaded
7. b continue from 1

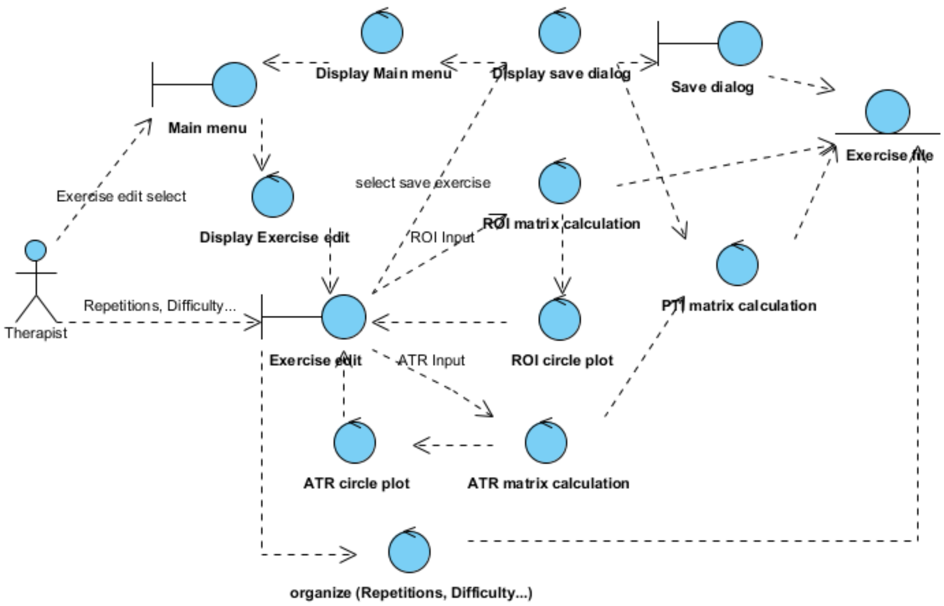


Figure 31 Exercise edit Use Case

Difficulty level and track data (or Options Use Case)

1. The user selects options from main menu
2. Options display is presented according to the therapist flag
3. The tracking option loads from the PPF
4. The increasing difficulty loads from the PPF
5. If the manual difficulty is exists in PPF loads
6. The controls loads from the PPF
7. The user change some parameter
8. User selects return to main menu
9. Changed parameters are saved in the PPF file
10. Main menu is displayed

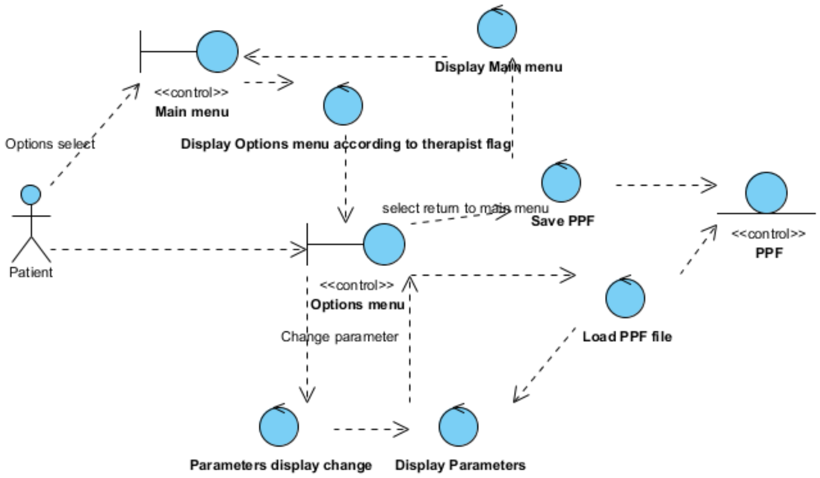


Figure 32 Options Use Case

Exercise playlist

1. The exercise playlist screen is displayed
2. The EPL file loads
3. The exercise list is displayed in the list box
4. The user selects an exercise in the box
5. The user selects up
6. The exercise replaces the preview in the queue and the previous becomes next for simplicity if the first exercise is selected it becomes last.
7. The user selects return to main menu
8. The queue is saved in the EPL file
9. Main menu is displayed

Alternative flow

5. a The user selects down
6. a The exercise replaces the next in the queue and the next becomes previous for simplicity if the last exercise is selected it becomes first.
7. a Continue from 7

5. b The user selects add
6. b A select file dialog opens
7. b The user selects exercise
8. b The selected exercise is added in the first place of the queue
9. b Continue from 7

5. c The user selects remove
6. c The selected exercise is removed
7. c If none is selected nothing happens

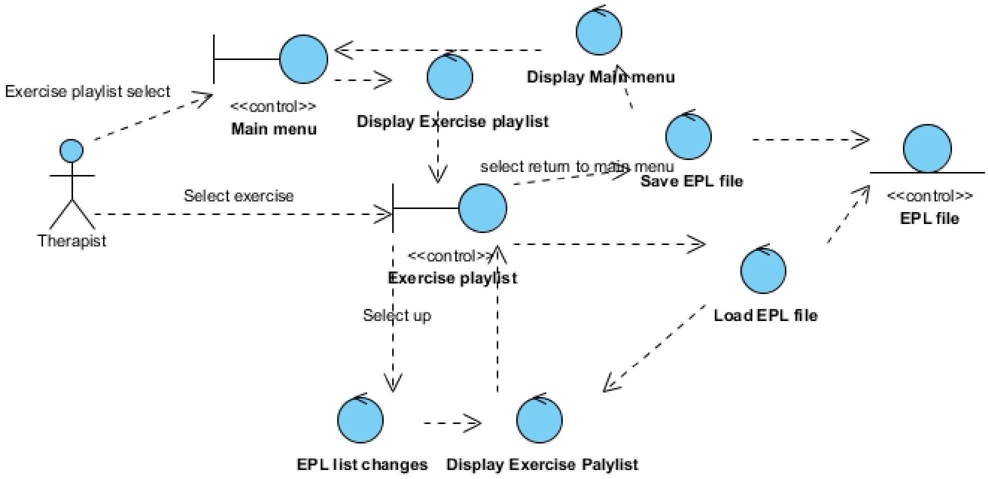


Figure 33 Exercise playlist Use case

4.3. Detailed Design

Sequence diagrams

The sequence diagrams and the class diagram are presented below

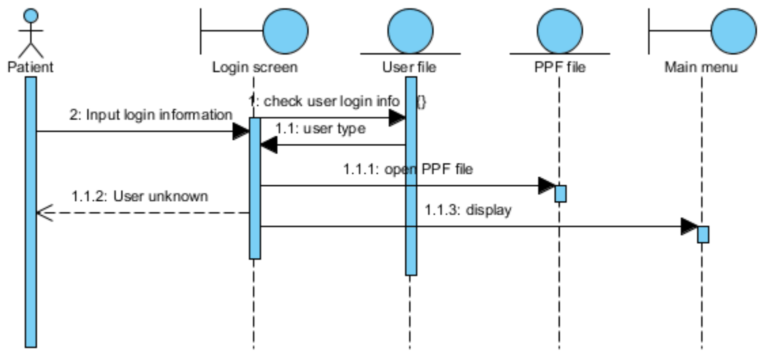


Figure 34 Sequence diagram for Login User Case

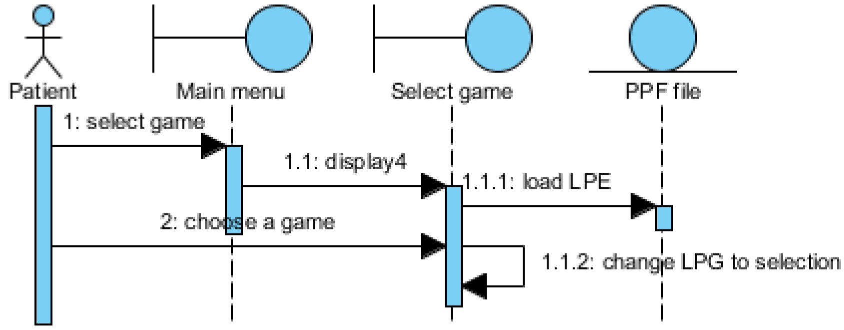


Figure 35 Sequence diagram for Use case select game

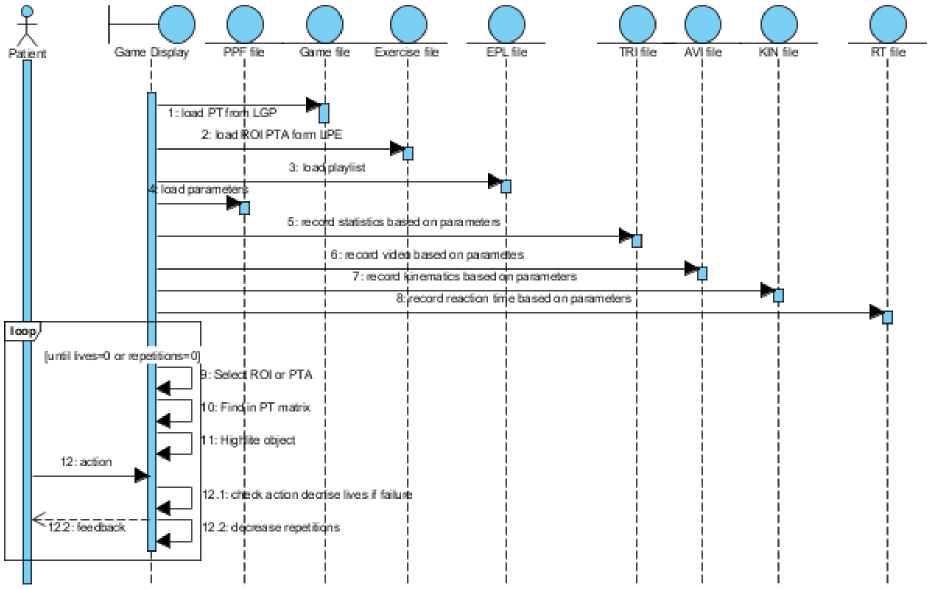


Figure 36 Play game 2D Use Case Sequence Diagram

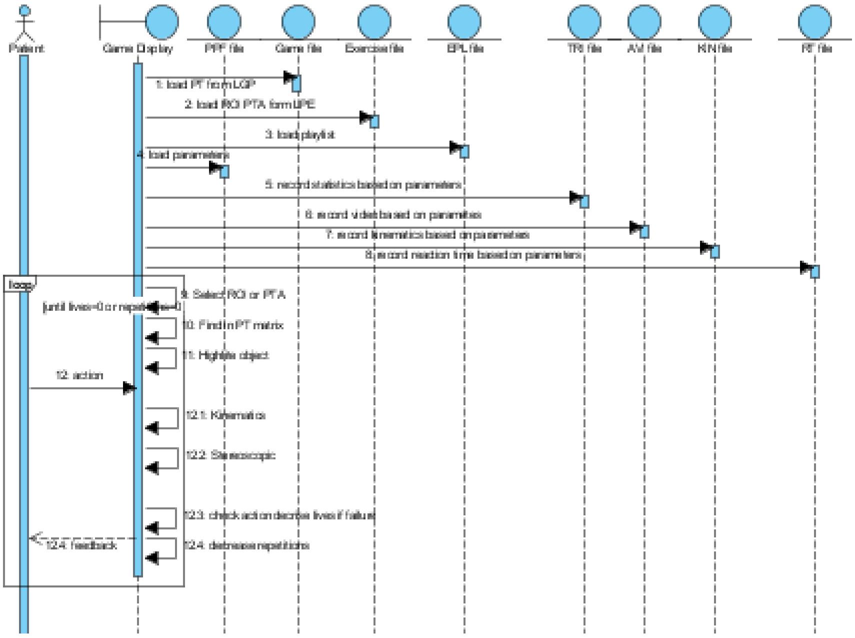


Figure 37 Play game 3D Use Case Sequence Diagram

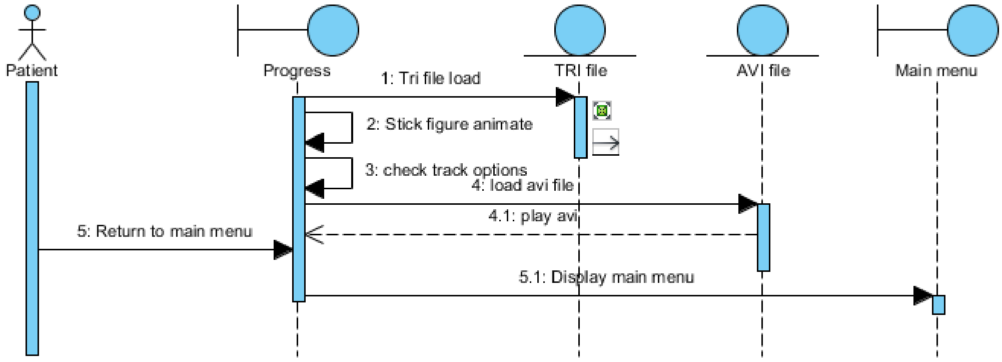


Figure 38 Progress Use Case Sequence diagram

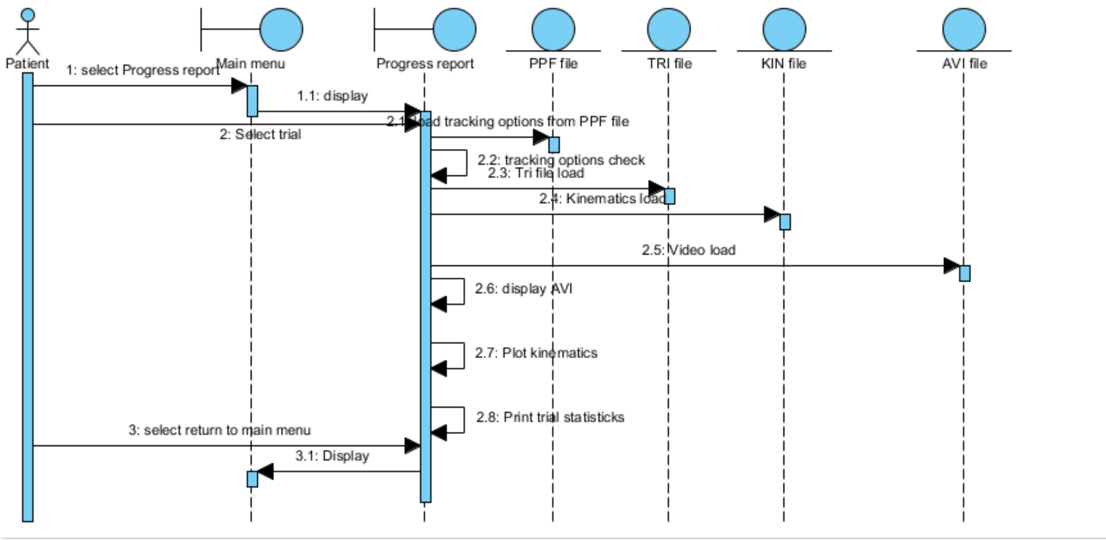


Figure 39 Progress report Sequence diagram

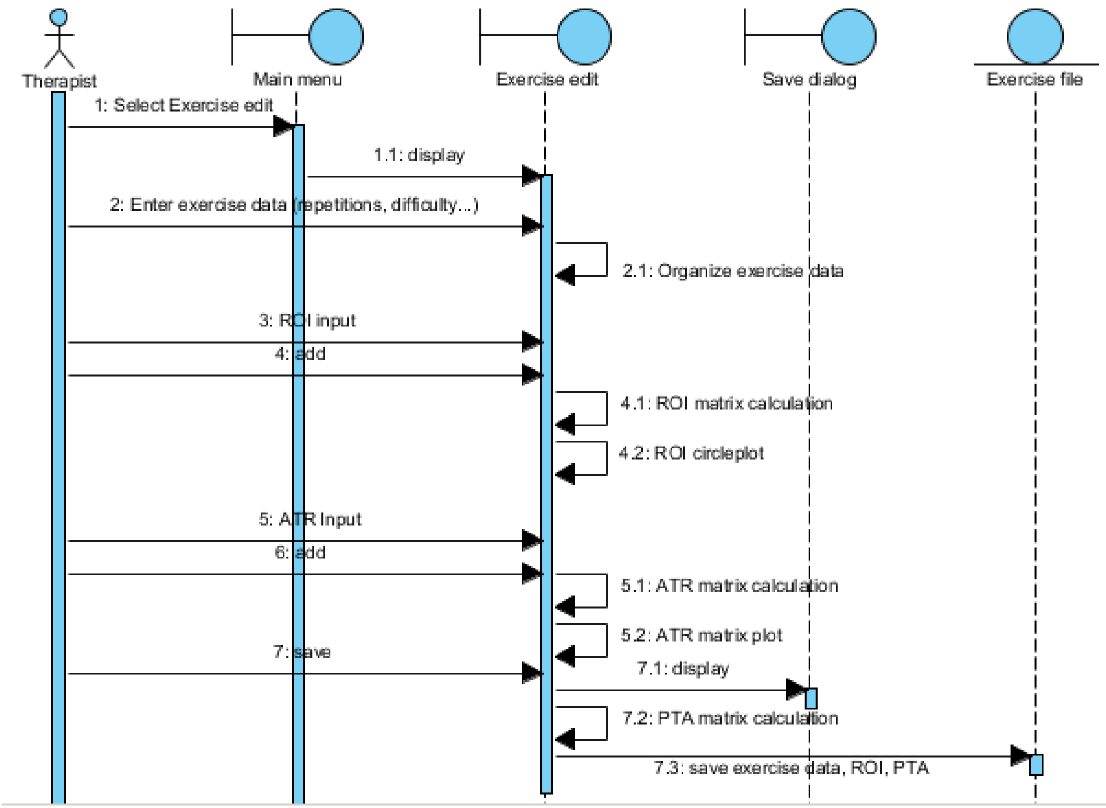


Figure 40 Exercise edit Use case sequence diagram

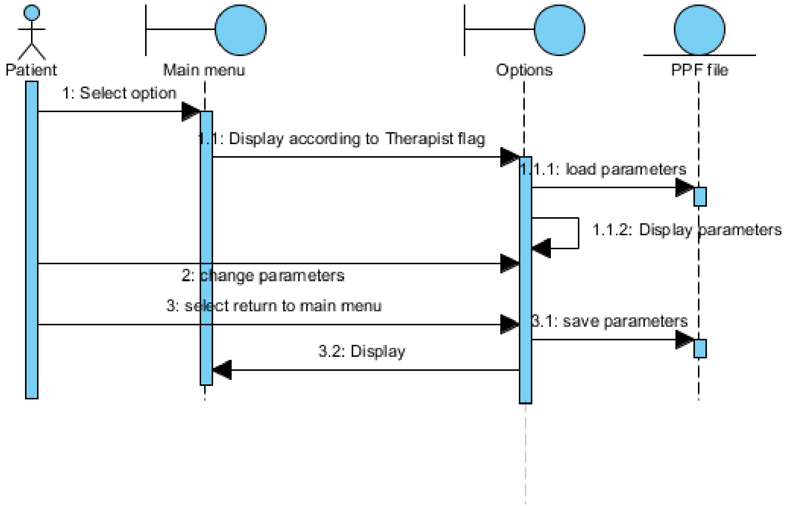


Figure 41 Options Use Case Sequence Diagram

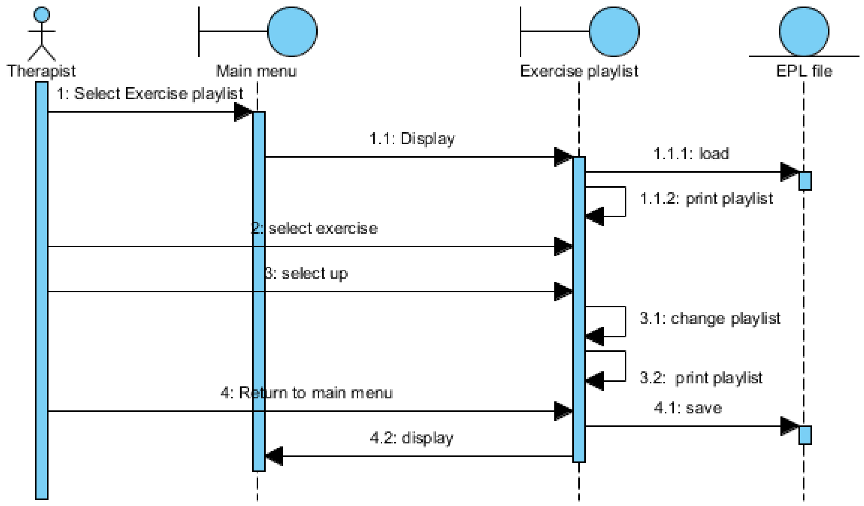


Figure 42 Exercise playlist Use Case sequence diagram

Class Diagram

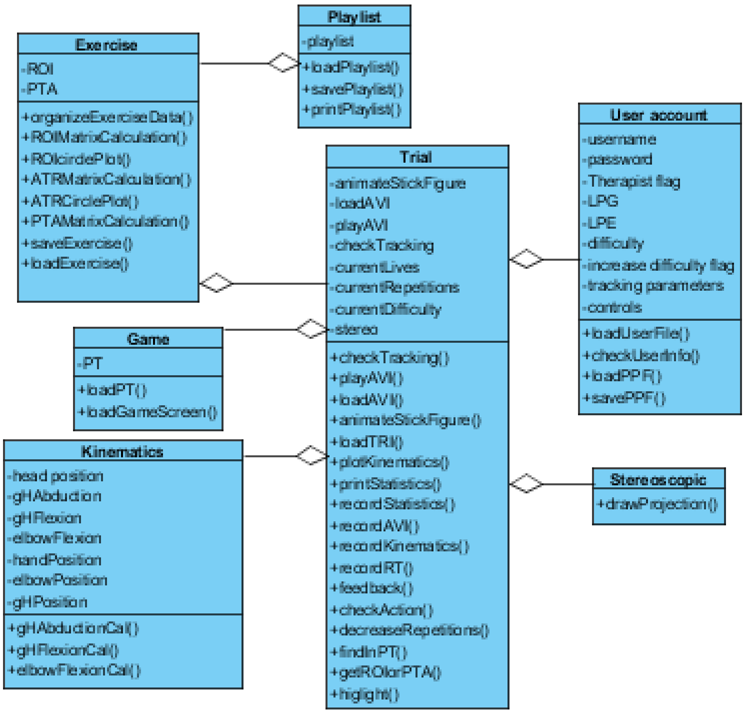


Figure 43 The class diagram that will be used for programming

5. IMPLEMENTATION

5.1. Upper limb functional anatomy

The upper limb has 9 degrees of freedom, 2 at the sterno- clavicular joint, 3 at the gleno- humeral joint 1 at elbow and 3 at the wrist the joints are connected with 4 links, the scapula, the upper arm, the lower arm and the hand. The hand is the end- effector of the mechanical model of the upper limb, as presented in the figure below.

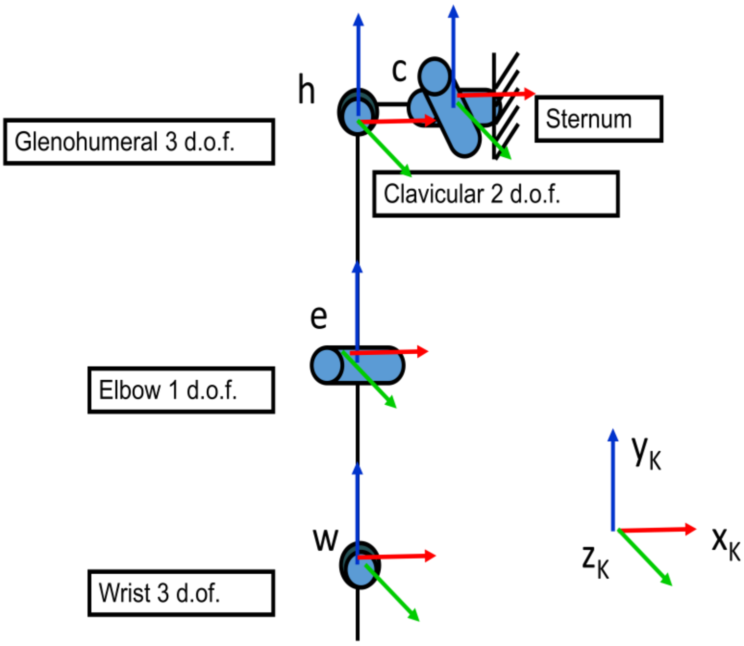


Figure 44 Upper limb degrees of freedom and Kinect coordinate system

The proposed physiotherapy system focuses on 3 d.o.f. of the shoulder joint (gleno- humeral) of the upper arm and 1 d.o.f. at the elbow joint. Thus the base of the kinematic chain is at the gleno- humeral joint with 3 revolute joints and one revolute joint at the elbow with two links the upper arm, the lower arm with end - effector the distal point of lower arm which is the wrist. The reason for ignoring the rest of the d.o.f. was to have a restricted number of exercise types, since this work is part of a thesis.

The motions that can be performed from these joints are for the elbow: flexion-extension, and for the shoulder flexion- extension, abduction- adduction and horizontal abduction- adduction. As presented in the figure below.

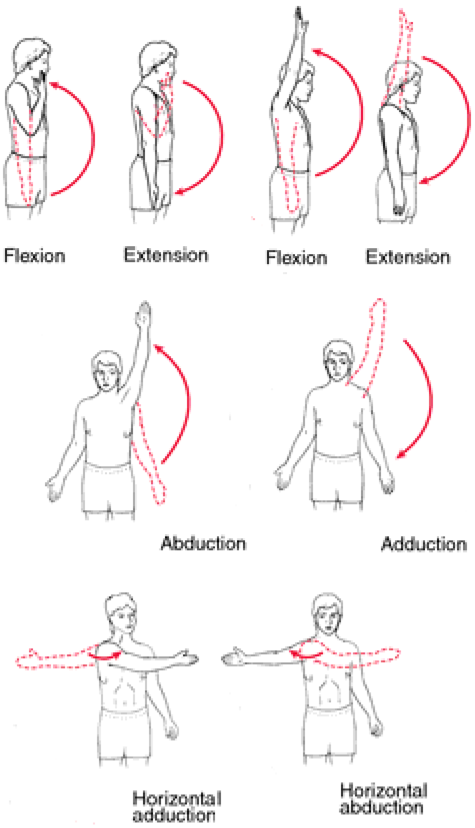


Figure 45 Elbow and shoulder motions (adapted from http://medical-dictionary.thefreedictionary.com/isotonic+exercise)

The palpable anatomical points that can be used to define the upper arm are the acromyon on the scapula and the elbow epycondyles. While for the lower arm are the elbow epicondyles and the styloid processes of the radius and the head of the ulna at the wrist. The joint positions are considered for the gleno- humeral joint 7 cm below the acromyon (Kontaxis et al.2009) and for the elbow joint at the axis connecting the two epicondyles.

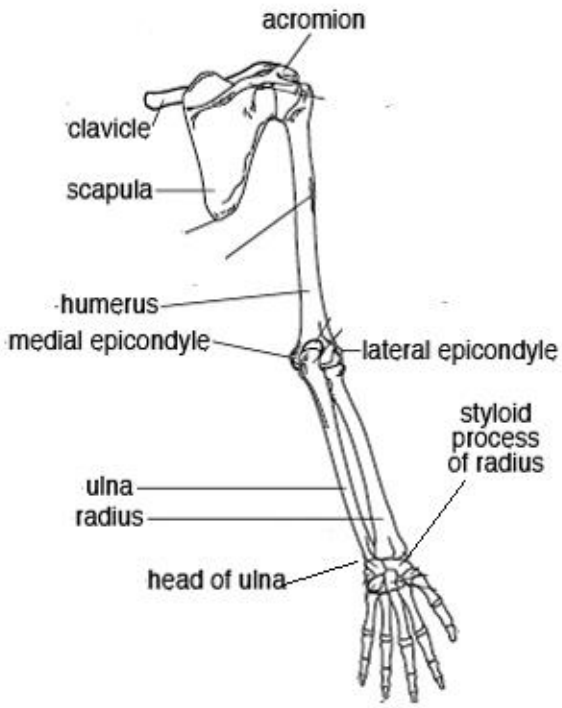


Figure 46 Upper limb palpable anatomical points (adapted from http://www.cliffsnotes.com/sciences/anatomy-and-physiology/the-skeletal-system/upper-limb)

5.2. Kinect skeleton tracking and camera interface

The skeleton tracking interface of Kinect was used to capture the upper limb kinematics. Since the Kinect for windows sensor was used the upper body model of the user was tracked. This model is referred as the seated model.

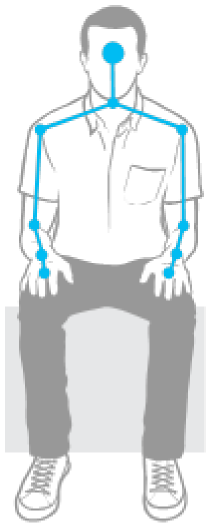


Figure 47 Kinect seated skeleton

The joints tracked by this model are both wrists, elbows and shoulders a joint at the base of the neck and one at the head. These joints are sufficient for the tracking of the upper limbs although however they don’t track the longitudinal axis rotation. The interface provides joint’s 3D position coordinates in meters of distance from the origin of the coordinate system which is fixed on the Kinect.

Since the user is considered seated near the screen the near view mode of the sensor was used. This mode allows the functionality of the sensor at a minimum distance of 0.4m.

The skeleton interface as well as the depth and color camera interface of the Kinect sensor are event driven. In this fashion an event handler is used with a callback method to process the event send by the corresponding framework.

In the project application a base class is implementing all the functionality of the Kinect sensor and then it calls a method that is overridden in every game where the game specific functionality is implemented.

5.3. Kinect Natural User Interface

Kinect has an ad-hoc developed Natural User Interface (NUI) that includes speech recognition and GUI elements.

The GUI interface is based on the Kinect Interaction Framework and includes graphical elements that interact and represent the hand motion on the screen, that support actions as different levels of press and grab and release gestures, while it can identify between the left and right hand.

Figure 48 Different actions on a NUI button element from left to right: hover, press and grab.

The Kinect NUI was used in the Post Office game with each drawer for the post represented by a Kinect button. However the Kinect NUI doesn't provide skeleton tracking data and for this reason the skeleton tracking framework was used in parallel.

The Kinect NUI also supports speech recognition. Kinect has a microphone array that support directional audio capture and noise cancelation. The speech recognition engine is language specific and supports several languages, but unfortunately Greek is not one of them, however Greek words can be supported with phonetic transcription. The speech recognition is functioning with a group of keywords that are relative to the application functionality and outputs the probability of a keyword to be one of the ones in the group.

The speech recognition functionality was used as well in the project on the navigation of the user menus where the user can say the name of the button and the button is pressed.

Speech synthesis was used to inform the user for certain events and it was based on the Microsoft Speech Platform SDK. In this case again Greek is not supported, however prerecorded phrases can be used instead.

5.4. Facial expression recognition

Facial expression recognition is the procedure that parameterizes the facial shape characteristics and classifies them in specific expression. The classes that are used in the classification are defined from databases of images or videos of volunteers performing certain expressions. These databases are labeled from scientists or from volunteers and are used to train the classification algorithms (Bettadapura, V., 2012).

The Kinect face tracking toolbox is using for the facial parameterization the Facial Action Coding System, Action Units (AU) (Ekman et al., 1971), by employing the CANDID3 face model (J. Ahlberg, 2001).

Six prototypic expressions i.e. happiness, anger, disgust, fear, sadness, pain and surprise are most commonly used in the literature and were defined in (Ekman et al., 1971). These expressions with the addition of pain are used in the physiotherapy system.

The Kinect face tracking toolbox includes the following functionality:

- 3D head pose estimation (head position and orientation in space)

- Face Shape Units (SU) including head height, eyebrows vertical position, eyes vertical position, eyes width, eyes height, eye separation distance, nose vertical position, mouth vertical position, mouth width, eyes vertical difference, chin width.

- Face Animation Units (AU) including AU0 - Upper Lip Riser, AU1 – Jaw Lowerer, AU2 – Lip Stretcher, AU3 – Brow Lowerer, AU4 – Lip Corner Depressor, AU5 – Outer Brow Raiser.

The face SUs are used in the system to identify the user's face and are recorded per minute of exercise in order for the system to record which person is performing the exercise. While the face AUs are used to classify if the user is feeling discomfort (negative expressions including anger, disgust, fear, sadness, pain) or enjoys the exercise (positive expressions happiness and surprise).

The classification of facial expressions is based on the minimum Eucleidian distance from centroids, of each expression, in the 6 dimensions space of AUs. The centroids were calculated from the feedback experiment that was performed with volunteers concerning.

5.5. Data storage

For each normal user of the system a directory structure is created containing his exercises, trial's information, user file, playlist and images. These files are stored using the Extensible Markup Language format.

The Extensible Markup Language (XML) is a markup language with rules for the format of the data. XML is easily readable from humans and computers while it supports Unicode data format something that was useful for the storage of the names of the cities in the Post Office game. Elements were used to store its property of a class. This is the most basic functionality of XML, in more complicated scenarios XML supports data validation with XML schema or in past with Document Type Definition which using a "grammar" ensures that the data stored is correct. In our case this functionality was much more advanced than the requirements of the applications so it was not employed.

Classes that contain the application’s data structures were created for each type of data that should be stored while an abstract class with two methods as static members was created in order to load and save the xml data. The classes that were created for this purpose are presented in the figure below.

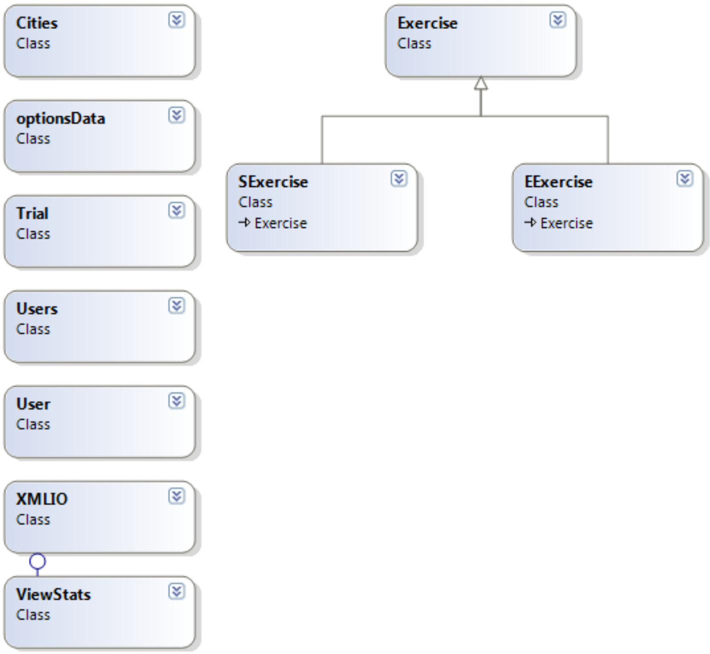


Figure 49 Classes with data structures

A sample of the contents of an XML file is presented in the figure below

```
<?xml version="1.0"?>
<User xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:xsd="
http://www.w3.org/2001/XMLSchema">
  <name>Anonymous</name>
  <gameSelection>0</gameSelection>
  <playlistPos>3</playlistPos>
  <completed>0</completed>
  <shoulder>1.5</shoulder>
  <armU>0.2</armU>
  <armL>0.3</armL>
</User>
```

5.6. Tele- medicine functionality

Tele- medicine functionality was developed in the application with two targets.

- Data exchange through internet
- Video and kinematics communication

Data Exchange

The data exchange implementation alows the communication of stored data through the Internet between the patient and the doctor. This way the doctor can be informed for the progress of the patient and send him new exercises.

The implementation of this functionality is based on the Websocket interface. Client functionality was implemented on the application and a separate server application was developed. The client can connect to the server IP address and make a request for a new Exercise files or send completed trials. The server application should be active during the process.

Video and kinematics communication

The implementation allows the distant connection of a medical professional to the user of the system in order to supervise and assess the performance of the exercise based on video and kinematics data.

The implementation was based on the “Coding4Fun Kinect Service” library which allows streaming color, depth or skeleton data from one server computer

(computer of the user) with a connected Kinect to a client computer (computer of the medical professional) through the Internet.

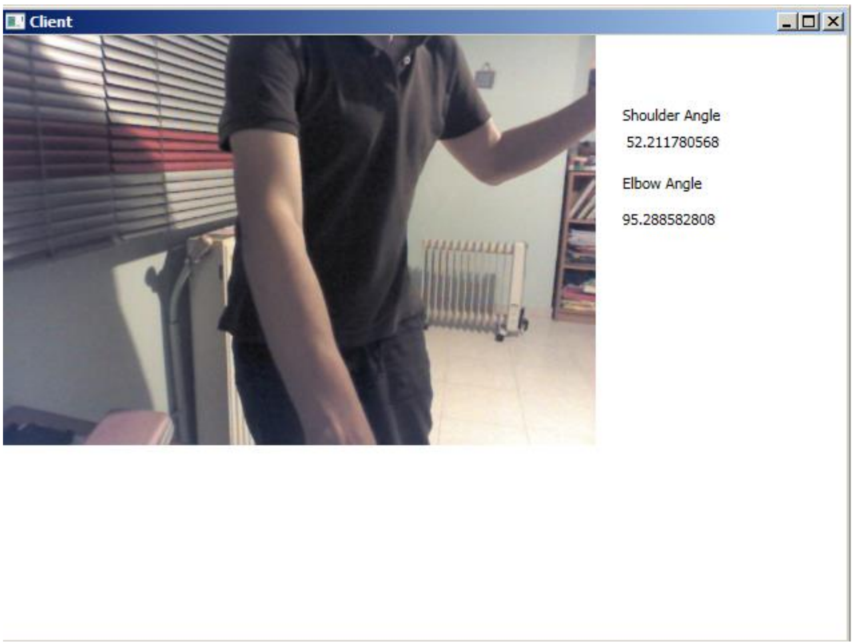


Figure 50 The window at the client computer showing the user of the server computer

5.7. Graphical User Interface

For the Graphical User Interface (GUI) the Windows Presentation Foundation (WPF) was used. The Windows Presentation Foundation is a graphical system for creation of common 2D window interfaces as the window forms in the past. WPF further supports imaging, media types as video and 3D graphics and for this reason it was selected for the application.

WPF is configured with GUI tools as the windows forms but its full potential can only be unlocked with the use of the eXtensible Application Markup Language (XAML) language. XAML is a markup language based on the XML. With the use of XAML a description of the element properties and their data binding is easily implemented from the user while he can have a fast overview of all the elements in the window. The XAML file representing its window is part of the class for the specific window. This way the functionality of the class is in a seperate file from its visual representation.

For the application of the project for each Window a “partial class” was created containing the functionality and an XAML file containing the visual part.. The classes are presented in the figure below.

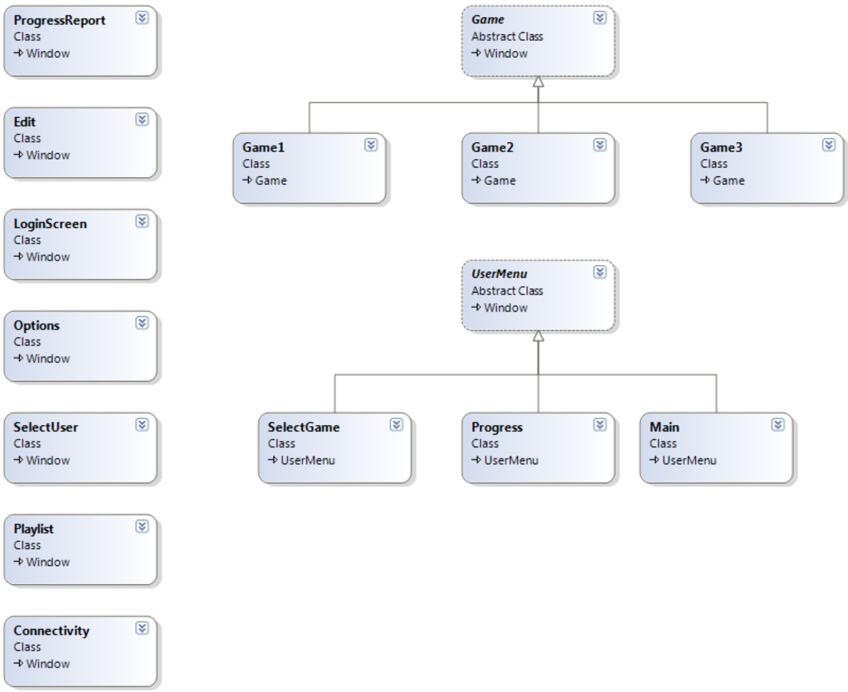


Figure 51 Classes used for the windows of application

The implementation of the Main menu in XAML is presented below.

```
<src:UserMenu  x:Class="PhysioWPF.Main"
                xmlns:src="clr-namespace:PhysioWPF"
        xmlns="http://schemas.microsoft.com/winfx/2006/xaml/pr
esentation"
        xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
        Title="Kinect for Physiotherapy: Main Menu" Height="48
0" Width="640"  Closing="WindowClosing" Activated="WindowActiv
ated">
        <Grid Width="631" Height="441">
```

```
            <Button Name="quickStart" Click="quickStart_Click"
 IsDefault="False" Content="Quick Start" Margin="228,73,246,33
7"  />
        <Button   Name="selectGame" Click="selectGame_Click" I
sDefault="False" Content="Select game" Margin="228,110,246,302
"  />
        <Button   Visibility ="Hidden" Name="edit" Click="edit
_Click" IsDefault="False" Content="Edit Exercise" Margin="228,
285,246,128"/>
        <Button  Visibility ="Hidden" Name="options" Click="op
tions_Click" IsDefault="False" Content="Options" Margin="228,3
19,246,93" />
            <Button   Name="exit" Click="exit_Click" IsDefault
="False" Content="Exit" Margin="228,354,246,62"  />
        <Button Content="Progress" IsDefault="False" Margin="2
28,145,246,265" Name="progress" Click="progress_Click" />
        <Button Visibility ="Hidden" Content="Progress Report"
 IsDefault="False" Margin="228,182,246,230" Name="progressRepo
rt" Click="progressReport_Click" />
        <Button Visibility ="Hidden" Content="Playlist" IsDefa
ult="False" Margin="228,251,246,162" Name="playlist" Click="pl
aylist_Click" />
        <Button Content="Connectivity" IsDefault="False" Margi
n="228,217,246,196" Name="connectivity" Click="connectivity_Cl
ick" />
    </Grid>
</src:UserMenu>
```

5.8. 3D Computer Graphics

3D computer graphics are used as a better represent of our 3D world. Geometric models are created for each object and these models are rendered and animated using a 3D application programming interface (API) with the most popular being OpenGL and Direct3D. The project application is using the Direct3D through the WPF.

With these APIs the 3D world is represented using a scene graph. The scene graph contains children that are cameras, geometric primitives, meshes, lights, effects or transformations.

The representation, placement and manipulation of the objects for the implementation of 3D graphics are based on linear algebra and more precisely on matrix transformations.

The coordinates of each point based on a inertial coordinate system O[0,0,0,1] are represented in a vector of homogenous coordinates. This is a four element vector with the x,y,z coordinates and 1 for the last element.

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Translation, rotation and scaling or a combination of the previous mentioned transformations can be performed by multiplying the vector with a homogenous matrix. A homogenous matrix is a 4x4 matrix with its simplest form being the identity matrix.

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

If the homogenous coordinates are multiplied with the identity matrix no transformation will be performed. If a translation is required a translation matrix should be used.

$$\begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The elements t represents the corresponding translation in the axis of the inertial coordinate system. Correspondingly for scaling and rotations around the each axis of the coordinate system respective matrix exists. Below is a scaling matrix.

$$\begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & t_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

And the three rotation matrices for each axis of the inertial coordinate system X,Y,Z respectively.

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(v) & -sin(v) & 0 \\ 0 & sin(v) & cos(v) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} cos(v) & 0 & sin(v) & 0 \\ 0 & 1 & 0 & 0 \\ -sin(v) & 0 & cos(v) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} cos(v) & -sin(v) & 0 & 0 \\ sin(v) & cos(v) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In the project application a rotation transformation is performed around the X axis due to the Kinect sensor variable elevation angle. The calculation is presented below.

```
            Matrix3D elevationCompensation = Matrix3D.Identity;
            double eRad = elevationAngle * Math.PI / 180;
            elevationCompensation.M22 = Math.Cos(-eRad);
            elevationCompensation.M23 = Math.Sin(-eRad);
            elevationCompensation.M32 = -Math.Sin(-eRad);
            elevationCompensation.M33 = Math.Cos(-eRad);
            Vector3D vec;
            foreach (Joint joint in skeleton.Joints)
            {
                vec = new Vector3D(joint.Position.X, joint.Position.Y, join
t.Position.Z);
                vec = Vector3D.Multiply(vec, elevationCompensation);
                i++;
            }
```

For complex transformations that combine rotations and translation transformation matrices can be combined in one matrix but care should be taken on the sequence of transformations. Further rotations around random axis are possible.

In the Ping Pong game a rotation and translation transformation were performed on the cube with the following code.

```
            Transform3DGroup transform = new Transform3DGroup();
```

```
            transform.Children.Add(new RotateTransform3D(new AxisAngleRotat
ion3D(new Vector3D(0.0, -
0.01, 0.05), 1 * cubePosition * System.Math.PI )));
            anaglyphView1.Children[1].Transform = transform;//rotational tr
ansform
            transform.Children.Add(new TranslateTransform3D(new Vector3D(0,
 0, 0.35) * cubePosition / 300));
            anaglyphView1.Children[1].Transform = transform;// translationa
l transform
```

In order to perform stereoscopic rendering of the scene two cameras are needed one for each eye. These cameras are attached to the coordinates of the head of the user and are rigidly connected with a horizontal distance commonly of 6.4 cm which is the most common intra-ocular distance of humans. The image for each eye is filtered using red and cyan glasses (anaglyph stereo), shutter glasses or auto- stereoscopic scenes. On the screen a perspective projection of the 3D scene is presented. However to have a correct representation of the position, an accurate position of the user's eyes is needed. For this reason the head tracking capabilities of the Kinect Face Tracking Toolbox was employed. Below is the code for the positioning of the two cameras.

```
            anaglyphView1.LeftCamera.Position = new Point3D(-0.03, -
0.1, 0.8);
            anaglyphView1.LeftCamera.LookDirection = new Vector3D(0, -
0.1, -0.8);
            anaglyphView1.LeftCamera.UpDirection = new Vector3D(0, 1, 0);
            anaglyphView1.RightCamera.Position = new Point3D(0.03, -
0.1, 0.8);
            anaglyphView1.RightCamera.LookDirection = new Vector3D(0, -
0.1, -0.8);
            anaglyphView1.RightCamera.UpDirection = new Vector3D(0, 1, 0);
            anaglyphView1.SynchronizeStereoModel();
```

5.9. Kinematics

Inverse Kinematics

The kinematics information Kinect is providing is only joint positions, while for physiotherapy the joint angles are important, for this reason a transformation called Inverse Kinematics (IK). IK are used to calculate the joint angles based on the position and orientation of the links.

The calculation of the 3 angles of interest for the upper limb is done with an analytical, geometric method. For the elbow, vectors are assigned to the upper and lower arm; the cosine of the elbow flexion angle is the dot product of the two vectors. For the shoulder abduction and flexion and horizontal abduction angle the angle's tangent calculation is performed in 2D with the projection of the upper arm vector to the planes of the base frame at the shoulder.

Forward Kinematics

For the performance of the exercise the user must move his arm in a certain way in order the joint angles to take the values required from the exercise. In order to present to the user, the target postures for these specific angles, the positions and orientation of the links are calculated, this procedure called forward kinematics.

A standardized methodology for the calculation of the hand (end- effector) position relative to the shoulder (base) based on known angles is performed with the use of the Denavit- Hartenberg convention. The Denavit- Hartenberg convention is using certain joint parameters as the link length, the link twist, the link offset and the joint angle, and following certain rules for the joint frame definition can create a transformation matrix that can be used to calculate the position and orientation of an end- effector relative to its base.

5.10. Exercise Games

The exercise games are a modular part of the system that concerns the visualization and the game play (the way the user interacts with game) with target the user engagement. The exer- games are children of the game class that includes all the game mechanics that concern the execution of the exercise and the feedback. In this way the exer- games are mere graphic representation, story, and different way of interaction with the computer while the exercise is performed.

Post office game

The post office is an exercise game related to the gleno- humeral joint. In this game the user is moving his hand in specific areas of the screen. The target of the game is the user to move the letter to a specific drawer according to their address. The game is selecting letter destinations presented at the bottom of the screen and the player is pressing the corresponding box. The selection of drawers from the game is based on the description of the exercise. The destinations are separated in three categories ROI, PTA and ATR. The ROI area is there where the gleno-humeral needs training, the ATR is the area which should be avoided e.g. because it produces pain and PTA is the remaining area. These areas are part of the description of the exercise. The game algorithm is selecting alternatively one box from the ROI area and one from the PTA. If the patient presses the wrong box he loses one life and if presses the correct his repetition is decreased by one. The user must also complete the action in a specific timeframe as described from the exercise.

This game uses the natural user interface of Kinect and more specifically the Physical Interaction Zone of Kinect (PhIZ). This zone is from the navel to the head of the user and it is centered at the center of each hand area of motion (Microsoft, 2013) as depicted in the figure below.

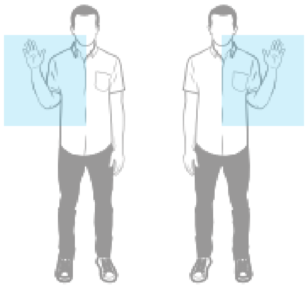


Figure 52 Physical Interaction Zone Phiz (adapted from Microsoft, 2013)

Figure 53 The game represent the work position of post office employee with the task to sort the letters according to their destination. Photograph: Hulton Archive adapted from The Guardian.co.uk Newspaper

Even though this work is a little dull to be considered for a game it was selected as a game for the system because

- It is very straightforward to establish a connection between the motion of shoulder (abduction-adduction, flexion-extension, medial- lateral rotation) based on the position of the user's torso (distance from the screen) and the hand (end-effector position).
- It is quite easy to implement with a simple GUI interface.

The implementation follows on the next figure

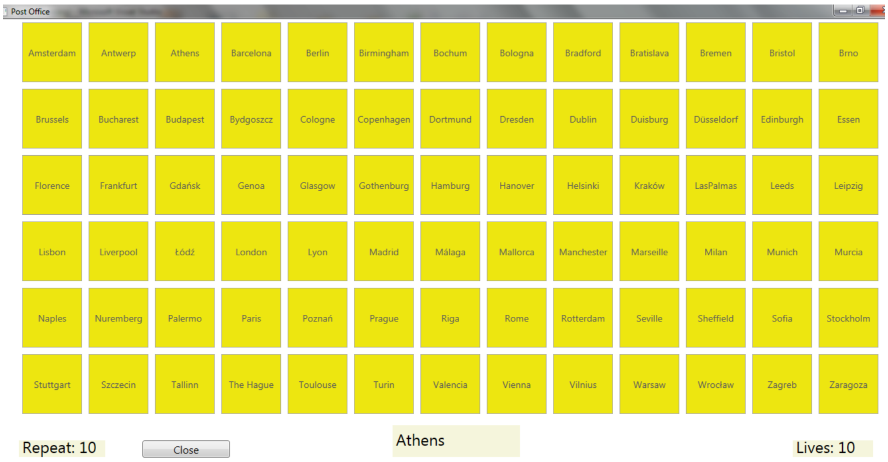


Figure 54 Post Office game

Mirror Game

The second game is an exercise game for the elbow joint (flexion- extension). An avatar of the patient is drawn on the screen like on a mirror. Two spheres one representing the hand of the user and the other the target position of the hand are drawn. The sphere representing the target position is placed in specific position calculated from the Denavit Hartenberg convention according to the required elbow flexion angle from the exercise. The user is moving his arm as if he was lifting handheld weights. When the user moves his hand to the target position the sphere changes places for the next repetition. The medical professional can configure if the motion must be performed in specific time or not.

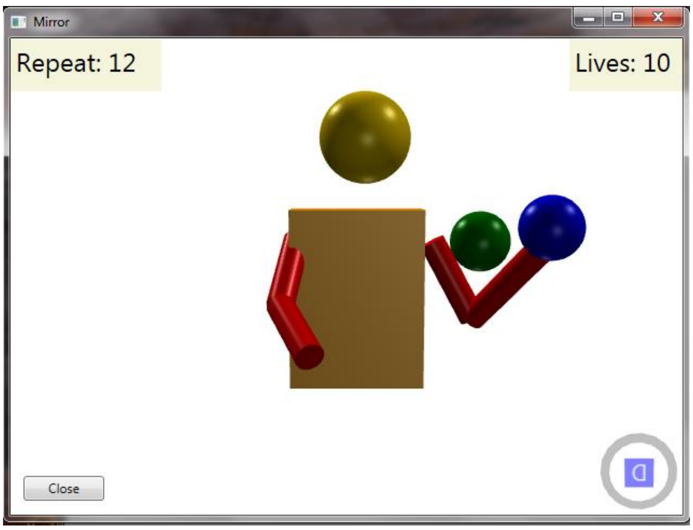


Figure 55 Mirror game with an avatar representing the user

Stereoscopic Game

A stereoscopic game for the elbow joint was also implemented. This game uses red-cyan glasses for the stereoscopic effect. In this game the user with his hand must follow a rotating cube moving from the screen towards him and back. In this game the head position is tracked from the face tracking algorithm developed available from Micorosoft for the Kinect Toolking. Since this algorithm is using face recognition for tracking the use of stereoscopic glasses produces some tracking problems while the algorithm is very resource demanding and there are occasional slowdowns.

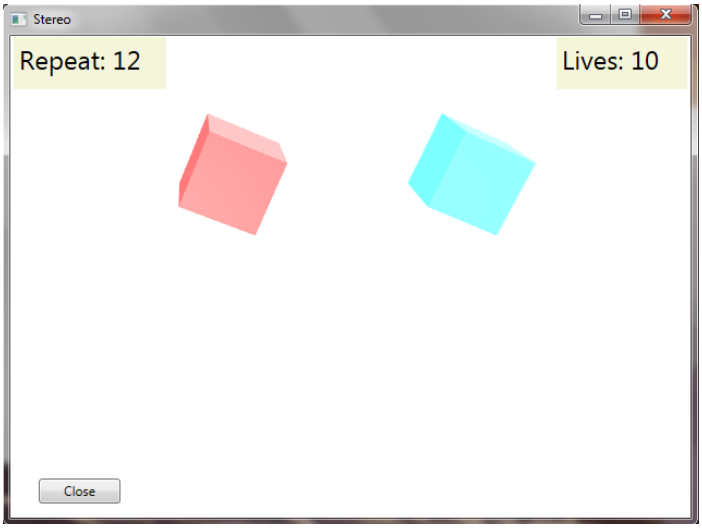


Figure 56 Stereoscopic game with a moving cube

Stork game

For the motion of shoulder abduction and adduction a 2D game was developed. In this game there is a stork that is falling down until the user performs shoulder abduction at an angle specified from the exercise. The user must perform this motion fast enough before the stork collide with an obstacle that can be a tree or a house.

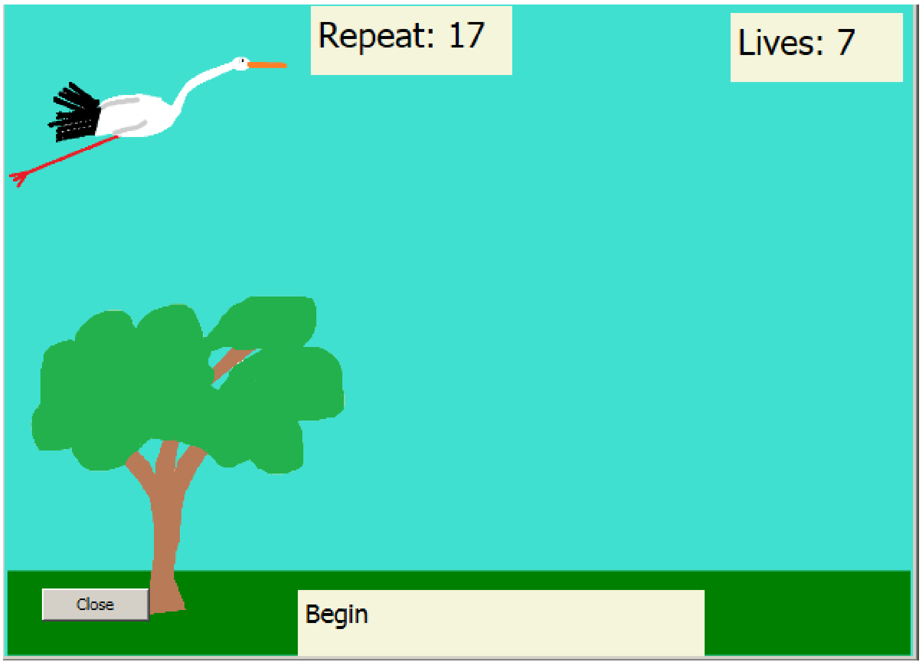


Figure 57 Stork game

5.11. Control and Feedback

The game class includes a controller of the user feedback. This controller at its simplest form is a proportional controller (P-controller) for the performance of the exercise. It adjusts the difficulty of the exercise in order the user to don't feel discomfort and to perform the required repetitions.

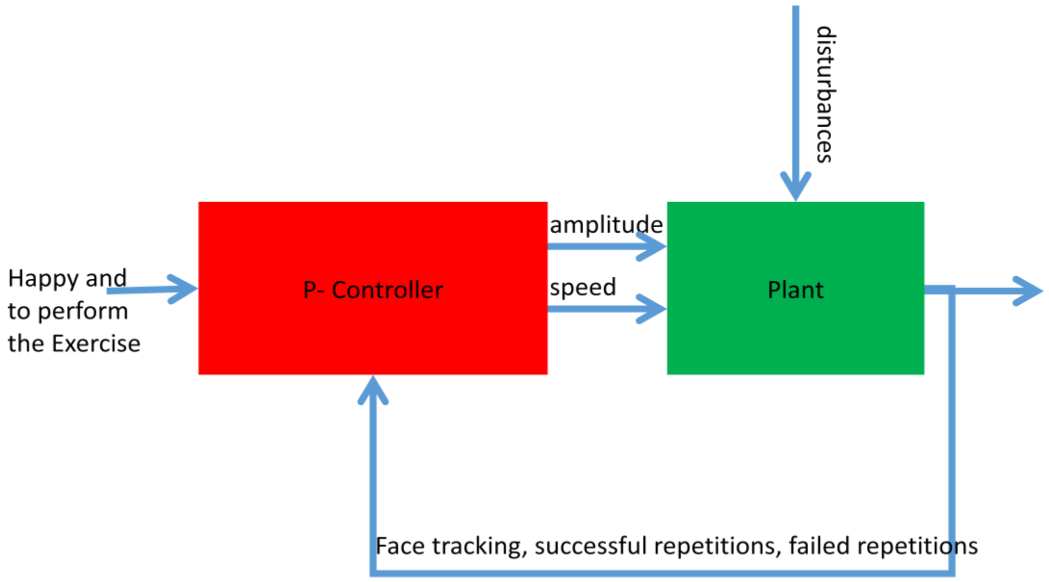


Figure 58 System as a proportional controller of the exercise

The control variable is the performance of the user at the exercise (successful or failed repetitions) and the face expression recognition (comfort-discomfort). The set point of these variables is that the user is performing successful repetitions and he is not feeling discomfort. The manipulated variable is the speed of the exercise and the difficulty (the amplitude of the motions). Disturbances are the change of posture of the user, the fatigue of the user etc. Three continued failed repetitions or successful are considered as an event for the controller to act

When the controller needs to increase the difficulty of the exercise always asks the user's permission while for decreasing the difficulty is done automatically. The user is giving his permission with a voice command.

The user can also control the difficulty of the game by giving voice commands to the controller. While at the end of the exercise he can record a small message for the medical professional concerning the difficulty of the exercise he performed, if he felt pain or if you wants to note something.

6. FEEDBACK EXPERIMENT AND SYSTEM EVALUATION

To evaluate the accuracy of Kinect input channels an experiment with volunteers was performed, while the system was evaluated against the initial requirements and volunteers reviewers.

6.1. Feedback experiment

Introduction

An experiment was performed in order to assess the accuracy of the various feedback channels that are used for the control of the exercise from the system. These feedback channels are the face expression recognition, the skeleton tracking and the voice recognition. The volunteers were informed about the purpose of the experiment and the system that was in development. Anthropometric measurements were performed on the right arm of the volunteers and then the experiment took place. The Kinect streams (color, depth and skeleton) were recorded with Kinect Studio (Microsoft Corporation, Redmond, WA) and the audio was recorded with the Windows 7 Sound Recorder (Microsoft Corporation, Redmond, WA). The volunteer was operating the software of the experiment during the experiment. A picture of the software is presented below. Seven volunteers participated in the experiment. Five male and three female volunteers with an average age 34 years old. participated in the experiment. The methodology and the results for each channel are presented below separately while they are discussed together at the end of the paragraph.

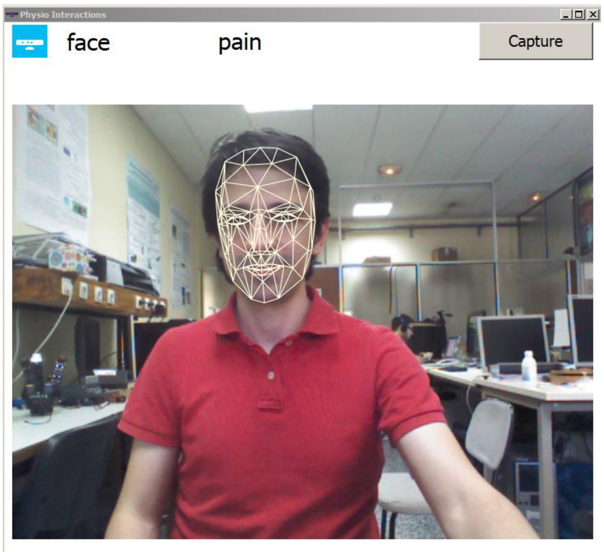


Figure 59 Software for the experiment

Face expression recognition

The software was presenting an emotional condition to the volunteer and he had to perform the corresponding facial expression 7 times with a pause in between each repetition in which the volunteer changed to a neutral expression. When the volunteer was making the expression he was required to press the capture button. The facial expressions asked to the volunteer were the basic six facial expressions (happiness, anger, disgust, fear, sadness, surprise) and pain. The AUs for each expression were recorded.

This data was used in the application for classification with a clustering algorithm based on the Euclidian distance from the average value of each AU for each expression.

The average values for the AUs were calculated for each expression and then the expressions were classified based on the distance of their AUs from the average of each expression. The results are presented in the table below.

The percentage of correct classification of each expression for each volunteer is presented below.

Table 6 The percentage of correct classification of each expression for each volunteer.

Volunteer	happiness	anger	disgust	fear	sadness	pain	surprise
V1	0.571	0.875	0.625	0.625	0.500	0.625	0.750
V2	0.375	0.222	0.556	0.111	0.667	0.333	0.667
V3	0.714	0.500	0.375	0.286	0.500	0.250	0.250
V4	0.714	0.625	0.375	0.625	0.625	0.625	0.375
V5	0.857	0.714	0.125	0.125	0.500	0.375	0.375
V6	0.429	0.375	0.500	0.250	0.875	0.286	0.500
V7	0.833	0.833	0.750	0.750	0.875	0.250	0.750
V8	0.692	0.786	0.333	0.538	0.250	0.133	0.563

The average value of correct classifications of each expression is presented below.

Table 7 The average value of correct classifications of each expression

Expression	happiness	anger	disgust	fear	sadness	pain	surprise
Average	0.648	0.616	0.455	0.414	0.599	0.360	0.529
Standard Deviation	0.176	0.233	0.194	0.250	0.210	0.178	0.187

The average value and standard deviation of correct classifications per volunteer is presented below.

Table 8 The average value and standard deviation of correct classifications per volunteer.

Volunteer	V1	V2	V3	V4	V5	V6	V7	V8
Average	0.653	0.419	0.411	0.566	0.439	0.459	0.720	0.471
Standard Deviation	0.123	0.218	0.172	0.135	0.277	0.207	0.213	0.239

From the results can be concluded that the classification is around 50% successful except in the case of volunteer 7 which is more than 70% accurate. The least correctly classified expressions were the ones of pain, fear and disgust.

Kinematics

Two kinds of motions were requested to be performed from the volunteers shoulder abduction- adduction and elbow flexion- extension. The volunteers were instructed on how to perform these motions. All the volunteers that participated in the experiment were healthy. They were asked to stand and perform these motions at a plane vertical the field of view of Kinect. The reason was that the color stream of Kinect was analyzed with photogrammetry methods independently with a motion tracking software in order to compare the results with skeleton tracking stream of Kinect.

According to (Sato et al., 2007), (Ruvio et al., 2013), (Li et al., 1990) photogrammetry has high intra and inter-rater reliability and is also a valid tool for angle measurement as long as the angle is on a plane vertical to the camera axis. Further the Kinect cameras' lenses are of high quality and have very low distortion error based on a Kinect camera calibration performed in (ROS n.d.).

The motion tracking software used for the photogrammetry analysis of the color stream was Digitizing tools (University of North Carolina, NC) which is a toolbox for Matlab (Mathworks Natick MA). Landmarks (gleno -humeral joint, elbow joint and wrist joint) were semi-automatically tracked in the color-stream in order to be able to calculate the shoulder abduction and elbow flexion angle. The comparison of the joint angles from the Kinect skeleton data and the one of the digitizing software is presented below. The data analysis was performed in Matlab.

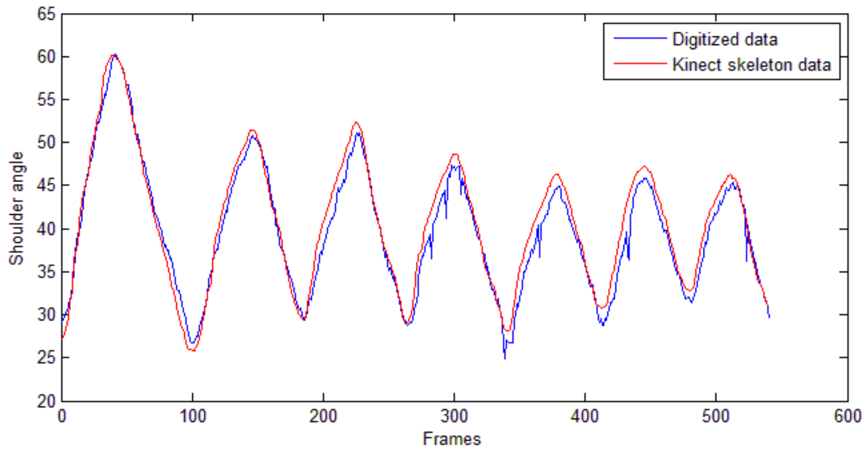


Figure 60 Shoulder abduction angle comparison

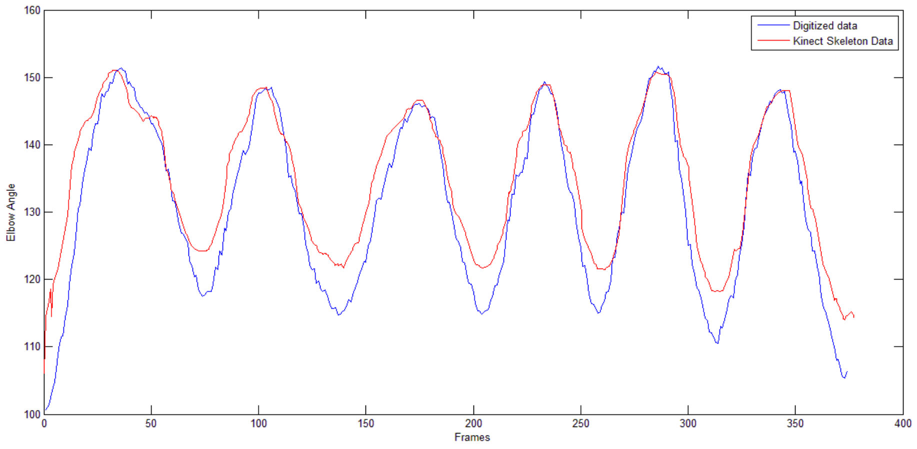


Figure 61 Elbow flexion angle comparison

Further the length of the links of the upper limb (upper arm, lower arm) was calculated during the motions from the skeleton stream and presented in the figures below.

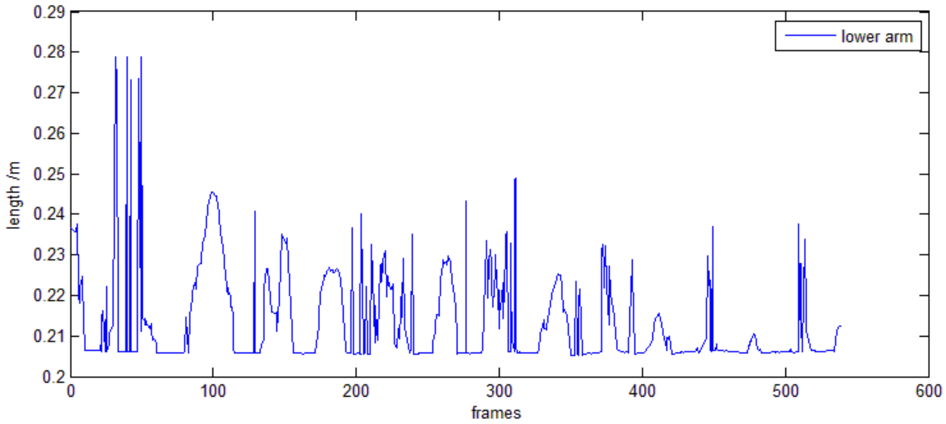


Figure 62 Lower arm length

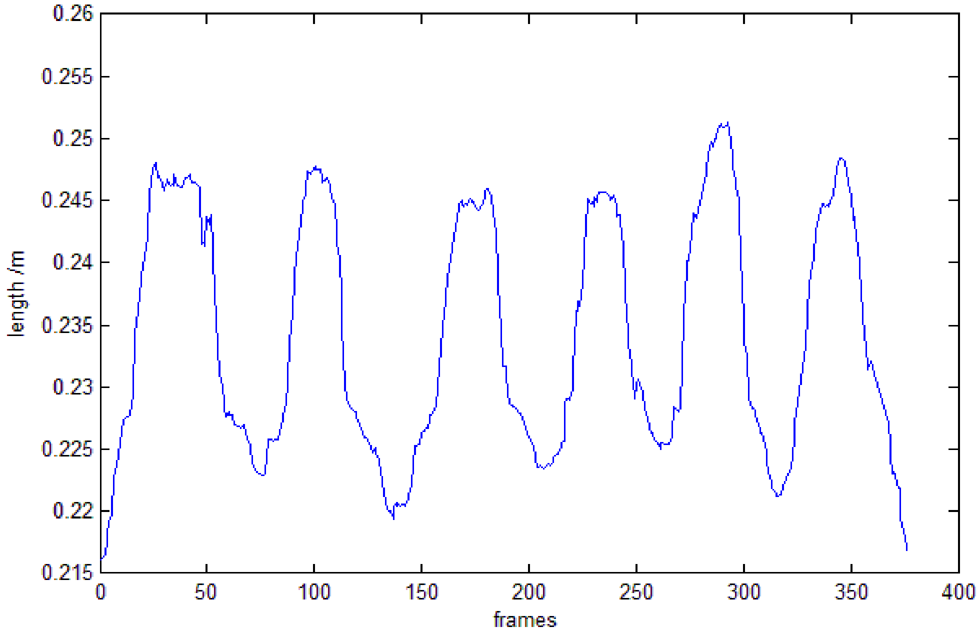


Figure 63 Upper arm length

The link lengths per each volunteer are presented below.

Table 9 Upper arm length

Volunteer	V1	V2	V3	V4	V5	V6	V7	V8
Average	0.212	0.230	0.227	0.235	0.211	0.246	0.204	0.214
Standard Deviation	0.016	0.013	0.017	0.016	0.006	0.022	0.014	0.011
Max distance from average	0.036	0.035	0.060	0.065	0.040	0.063	0.065	0.051
RMSE from average	0.016	0.013	0.017	0.016	0.006	0.021	0.014	0.011

Table 10 Lower arm length

Volunteer	V1	V2	V3	V4	V5	V6	V7	V8
Average	0.236	0.236	0.250	0.266	0.211	0.224	0.198	0.238
Standard Deviation	0.016	0.013	0.013	0.013	0.012	0.014	0.005	0.019
Max distance from average	0.028	0.028	0.024	0.022	0.033	0.027	0.017	0.053
RMSE from average	0.016	0.013	0.013	0.013	0.012	0.014	0.005	0.018

As it can be seen the Root Mean Square Error from the average measured length varies during the test in average less than 2 cm while the max error is 5.3cm for the elbow and 6.5 cm for the shoulder, for the specific exercises.

Voice recognition

The software was used for voice recognition a word was presented to the volunteer and he had to repeat it 7 times with a pause between each repetition. After each repetition the volunteer was pressing the capture button in order the next word to appear. The words that were used for the recognition were the following. OK, stop, faster, slower, yes, no.

The confidence level that the voice recognizer was selecting a word was recorded. 6 repetitions were used for each word since sometimes the volunteer was losing count of the repetitions.

None of the volunteers was native speaker. The average confidence level for all volunteers and all the words was 0.7 (1 is 100% confidence) with total standard deviation 0.32.

The average value and standard deviation for all the words for each volunteer is presented in the following table. Five from the eight volunteers had more than 70% successful recognitions with less than 20% standard deviation. By performing an unpaired t-test to the two groups we can say with 95% confidence that two groups are significantly different (p value 0.004). It is interesting to note that 1 volunteer of the second group did not have a good grip of the English language and another one was trying different accents during the experiment even though he was not instructed to do it, the highest rated volunteer was currently an English student. All the volunteers were using English almost every day except two of the second group's volunteers.

The statistics for each word are presented below.

Table 11 The average value and standard deviation of confidence for each correct recognition per volunteer.

Volunteer	V1	V2	V3	V4	V5	V6	V7	V8
Average	0.774	0.792	0.563	0.835	0.538	0.608	0.713	0.785
Standard Deviation	0.138	0.192	0.261	0.133	0.094	0.341	0.174	0.165

Table 12 The average value and standard deviation of confidence for each correct recognition per word.

Words	OK	stop	faster	slower	yes	no
Average	0.630	0.783	0.625	0.729	0.634	0.808
Standard Deviation	0.325	0.326	0.381	0.243	0.361	0.229

Again there are words that are well recognized (stop, slower, no) and ones that are less well recognized (OK, faster, yes). The difference is also statistically significant (p value 0.0085). The reason for this difference is probably that the words from the second group were mispronounced. However the standard deviation is more or less similar. It is important to note that the word no has the higher confidence since it is a keyword for declining questions for changing the difficulty of the exercise.

Discussion and conclusion

The facial expression recognition algorithm even though an interesting feature of the Kinect sensor, it had low success rate in recognizing expression. During the experiment the volunteers had difficulty in finding a way of performing the expressions of pain, fear and disgust while for the rest happiness, sadness, surprise they largely exaggerated them. This is a problem noted in the literature concerning of how natural can be a pretended expression. Another reason of failed classifications can be the low resolution depth camera as well as mislabeling from the volunteer while performing the expression. Also a more advanced classification algorithm could improve the results.

The accuracy of kinematics from the Kinect skeleton stream compared to the photogrammetry methodology was high while the RMSE error of 2 cm is low making the system useful for physiotherapy purposes. However it should be noted that the exercises were chosen in order the Kinect to have high visibility of the user and no occlusion to occur.

The findings concerning the voice recognition show a confidence level of successful recognitions in average 70%. While further it is shown the importance of having the voice recognition software in the native language of the user. Since the software is recognizing only certain words this can be done by transcribing the words from the native language of the user with phonetics.

Based on the above findings can be concluded that the Kinect sensor’s channel accuracy is sufficient for the purpose of a physiotherapy system although caution should be taken in its face expression recognition software and the type of exercises (avoiding body part occlusion) it is used for. Further a voice recognition algorithm in the native language of the user can improve its accuracy.

6.2. System evaluation

Implemented requirements

The functional and non functional requirements as described in system development that were implemented and the ones that were not implemented are presented below.

Implemented Functional requirements

1. System for arm physiotherapy
2. User's movements are presented with an avatar as captured from the system
3. Motion compensation control
4. Sessions to adjust the difficulty of the exercise
5. Encouragement for the user to start and continue the exercise
6. Progress tracking and analysis
7. Feedback for the user's motion performance
8. Presentation of all data captured
9. A parametric virtual environment
10. Basic online functionality for tele -medicine purposes

Not Implemented Functional requirements

1. Multiplayer support for social games

Non-functional requirements

1. Easy to start using the system at home (hardware software compatibility, setup)
2. Use a natural user interface (gesture and/ or voice control)
3. User selection of exercise goals
4. Options for different presentation of the results
5. Feedback can be enabled and disabled
6. Keep system noise and obstructions minimal
7. The user can selected what type of data is captured

Not Implemented non-functional requirements

1. Exercise presentation before its performance from the user
2. Different avatar's for the user and the coach that can be selected according to the user's preferences

6.3. Evaluation with questionnaires and focus group

The evaluation of the system was performed by volunteers with the use of questionnaires and focus group discussion. The system was presented to the volunteers from the researcher and then they had the opportunity to try it themselves. Only the functionality concerning the patient side of the system was evaluated. The volunteers rated based on their agreement in a scale from one to five

The following aspects of the system were evaluated.

- Functionality and usefulness of the system
- Use of Personal data from the system
- Exer- game preference

Seven volunteers participated in the study.

The volunteers strongly agreed on the use of the proposed system, concept of home rehabilitation, the supervision from a specialist from distance. They strongly agreed with the transmission of video during the exercise for specialist supervision and the use of feedback to the user concerning his performance. A volunteer rated with four the voice navigation and the manipulation of the exercise from the user and another user the use of feedback for supervision, due to the fact that some voice commands did not function properly as was discussed on the focus group.

They strongly agreed in the use of kinematics, voice and video data for the performance of the exercise. They agreed in the use of facial expression recognition data, except one user that did not agreed (rated with 3), the reason was due to his sensitivity for the use of such form of data.

Concerning their preference in the exer-games all the users strongly agreed on the Mirror game. One user rated with 3 the stork game due to the abstraction of the 2D game from the human motion. 3 users rated the Ping Pong game with 4 mainly due to difficulty to experience the stereoscopic effect and some slowdowns of the game. The rest of the users strongly agreed with the games.

7. CONCLUSION AND FUTURE WORK

7.1. Conclusion

During this project an integrated physiotherapy system based on Kinect was developed. The system was designed and developed using the ICONIX methodology. A project plan was established at the beginning and followed, however with changes, due to a successful ERASMUS application.

Kinect was used as a multi channel input device while capabilities offered from its software development toolbox as face tracking and speech recognition were also employed. The system implemented a controller that allowed unsupervised exercise from the user. The system allows the user to perform exercises designed from a medical professional, with four different exercise games (exer- games). It uses the motion tracking capabilities and the natural user interface of Kinect in combination with 2D, 3D and stereoscopic 3D graphics. An interface is provided for the medical professional to create and plan exercises as well as to review the progress of users. Multiple users' management, as well as patient data protection are offered at a basic level. Tele- medicine functionality was implemented including connection to a server for download of new exercises and upload of progress as well as support for supervision of the exercise from medical professionals from distance.

An experiment with volunteers was performed in order to evaluate the system feedback accuracy including the face expression recognition, kinematics and voice recognition. From the experiment the motion tracking capabilities and the voice recognition were found accurate enough, while the face expression recognition algorithms had lower success rate. The issue with face tracking was considered to be the labelling done by the volunteers. A system assessment with questionnaires and a focus group took place in order to evaluate the functionality, the use of personal data and their exer- game preference. The reviewers found the system useful and noted its potentials for home rehabilitation.

7.2. Future work

The system implemented during the thesis should be further validated with a state of the art motion capture systems. It should be also assessed in rehabilitation centers towards a control group of volunteers in need of rehabilitation.

Further updates to the system should be implemented mainly on its graphics and with the addition of new exer- games. While multiplayer aspects and social interactions should be investigated with leader boards and a network of friends competing or collaborating during their exer- game rehabilitation.

The new Kinect sensor is also planned to be available in July 2014 with enhanced accuracy and more bio- feedback functionality as heart rate monitor and inverse dynamic calculation for estimated muscle forces. This new sensor will be an interesting enhancement to the proposed system.

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9. APPENDIX

APPENDIX 1

The most important parts of the classes related with the activation and functionality of the Skeleton Traking, Video Capture and Speech Recognition, streams from the Kinect sensor are provided below. The first class concerns the initialization of the speech recognition engine of Kinect. The second class presents the initialization of the skeleton tracking and the color camera.

9.1. Speech recognition

```
namespace PhysioWPF
{
    using System;
    using System.Linq;
    using System.Collections.Generic;
    using System.ComponentModel;
    using System.IO;
    using System.Text;
    using System.Windows;
    using System.Windows.Documents;
    using System.Windows.Media;
    using Microsoft.Kinect;
    using Microsoft.Speech.AudioFormat;
    using Microsoft.Speech.Recognition;
    using System.Windows.Controls.Primitives;


    public abstract class UserMenu : Window
    {// Voice recognition abstract class for the menus of the normal user


        protected KinectSensor sensor;
        protected SpeechRecognitionEngine speechEngine;

        protected void WindowLoaded(object sender, RoutedEventArgs e)
        {// on window load
            startSensorVoice();

        }
```

```
        protected void WindowActivated(object sender, EventArgs e)
        {// window gains focus

            startSensorVoice();

        }
        protected void startSensorVoice()
        {// start only the voice stream of the kinect
            sensor = KinectSensor.KinectSensors.FirstOrDefault();
            sensor.ColorStream.Disable();
            sensor.DepthStream.Disable();
            sensor.SkeletonStream.Disable();
            sensor.Start();

            //gets information about the installed speech recognizers
            RecognizerInfo recognizer = SpeechRecognitionEngine.InstalledRe
cognizers().FirstOrDefault();

            if (recognizer != null)
            {
                speechEngine = new SpeechRecognitionEngine(recognizer.Id);
                //create the grammar(vocabulary) for the recognizer
                Choices commands = voiceCommands();
                var gb = new GrammarBuilder();
                gb.Append(commands);
                var g = new Grammar(gb);
                speechEngine.LoadGrammar(g);
                //eventhandler
                speechEngine.SpeechRecognized += SpeechRecognized;
                // recognizer settings connection and start of the sensor a
udiostream
                speechEngine.SetInputToAudioStream(sensor.AudioSource.Start
(), new SpeechAudioFormatInfo(EncodingFormat.Pcm, 16000, 16, 1, 32000, 2, n
ull));
                //asychronus audio recognition
                speechEngine.RecognizeAsync(RecognizeMode.Multiple);
            }
        }

        protected virtual Choices voiceCommands()
        {   //voice commands
            Choices commands = new Choices();
            return commands;
            //commands.Add("progress");
            //commands.Add("exit");
            //commands.Add("next");
            //commands.Add("repeat");
            //commands.Add("return");
            //commands.Add("post");
            //commands.Add("ping");
            //commands.Add("mirror");

        }

        protected virtual void WindowClosing(object sender, CancelEventArgs
 e)
        {
            closeSensor();
```

```
        }

        protected virtual void SpeechRecognized(object sender, SpeechRecogn
izedEventArgs e)
        {   //confidence threshold for correct recognition
            double ConfidenceThreshold = 0.3;

            if (e.Result.Confidence >= ConfidenceThreshold)
            {
                makeChoice(e.Result.Text);
            }
        }

        protected virtual void makeChoice(string choise)
        {
            switch (choise)
            {
                case "progress":
                    MessageBox.Show(choise);
                    //button1.RaiseEvent(new RoutedEventArgs(ButtonBase.Cli
ckEvent));
                    break;

                case "exit":
                    MessageBox.Show(choise);
                    break;

                case "repeat":
                    MessageBox.Show(choise);
                    break;

                case "return":
                    MessageBox.Show(choise);
                    break;
            }
        }
        protected void closeSensor()
        {
            if (sensor !=null )
            {
                sensor.AudioSource.Stop();
                sensor.Stop();
                sensor = null;
            }

            if (speechEngine!=null)
            {
                speechEngine.SpeechRecognized -= SpeechRecognized;
                speechEngine.RecognizeAsyncStop();
            }
        }
    }
}
```

9.2. Parts of the Skeleton tracking class

```
using System;
using System.IO;
using System.Windows;
using System.Windows.Media;
using System.Windows.Media.Imaging;
using Microsoft.Kinect;
using Microsoft.Kinect.Toolkit;
using System.Windows.Media.Media3D;
namespace PhysioWPF
{
    public abstract class Game : Window
    {
        //game abstract class
        protected List<Point3D> Hand = new List<Point3D>();
        protected List<Point3D> Shoulder = new List<Point3D>();
        protected KinectSensor sensor;
        protected WriteableBitmap colorBitmap;
        protected byte[] colorPixels;
        protected Timer timer;
        protected double largeDistance, smallDistance, b = 0.2, c = 0.3, sm
all, large;

        public Game()
        {

        }

        virtual protected void loadControls()
        {

        }
        protected void WindowLoaded(object sender, RoutedEventArgs e)
        {
            sensor = KinectSensor.KinectSensors.FirstOrDefault();
            var SmoothParameters = new TransformSmoothParameters
                   {
                       Smoothing = 0.75f,
                       Correction = 0.0f,
                       Prediction = 0.0f,
                       JitterRadius = 0.02f,
                       MaxDeviationRadius = 0.04f
                   };
            sensor.SkeletonStream.Enable(SmoothParameters);
            sensor.ColorStream.Enable(ColorImageFormat.RgbResolution640x480
Fps30);
            sensor.ColorFrameReady += SensorColorFrameReady;
            sensor.SkeletonStream.Enable();
            sensor.SkeletonFrameReady += SensorSkeletonFrameReady;
            sensor.SkeletonStream.TrackingMode = SkeletonTrackingMode.Seate
d;
            sensor.SkeletonStream.EnableTrackingInNearRange = true;
            sensor.Start();
```

```
        }
        protected void WindowClosing(object sender, System.ComponentModel.C
ancelEventArgs e)
        {

        }
        protected void SensorSkeletonFrameReady(object sender, SkeletonFram
eReadyEventArgs e)
        {
            Skeleton[] skeletons = new Skeleton[0];

            using (SkeletonFrame skeletonFrame = e.OpenSkeletonFrame())
            {
                if (skeletonFrame != null)
                {
                    skeletons = new Skeleton[skeletonFrame.SkeletonArrayLen
gth];
                    skeletonFrame.CopySkeletonDataTo(skeletons);
                }
            }
            if (skeletons.Length != 0)
            {
                foreach (Skeleton skel in skeletons)
                {
                    if (skel.TrackingState == SkeletonTrackingState.Tracked
)
                    {
                        Point3D[] skel3D = skeletonTo3D(skel, sensor.Elevat
ionAngle);
                        Draw(skel3D, skel);

                    }
                    else if (completed || failed)
                    {
                        sensor.SkeletonFrameReady -
= SensorSkeletonFrameReady;
                        closeSensor();
                        return;
                    }
                }
            }
        }
        protected void SensorColorFrameReady(object sender, ColorImageFrame
ReadyEventArgs e)
        {
            colorPixels = new byte[sensor.ColorStream.FramePixelDataLength]
;
            colorBitmap = new WriteableBitmap(sensor.ColorStream.FrameWidth
, sensor.ColorStream.FrameHeight, 96.0, 96.0, PixelFormats.Bgr32, null);

            using (ColorImageFrame colorFrame = e.OpenColorImageFrame())
            {
                if (colorFrame != null)
                {
                    colorFrame.CopyPixelDataTo(colorPixels);
                    this.colorBitmap.WritePixels(
                        new Int32Rect(0, 0, this.colorBitmap.PixelWidth, th
is.colorBitmap.PixelHeight),
```

```
                        colorPixels,
                        this.colorBitmap.PixelWidth * sizeof(int),
                        0);
                }
            }
        }
        protected virtual Point3D[] skeletonTo3D(Skeleton skeleton, int ele
vationAngle)
        {
            Point3D[] skel3D = new Point3D[skeleton.Joints.Count];
            int i = 0;
            Matrix3D elevationCompensation = Matrix3D.Identity;
            double eRad = elevationAngle * Math.PI / 180;
            elevationCompensation.M22 = Math.Cos(-eRad);
            elevationCompensation.M23 = Math.Sin(-eRad);
            elevationCompensation.M32 = -Math.Sin(-eRad);
            elevationCompensation.M33 = Math.Cos(-eRad);
            Vector3D vec;
            foreach (Joint joint in skeleton.Joints)
            {
                vec = new Vector3D(joint.Position.X, joint.Position.Y, join
t.Position.Z);
                vec = Vector3D.Multiply(vec, elevationCompensation);
                skel3D[i].X = -vec.X;
                skel3D[i].Y = vec.Y;
                skel3D[i].Z = vec.Z;
                i++;
            }
            return skel3D;
        }
         virtual protected void Draw(Point3D[] skel3D, Skeleton skel)
        {
        }
        protected void closeSensor()
        {
            if (sensor != null)
            {
                sensor.ColorFrameReady -= SensorColorFrameReady;
                sensor.SkeletonFrameReady -= SensorSkeletonFrameReady;
                sensor.Stop();
                sensor.Dispose();
                sensor = null;
            }

        }
    }
}
```

APPENDIX 2

The information sheet, the protocol of the experiment, the consent form of the volunteers and the questioner for the assessment of the system are presented in the following pages.

Information Sheet

Study title:

Physiotherapy with Kinect

Name, position and contact address of Researcher:

Ioannis Symeonidis, Student in Informatics Master HOU, Fotolivos Drama, Greece

The experiment you are taking part concerns the development of a Physiotherapy system for home rehabilitation. The system is using the Kinect device to capture the kinematics of the user, his face expressions and his voice. The system instructs the user to perform specific motions; his kinematics are captured for the evaluation of the motions while the user's voice and face expressions are the feedback of the user to the system in order to increase, decrease the exercise intensity or stop if there is any difficulty or pain encountered.

In this experiment you will perform specific motions, face expressions and voice commands in order to evaluate the accuracy of the Kinect device. A **video** and **audio** recording of the experiment will take place. The type of action you need to perform will be displayed on the left top of the screen and the specific action on the middle.

During the performance of the face expression actions a triangle mesh mask should be visible over your face. When you take the described expression you need to press the capture button without changing your expression as if you are taking a snapshot, between expressions please take your normal expression.

During the performance of the arm-motions a skeleton stick figure should be visible over your body. After you start performing several repetitions (more than 5) of the instructed motion you must press the capture button.

During the performance of the voice commands there is no requirement for any visible cue. After you start repeating (more than 5 times) the instructed word you must press the capture button, please make a small pause between each repetition.

Protocol

Study title:

Physiotherapy with Kinect

Name, position and contact address of Researcher:

Ioannis Symeonidis, Student in Informatics Master HOU, Fotolivos Drama, Greece

1. Explain the experiment to the volunteer
2. Answer any questions of the volunteer
3. Give the consent form to the volunteer
4. Perform anthropometric measurements (coracoids process, lateral epicondyle, styloid process of radius)
5. Start the recording software
6. Perform the experiment with the guidance of the researcher
7. Safely store the data in the volunteers directory

Consent Form

Study title:

Physiotherapy with Kinect

Name, position and contact address of Researcher:

Ioannis Symeonidis, Student in Informatics Master HOU, Fotolivos Drama, Greece

Please tick the box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason. ☐
3. I agree to take part in the above study. ☐

Please tick the box

4 I agree that my data gathered in this study may be stored (after it has been anonymised) may be used for future research.

☐ Yes ☐ No

Name of Participant

Place, Date, Signature

____

____

Questionnaire

Study Title:

Physiotherapy with Kinect

Name, position and contact address of Researcher:

Ioannis Symeonidis, Student in Informatics Master HOU, Fotolivos Drama, Greece

Please fill the following questioner selecting one if you fully disagree and one if you fully agree.

	1	2	3	4	5
Concerning the functionality of the system					
1. The use of the proposed physiotherapy system…………………………………………	☐	☐	☐	☐	☐
2. Exercise at home………………………………………………………………………………….	☐	☐	☐	☐	☐
3. The supervision from a specialist from distance………………………………………….	☐	☐	☐	☐	☐
4. The use of feedback for supervision…………………………………………………………….	☐	☐	☐	☐	☐
5. The transmission of video during the exercise for specialist supervision……..	☐	☐	☐	☐	☐
6. Voice navigation……………………………………………………………………………………..	☐	☐	☐	☐	☐
7. The manipulation of the exercised based on the volunteers' needs……………	☐	☐	☐	☐	☐
8. Feedback to the user concerning his performance…………………………………….	☐	☐	☐	☐	☐
Concerning the use of perdonal data					
9. Kinematics data………………………………………………………………………………………	☐	☐	☐	☐	☐
10. Voice data……………………………………………………………………………………………	☐	☐	☐	☐	☐
11. Video data……………………………………………………………………………………………	☐	☐	☐	☐	☐
12. Face expression recognition data…………………………………………………………	☐	☐	☐	☐	☐
Preference in the exer-games					
13. Post office…………………………………………………………………………………………….	☐	☐	☐	☐	☐
14. Mirror………………………………………………………………………………………………….	☐	☐	☐	☐	☐
15. Ping- pong……………………………………………………………………………………………	☐	☐	☐	☐	☐
16. Stork…………………………………………………………………………………………………..	☐	☐	☐	☐	☐

Signature of the volunteer

____