



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# A mobile game/app for enhanced ultrasound interpretation

**Mina Khosravifard**

Master in Information Systems

Submission date: November 2014

Supervisor: Frank Lindseth, IDI

Norwegian University of Science and Technology  
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# MasterNeuroSurgeon

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# Assignments Text

## **A mobile game/app for enhanced ultrasound interpretation: Neurosurgery**

The national competence center for ultrasound and image guided therapy was established in 1995 and is a collaboration between SINTEF, NTNU and St Olav. Within the center ultrasound-based navigation technology is being developed and used in various clinical fields in order to guide surgical instruments safely into the human body (similar to GPS navigation). One of the main challenges in order to make use of this technology is sufficient knowledge about interpreting ultrasound images. Each week unique data material is collected within the center. If presented in an easy and knowledgeable way, selected parts of the anonymous material can be used to teach relevant groups to interpret ultrasound images in an entertaining manner. A serious game for mobile devices (iOS and maybe Android) has huge potential in this regard.

The possibilities are almost endless but some basic suggestions could be to learn ultrasound interpretations of brain images by presenting:

- Anatomy – The user sees an ultrasound image as well as names of anatomical structures and is challenged to drag each name onto the correct structure.
- Pathology – The user sees ultrasound images of various tumors and is asked to identify the tumor and state the type (multiple choice).
- Tumor borders – Some tumor types have diffuse border to normal tissue. The user sees such images and is asked to draw the border.

A scoring system should be developed and based on the available data material random questions, tutorials and skills validation can then be generated. This can be made very advanced with global user profiles and benchmarking but it's probably wise to start easy.

It should be easy to generate and upload new material and when new cases become available the users are notified and asked if they would like to download the new material.

Frank Lindseth

# Acknowledgments

I would like to express my deepest sense of gratitude to my supervisor, Dr. Frank Lindseth, Senior Researcher Scientist at SINTEF medical technology and Associate Professor at Computer and Information Science (IDI), who offered his continuous advice throughout the specialization and thesis project. I thank him for the guidance, useful critiques and constructive suggestions. I would like to express my gratitude to Prof. MD. Geirmund Unsgård, head of neurosurgical Department at St Olav's university hospital, Trondheim, who provided the gold standard for tumor border and participating in the experimental session.

I would like to dedicate this thesis to all patients around the world.

Mina Khosravifard

Trondheim November 1st, 2014.

# Abstract

Ultrasound imaging is widely used imaging modality. Ultrasound has many advantages: it is supporting continuous realtime imaging in 2D or 3D, relatively inexpensive, non invasive, and free of harmful radiation. Beside those advantages, it is being used in combination with navigation technology. Nevertheless, neurosurgeons need considerable experience to interpret ultrasound images. One possible solution is using the advantages of serious gaming to improve neurosurgeon's skill. The feasibility of this solution was investigated by implementing a basic drawing application for drawing the tumor border in the specialization project. This thesis is a continuation of the specialization project. The first goal of this project was designing and implementing a full set of drawing and evaluation tools in the form of a serious game. After implementation, the most important goal was testing the effectiveness of the application. The goal was achieved by running a systematic experiment with real users. Participant's results showed that they can learn to interpret by playing the application (MasterNeuroSurgeon). Feedback also reveals that the application is usable.

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# 1 Introduction

## 1.1 Background

Ultrasound imaging is widely used as an intra-operative image modality [1]. It has significant advantages such as realtime imaging, flexibility, safety, low cost and portability. However, the interpretation of intra-operative ultrasound images needs years of experiences. Currently, attending to surgery session is the only way for students to learn the ultrasound interpretation.

Serious games are designed to educate or train a specific group of audiences. Many serious games are pursued to teach inexperienced students in the health care system. Most serious games attempt to enhance student's knowledge by using either simulation of surgery or using a fancy questionnaire. The simulation strategy turns into one of the following output: video serious games that could not transfer a great amount of knowledge, or simulation game that are close to reality and expensive to implement [2]. Regarding games with concept of fancy questionnaire, only some of them can keep student's motivation for playing for a long time [3]. The main purpose of this thesis is using serious game concept and address the problem of ultrasound interpretation.

## 1.2 Motivation

My motivation was developing an application which helps patients in some way. I wanted to develop an application that might be useful in the treatment process of the patient. As a result of my interest, I found this thesis proposal. My supervisor, Frank Lindseth, proposed a thesis to design an application where inexperienced students can increase ultrasound knowledge. The motivation is creating a serious game as an alternative way to traditional learning of ultrasound interpretation in the surgery session.

## 1.3 Project Context

Norwegian University of Science and Technology, SINTEF and St Olav are collaborating to develop an ultrasound based navigation system. Interpretation of ultrasound images is one of the main concerns with ultrasound based navigation. This project is defined to enhance the ultrasound interpretation by a serious game. This thesis puts focus on interpretation of the tumor borders in ultrasound images.

## 1.4 Problem Definition

The main purpose of this thesis is designing an iOS serious game for enhancing the ultrasound interpretation. This project gives the attention to the tumor borders in the ultrasound brain images. To design an effective serious game for promoting ultrasound experience, the following research questions are defined:

RQ1: Are there any similar serious games to this project (MasterNeuroSurgeon)? Do they exhibit any features, which can enrich MasterNeuroSurgeon as well?

RQ2: How does MasterNeuroSurgeon application assist to widen the experience of novice neurosurgeon? Does the MasterNeuroSurgeon application assist to widen the experience of novice neurosurgeons?

RQ3: How effective is the output application designed? How easy is it to use the Master neurosurgeon application to draw a precise interpretation?

RQ4: what features can be highlighted or added by the next generation of Master Neurosurgeon to enhance ultrasound image interpretation? What features should be modified for the next generation to get the ideal learning outcome?

## 1.5 Limitation

As stated in the assignment text, the output application is expected to run on iOS devices. But Apple Inc. defines a set restriction for developing iOS application. According to Apple Inc, developers who wish to develop an application for apple products need to develop on Mac computer. In addition to hardware restriction, they need to purchase a developer subscription for testing applications on physical device. As a result, the implementation faced some delay to fulfil these requirements.

## **2 Research Method, Medical Imaging and Existing Solutions**

This chapter consists of three main sections: The first section explains the employed research methods for addressing the research questions. The second section presents an introduction to medical imaging and related visualization techniques. The last section presents reviews on similar serious games and their features.

### **2.1 Research Methods**

The right choice of research method can significantly help to address the research questions. Briony J Oates mentions in his book “Research Information systems and computing” that there are various strategies to for addressing research questions such as survey, design and creation, experiment, case study, action research and ethnography. Literature review is another common approach to deal with the research question. Among these approaches, literature review, design and creation and experiment are employed to address the research questions [4].

#### **2.1.1 Literature review**

The first phase of Literature review considers different approaches for developing mobile application. The advantages and disadvantages of hybrid and native applications were reviewed to find a suitable developing approach. Beside the developing approach, a systematic literature review was done to find out usable features of existing serious games for this project. In fact, the second phases of literature review tried to address the first research question by gamifying the basic idea of drawing the tumour border.

#### **2.1.2 Design and creation**

The design and creation strategy is useful for developing a new IT product. In fact, it is a problem solving approach. The design and creation cycle consists of five iterative steps: awareness, suggestion, development, evaluation and conclusion.

- Awareness is the first phase to identify a problem. Problem can originate from the research question or from developing new software, and so on.
- Suggestion is process of presenting tentative proposals of how this problem may be tackled.
- Development is an implementation of the tentative proposal for addressing the problem.

- Evaluation is analysing the implemented artefact to see positive and negative points from anticipation.
- Conclusion phase is summarizing the result form the evaluation of implemented artefact. The loose point could use to start over the design and creation process [5].

Design and creation is applied during the planning and development process of MasterNeuroSurgeon.

### **2.1.3 Experiment approach**

The experiment is an approach to study cause and effect relationship between factors. The second research question is addressed by running an experiment. The experiment process starts by defining a hypothesis. The underlying hypothesis is formed based on “Factor A causes B” [6].

Hypothesis: Playing “MasterNeuroSurgeon” widen the student’s experience and makes it easier to recognize the diffuse tumor border in ultrasound images.

### **2.1.4 Data Collection methods**

Different data collection methods are used to assess the stated hypothesis. An introduction of the employed data collection methods are presented in the following:

- **Questionnaire**

Questionnaire is a set of questions that are ordered on purpose. One of the common problems with questionnaire is ignoring to answer all of them by the respondents. It is important how to design a questionnaire. A well designed questionnaire can raise the answer rate, while a long list of questions is chancy to get response. Questions can be categorized in two types: open and closed questions. Closed question can save respondents time, although it is harder to define a close questionnaire than open questionnaire. Closed questions should cover all possible answer. A closed questionnaire seems a suitable method to generate data for the MasterNeuroSurgeon project [8]. Time limitation on experiment session has also forced us to design a short well-made questionnaire. The specified questionnaire in this project follows the “Degree of agreement or disagreement” format. It consists a set of 14 questions that respondent express their agreement or disagreement on a scale from 1 to 5. The usability is addressed by the SUS questionnaire by the ISO standard ISO 9241. The first 10 question are predefined SUS questions [9]. The rest of the questions are also following the “Degree of agreement or disagreement” approach. They are designed to determine the effect of the MasterNeuroSurgeon on knowledge improvement.

- **Observation**

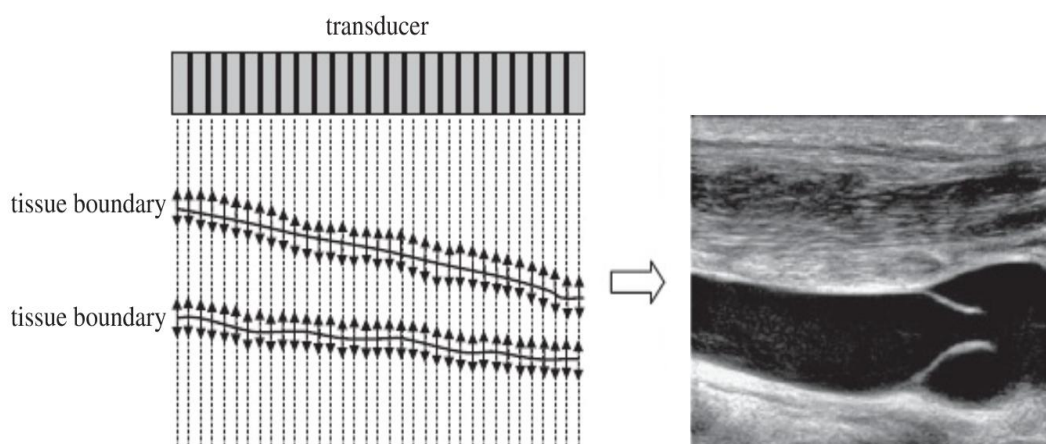
Observation is used as a data generation method. It is compatible with any research strategy. It can be used to watch the behaviour of people to an inanimate object; here observation is applied to gather behaviour of users (Student, technical and experienced neurosurgeon), their reaction and their decision toward the MasterNeuroSurgeon application. Observing the participants assist to realize unrevealed problem areas. Observer can also take a role of instructor, if the participants need any help. Observation is used here to examine stated hypothesis in section 2.2.3 Observation should be done in “convert” or “overt” approach. If people know that they are being observed, it is an overt approach. In the “convert” approach, no one knows that they are being watched [7].

## **2.2 Medical Imaging**

Medical imaging refers to different technologies that it is used to scan human bodies for clinical reasons. It is applied for diagnosing, controlling and treating medical conditions. There are different image modalities. Each modality shows different information about the area of body that is being examined. Medical imaging is applied in different stages of an operation. The first stage is before an operation that is called pre-operative images. Pre-operative imaging is useful method to make a therapy decision, overall diagnosis and planning a surgery. The second stage is called intra-operative imaging, which is highly vital to update images for guiding purpose during the surgery. The last phase is called post-operative imaging, which is required to evaluate treatment [1]. MasterNeuroSurgeon focuses on enhancing the interpretation of intra-operative brain surgery images. There are different image modality options for the intra-operative image such as CT-Computed tomography, MRI-Magnetic Resonance imaging and Ultrasound. Using CT as intra-operative image modality exposes the patient and medical personals to significant radiation doses. Another alternative is MRI images, it is expensive options, because it needs a special operating room (OR), as well as special surgical equipment. Beside high expenses, MRI images lose quality to reach near real time imaging in 2D. Some groups applied the ultrasound as the intra-operative image modality in neurosurgery. They preferred the ultrasound imaging, because of the low cost [1]. MasterNeuroSurgeon is designed to enhance the interpretation of intra-operative ultrasound images. Beside ultrasound, preoperative MRI is used as guidance for the surgeon. It is necessary to display both MRI and ultrasound simultaneously for neurosurgeons. Since each image modality has its own characteristics, for example MRI Images present anatomy and pathology whereas ultrasound image depicts tumour borders and vascularization. Integration of preoperative MRI data and intra-operative ultrasound images is the best approach to familiarize with ultrasound images for inexperienced neurosurgeons. They can notice the differences of an identical structure which is imaged using the two modalities [1].

### 2.2.1 Ultrasound

Ultrasound is mechanical wave, with a frequency above 20 kHz. The frequency for medical issue is between 1 and 15 MHz. The mechanical waves are produced by transducer which has an array up 512 individual active sources. A tiny set of these elements is fired consecutively to formed ultrasound beams. When the ultrasound beam goes throughout the tissue, a small part of energy is backscattered to transducer from tissue boundaries. The tissue boundaries have different acoustic. The rest of energy passes through the boundary. Distances among tissue boundaries are determined from time between pulses transmission and signal reception. Electronic steering of the beam across the sample produce lines which finally form the ultrasound images in a fraction of a second [10].



*Figure 1 Basic principle of ultrasound imaging [10]*

Ultrasound is the most economical medical imaging and the most portable medical imaging. It is a fast approach which enable continues imaging at realtime. In many cardiovascular applications is employed, ultrasound is very useful in medical navigation system to guide the path and positioning of needles [10, 11].

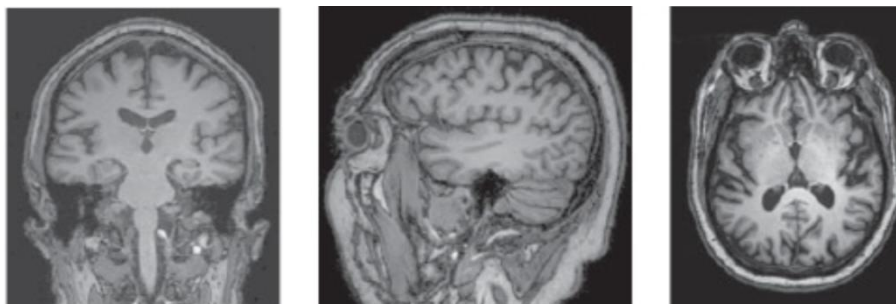
### 2.2.2 Magnetic Resonance Imaging (MRI)

MRI is designed to use for non-invasive scan of the body to diagnose medical conditions. MRI can image all internal body structure with a high level of details. MRI uses a powerful magnetic field, radio frequency and a computer for obtaining an image. In contrast to X-ray and CT scans, MRI does not rely on ionizing radiation [10]. Radio waves change the axes of spinning hydrogen atoms. When the hydrogen atoms turn back to the natural alignment, they produce energy. This energy is differing based on the tissue type. The MR scanner gets this energy and produces an image of the examined tissue.





*Figure 1 MRI machine[4]*



*Figure 2 MR images within coronal, sagittal and axial orientations[4]*

There are several limitations for using MRI. The patient needs to be lying without movements while image being recorded. Movement is producing images with distortion. The presence of metallic object makes it difficult to obtain an apparent image. MRI may not make a distinction between cancer tissue and fluid, which is known as edema [12]. It is important to mention that MRI still presents a better diversity of the abnormal and normal tissue compare with other medical. In comparing to other medical imaging, MRI costs higher than others. Beside the cost, it takes more time to produce an MRI image [10].

### **2.2.3 Visualization of intra-operative Image Information**

There are different approaches to visualize and render volumetric data which are made from medical images such a MRI, ultrasound and CT. Volume visualization means extracting meaningful data and displays them. Volume data is three dimensional entities. A voxel or volume element is a value in three dimensional space at the location of  $(x,y,z)$  that can be shown like this  $(x,y,z,v)$  [13]. Common approaches are slicing, volume rendering and

geometric rendering. Slicing method illustrate a 2D plane out of 3D data. Slicing method can be separated based on method of generating 2D slice data and the way to present the data. Row slices refer to a sequence of slices which is used to produce a typical image volume. The orthogonal and oblique views can be acquired from reconstructed volumes. Volume rendering and geometric rendering are similar and both strategies can generate similar results. Geometric surface rendering is applicable for rendering geometric texture mapped quads which is used for rendering geometric surface representations. A precise geometric model needs applying segmentation at first. Geometric primitive is a technique to approximate a surface, including volumetric data using a lot of simple geometric triangles [1].

Charles and Christopher mentioned that “Volume rendering is the process of creating 2D images directly from 3D volumetric data” [13]. There are many approaches to implement volume rendering. One most common method is volumetric ray casting [11].

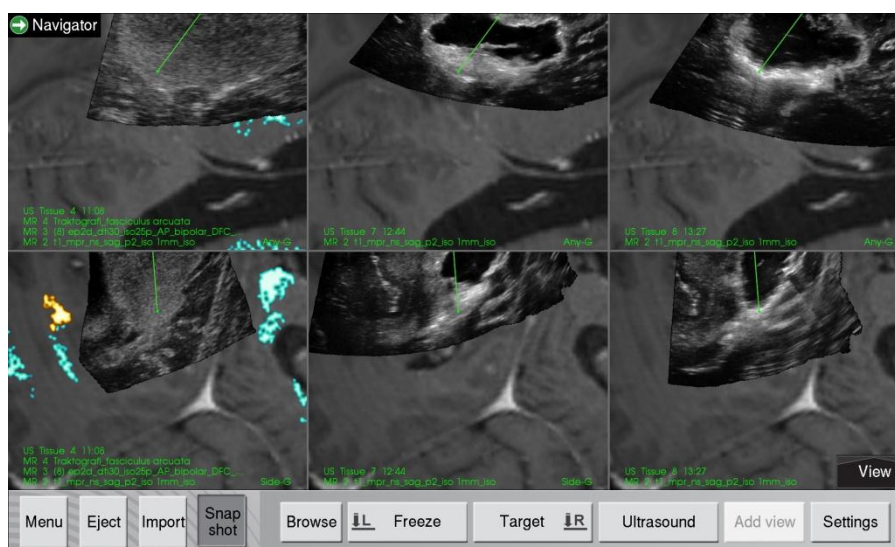


Figure 3 Screenshot of a patient case from MNS-image fusion example

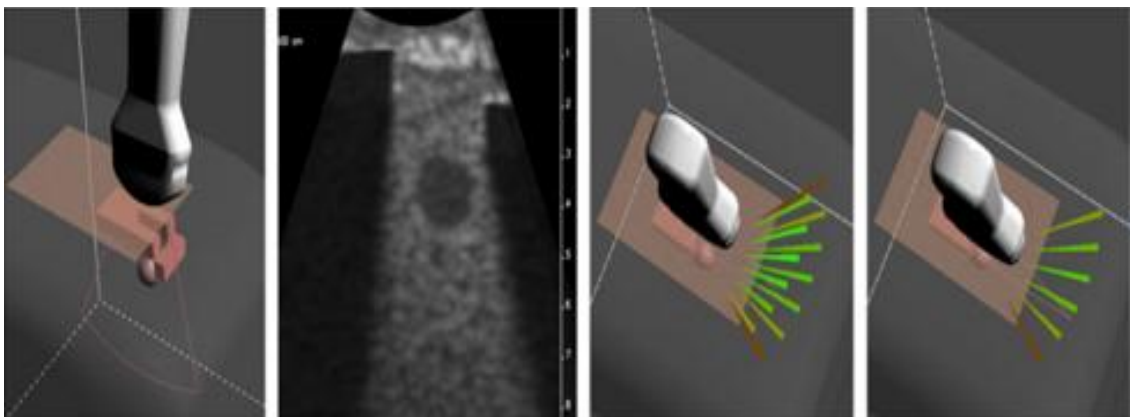
Another option to represent three dimensional data is an image fusion suggested by Frank Lindseth. This technique assists to fuse image data from the same scene. One significant advantage of image fusion is a chance to pick most relevant data from all the related datasets. In addition to relevant data, it is excellent choice to mix the MRI and Ultrasound images data from the same scene [1]. In Master Neurosurgeon there is need to use both MRI and US data to interpret intra-operative ultrasound images. This requires using image fusion as a visualization technique. Therefore, all image data imported into MasterNeuroSurgeon use image fusion visualization technique. Figure 4 shows an example of image fusion.

## 2.3 Existing Solutions

Mike zyda mentioned that “a game is a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participant.” A video game is an electronic game that players interact with user interface to have fun [14]. The first electronic game (XOX) was designed in 1952 by Alexander Dauglas[15]. Games have various genres. A serious game is one type of the games which enhances traditional learning activities with new multimedia technology. Mike zyda stated a definition of the serious game based on his first explanation on the game: “a serious game is a mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives”. The main goal of serious game is not entertainment. In fact, the main purpose is training a specific group of people [14]. In the following, a summary of some serious games in the healthcare field is presented. Unfortunately there are few serious games with a focus on surgical training.

### 2.3.1 A serious game for learning ultrasound-guided needle placement skills

This is a computer serious game for radiologists. The game puts focus on learning contents such as guidance image acquisition, block tissue identification, vital tissue identification and insertion path planning. A player communicates with 3D object in virtual interface. In addition to the virtual environment, the player manipulates surgical tool in 3D space with a 6-DOF haptic device (needle) and a 6-DOF tracker (transducer). It supports a variety of the serious game features like realistic modelling, Learning skills through game play and lastly Evaluation and feedback [19].



*Figure 4 Game component of ultrasound-guided needle placement skills [5]*

### 2.3.2 Learning Blood Management in orthopaedic surgery through Gameplay

Orthopedic blood management game has developed by Jing, Yim-pan and Wai-man. They simulated bleeding at several difficulty levels based on the blood loss severity. Novice surgeons play this game and they can quickly learn about the consequences of their actions by instance feedbacks. The game provides an assessment to analysis the surgeon's proficiency to control the bleeding situation and it gives an interactive experience to users. Time and performance score are recorded to use as evaluation factors. This game needs to play in computer due to the requirements for heavy rendering of complex scenes [2].

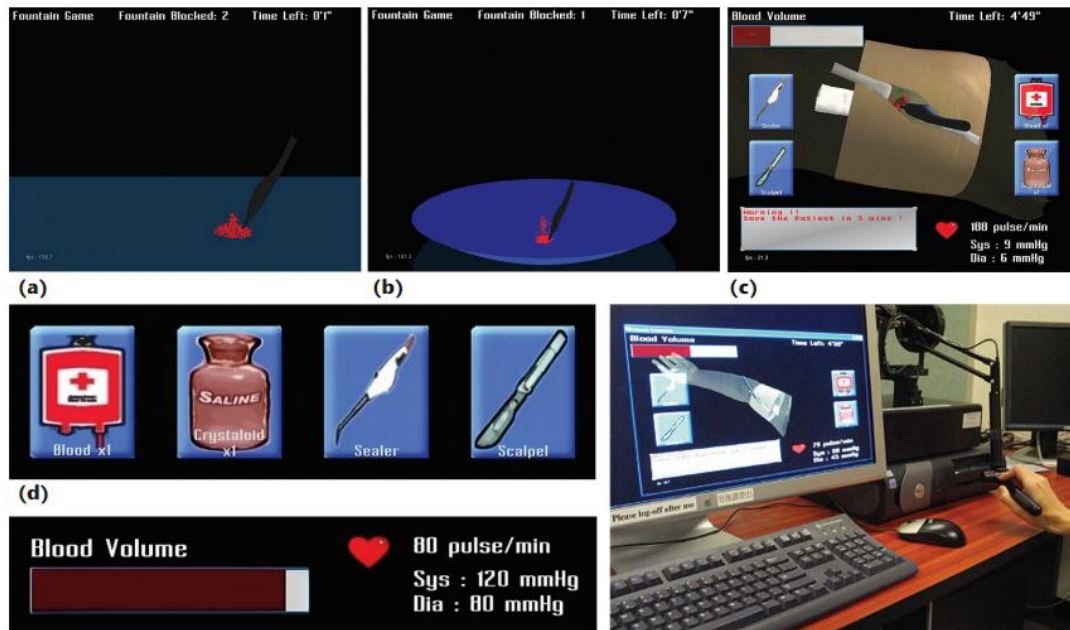
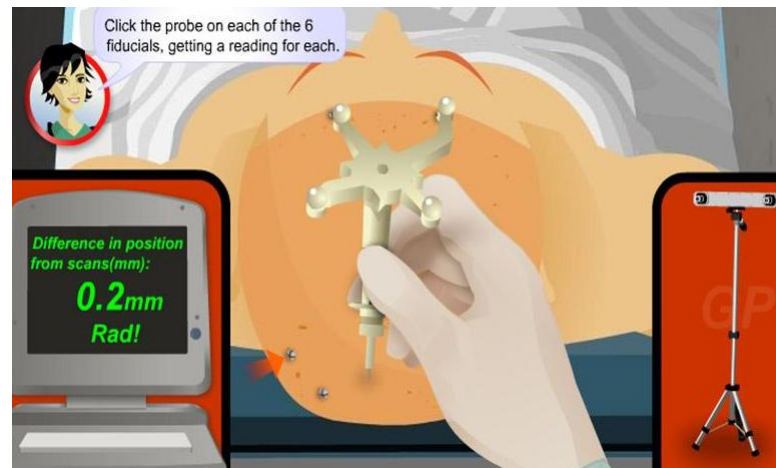


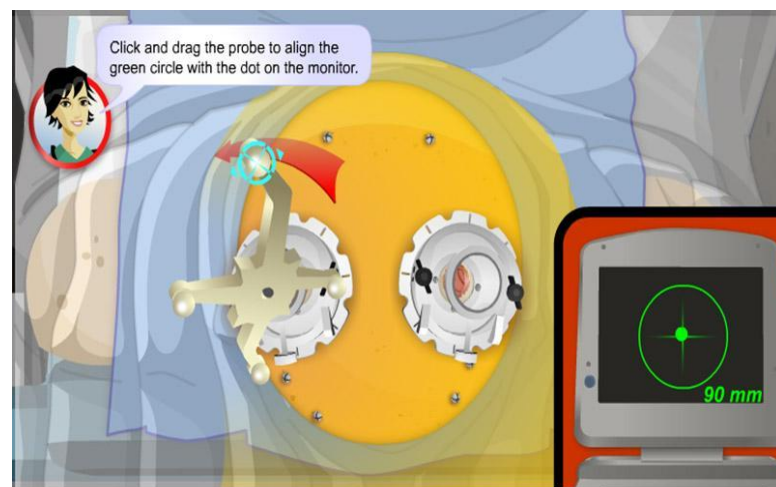
Figure 5 Blood management Game Components [2]

### 2.3.3 Virtual Deep Brain Surgery

An enormous number of serious games use simulation (Like video game) to convey information to their user. Unfortunately, there is not enough documentation for most of these games. Virtual Deep Brain Surgery game presents a simulation for all steps before and after surgery for a patient with movement disorder or Parkinson's disease. This game is a single player game which a player plays as a surgeon. The Player plays three steps out of five steps through treatment process: Evaluating a patient, putting fiducial, performing brain surgery, putting the battery, activating the battery and finally set the system. During each step, some quiz pops up and ask the player related theoretical questions that are necessary to know as a neurosurgeon [20]. This game gives an overview for neurosurgeon, but it does not cover any exception during the surgery, which may make the player's mind too optimistic. The instance feedback is used to raise awareness for a player about the consequence of his/her actions.



*Figure 6 Virtual surgery[6]*



*Figure 7 align the probe[6]*

### 2.3.4 Serious Game Feature

Serious games are different based on their concept. However, serious games are also similar in some features. In the following a series of important features for serious game are presented.

- **Psychosocial Moratorium and Sandbox**

James Paul defined a set of principles. He claims that considering these principles could improve learning in the games. One of these principles is known as a psychosocial moratorium [16]. It means that end-user can take risks in the game environment where there are lower consequences than real-world. User can play a serious game and fail it without any consequences. The sandbox has a same meaning to psychosocial moratorium theory. Sand box is a metaphorical term, means a learners face into a similar situation to the real word but without any risk and dangers mitigate [17].

- **Identity**

A good game offers an identity to their end users. Most video games follow this rule and define characters in the content of story. This feature is originated from the video games. But, it is also used in serious games. The identity reminds them why they want to play the game. Players need to do certain behaviours and actions to be a certain character. With a concept of identity, player remembers that why do they need to play game again and again to gain certain knowledge [17]. The identity of being a master neurosurgeon is used in this project.

- **Realistic Modeling**

Realistic modelling is a required feature for serious games with a concept of simulation of operations. There are many video games that simulate operations. In comparing to video game, serious games should have higher level of realism. Some serious game reviewed to have a violent scene; however an actual educative game in healthcare needs to simulate the reality [17]. Using real images from the navigation system is a way of implementing realistic modelling in this project.

- **Fish Tank**

A fish tank is a simplified version of real ecosystems. The fish tank is metaphorical term. This metaphorical term means that designer of serious games should simplify the real world and just focus on limited specific concepts; if a game turns into a complex system, users will be confused and they cannot learn required technique from the game [17]. To simplify the surgery session, MasterNeuroSurgeon just put focus on the images from the navigation system. It does not attention to other aspects of the brain surgery. Since, the main purpose of this project is image interpretation.

- **Out of Content**

L. ACHTERBOSCH, R. PIERCE AND G. SIMMONS run a case study on all MMORPG. They listed top five MMORPG features: having a Lot of class/skills options, Graphics and effects, large world to explore (lots of contents), PVP (Player versus Player) and socialization [18]. Lots of content is a popular issue among all genres of games which is mentioned in different ways. It is a normal reaction that a player does not want to play the game within repetitive content. This requirement fulfils with having a large number of patient cases in the MasterNeuroSurgeon. Players can learn interpretation from each of them, since each patient case is unique.

- **Learning trough the game play**

Learning can acquire when a serious game starts from a basic scenario and it becomes more challenging and tough. In addition, serious game should have a guide for the novice learners [17].

- **Evaluation and Feedback**

Serious games should give feedback to the users. Feedback and evaluation notifies users, whether they are on right trail to be master in the subject or not. Games usually offer several ways to give feedback to users [17]. The introduction of how to implement evaluation and feedback capability is presented in the chapter 3 (Requirements specification section).

## 3 Application Development

This chapter consists of four sections: the first section presents the requirement specification for developing the MasterNeuroSurgeon. The next section presents the applied architecture. It also depicts the architecture of MasterNeuroSurgeon from different viewpoints. The third section presents the chosen technologies for implementing the MasterNeuroSurgeon. The last section briefly presents how the main functions are implemented.

### 3.1 Requirements Specification

This section outlines a detailed description of the requirements, which are divided into functional requirement and non-functional. The requirements are documented based on the RSI convention.

#### 3.1.1 Audiences (user description)

There are mainly two users in the master neurosurgeon: students and experienced neurosurgeons. Students are main target users but also experienced neurosurgeons that are most experienced ultrasound users. Experienced neurosurgeons also plays vital role in master neurosurgeon, since the interpretation used as a gold standard. Gold standard is provided by an experienced ultrasound user from the group. In addition to clinical users, people with technological background working within the field will probably also find it helpful.

#### 3.1.2 Functional requirements (system features)

Functional requirements define what the application should do. All of them are listed with their respective complexities and priorities. Here functional requirements are written based on the user type and the following template: “As a <role>, I want <goal/desire>, so that <benefit>”. This template is used for defining user stories. This method is useful for specifying the requirements. Since, it constantly pays attention to the users. It also puts focus on goals and respective results [28]. Table 1 presents a list of functional requirements.

*Table 1 Functional requirements*

<i>ID</i>	<i>Functional Requirements</i>	<i>complexity</i>	<i>Priority</i>
<i>FR1</i>	<i>As a student or an experienced neurosurgeon, I want to log in to the MasterNeuroSurgeon via Facebook, so that I identify as a student.</i>	<i>Low</i>	<i>Low</i>
<i>FR2</i>	<i>As a student or an experienced neurosurgeon, I want to see a list of different patient cases, so that I can choose a patient case among them.</i>	<i>Medium</i>	<i>Medium</i>
<i>FR3</i>	<i>As a student or an experienced neurosurgeon, I want to choose and load a patient case among of patient list, so that I can start</i>	<i>Medium</i>	<i>Medium</i>



	<i>drawing my interpretation of the selected patient case.</i>		
<i>FR4</i>	<i>As a student or an experienced neurosurgeon, I want to able to scroll and lock screen position on the tumor position, so that I can start drawing.</i>	<i>Medium</i>	<i>High</i>
<i>FR5</i>	<i>As a student or an experienced neurosurgeon, I want to be able to draw my interpretation around the tumor border, so that I can see my interpretation.</i>	<i>High</i>	<i>High</i>
<i>FR6</i>	<i>As a student or an experienced neurosurgeon, I want to able to erase my drawing, so that I can correct my interpretation.</i>	<i>High</i>	<i>High</i>
<i>FR7</i>	<i>As a student or an experienced neurosurgeon, I want to able to use reset my drawing, so that I can start drawing from the scratch.</i>	<i>low</i>	<i>High</i>
<i>FR8</i>	<i>As a student, I want to see deviation scores (which is measured in millimeters), so that I can be aware of my progress.</i>	<i>High</i>	<i>High</i>
<i>FR9</i>	<i>As a student, I want to see visual matching between student drawing and gold standard, so I can learn about my incorrect interpretation.</i>	<i>High</i>	<i>High</i>
<i>FR10</i>	<i>As an experienced neurosurgeon, I want to save my interpretation on each patient case, so that I can provide gold standards for students.</i>	<i>High</i>	<i>High</i>

### 3.1.3 Non-Functional requirements (Quality Requirements)

This section represents non-functional requirements that are listed with their respective complexities and priorities. Non-functional requirements are categorized into usability, security, safety and others [28].

#### 3.1.3.1 Usability

Usability requirements concerns with the ease of using the application and learning. Table 2 describes the usability requirements.

*Table 2 non-functional requirements -usability*

<i>ID</i>	<i>Non-Functional Requirements</i>	<i>Complexity</i>	<i>Priority</i>
<i>NFR</i>	<i>The game should be easy for drawing the borders of the tumor.</i>	<i>High</i>	<i>High</i>
<i>NFR</i>	<i>The game should be easy to work with.</i>	<i>Low</i>	<i>High</i>

#### 3.1.3.2 Security and Safety

Security requirement considers user accessibility. Safety requirements pay attention to any possible loss or damage that can occur using the end product. Safety requirement defines safeguards to prevent such consequences form using the end product. Table 3 presents a list of security and safety requirements [28].

*Table 3 non-functional requirements- security and safety*

<i>ID</i>	<i>Non-Functional Requirements</i>	<i>Complexity</i>	<i>Priority</i>
<i>NFR</i>	<i>The application should only give access to experienced surgeon for storing and updating the gold standard.</i>	<i>Medium</i>	<i>High</i>

### 3.1.3.3 Others

This part of the requirements is designed to cover any other needed quality attributes such as availability, efficiency, interoperability, modifiability, portability, reliability and reusability. Table 4 presents other quality attributes [28].

*Table 4 non-functional requirement- other quality attributes*

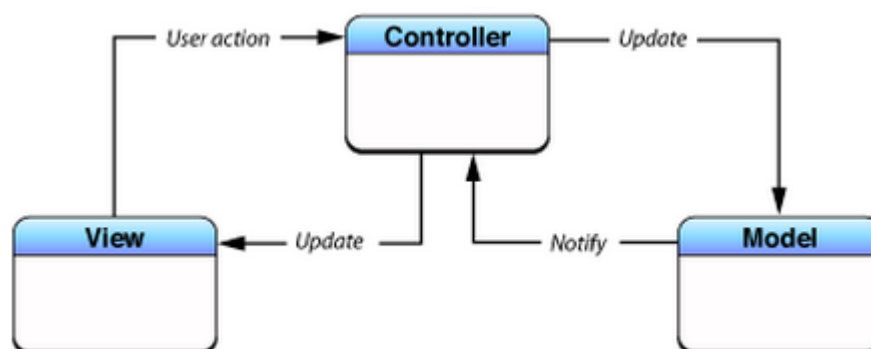
<i>ID</i>	<i>Non-Functional Requirements</i>	<i>Complexity</i>	<i>Priority</i>
<i>NFR</i>	<i>The code should be defined in a way that can be reused later.</i>	<i>Medium</i>	<i>Low</i>
<i>NFR</i>	<i>The application should design for the iOS.</i>	<i>High</i>	<i>High</i>
<i>NFR</i>	<i>The application should be easy to expand for iPad.</i>	<i>Medium</i>	<i>High</i>

## 3.2 Architecture

This section presents chosen architecture of MasterNeuroSurgeon. The architecture of MasterNeuroSurgeon is presented based on the “4+1” view model. This is a standard approach for demonstrating the multiple and concurrent view points on the architecture.

### 3.2.1 MVC (Model View Controller)

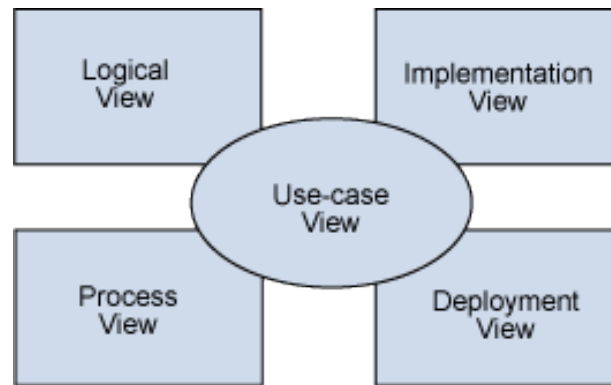
The Model-view-Controller architecture divides application’s objects into three concepts: model, view and controller. MVC has many advantages. For example, applications with MVC pattern seem that they are more reusable. In addition to the reusability, they are more extensible. Cocoa and cocoa touch technologies are based on the MVC pattern. The model package contains data in an application. View package mainly concerns displaying information on the window. Controller package places in between view and model controller. MVC architecture not only assigns objects to these three concepts, but it also specifies the way objects communicate. The controller package has a responsibility to give information from the model and pass it to the view and the other way around [25]. Figure 8 depicts the MVC architecture.



*Figure 8 illustration of MVC architecture [7]*

### 3.2.2 “4+1” Views

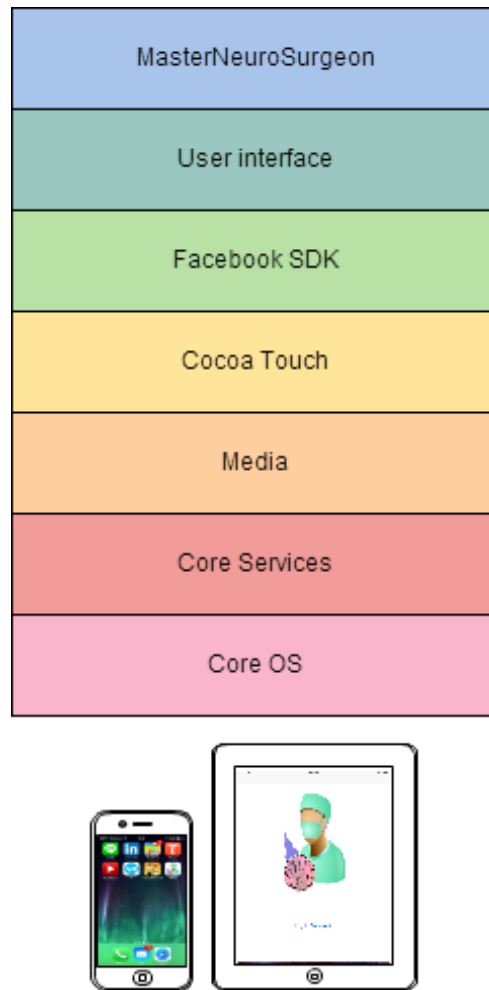
Philippe Kruchten designed the “4+1 views” which is a useful approach to define the architecture of software intensive systems. This approach separates the architecture views based on the stakeholder’s concerns. It presents four views: the logical view, the process view, the deployment view and the implementation view. The fifth view composes of the first four views. This view is presented either as a use case or scenarios [29].



*Figure 9 illustration of “4+1” views [8]*

#### 3.2.2.1 Deployment View

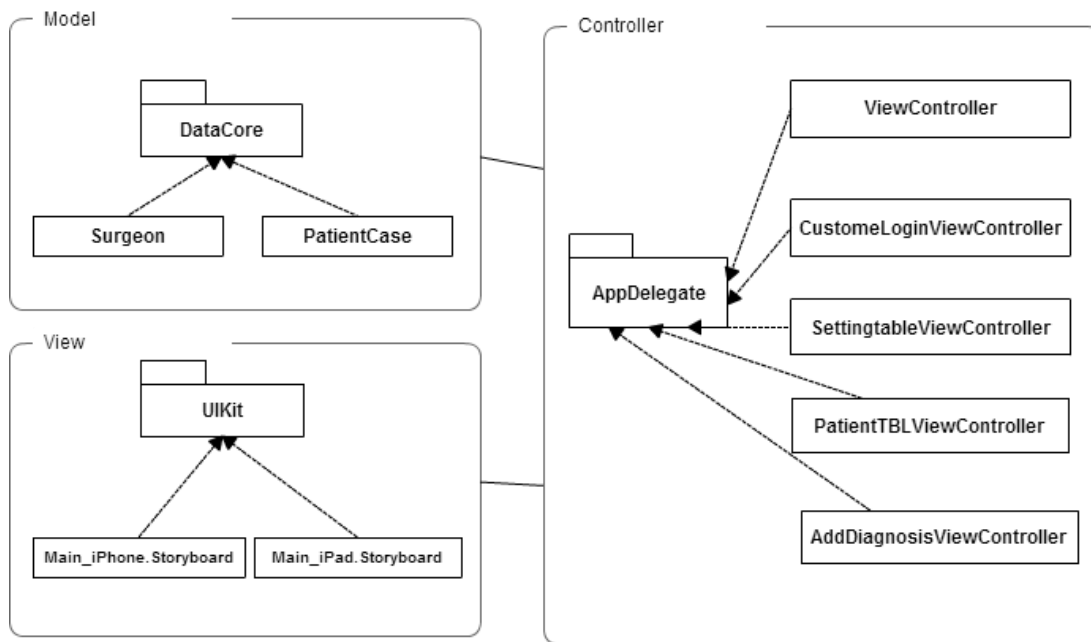
The deployment view is also known as physical view. It demonstrates the mapping of the software into the hardware. This view displays the system from the system engineer’s view point. It presents the impression of the system and its communication [29]. The physical view of MasterNeuroSurgeon is shown in the Figure 10. The MasterNeuroSurgeon application cannot directly communicate with hardware. The hardware (iPhone/ iPad) is presented at the bottom. The core OS, core services, media and cocoa touch provide the communication between hardware and user interface [30]. These four layers are common layers between all iOS application. The Facebook SDK also positions below the user interface. Finally the MasterNeuroSurgeon application places in the top of the user interface.



*Figure 10 Physical view*

### 3.2.2.2 Logic View

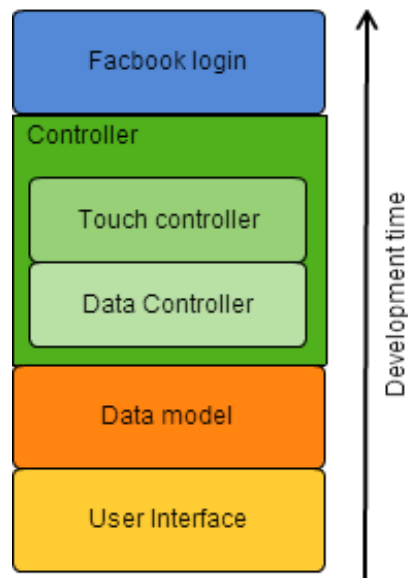
The logical view presents an object oriented model of systems. This view is used for supporting the functional requirements. The logic view present concepts like abstraction, encapsulation and inheritance [29]. Class diagram and static state diagram are good examples for demonstrating the logical view. Figure 11 present a static state diagram of the MasterNeuroSurgeon. Classes place into three different categories based on the MVC architecture. As stated earlier, the MVC architecture pattern is selected for the MasterNeuroSurgeon.



*Figure 11 Static state diagram*

### 3.2.2.3 Deployment View

The Development view is recognized as implementation view. This view designed for the programmers. It considers the organization of software modules in the software [29]. In fact, this view presents the dependency between parts of the system. Figure 12 depicts the order of the development process of MasterNeuroSurgeon. The development process started from the designing the user interface. Then it follows into the creation of database. After that controllers are implemented. The controllers provide the communication between the user interface and data. User interface, Data and controller are the main elements. The Facebook log in is on the top of all three parts, which can implement even separately.



*Figure 12 Development view*

#### **3.2.2.4 Process View**

Process view is used to demonstrate concurrency and synchronization. It demonstrates how different parts of the system exchange information and communicate. In fact, it puts focus on the run time behaviour of the system. Sequence diagram is a good diagram that can capture sequence processes [29]. The Figure 13 shows the message exchanges from the user to internal parts of the MasterNeuroSurgeon. A user interaction starts with sending “Facebook log in” request. The “CustomViewController” handles the request and log in process. After a successful log in, “Start” button will appear. The user can enter to the menu by clicking the button. Then, choosing “patient case” from the menu redirects the user to the list of patient cases which is controlled by the “PatientTBLviewController”.

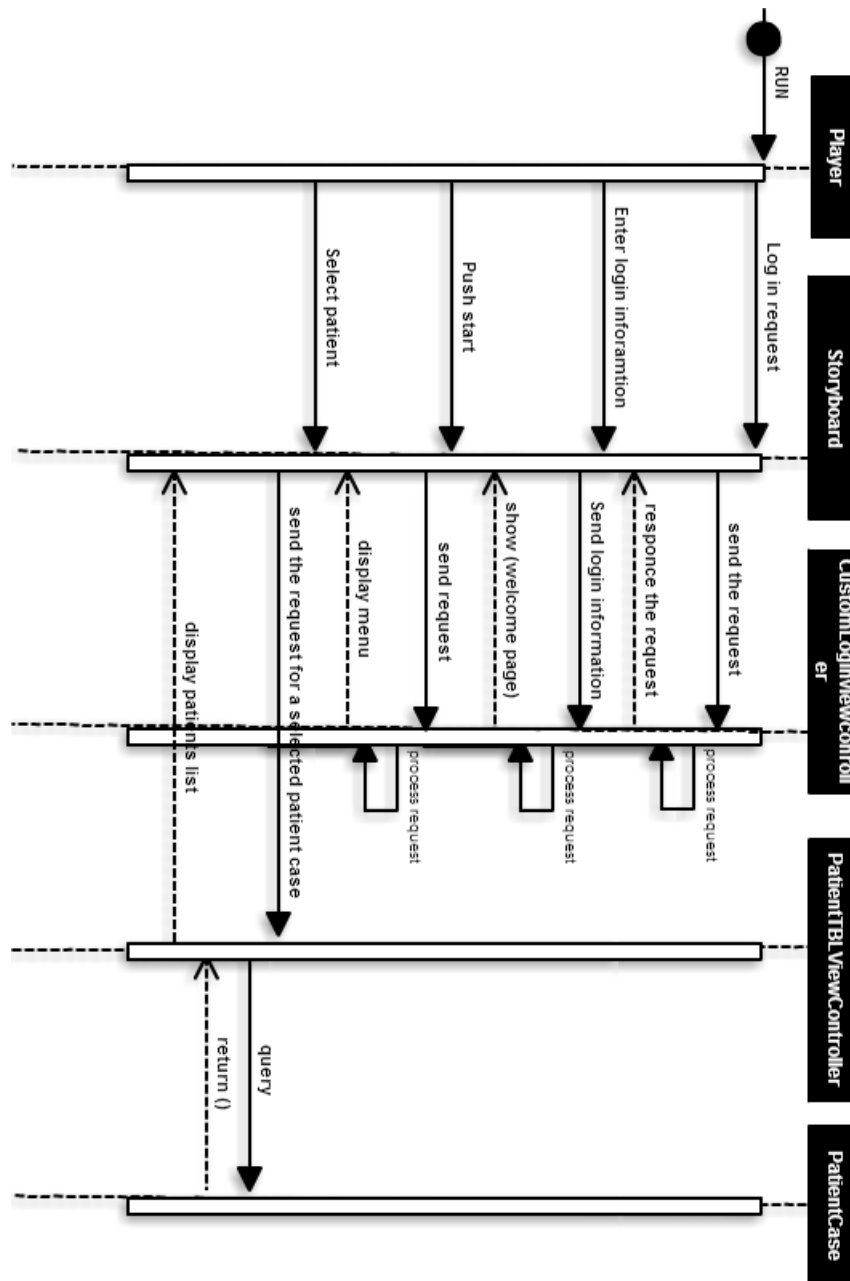


Figure 13 Process view-sequence diagram

The rest of the user interactions are depicted in the form of activity diagram in the Figure 14. Activity diagram can use for capturing the concurrent activities. This diagram shows the activities inside the main window of MasterNeuroSurgeon. The main window depicts an image of patient case. Besides that, there is a toolbox offering various tools for drawing and scoring. The scrolling is the default active tool, when a user enters into the main window. There are three prerequisites for drawing a path: First the user must scroll to the tumour area. Second the user must choose pan to lock the window position. Finally the user must choose the pen from the toolbox. User can move his/her finger on the screen and the respective path appears concurrently on the screen. If he/she satisfies with the drawing content, he/she can choose either score or match tool from the toolbox. The reset and eraser tools can select in three circumstances: after drawing a tumour border or after matching two

patterns or after watching the score. Process of refinement of drawing a tumour border can continue till the user satisfies from the score result.

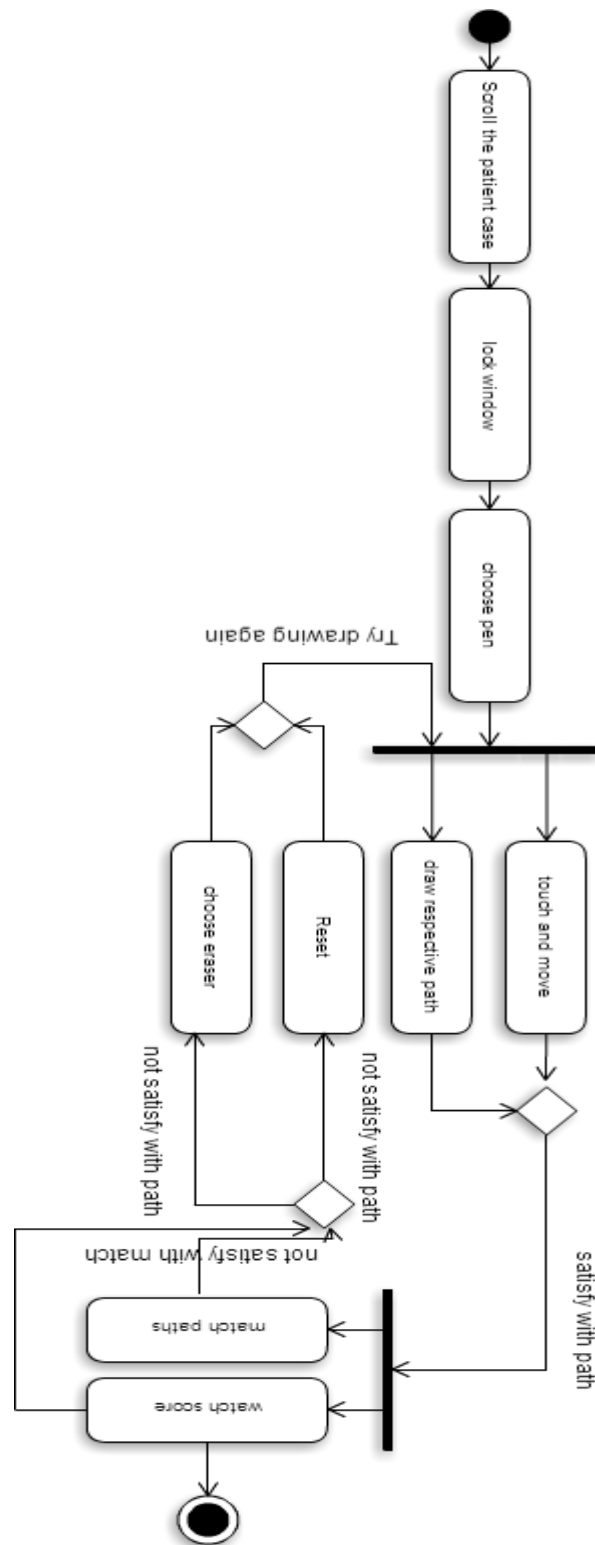


Figure 14 Activity diagram



### 3.2.2.5 Use case View

Four views can collaborate together by using a set of scenarios [29]. The abstraction of requirements is present in scenario view. This view can depict with either scenario or user case diagram. The use case diagram used to represents user's interactions with the Master neurosurgeon application. Figure 15 illustrates the use case diagram of the overall application in relation to the players.

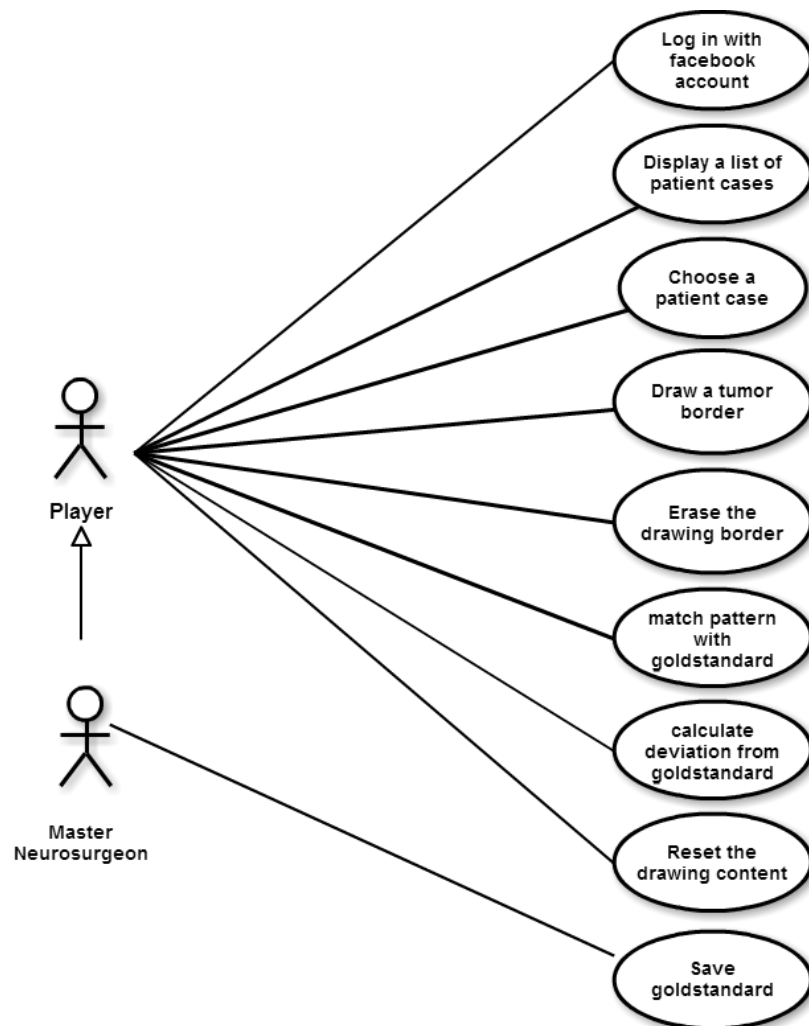


Figure 15 illustration of use case diagram

## 3.3 Chosen technology

This section represents technologies that are chosen to develop the MasterNeuroSurgeon application. A part of this section reviews technologies that are chosen in the specialization projects.

### 3.3.1 Native application development

A native application is an application that is developed for a specific platform. It is coded with a specific programming language. Objective C and Java are coding languages for iOS application and android application respectively. Native applications run faster than hybrid applications. Beside the fast performance, they have more reliability. They also have access to most of the phone's components such as camera, location, GPS. In addition, native applications do not need the internet connection to be run (except for client-server applications). Nevertheless, developing a native application is an expensive approach, since an output application relies on one specific operating system [21]. Native application development gives access to a great graphic library. A rich graphic library is needed for implementing a drawing concept. This is a main reason for choosing the native application development approach.

### 3.3.2 Objective-C

Objective-C was created in the early 1980s. Objective-C is similar to the C programming language. It also contains object-oriented capabilities. It is the main coding language for developing iOS applications [22]. According to the task summery, iOS application is preferred to android application. Therefore, Objective C is the chosen language for developing a native iOS application.

### 3.3.3 Xcode

Xcode is a software development tool. Apple developed Xcode for OS X and iOS developers. Xcode is an integrated development environment-IDE- that the first version was released in 2003. Xcode 5.0 is chosen for developing the MasterNeuroSurgeon in the first phase of the implementation (specialization projects). In the second phase of implementation, Xcode 5.1 is used for keeping MasterNeuroSurgeon updated with new iOS version (iOS 7.1.2).

### 3.3.4 iOS

iOS is the operating system for iPhone, iPod touch, iPad, iPad mini and second generation of apple TV. The latest iOS version is iOS 8 which was released on 17 September 2014. MasterNeuroSurgeon was developed first on the iOS 7 SDK and later on the iOS 7.1.2 SDK (which was released on 27 June 2014) [24].

## 3.4 Implementation

This section presents how the intended requirements are implemented in the MasterNeuroSurgeon application.

### 3.4.1 Drawing and Erasing

Quartz is the preferred technology to implement drawing functionality rather than the OpenGL based on the MasterNeuroSurgeon needs. The UIKit is constructed on characteristics of the Quartz. The UIKit contains UIImage, UIColor and drawing classes. Drawing and erasing functions implemented based on three methods of the UIKit: TouchBegan, TouchMoved and TouchEnded.

Drawing function works like the following process: The first touch position is specified as current point or start point of the path in the TouchBegan method. When the user moves his/her finger, TouchMoved method calls and gets the second point. Then a line is drawn between the current point and the second point. Afterward, The TouchEnded method checks if your finger swiped or not. If User's finger still swiped, then TouchMoved calls again. This process produces a series of very short straight lines that they look like a smooth path.

### 3.4.2 Scoring

The scoring function is implemented by using the nearest neighbour search and the euclidean distance. The score function receives the drawing as a set of points. A point is defined by a float positive number or a float negative number in the iOS application. The float part of the point can be either 0.0 or 0.5. The origin of the coordinate system in iOS applications is on the upper left part of the window. The visible part of the screen contains only the float positive points. The score function compares euclidean distance of each point from the student drawing set to all points from the truth set to find a smallest euclidean distance. Then the deviation average is the sum of the smallest euclidean distance of each point and divides by the total number of points in the student drawing set. However the resulting score is based on the point (pt) that is not understandable for user. To make the score apprehensible to the users, some transformations should perform. In the following nearest neighbour search, euclidean distance and transformation theories are presented.

#### 3.4.2.1 *Nearest neighbor search*

Nearest Neighbour Search (NNS) is identified as similarity search and proximity search. This algorithm finds closest neighbour among points of the set to a query point. Dissimilarity function is used to define closeness concept. The more similar are the points, the smaller are the function values and vice versa. Inputs are a set  $S$  of  $N$  points in the  $d$  dimensions and  $q$  is a point as a query. The output is a single point which has a smallest function value among the points of set  $S$ . Figure 16, 17 shows a query point in two dimensional space and the nearest neighbour point to the query point respectively [9].

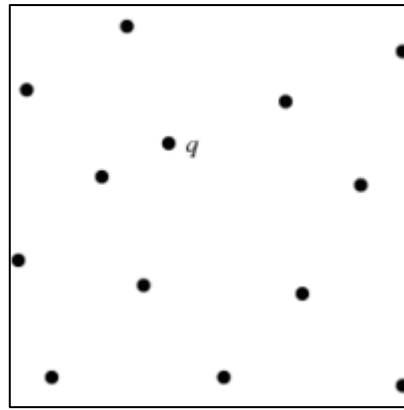


Figure 16 query input [26]

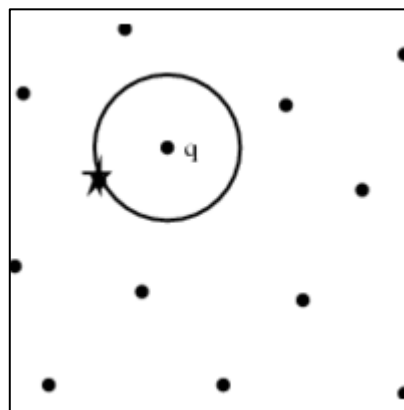


Figure 17 the nearest neighbor point to the query[26]

### 3.4.2.2 Euclidean distance

The length of the path between two points is defined as a Euclidean distance. Distance between two points can be measured with the assistance of the Pythagorean Theorem by applying equation (2). X, Y are the position of the point in the 2 dimensional axis[10]. The distance (d) between points (x1, y1) and (x2, y2) is defined as follows:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad [10] \quad (2)$$

### 3.4.2.3 Point into Inch

The transformation from the point into inch is done in two phases. First, Point needs to map into pixel. It is important to carefully consider this mapping, since one point can be mapped into one or two physical pixels. One point maps into two physical pixels in a Retina display (the MasterNeuroSurgeon is designed for screens with retina display). Thus, the average deviation score should multiply two. Then the value (Inch) is easily calculated by multiplying 326 PPI –Pixel Per Inch relies on screen type which is retina here.

### 3.4.2.4 Inch into Millimeter

The Inch is apprehensible for end users. However, it is not a good unit for this application. The deviation score is small value. Therefore, the MasterNeuroSurgeon uses

millimetre to present deviation value. The conversion is straightforward from inch to millimetre. The value (which is based on inch) should multiply by the “25.4”.

### 3.4.3 Gold Standard

The gold standard is Meta data for patient cases. The gold standard is a set of points. In the first step of implementation, gold standard is supposed to receive with patient cases. But there is a difference between the origin of the coordinate systems between iOS device and the navigation system. This difference forced this project to implement the gold standard in the application. The gold standard can produce by saving the interpretation of the chief neurosurgeon in the MasterNeuroSurgeon application. While a chief neurosurgeon is drawing his interpretation, all touch points are stored in the system as a row Meta data. However, the row Meta data is not enough to use for doing the comparison on student drawing. The row Meta data lacks all points in the Master neurosurgeon’s drawing. As a result, the row Meta data are expanded first and then the expanded Meta data save into SQLite database.

#### 3.4.3.1 Finding All Point in the Drawing

A drawing path consists of a number of small lines that are connected together. All points on each line should calculate to expand the row data. As stated in the implantation of drawing functionality, a line is drawn by having first ( $y_1, x_1$ ) and second points ( $y_2, x_2$ ). According to the point slope equation [11], with having one point on the line and the slope of the line ( $m$ ), the other point can calculate. This new point should fulfil one more condition to be part of the expanded point set. The new obtained point should be in between of first and second point. This approach is used to find all points in the drawing path. The point slope equation is presented in the below:

$$y - y_1 = m(x - x_1)$$

### 3.4.4 Facebook Login

The Facebook SDK is used in the MasterNeuroSurgeon. The Facebook framework contains various implemented log in experience[12]. A “custom Facebook login” is added in the CustomLoginViewController. The Facebook login let the application to get information from the end user’s profile. However, the custom login is customized to get only email from Facebook profile.

## 4 Application Evaluation

This chapter presents systematic evaluation approaches for assessing the MasterNeuroSurgeon in different aspect. In addition to evaluation methods, an introduction of participants and environments setting for the experiment day are presented.

### 4.1 Evaluation methods

As stated in chapter two, the questionnaire and observations are used as data collection methods to evaluate the MasterNeuroSurgeon application. The System usability score questionnaire is used to evaluate the usability of the MasterNeuroSurgeon. In addition to the usability evaluation method, knowledge improvement questionnaire is created to consider if the MasterNeuroSurgeon enhances the student's knowledge or not. The systematic and board observations are used to gather information for evaluating the recorded output of the MasterNeuroSurgeon. In the following, the evaluation methods are described in detail

#### 4.1.1 System Usability Score (SUS)

The effectiveness of a serious game should be assessed by considering the context, but there is a need for general evaluation as well. Generally, SUS is an approach to estimate the usability of various kinds of IT product like mobile applications. John Brooke defined a sample questionnaire which can be efficiently applied to differentiate between usable and unusable product. An important advantage of using SUS is its capability to handle small sample sizes (sizes refer to number of participants) and get a reliable result out of it. The smallest sample can be with just two participants. Every question has a scale from 1 to 5. The score contribution for questions with odd number are the scale minus 1 and for questions with even are five minus the scale. The total score is calculated by summing of score contribution of each question and multiply by 2.5. The total score is defined from a range of 0 to 100. The underlying formula presents the respective equation for the SUS [9].

$$T = 2.5 * \sum_{i=1}^{\frac{N}{2}} \left( (S_{2i/1} - 1) + (5 - S_{2i}) \right)$$

N is equal to the number of questions. S is the average score that a question has gotten. T is the total score [9]. It should be noted that total SUS is not a percentage. The SUS questionnaire is represented in appendix B.

#### 4.1.2 Knowledge Improvement Questionnaire

The main purpose to design and implement the MasterNeuroSurgeon is promoting ultrasound interpretation knowledge of students. The knowledge improvement questionnaire

is presented in Table 5. Indeed, these four questions try to consider whether the MasterNeuroSurgeon increases the student's knowledge or not. Knowledge improvement questionnaire has the same pattern as the rest of questions. Every question has a score contribution from 1 to 5 and it is following the "Likert scale" structure [8]. The average score for each question is obtained from summing of score contributions of responses to that question and divided by the number of respondents.

*Table 5 Knowledge Improvement Questionnaire*

#	Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
11	<i>I think I gained some practical Ultrasound interpretation experience without attending surgery by using the MNS.</i>					
12	<i>I found that MNS could not increase my ultrasound interpretation experience.</i>					
13	<i>I think I can learn the interpretation of various unique patient cases with playing the MNS.</i>					
14	<i>I think the regular use of the MNS will help me to be experienced surgeon regarding ultrasound interpretation quickly.</i>					

#### **4.1.3 Systematic and board focus Observation**

Generally observation is applied to gather behaviour of the users toward an application. The systematic and board observations are applied to assess the recorded output of the MasterNeuroSurgeon. Because of ethical reason, the overt approach is chosen to watch the MasterNeuroSurgeon's users. The systematic observation is helping to produce a substantial amount of the quantitative data. The plan for systematic observation is presented in Table 6.

*Table 6 Systematic observation planning*

User	#Case	#Trial	#difficulty level	Time	Deviation score

Systematic observation is a worthy method to collect data. In addition to systematic observation, some interesting data can collected via board focus observation. The board focus is perfect tactic to see people's reaction in a reality [7]. As a result, a board observation is also applied to gather general facts about the MasterNeuroSurgeon.

## 4.2 Environment and Participants

The experiment took place on October 4th, 2014 at one the meeting room in the Olavs hospital, Trondheim, Norway. There was a chief neurosurgeon and his interpretation was used as the gold standard in the MasterNeuroSurgeon. There were two consultant neurosurgeon, four technical persons and two students.

## 4.3 Experiment Preparations

The MasterNeuroSurgeon was installed on the iPad Air. A fine point stylus was prepared. This special pen was preferred to use instead of the finger. It helped participants to see exactly where they wanted to draw. My supervisor, Frank Lindseth, and I presented briefly the idea behind the MasterNeuroSurgeon. Later a video tutorial on the Master neurosurgeon application presented to the participants. Before running the experiment, the chief neurosurgeon played with the MasterNeuroSurgeon to provide the gold standard on patient cases. Lindseth watched the chief neurosurgeon to certify that the Meta data was stored correctly. While the chief neurosurgeon drew his interoperations on the selected patient cases, other participant should not look on his interpretation. This is a restriction to make sure that none of the participants become aware of the correct answer in advance.



*Figure 18 A fine point stylus[13]*

## 4.4 Experiment Execution

The experiment took place after the Experiment preparation. Participants played the MasterNeuroSurgeon application one by one. Each participant was observed one by one. They were instructed to use the match tool when they wanted to assure about their interpretation.



## 5 Result

The first part of this chapter presents the result of the implementation. This part represents main functionalities of the MasterNeuroSurgeon. In addition to result of implementation, the result and evaluation of the MasterNeuroSurgeon is presented.

### 5.1 Application

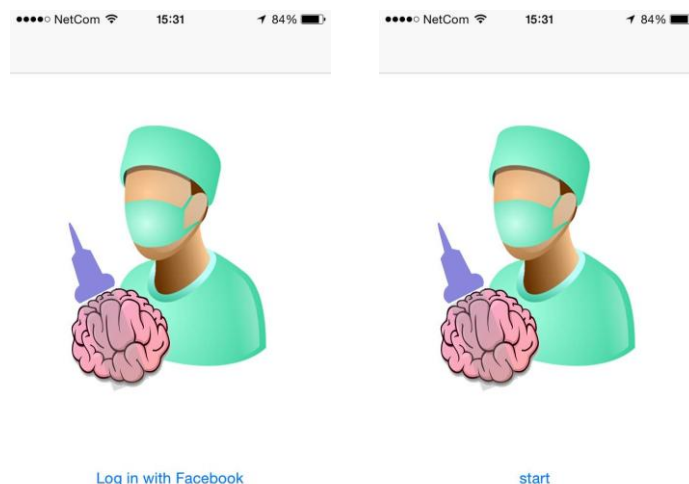
This section briefly presents the MasterNeuroSurgeon application. A short description of each function is presented. Figure 19 shows the Master neurosurgeon toolbox. Icons from left to right are responsible for scrolling/locking, drawing, erasing, resetting the content, matching, scoring, playing background music and saving.



*Figure 19 MasterNeuroSurgeon toolbox*

#### 5.1.1 Logging in the Facebook

The Facebook log in function is used for identifying the user. The user can be either student or experienced neurosurgeon. The process of identification begins by pressing “Log in with Facebook”. “Start” button will be appearing after a successful log in. The Figure 20 shows screen-shots from MasterNeuroSurgeon before and after the log in steps.



(a)

(b)

*Figure 20 a) Before Facebook log in b) after Facebook log in*

### 5.1.2 Displaying a list of patient cases

To access the patient case list, users need to choose “select patient”. Then a list of patient case will appear. Figure 21-b presents a list of patient case within a small preview of them.

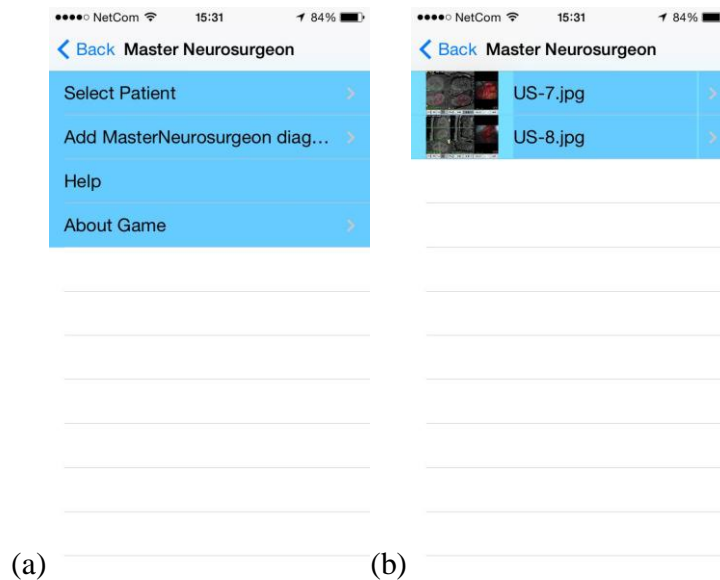


Figure 21 Screenshot a) menu of MasterNeuroSurgeon b) patient case list

### 5.1.3 Panning

The panning function lets the end-user to scroll the patient case. The size of the patient case is larger than the size of the iPhone 5s or the iPad air screen. The scroll function is enabled in the figure 22-a. After scrolling to the desired place, the screen should lock to start drawing. This is done by choosing the hand icon. Pushing the pan button once more re-activates the scrolling function. The Figure 20-b shows the screen after scrolling to the tumor area and locking on the desired position.

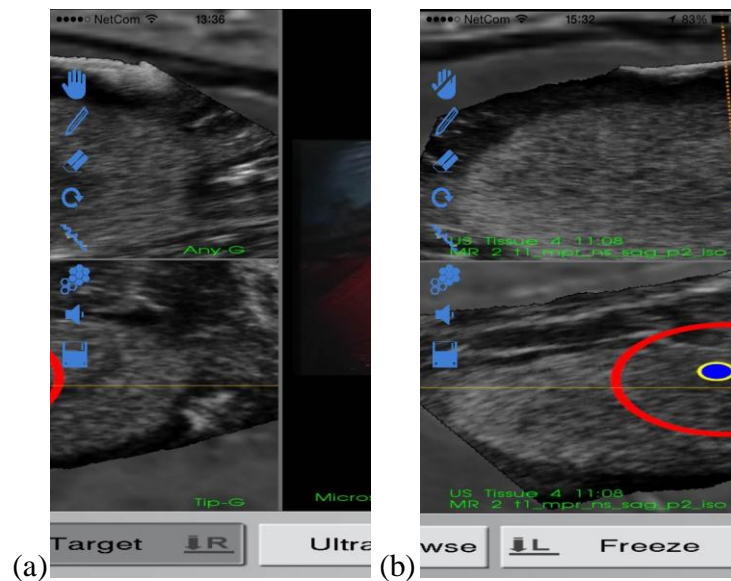


Figure 22 Screenshot from a) scrolling is enabled b) the screen is locked

#### 5.1.4 Drawing, Erasing and Resetting

Drawing, erasing and reset are the main functions for drawing interpretations. These three functions are depicted in the Figure 23. The reset function is used to clear the whole drawing path. The user can draw, erase or reset by choosing the pen, eraser and reset button. After using an eraser tool or a reset tool, users need to press the pen button again to restart drawing again.

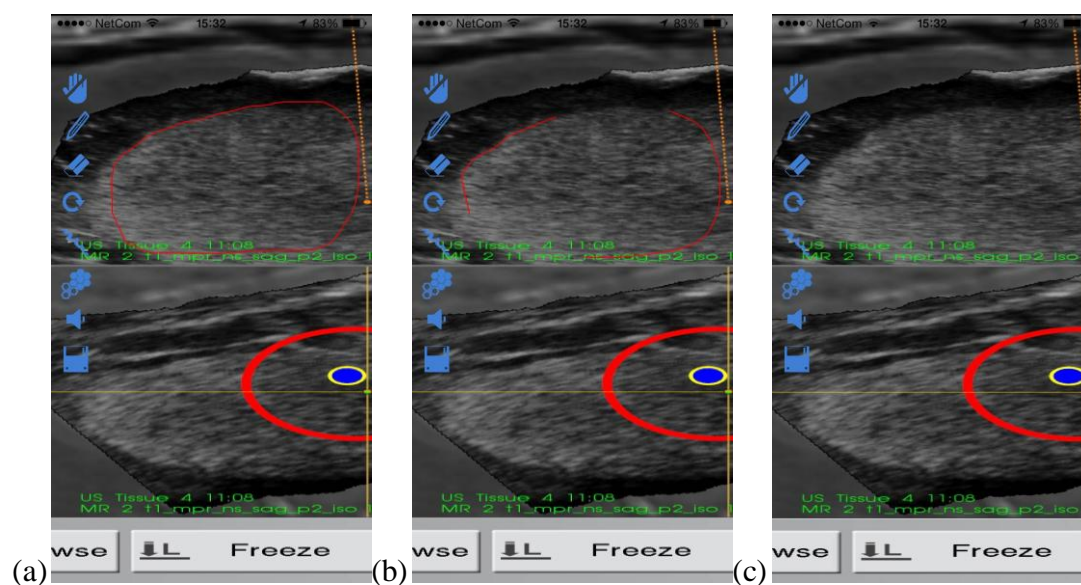
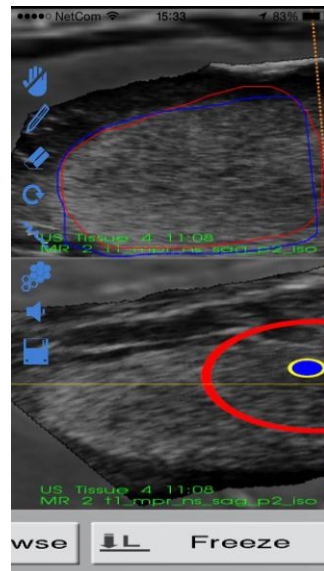


Figure 23 Screenshot from a) drawn path b) erasing path c) after resetting the content

### 5.1.5 Matching

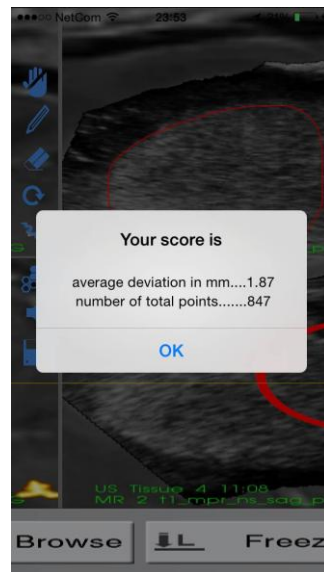
The match function presents the gold standard path and the student drawing path at the same time. This view depicts deviation from the gold standard visually. In the Figure 24, the student's interpretation is depicted in red colour. When a student draws his/her interpretation, the match function can apply. After pressing the match button the blue path will appear. This path is corresponding to the gold standard.



*Figure 24 Screenshot form matching*

### 5.1.6 Deviation Scoring

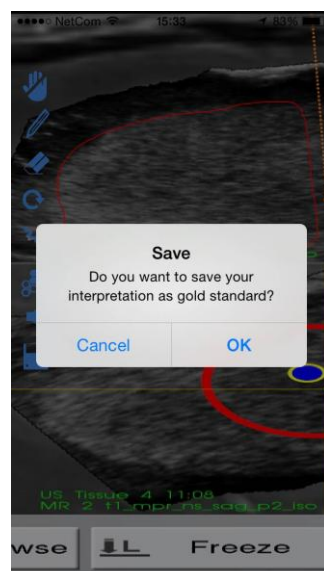
Deviation score is the main feature for learning interpretation. The deviation score shows the average deviation from the gold standard. This value is presented in millimetres. Figure 25 presents an example of deviation score. In addition to the deviation score, a value for the total number of points on the gold standard's path is presented. There is a precondition for using a deviation score function. Students must first draw their interpretation and then press the deviation score button. If users try to push deviation button without drawing their interpretation, a proper message is presented to them.



*Figure 25 Screenshot from deviation score*

### 5.1.7 Saving the gold standard

Saving the gold standard is one of the key functions. This feature is defined for providing the gold standard by experienced neurosurgeon. The process of saving the gold standard is straight forward. First, the experienced neurosurgeon draws his interpretation of the tumour borders. When he satisfies with his interpretation, the drawing path can store as the gold standard by pushing the save button. Figure 26 shows the pop up message for saving the gold standard. When the experienced neurosurgeon pushes the “OK” button, the gold standard will be saved. This function also lets updating the gold standard. The updating process is in the same way as saving the gold standard for the first time.



*Figure 26 screenshot from the saving goldstandard*

### 5.1.8 Background music

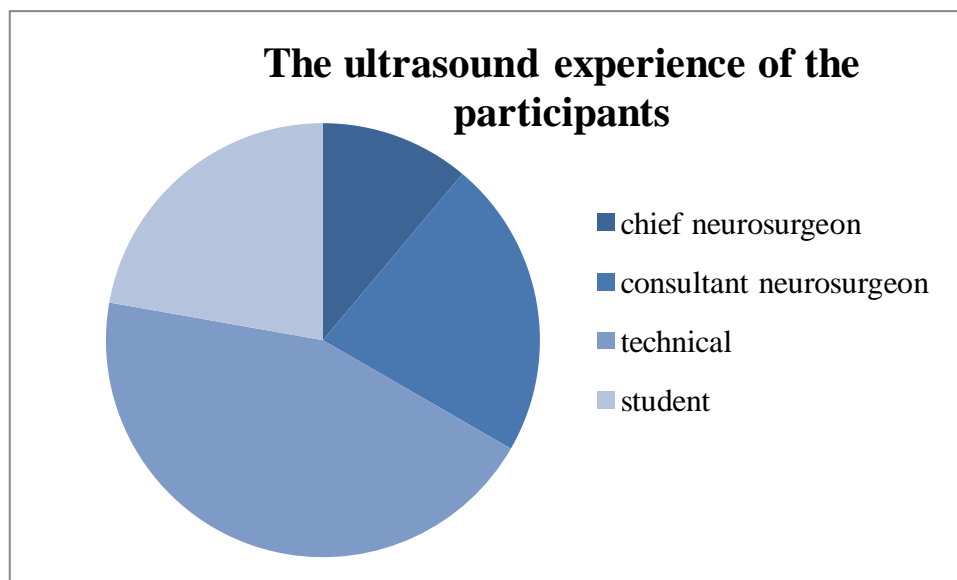
The background music is not active by default.

## 5.2 Evaluation

This Section presents the results of the experimental session. This section contains three sub-sections: the ultrasound experience of the participants, questionnaires and observation.

### 5.2.1 The ultrasound experience of the participants

Participants were asked to specify their title. In fact, the experience levels for ultrasound interpretation are shown by using their title. The following chart shows the number of contributors based on their ultrasound knowledge. The darker blue color shows the higher ultrasound knowledge. The lighter color shows the lesser ultrasound knowledge.



*Figure 27 illustration of participant's ultrasound knowledge*

### 5.2.2 Questionnaires

- **SUS Questionnaire**

The SUS Questions can be separated in two groups: The Statements with odd numbers are positively-worded items (1, 3, 5, 7 and 9) and the statements with even numbers are negatively-worded items (2, 4, 6, 8 and 10). The calculation for each group is different. The formula for calculating SUS is presented in detailed in chapter 4.

In Table 7, the average column shows the average of score for all answers to a specific question. The score contribution is presented in the score column for each question. The total SUS score is the most important value for assessing the application.

Table 7 SUS questionnaire result

#	Question	Average	Score
1	<i>I think that I would like to use this system frequently.</i>	3	2
2	<i>I found the system unnecessarily complex.</i>	2	3
3	<i>I thought the system was easy to use.</i>	3.66	2.66
4	<i>I think that I would need the support of a technical person to be able to use this system.</i>	1.3	3.7
5	<i>I found the various functions in this system were well integrated.</i>	3.66	2.66
6	<i>I thought there was too much inconsistency in this system.</i>	2.33	2.67
7	<i>I would imagine that most people would learn to use this system very quickly.</i>	4	3
8	<i>I found the system very cumbersome to use</i>	2.33	2.67
9	<i>I felt very confident using the system.</i>	3.33	2.33
10	<i>I needed to learn a lot of things before I could get going with this system.</i>	2	3
	<i>Total result</i>		85.12

If a total SUS score is above 68, then the usability of application considered to be above the average rate (acceptable range) and anything below this threshold is considered to be below the average(not acceptable). The MasterNeuroSurgeon got the 85.12 out of 100, despite the crash issue. According to calculated result the application has a high usability. AS seen in Figure 28, MasterNeuroSurgeon received a place in an acceptable range. In addition, it's got an excellent adjective among the adjective ratings and grade B from the grade scales.

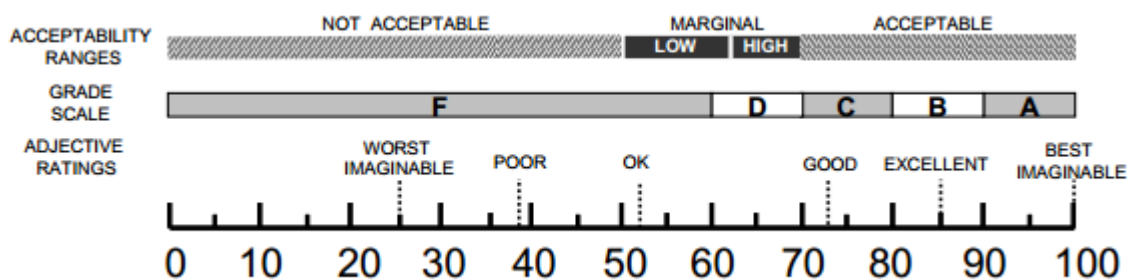


Figure 28 Accessibility ranges from SUS [34]

- **Knowledge Improvement Questionnaire**

The knowledge improvement questionnaire contains 4 questions that study if the MasterNeuroSurgeon improves ultrasound interpretation skill or not. The knowledge improvement questions are numbered from 11 to 14. All the statements are on the same style as the “Likert scale”. Likert scale is a bipolar scaling method to measure the negative and positive response to the statements[14]. The average scores are summarized in Table 8.

Table 8 result of knowledge improvement questionnaire

#	Question	Total average
11	<i>I think I gained some practical Ultrasound interpretation experience without attending surgery by using the MNS.</i>	3
12	<i>I found that MNS could not increase my ultrasound interpretation experience.</i>	2.66

13	<i>I think I can learn the interpretation of various unique patient cases with playing the MNS.</i>	3.6
14	<i>I think the regular use of the MNS will help me to be experienced surgeon regarding ultrasound interpretation quickly.</i>	3.6

Statements with number 11, 13, 14 are positive worded. A high score for them shows that the desired application can increase knowledge. Statement 12 is negatively worded and mentioned in the questionnaire to see if the application has no positive effect for learning purpose. It is important to consider the score of question 12 in relation with positive worded question to have a perfect elucidation.

As it can be seen in the Table 8, participants rate a high score on (question 11, 13, 14) which shows MasterNeuroSurgeon could promote their ultrasound knowledge. In addition, Question 12 received a lower score than other question indicates that MasterNeuroSurgeon could help to improve ultrasound knowledge.

### 5.2.3 Observation

- **Systematic Observation**

The systematic observation is done by recording the output, i.e. Difficulty level, time and deviation score. Figure 29 shows the output for one of the participants. In the experimental session, the chief neurosurgeon started each round for each patient case, since he provided the gold standard. As a result, the deviation score does not exist the first time that he wanted to draw the gold standard. This fact is depicted in the table 9.

The timing for some of the sessions are not available, but the available ones clearly show that time has a decreasing trend. As seen in the table 9, the average time in the first round in the simple case is about 6 and a half minutes, while the average time in the first round in the difficult case is about the 2 and a half minute. The decreasing trend in duration shows that students improve in both using the application and interpreting skill.



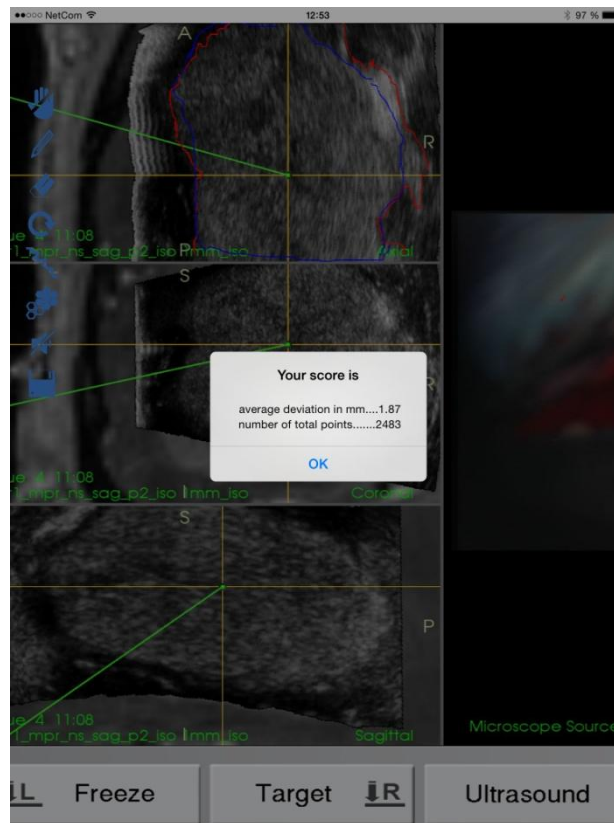


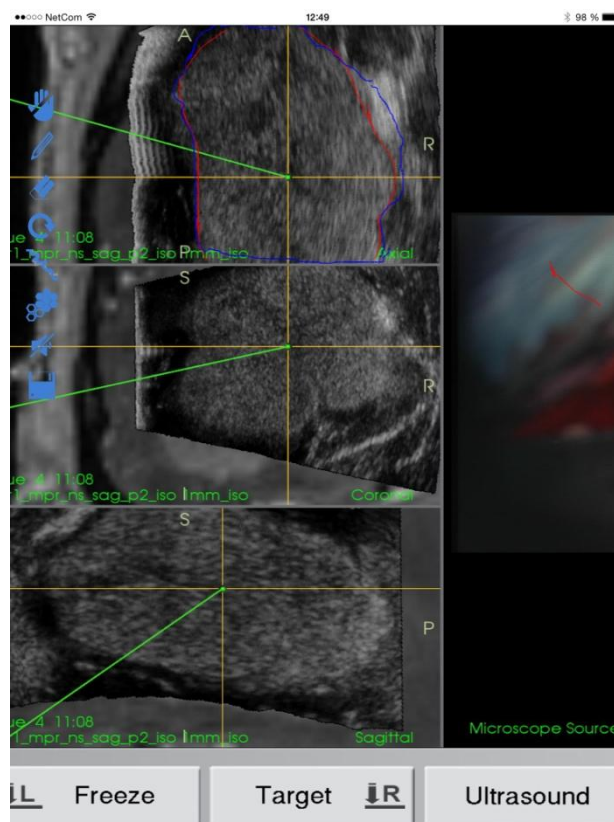
Figure 29 Screenshot from deviation score for one participant

Table 9 Result of systematic observation

<i>User</i>	<i>#Case</i>	<i>#Trial</i>	<i>#difficulty level</i>	<i>Time</i>	<i>Deviation score</i>
<i>Chief neurosurgeon</i>	8-1	1	<i>Simple</i>	7 min	-----
<i>Student</i>	8-1		<i>Simple</i>	7 min	1.25 mm
<i>Student</i>	8-1		<i>Simple</i>	5 min	1.25 mm
<i>consultant neurosurgeon</i>	8-1		<i>Simple</i>	3 min	0.62 mm
<i>Chief neurosurgeon</i>	8-1	2	<i>Simple</i>	4 min	0.78 mm
<i>Chief neurosurgeon</i>	8-2	1	<i>Hard</i>	2 min	-----
<i>Student</i>	8-2	1	<i>Hard</i>	1 min	4.83 mm
<i>consultant neurosurgeon</i>	8-2	1	<i>Hard</i>	3 min	1.87 mm
<i>Technical scientist</i>	8-1	1	<i>Simple</i>	-----	-----
<i>Technical scientist</i>	8-1	1	<i>Simple</i>	----	1.40 mm
<i>Technical scientist</i>	8-1	1	<i>Simple</i>	----	1.40 mm
<i>Technical scientist</i>	8-2	1	<i>Hard</i>	----	1.40 mm
<i>Technical scientist</i>	8-2	1	<i>Hard</i>	----	2.7 mm

The consultant neurosurgeon got the highest similarity to the gold standard. His deviation score on the simple case is not a surprising result. In fact, he has the second highest level of ultrasound knowledge. The chief neurosurgeon got the 0.78 mm deviation to his first interpretation. The possible explanation is he spent less time on redrawing, since the MasterNeuroSurgeon crashed two times while that he was drawing his interpretation. As a result of the crashes, he had to start drawing from the scratch. The total time is for his second interpretation was 4 minutes, which include times for two failed drawings.

One of the students drew a somewhat similar interpretation to the gold standard on the difficult case, and she got 4.83 mm deviation. The figure 30 shows why she received this score. The red colour shows her interpretation and the blue colour shows the gold standard. She got this score because of drawing a small red line outside the tumour area. This line is drawn as a result of putting her wrist on the screen unintentionally.



*Figure 30 screenshot from unwanted drawing on the middle right of screen*

- **Board Focus Observation**

Participants were watched when they were playing to examine their reactions. It was interesting that they learned how to play the MasterNeuroSurgeon in the first place. One of the participant note that the icons from toolbox are self-explanatory and easy to understand. Another participant expressed that he would like to have competitions in ultrasound interpretation with his collages. Two players also announced their deviation scores to others. Both comments and observations show that the user interface of the toolbox is designed

clearly. Competition between some of the participants is a notable feature for future works. They also pay attention to the name of the application (MasterNeuroSurgeon).

## 6 Discussion and Future work

This chapter presents the discussion and potential future work. The research questions guided the research, implementation and evaluation of the project. For this reason, the research questions are used to structure the discussion chapter as well.

### 6.1 Discussion

RQ1: Are there any similar serious games to this project (MasterNeuroSurgeon)? Do they exhibit any features, which can enrich MasterNeuroSurgeon as well?

A literature review was conducted to look into existing serious game and their features. The review of similar games with focus of health care is presented in the chapter 2. The conducted literature review gave some strategy on how to implement this project. In the following an abstraction of employed features and their importance for this project are presented.

- MasterNeuroSurgeon let students interpret the tumor border without any consequences for the patient (Psychosocial moratorium theory). In comparison to the real situation, the consequence of wrong interpretation is zero.
- Aside from no risk to play, students can learn trough the game play. They can draw an interpretation and check their score iteratively for each patient case (learning skills through the game play).
- MasterNeuroSurgeon make a use of “identity” from serious game features and offer a motivation to be a master neurosurgeon in ultrasound interpretation by playing regularly. As stated in the result, the participants pay attention to the defined identity.
- The fish tank theory is used to just focus on the tumor border of ultrasound images and not on any other concept of operation and navigation system. In fact, the environment of operation is highly simplified. In comparison to the serious games with a reality simulation feature, MasterNeuroSurgeon simplify the environment. At a same time, MasterNeuroSurgeon is close to reality. Since it uses a series of images from the navigation system.

RQ2: How does the MasterNeuroSurgeon application assist to widen the experience of novice neurosurgeons? Does the MasterNeuroSurgeon application assist to widen the experience of novice neurosurgeons?

- Master neurosurgeon is supposed to have a great number of patient cases. Students faces with lots of unique patient cases (a Lot of contents). A Lot of content motivate them to keep continue playing. It is clear that repetitive patient case is not interesting for students. Beside the interest factor, playing with the small set of patient cases cannot convey a great amount of experience to students.
- The deviation and match tool are key functions. These features enable students to assess their interpretation. In the learning process, students need to understand if they interpret correctly or wrongly. These two tools help students to grasp interpretation knowledge through playing the MasterNeuroSurgeon.
- The results of knowledge improvement questionnaire show that the participants believed that they can learn the interpretation of unique patient cases through playing the MasterNeuroSurgeon application. According to the result of the questionnaire, the regular uses of MasterNeuroSurgeon helping students to be experienced neurosurgeons regarding the ultrasound interpretation. This result confirms the stated hypothesis on effectiveness of playing MasterNeuroSurgeon for promoting ultrasound.
- The “Lots of contents” and “evaluation and feedback” features are employed in the game to promote student’s ultrasound knowledge. The second part of research question two is answered by using a questionnaire. The questioner result reveals that using these features can promote ultrasound knowledge of the user.

RQ3: How effective is the output application designed? How easy is it to use the MasterNeuroSurgeon application to draw a precise interpretation?

- The ease of use is demonstrated via SUS questionnaire. The MasterNeuroSurgeon application received a high score, 85.12 out of 100, that shows a positive feedback for usability. This means that the MasterNeuroSurgeon is easy to use.
- The observation of experiment implies that the toolbox user interface is self-explanatory.

## 6.2 Future Work

In this section, the future technical changes and non-technical feature that can improve the MasterNeuroSurgeon experience for the end users are discussed.

RQ4: what features can be highlighted or added by the next generation of Master Neurosurgeons in the neurosurgery field to enhance ultrasound image interpretation? What features should be modified in the next generation?

- Some of participants encountered crash on the experiment day, while they were drawing. One of the reasons behind the crash issue was using the old Facebook SDK. The “Facebook log in” got about 200 Mb of memory. Upgrading the Facebook SDK can release most of the memory. Another reason was using too many print statements for checking the application output.
- The match tool lets the students to watch his/her interpretation and gold standard together. The match tool redraws the path of gold standard. However redrawing a path has some difficulty. The current version work properly when the experienced neurosurgeon does not use the eraser. This problem can be addressed by saving the picture of the gold standard, instead of redrawing it.
- Using the fine point stylus was not exactly like using the finger for drawing purpose. Although it assisted participants to see where they were drawing, it caused drawing small discrete lines. Adding a cursor is an alternative. It helps users to watch where they are drawing.
- According to the observation in the experiment session, participants like to take part in competition. Participant just announced their deviation score to others. This is an important clue to pay attention to future work. Increasing the usage of social network can easily assist us to hold a competition. For example Facebook friend list can be used to group students. A group of students can compete with each other. It is a good approach to conducting a literature review to see how other serious games implement competitions.

## 7 Conclusion

The motivation behind this thesis is developing a serious game which promotes the student's ability to recognize the tumor border in the ultrasound images of the brain. Ultrasound is widely used for guidance and navigation in the space like surgery. Therefore, students need to recognize diffuse tumor borders in the ultrasound-based neurosurgery. In this Thesis, different features for serious games and exiting serious games in healthcare are presented. The recommended drawing tumor border approach is enhanced with serious game features.

The name of the output application (MasterNeuroSurgeon) is defined in a way that gives a first positive impression to the end-users. Being a master Neurosurgeon motivates them to start and keep playing. According to the serious game features, students can learn interpretation while playing the game. Playing MasterNeuroSurgeon provides an environment without any danger cost or consequences for miss treatment. The MasterNeuroSurgeon simplifies the navigation system and surgical environment. It just focuses on one image at the time, instead of focuses on continues imaging output. This feature also helps students to learn trough the game play. MasterNeuroSurgeon makes use of large list of unique patient cases, as well as the deviation tool and match tool in order to convey ultrasound experience to students.

Then an evaluation of MasterNeuroSurgeon is presented in the thesis. The result of evaluation showed that the MasterNeuroSurgeon game is useful application. Further, the participants claimed that the user interface is easy to use. Beside those result, participants claimed that they can gain knowledge about ultrasound interpretation by playing the MasterNeuroSurgeon regularly.

# Appendix A

## Acronym

2D	Two Dimensional
3D	Three Dimensional
CT	Computed Tomography
IDE	Integrated Development Environment
iOS	iPhone Operating System
MHz	Mega Hertz
MRI	Magnetic Resonance Imaging
MNS	MasterNeuroSurgeon
NNS	Nearest Neighbor Search
RSI	Requirements Service Interface
PPI	Pixel Per Inch
SDK	Software Development Kit
SUS	System Usability Score
OR	Operation Room
OS	Operating System



## Appendix B

### SUS Questionnaire

The underlying table presents predefine System Usability Score questionnaire.

*Table 10 SUS questionnaire used in the assessment [9]*

#	Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	<i>I think that I would like to use this system frequently.</i>					
2	<i>I found the system unnecessarily complex.</i>					
3	<i>I thought the system was easy to use.</i>					
4	<i>I think that I would need the support of a technical person to be able to use this system.</i>					
5	<i>I found the various functions in this system were well integrated.</i>					
6	<i>I thought there was too much inconsistency in this system.</i>					
7	<i>I would imagine that most people would learn to use this system very quickly.</i>					
8	<i>I found the system very cumbersome to use</i>					
9	<i>I felt very confident using the system.</i>					
10	<i>I needed to learn a lot of things before I could get going with this system.</i>					

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