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Tablet User Interface Evaluation for a Portable Ultrasound System and Real time Doppler SpectrumProcessing

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MASTER THESIS

Department of Engineering cybernetics

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Problem Description

The aim of the thesis is to further develop the user interface and signal processing module of a portable ultrasound system, intended for midwives in rural areas of Africa, where Doppler based blood flow measurements during pregnancy can have an important impact on reducing the mortality of mother and unborn child. The thesis should focus on the following topics:

1. Carry out a pilot usability study (target group: midwives with no/limited ultrasound experienced) and define a minimal user interface that is necessary for successful completion of a typical ultrasound examination.

2. Implement the proposed interface on a tablet (Android device), to be used during real-time ultrasound scanning.

3. Optimize the quality, visualization and extract relevant parameters from the acquired Doppler spectrum based on raw data received from the scanner.

4. Develop a robust help module for the application, allowing the user to access a set of examples either of normal scans or acquisitions containing typical pathologic findings that are highlighted.

5. Define a usability testing protocol and evaluate it on two different user groups: midwives with and without prior experience in ultrasound.

Abstract

In this thesis, real time Doppler spectrum processing and Tablet user interface evaluation for portable ultrasound system is done.

In most ultrasound machines, fast fourier transform and other spectral processing requires a specialized hardware, which is costly. In order to have a low cost and portable ultrasound device for application in rural areas, a tablet ultrasound system can be developed. The cost of such a device can be minimized by doing as much real-time processing as possible on the tablet. In the thesis, Doppler spectrum processing and visualization is implemented using various techniques for application on a tablet user interface. The spectral properties are properly designed and the required components of the spectrum rendering window are fully developed. Various user control systems are also developed to allow user interactivity.

Tablet user interface evaluation was conducted to assess the usability of the user interface for intended end users (midwives). Before conducting the evaluation, some improvements were performed to the prototype user interface. The usability evaluation of the user interface was conducted by giving usability test task over a group of midwives and evaluated using various usability evaluation methods. By employing these methods, it was possible to measure the typical usability goals such as efficiency, task completion success rate and satisfaction of the users. The analysed results show that all the midwives have achieved high task completion success rate and good task completion time, which is acceptable and most of the users are satisfied with the application.

Due to some facility limitations at the beginning of the thesis work, a pilot usability study and its subsequent user interface improvement, which were planned at the beginning, are not included as part of this thesis.

Preface

This is my master's thesis work that is submitted to the department of Engineering Cybernetics at Norwegian university of science and technology (NTNU) and the department of circulation and medical imaging (ISB) at St. Olavs University Hospital for evaluation of my work. All the thesis work is performed at the department of circulation and medical imaging.

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Thanks to muffins, apples for being immediate source of energy and coffee for making me active most time of the day.

Contents

acronyms

US	Ultrasound
TUIwindow	Tablet User Interface window
UCD	User-centered design
HCI	Human computer interaction
SUS	System Usability Scale
L&S	Lewis and Sauro
FFT	Fast Fourier Transform
RFFT	Reverse Fast Fourier Transform

Chapter 1

Introduction

This chapter introduces the motivation for this thesis, the general and specific problems addressed in the thesis and the components and structure of the remaining chapters of the thesis. Section 1.1 discusses the advantages of a tablet based ultrasound system. Following this, the UMOJA project, of which this thesis is part of, is introduced in Section 1.2. Then, earlier works on portable ultrasound system are reviewed in Section 1.3. Section 1.4 discusses the motivations behind this thesis in particular and discusses the two main parts of this thesis. Finally, Section 1.5 describes the organization of the rest of the thesis.

1.1 Motivation

In developing countries, there are various pregnancy related health problems. Developing countries are significantly affected by high morbidity and mortality rates among the unborn and children below 5 years of age and high mortality rate among pregnant women as a consequence of inadequate detection of basic, often simple, problems in pregnancy.

Ultrasound is a very important technology in the health sector that helps to monitor various problems in the body and is the only imaging method to be used in pregnancy and widely offered to the general population in the form of screening programs. Therefore, the access to ultrasound technology is very essential in preventing deaths of unborn children and pregnant women by following up their pregnancy symptoms.

Most current ultrasound systems are too expensive, less portable and very sensitive to be used in the rough environment of developing countries. Therefore an ultrasound imaging system that is robust & and low-cost needs to be designed particularly for operation in rural areas of developing countries. Tablet form ultrasound scanner is a good solution for this. Tablet based scanner aims to develop an ultrasound scanner in the form of a tablet that is cost effective, easy to use, user friendly, portable, durable and of sufficiently high image quality.

1.2 The UMOJA Project

The UMOJA Project: is a project whose main objective is to develop an ultrasound imaging system that is low-cost, super durable, easy to use and of sufficiently high image quality particularly designed for operation in rural areas of developing countries. The project is specially targeted for South Africa where there are a lot of pregnant women, and where they also suffer maternal death and loss of their fetuses/children, as a consequence of inadequate detection of basic, often simple, problems during pregnancy. The project is targeted to the specific needs and challenges for obstetric ultrasound in rural area of South Africa that have been identified through the extensive experience of the National Center for Fetal Medicine at NTNU. The project to develop the UMOJA ultrasound machine is a joint effort between the National Center for Fetal Medicine, the Department of Circulation and Medical Imaging, and the Medical Imaging Lab, all at NTNU, and the Norwegian company GE Vingmed Ultrasound.

1.3 Earlier Work on Portable Ultrasound System

In this section, some earlier works on portable and flexible ultrasound system implementation are reviewed.

- This thesis builds on my project work ("*A tablet user interface for Doppler ultrasound scanner*") that was carried out during the fall 2012 [26].
  The tablet user interface developed in my project is a touch screen application that allows various user interactions and controls and it is developed in a way that optimizes the screen size of the tablet. It has a user controller in icon representations form with different applications for optimal use of space and effective representation. It supports also

two finger swipe and (single/double) tap applications for controls such as zoom, sample volume and color box. The Tablet User Interface Window (TUIwindow) mainly consists of the the icons as user controller, bitmap and the Doppler spectrum. Successful streaming of the bitmap and Doppler spectrum is implemented between the tablet and the Vivid q scanner during scanning. The tablet user interface also supports switching to a freeze mode where the user can stop and investigate the scanning process by going through the stored images.

- Johan Morten Dreier's thesis ("*User centered design in rural South Africa: How well does current best practice apply for this setting*?") [23]:
  This thesis focuses on user centered development process based on ISO 9142/210 to develop and test the prototype of an ultrasound help system. The prototype that is used is made by Aurotech Ultrasound AS and two prototypes of the Umoja ultrasound machine (US machine for Umoja project) have been made by Aurotech Ultrasound AS. These prototypes have main ultrasound unit connected to a power supply, probe and Ethernet cable that connects the PC to the US unit [23].

- U697/A97: is touch screen ultrasound device made by Canyearn Medical Equipment. It is tablet-sized form and supports various display modes to realize comparative observation from multiple angles and direction. The GUI of this device consists of various buttons and navigation is performed by applying touch application on the user interface. It can be used for various applications, such as in abdominal, fetal/OB, cardiology imaging and it also supports various probes for instance linear, convex, endorectal etc [2].

- Change projects: Change is a group at the University of Washington whose main focus is exploring how technology can improve the lives of populations in low-income regions. They have designed and developed a low-cost portable ultrasound device that consists of a USB ultrasound probe and a touch screen netbook. The GUI is simple and contains the necessary functionality for fetal imaging [7].

1.4 The need for Doppler Spectrum Processing and User Interface Evaluation

1.4.1 Why is Doppler spectrum processing needed?

In my earlier project work (discussed in Section 1.3), the Doppler spectrum was processed on the scanner side and the processed spectrum is streamed to the tablet. Fast Fourier Transform (FFT) computation and other spectrum processing tasks are done on the ultrasound machine. Generally, FFT computation for spectrum generation on ultrasound machine is very costly especially in-terms of hardware because it requires it's own hardware for FFT computation.

In order to have low cost scanner for applications in rural areas, as much real-time processing as possible should be done in the tablet. In the tablet, the general purpose hardware (already used for other purposes) supports FFT computation and there is enough computation power in the tablet to compute FFT and other spectral processing. Therefore it needs only software application to be developed for the FFT computation and other processing; thus, a cost effective tablet ultrasound system can be developed.

Integration into tablet user interface: The Doppler spectrum processing code development was conducted on a windows platform and tested using a stored data of a carotid artery at first. The spectrum processing code has been also tested in real time spectrum processing at the end. Because of two basic limitations, the spectral processing code was not directly developed into the tablet ultrasound system. These two limitations were 1.) the Vivid q scanner which is useful for real time testing and 2.) the GE streamer code (a code that helps for streaming between the scanner and tablet/laptop) were both not available at the beginning of the thesis project.

Every of spectral properties and components of Doppler spectrum have been fully developed with the stored data and some of the implementations are tested in real time processing to make sure integration into a tablet based ultrasound is possible. Due to time limitation, it was not possible to integrate the developed code into the tablet user interface at the end, but all the codes and methods are developed, tested and how the development can be integrated into the laptop/tablet will be discussed in the later parts of this thesis.

1.4.2 Why is user interface evaluation needed?

Usability evaluation of user interface is very important to determine the usability of the developed user interface. Through different usability evaluation techniques of the user interface, it helps to identify any usability problems, collect quantitative data on user's performance (e.g., time on task), and helps to measure efficiency, effectiveness and satisfaction of users with the user interface. Based on these, it is possible to recommend improvements, implement the recommendations and re-test the user interface to measure the effectiveness of the changes.

1.5 Organization of the Thesis

As described in the problem description, this thesis will emphasize on:

- Doppler spectrum processing based on a raw data.
- Evaluation of the user interface introduced in Section 1.3.

In addition to this, improvements performed on the user interface from earlier work is also included and discussed.

Therefore the chapters in this thesis have sections that are written on each of these main parts. In the first part of each chapter, spectrum processing is discussed and the second part of each chapter belongs to the user interface evaluation.

1.5.1 Thesis organization

The remaining part of this thesis, consists of the following chapters.
Chapter 2 is the background chapter which introduces background theory on spectrum processing and prototype evaluation.
Chapter 3 discusses the methods used for spectral processing and user interface evaluation.
Chapter 4 shows the important results on spectrum processing and user interface evaluation obtained in this thesis.
Chapter 5 is a discussion chapter that discusses the results, some interpretations and possible improvements.

Chapter 6 shows the conclusions of this thesis and recommended further work.

Appendix A includes some additional information and developed code.

Chapter 2

Background

In this chapter, background information related to Doppler ultrasound, spectrum processing and visualization and prototype evaluation is discussed. First, the umbilical artery and how it is diagnosed using ultrasound image is discussed in Section 2.1. Section 2.2 discusses some background information on Doppler ultrasound and spectral imaging modes. The Section 2.3 continues by discussing visualization tools such as VTK and VES which are useful in spectrum and tablet user interface rendering. In the last part of the chapter, background theory on user interface evaluation techniques and principles is discussed in detail.

2.1 Umbilical Artery

☞ **Umbilical Artery**: is a paired artery that is located in the abdominal and pelvic areas. It transports deoxyginated blood from the fetus to the placenta in the umbilical cord [4].

There are three vessels that are located in the umbilical cord, two arteries and a vein. The blood that flows through the umbilical arteries arises from the fetus and enters the placenta. The blood that flow through the arteries is affected by the fetal heart contraction and the status of the placenta. The umbilical vein is used to transport the blood that is returning from the placenta to the fetus [1].

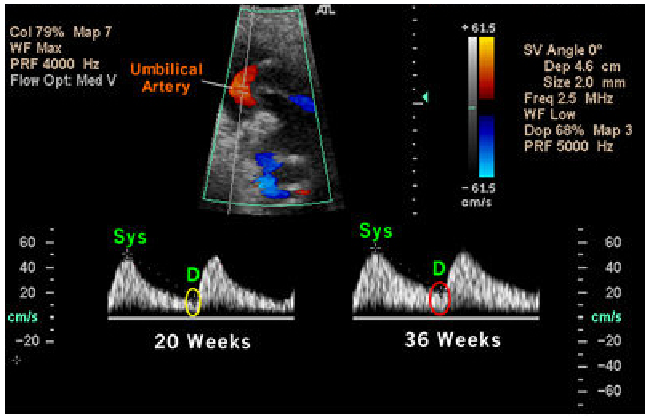


Figure 2.1: Systole (Sys) and diastole (D) are identified in green Note that diastole is less at 20 weeks (yellow ellipse) than at 36 weeks (red ellipse). [22]

How is the Umbilical artery waveform measured?

The umbilical artery waveform is estimated by measuring the blood flow velocity at peak systole (maximal contraction of the heart) and peak diastole (maximal relaxation of the heart). The Resistance Index is computed from these values. The Resistance Index (RI) is computed by measuring the peak of systole and then dividing it by the sum of measurements at peak systole and diastole. RI= systole/(systole+diastole)

The peak blood flow at diastole in later pregnancy is higher than in early pregnancy. As consequence of this, at late trimesters, the quantity of blood flowing in the umbilical artery increases during diastole. In other words the placenta is less resistant to blood flow, therefore provides more blood to flow from the fetus to the placenta [22]. Figure 2.1 illustrates Doppler wave forms at 20 and 36 weeks of pregnancy.

2.2 Doppler Ultrasound

In ultrasound scanners, a series of pulses is transmitted to detect the movement of blood. Echoes from stationary tissue doesn't change from pulse to pulse while echoes from moving scatterers exhibit slight differences in the time of the received signal [21]. These differences can be measured as a direct time difference or in terms of a phase shift from which the Doppler frequency is obtained. Then, the phase differences can be processed to produce either a color flow display or a Doppler sonogram. The Doppler frequency obtained from a blood flow of velocity v can be given by,

$$f_{doppler} = f_{transmitted} - f_{recived} = \frac{2 f_o v \cos(\theta)}{c} \tag{2.1}$$

where f_o is the transmission frequency, θ is beam/flow angle and c is speed of sound in tissue.

Doppler ultrasound measures the movement of the scatterers through the beam using the phase angle change in the received signal. The velocity the blood can be measured from the resulting Doppler frequency if the beam/flow angle is known. As equation 2.1 shows, The Doppler frequency is dependent on blood velocity and ultrasound frequency. The choice of transmission frequency is a compromise between better sensitivity to blood flow and better penetration. As the frequency increase, Doppler sensitivity increases but penetration depth decreases. The Doppler frequency also increases as the angle of θ between the beam and the direction of flow becomes smaller (as the Doppler beam becomes more aligned with the flow direction).

There are two widely known methods of transmission in Doppler ultrasound, namely continuous wave Doppler and pulsed wave Doppler.

Continuous wave Doppler: In this method, an US wave is continuously transmitted in to the tissue with one transducer while the back scattered signal is received by another transducer. Since the signals are continuously transmitted and received, there is no range resolution, no limit on the maximum velocity. Due to smaller transducer used, there is poor sensitivity than pulsed wave Doppler [15].

Pulsed wave Doppler: In this case, a short pulse of low duty cycle is transmitted at a constant pulse repetition frequency (PRF). After a pulse is transmitted, the transducer shifts to receiving mode and the received signal is sampled at a constant interval. As a result of this range resolution is possible but there is a limit on the maximum velocity and also there is possible range ambiguity [15] .

2.2.1 Aliasing

Aliasing is ambiguity in the Doppler signal that occurs when the blood velocity and beam/flow angle being measured combine to give a Doppler frequency value greater than half of the pulse repetition frequency. When pulses are transmitted at a given sampling frequency, the maximum

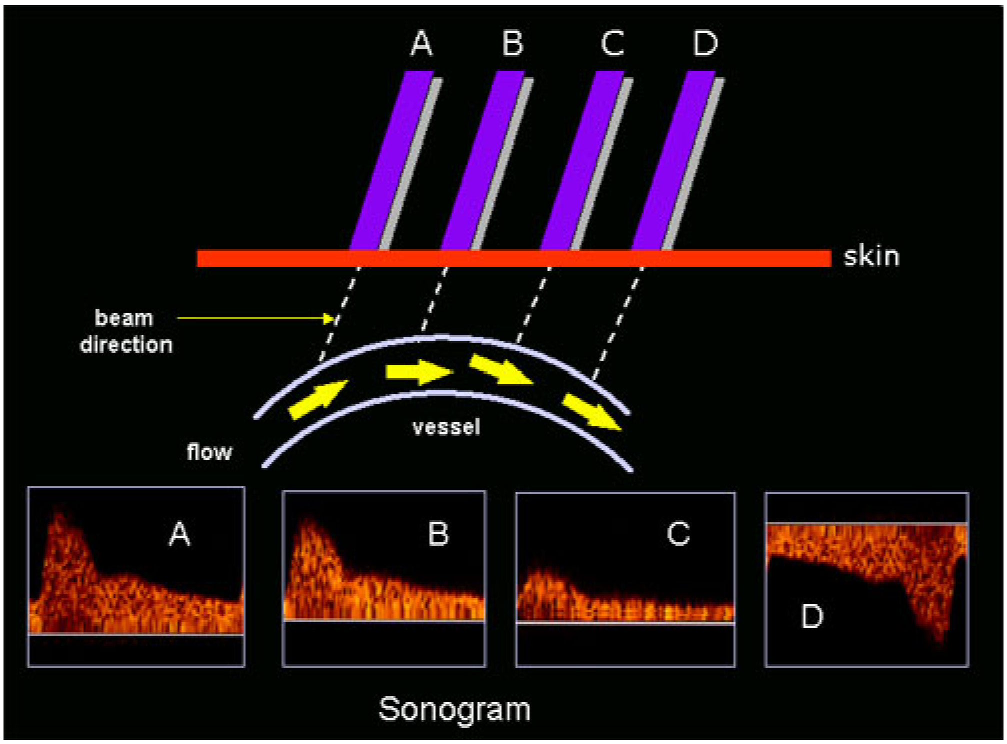


Figure 2.2: This figure illustrates the effect of the Doppler angle in the sonogram. (A) higher-frequency Doppler signal is obtained if the beam is aligned more to the direction of flow. In the diagram, beam (A) is more aligned than (B) and produces higher-frequency Doppler signals. The beam/flow angle at (C) is almost 90° and there is a very poor Doppler signal. The flow at (D) is away from the beam and there is a negative signal [21]

.

Doppler frequency that can be measured unambiguously is half the pulse repetition frequency.

$$f_d < \frac{f_s}{2}$$

This is the requirement of the Shannon sampling theorem for error free reconstruction of a sampled signal and often referred to as the Nyquist limit on the sampling frequency [15]. Low pulse repetition frequencies are used to examine low velocities. Aliasing will occur if low pulse repetition frequencies or velocity scales are used and high velocities are encountered. On the other hand if a high pulse repetition frequency is used to examine high velocities, low velocities may not be identified [21]. Therefore, the setting of the pulse repetition frequency is a trade-off.

2.2.2 Ultrasound flow modes

The main ultrasound flow modes are spectral Doppler, color flow and amplitude flow.

Spectral or Pulsed wave Doppler: is used to provide a sonogram of the artery or vein under investigation. The sonogram provides the distribution of velocities in the sample volume and the absolute velocities can be measured if an accurate angle correction is made [21]. During 2D freeze (B-mode image and color image are frozen), then best resolution of the sonogram occurs because all the time is employed for spectral Doppler.

Factors affecting Spectral or Pulsed wave Doppler:The main factors that affect affect the appearance of the sonogram includes:

- Power and gain: Power and gain should be set so that clear signals are obtained.
- Velocity scale/pulse repetition frequency: For low velocity flows low pulse repetition frequencies should be used. But if the PRF is set too low, aliasing may occur.
- Sample volume: A large gate may include signals from adjacent vessels, so the size of the sample volume should be set appropriately.

2.2.3 Smoothing

In spectral processing, it may be sometimes necessary to apply smoothing (filtering) to achieve a continuous and smooth variation of spectrum.

In smoothing, the data points of a signal are modified so that individual points that are higher than the immediately adjacent points due to noise are reduced, and points that are lower than the adjacent points are increased. This will result in a smoother signal [8]. The simplest smoothing algorithm is the rectangular or unweighted sliding-average smooth. In this algorithm, it simply replaces each point in the signal with the average of m adjacent points, where m is a positive integer known as the smooth width. For a 3-point smooth (m = 3) as an example :

$$x_j = \frac{z_{j-1} + z_j + z_{j+1}}{3}$$

for j = 2 to n-1, where x_j the j^{th} point in the smoothed signal, z_j the j^{th} point in the original signal, and n is the total number of points in the signal.

One important advantage of smoothing is its ability to reduce noise level in the spectrum. If the noise in the data is white noise and its standard deviation is s, then the standard deviation of the noise remaining in the signal after an unweighted sliding-average smooth will be [8],

$$\frac{s}{\sqrt{m}}$$

If windowing function weighted smoothing is applied, the noise in the signal also reduces accordingly. Smoothing operations can also be applied over and over on the same signal in other words, a previously-smoothed signal can be smoothed again.

2.3 Spectrum and Tablet User Interface Rendering Tools

2.3.1 Visualization Toolkit (VTK)

☞ The Visualization Toolkit (VTK) is an open-source, freely available software system for 3D computer graphics, image processing and visualization. In addition to 3D imaging, it helps to visualize 2D data such as geometry, images, and text . [13].

It supports a C++ class library and several interpreted interface layers including Tcl/Tk, Java, and Python. In addition, VTK allows the user to mix 2D imaging / 3D graphics by integrating imaging algorithms. It also supports a wide variety of visualization algorithms such as: texture, scalar, tensor vector and volumetric methods and advanced modeling techniques such as: implicit modeling, cutting, mesh smoothing, contouring, polygon reduction and Delaunay triangulation. It is cross-platform and runs on Mac, Unix, Linux and Windows platforms. It has a broad visualization framework, supports parallel processing, and integrates with various databases on GUI toolkits such as Tk and Qt.

vtkExtractVOI

vtkExtractVOI is a filter that selects a portion of an input structured points data set, or subsamples an input dataset [13]. The selected portion of region is called the Volume Of Interest, or VOI. The output of this filter is a structured points data set. The filter treats input data of any topological dimension such as point, line, image, or volume and can generate output data of any topological dimension. In order to use this filter, it is needed to set the VOI limits which are i-j-k min/max indices that specify a rectangular region in the data and these indices can be 0-offset. It is possible also to specify a sampling rate to sub-sample the data. The main applications of extractVOI are to sub-sample large volumes to reduce data size, extract a slice from a volume for image processing or extracting regions of a volume with interesting data.

vtkLookupTable

vtkLookupTable is an object that is used by mapper objects to map scalar values into rgba (red-green-blue-alpha transparency) color specification, or rgba into scalar values. By direct insertion of color values, or by specifying hue, saturation, value, and alpha range and generating a table, the color table can be created [13].

The setting of the IndexedLookup affects the behavior of this class. When IndexedLookup is set to true, vtkLookupTable enters a mode for representing categorical color maps. in other words by setting IndexedLookup to true, it is possible to indicate that the annotated values are the only valid values for which entries in the color table should be returned. By taking the modulus of the color index in the list of annotations, the colors in the lookup Table are assigned to annotated values. IndexedLookup affects the behavior of GetIndex, which in turn has effect on the way MapScalarsThroughTable2 behaves. MapScalarsThroughTable2 will search for scalar values in AnnotatedValues and use the resulting index to determine the color when IndexedLookup is set to true.

vtkAxis

vtkAxis is very important for rendering the axis properties such as axes label, tick marks and tick labels. vtkAxis works in screen coordinates. The range of values in the axes between a *Minimum* and *Maximum* is measured by the tick marks and labels. The *Minimum* and *Maximum* values of vtkAxis do not increase beyond the *MinimumLimit* and *MaximumLimit* values, respectively [13]. vtkPlotPoints is vtkAxis instances that determines scaling of the raw data for presentation. The axis Minimum, Maximum, and Limit values can be stored both in not scaled and with logarithmic scale applied.

This class includes member functions such as **SetPosition** (set the position of the axis (LEFT, BOTTOM, RIGHT, TOP, PARALLEL), **SetPoint1** (set point 1 of the axis (in pixels), this is usually the origin), **SetPoint2**(Set point 2 of the axis (in pixels), this is usually the terminus), **SetNumberOfTicks** (Set the number of tick marks for this axis and the default value is -1, which leads to automatic calculation of nicely spaced tick marks), **SetRange** (Set the logical range of the axis, in plot coordinates), **Update** (Update the geometry of the axis and it takes care of setting up the tick mark locations. It Should be called by the scene before rendering.),**AutoScale** (this function is used to autoscale the axes after setting the minimum and maximum values. It will cause the axes to select the best numbers that enclose the minimum and maximum values, and also to select an appropriate number of tick marks), **SetTickPositions**(it sets the tick positions with respect to the plot coordinates), **SetTickLabels**(it sets the tick labels for the axis.)

vtkImageFourierFilter

vtkImageFourierFilter is a class of filters that have the ability to process complex numbers. This class has various ways and techniques for implementing Fast Fourier Transform (FFT) [13]. some of the methods for executing FFT includes ExecuteFft(Execute Fast fourier transform), ExecuteRfft(Execute Reverse fast fourier transform), ExecuteFftStep2, ExecuteFftStepN, ExecuteFftForwardBackward.

vtkImageFourierFilter consists of two main classes, these are vtkImageFFT(Fast Fourier Transform) and vtkImageRFFT(Reverse Fast Fourier Transform) [13]. vtkImageFFT performs a fast Fourier transform and the input to this filter can be real or complex data, but the output is always complex. This filter is fastest for images that have power of two sizes. It uses a butterfly diagram for each prime factor of the dimension. It makes images with prime number dimensions much slower to compute, as a result multi-dimensional FFT's are decomposed so that each axis executes serially. vtkImageRFFT(Reverse Fast Fourier Transform): performs the reverse fast Fourier transform. The input to this filter can be real or complex data, but the output is always complex, which is the same as vtkImageRFFT. In most cases the RFFT will produce an image with imaginary values that are all zero's. In this case, this imaginary components can be removed using vtkImageExtractComponents and only real parts of the image are kept.

2.3.2 VES/Kiwi

VES is the VTK OpenGL ES Rendering Toolkit. It has different C++ rendering library for mobile devices using OpenGL ES 2.0. Most visualization capabilities on mobile application is performed by integrating VES with the Visualization Toolkit (VTK) [12].

VES is an open-source framework that highly helps mobile visualizations on mobile hardware. There are two main VES library, these are VES and Kiwi. The VES library supports rendering capabilities and scene management by using OpenGL ES 2.0. It uses OpenGL ES 2.0 as the underlying rendering API, which is part of OpenGL for desktop and replaces the fixed function transformations and fragment pipeline of OpenGL 1.x. The VES library provides a high-level, object-oriented API for the application development to reduce time and effort to build visualization applications where as OpenGL does not provide a high-level, object-oriented API for the application development. VES library have different components such as a scene graph (a data structure that provides spatial and logical relationships between different entities of a scene), rendering Pipeline (update, cull, render pass algorithm for rendering), programmable Pipeline and Geometry Data (data structure for defining geometry for the purpose of rendering).

Kiwi Platform supports a base for developing mobile applications that integrate VTK I/O, Filtering, and analysis with VES rendering. Kiwi library which is is built on top of VES and VTK provides an application framework. KiwiViewer is an application that is built on the Kiwi platform that provides basic geometry viewer capabilities on iOS and Android platforms. KiwiViewer provides a variety of file formats, including obj, stl, ply, and vtk [6].

2.3.3 Circular buffer

A circular buffer is a memory allocation process where memory is reused (reclaimed) when an index, incremented modulo the buffer size, writes over a previously used location [3]. When separate indices are used for inserting and removing data, it makes a bounded queue. The queue can be safely shared between processes without further synchronization so long as one process enqueues data and the other dequeues it.

A circular buffer with n elements is usually used to implement a queue with $n-1$ elements and there is always one empty element in the buffer. The fact that there is one empty element in the buffer is very important, if it wasn't then it becomes difficult to distinguish between a full and empty queue and the read and write pointers would be identical in both cases.

2.4 Tablet User Interface Evaluation

☞ Evaluation is a systematic determination of a subject's merit, worth and significance, using criteria that is governed by a set of standards. It can aid an organization to assess any aim, realisable concept/proposal, or any alternative, to help in decision-making; or to ascertain the degree of achievement or value in regard to the aim and objectives and results of any such action that has been completed or finished [25].

Before one designs and develops a system such as a user interface, one should find out how well the current user interface is working (if there is any), set measurable usability goals, and learn as much as possible about the users and their tasks.

In addition, evaluation of a user interface after development is essential to measure to what extent the usability goals are achieved and how much is the usability of the interface after development.

2.4.1 Usabilty basics

☞ Usability is a process by which users use a product to achieve their goals and includes their degree of satisfaction with the process [9].

Usability measures the quality of a user's experience when interacting with a system such as websites, software applications, mobile technologies and any user-operated devices.

Types of Evaluations: The methods used to asses the usability of a system is divided in to two types and these are [10].

1. Usability Evaluations: do not include users working with the product
2. Usability Tests: mainly focus on users working with the product

1 **Usability Evaluations**

Usability Evaluation methods involve a considerable judgement on the part of the evaluators or testers and usually do not include representative users. Evaluations such as surveys/questionnaires, expert reviews, heuristic evaluations, observational evaluations, guideline based reviews, etc can be considered as usability evaluation methods.

It is possible to conduct a usability evaluation as soon as the prototype is developed. Almost all usability professionals first do a usability evaluation and then follow it up with a usability test. They use the results obtained from the evaluation to develop hypotheses about what could be serious problems and then develop the usability test around those hypotheses.

2 **Usability Tests**

This type of evaluation includes test participants and it is the only way to know if the system(prototype) actually have problems that keep people from having a successful and satisfying experience. It is mostly performed by having one or more users actually struggle with some aspect of the system. A usability test gives a chance for the system to allow users to succeed or succeed with difficulty, or totally fail.

What is a Heuristic Evaluation?

In a heuristic evaluation, usability experts review the system (user interface) and compare it against accepted heuristics (usability principles) and the analysis results in a list of potential usability issues [10]. The issues identified in a heuristic evaluation are different than those found in a usability test, although the heuristics relate to criteria that affect the system (prototype) usability. Therefore a heuristic evaluation should not replace usability testing.
Heuristic evaluation have various advantages such as, it can provide some quick and relatively inexpensive means of feedback to the designers, assigning the correct heuristic can help suggest the best corrective measures to the designers, feedback can be obtained early in the design process, it can be used together with other usability testing methodologies, usability testing can be conducted to further examine potential issues. Heuristic evaluation disadvantages includes, it requires knowledge and experience to apply the heuristics effectively, it is expensive to find trained usability experts, multiple experts should be used and aggregate their results, and the evaluation can identify fewer major issues and more minor issues.

Usability Factors: Usability is not a single, one-dimensional property of a system(prototype); there are various factors that affect usability and these includes,Intuitive design(understanding of the system design), Ease of learning(how fast a user can accomplish basic tasks), Efficiency of use (how fast an experienced user can accomplish tasks), Memorability (is about if a user can remember enough to use the system effectively in future), Error frequency and severity(refers to the frequency of errors made by the users while using the system, how serious the errors are, and how users recover from the errors), Subjective satisfaction (the overall users satisfaction in using the system). Therefore the main key to develop highly usable prototype or any usable system is employing user-centred design which is mentioned on section 2.4.8.

Measuring Usability Goals: It is needed to create measurable usability goals in order to determine the systems usability. The main usability goals include time, accuracy, overall success, and satisfaction measures [10].

Time: Set a goal for the overall time the user will need to carry out a task on the system. One can also break that down into separate goals for time to get to the application, use the application, recover from an error.

Accuracy: Set a goal for the accuracy with which the user carries out the task. One can also break it down into separate goals for the number of unproductive searches, frequency of errors in using the system or application and misinterpretation of information.

Success: Setting a goal to measure users success with the system is another method for measuring usability goals. Success can be such as identifying an application new users will go to for help if they need it, find the help they need there, and get back to their original task within 2 minutes, set a goal that repeat users be able to successfully complete a task without using the help document or means.

Satisfaction: Set a goal that users are happy with their experience in using the system. One can also set satisfaction goals for navigation, search, Content detail and language.

2.4.2 Learning about the end users

To design a user interface that satisfies the needs of users, one have to understand about the end users. When designing a user interface, one cannot rely on assumptions about the users and their behaviour. One needs to verify or challenge those assumptions. To learn about users' realities, one need to get out and meet the users, work with them, and involve them in the development so that one will understand: Their level of knowledge about the subject matter, How they think about, group, and organize the needed information, How they work with information.

There are different techniques that that can be used to gather information about the end users and identify their needs. The main techniques are [9, 10, 30]:

1. Usability testing: typically involves asking users to accomplish some tasks while the tester observe actual behaviours and listen to user's comments.The goal is to identify any usability problems, collect quantitative data on participants' performance such as time on task, error rates and determine participant's satisfaction with the product.

   According to Jakob Nielsen [14], elaborate usability tests are a waste of resources; the best results come from testing no more than 5 users and running as many small tests as you can afford.In earlier research, Tom Landauer and Jakob Nielsen showed that the number of usability problems found in a usability test with n users is:

$$N(1-(1-L)^n)$$

   where N stands for the total number of usability problems in the design and L is the pro-

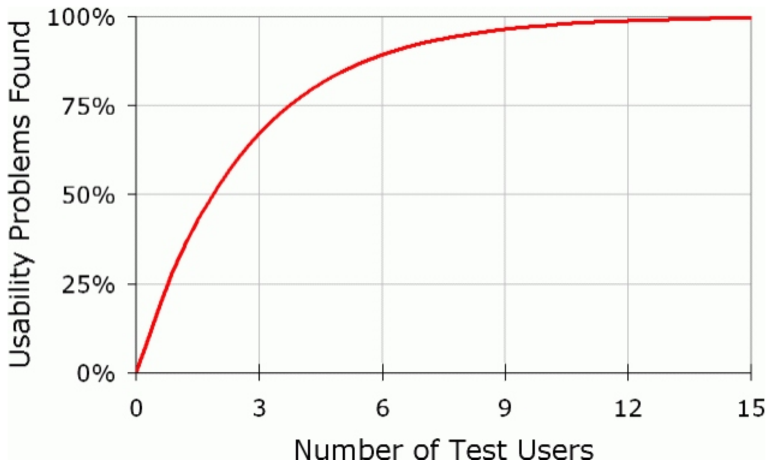


Figure 2.3: Usability issues vs Test users

portion of usability problems discovered while testing a single user. The typical value of L is 31 % , averaged across a large number of projects studied. Plotting the curve for L =31 % gives the result shown in Figure 2.3 .

As illustrated in Figure 2.3, zero users give zero insights.The curve clearly shows that you need to test with at least 15 users to discover all the usability problems in the design, then what is the need of testing with a much smaller number of users? According to Nielsen, one needs to run multiple small user group tests rather than a lot of users in a single shot, because the real goal of usability engineering is to improve the design and not just to document its weaknesses. After the first study with 5 users has found 85 % of the usability problems, one will want to fix these problems in a redesign. Also, the second test with 5 users will discover most of the remaining 15 % of the original usability problems that were not found in the first test (There will still be 2 % of the original problems left, they will have to wait until the third test to be identified). The ultimate user experience is improved much more by three tests with 5 users than by a single test with 15 users [14] .

2. Contextual interviews: It enables the tester to observe and listen to user's actual behaviours in their own environment with the technology they use. It is conducted in the user's own environment rather than in a lab. As a result of this, contextual interviews are more natural and sometimes more realistic. In a contextual interview, one watch and listen as the user works and user tasks or scenarios are not given.

3. Individual interviews: are performed with one user at a time and are a good method for self-reported attitudes and experiences. In individual interviews, it is a talk with one user for 30 minutes to an hour face to face, by telephone, with an instant messaging system. Individual interviews enables a deep understanding of the people who use the system. One can probe their attitudes, beliefs, desires, and experiences and it is possible to rate or rank choices for system content.

4. Focus groups: It involves small group discussions lead by trained facilitators. It mostly involves eight to 12 people in the same place.

2.4.3 Task analysis

A task analysis is a method that helps to complement what one have learned about the end users [10]. It uncovers the users' goals, what they want to do on the system and how to work with the system. It can also help to show the specific task users must do to meet their goals and what steps they take to accomplish those tasks. It helps to understand tasks that the system must support, determine appropriate system's content scope, refine or re-define the systems navigation.

2.4.4 Personas

A persona is a written representation of the system's intended users description of the goals, expectations and values of the intended users of the system [10]. Personas do not represent all the users or address all needs of the system . They simply focus on the major needs of the most important user groups. Personas can inform the systems functionality, help uncover gaps, or highlight new opportunities. Persona can represents a major user group for the system, gives a clear picture of the user's expectations and how they're likely to use the system, describes real people with backgrounds, goals, and values etc.

2.4.5 Scenarios

Scenarios are questions or tasks that users come with the system and the system should fulfil them [10]. It is very fundamental both for designing user interface and for usability testing and it may include specific user, major user group or previously defined persona with a specific goal.

Types of Scenarios

Goal- or Task-Based Scenarios: It deals with what the user needs to accomplish and it doesn't provide any help or information that enables the user to complete the scenario. when this type of scenario is given to users during usability testing, it gives them a reason to go to the system and how they would use the system to accomplish the goal.

Elaborated Scenarios: It presents user story details and these details helps the developer a good understanding of the user and user's behaviour in the development of the system. Based on this, the developer is more likely to develop content, functionality, and system behaviour that users find comfortable and easy to work with.

Full Scale Task Scenarios: This type of scenarios include the steps to accomplish the task and it includes all the steps that a specific user currently takes to accomplish the task or it can describe the steps one plan to set up for users in the system. It lays out the steps from the user's point of view rather than from the systems point of view and it explains how the system supports the goal-oriented scenarios that one started with.

2.4.6 Prototypes

A prototype is a draft version of the system and it should be build at any time but ideally one should create them as early as possible. Prototyping allow you to change a product early in the development process than to make change after one have developed the product and it also allows to gather feedback from users while you are still planning and designing the system(prototype). Nielsen, states that the biggest improvements in user experience come from gathering usability data as early as possible. He estimates that it's 100 times cheaper to make changes before any code has been written than to wait until after the implementation is complete [14].

Prototype Fidelity

Fidelity considerations states about the degree of realism in a prototype. A low fidelity prototype can be rather abstract and is mainly used to test concepts and ideas and have very limited functionality. On the other hand a high fidelity prototype looks like the real product. In [20], the authors break up the fidelity dimensions into two main dimensions and four sub dimensions. According to them, fidelity can be divided in to two main dimensions: physical and psychological fidelity. Physical fidelity is divided further into equipment and environment fidelity; whereas, psychological fidelity is divided into task and functional fidelity.

Equipment fidelity: states that the equipment should be as realistic as possible. This has a major effect in achieving the goals of the system.

Environment fidelity: It includes the both the physical and social factors on how a user uses a system.

Task fidelity: deals that the tasks at hand should be as realistic as possible. Tasks that seem meaningless to the user may result in the user not taking the system seriously.

Functional fidelity: Deals with the degree of reality in terms of function that the system has. It assures if the prototype function in a correct way as the real object.

2.4.7 SUS - System Usability Scale

The System Usability Scale (SUS) is a simple, ten-item point scale that provides a global view of subjective assessments of usability. It is a Likert scale , a scale that is based on forced-choice questions where a statement is made and the respondent then indicates the degree of agreement or disagreement with the statement on a 5 (4) point scale [19]. The de-facto questions (items) included in SUS measurement are listed in Appendix A.3.

SUS is generally used after the respondent or user has had an opportunity to use the system being evaluated, but before any discussion takes place. The users should be asked to record their immediate response to each item, rather than thinking about items for a long time after they have evaluated the system(prototype). SUS yields a single number representing a composite measure of the overall usability of the system being evaluated or investigated. SUS scores have a range of 0 to 100 point scale and to calculate the SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1, 3, 5, 7 and 9, the score contribution is the scale position minus 1. For items 2, 4, 6, 8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU scale [19].

For usability and Learnability, it is good to follow the suggestions of Lewis and Sauro [27], and calculate usability (sum of the items 1, 2, 3, 5, 6, 7, 8, and 9) and learnability (sum of the items 4 and 10) in addition to the total score of SUS. To make the usability and learnability scores comparable with the overall SUS value (ranging from 0 to 100), the summed score was multiplied by 3.125 and 12.5, respectively.

2.4.8 User centered design

User-Centred Design (UCD) is a design methodology and process that focuses on the needs, preferences and limitations of end users. The system that is going to be developed should center the end users.

Importance of user centred design: By focusing on the end user, it is possible to satisfy the user with a more efficient and user-friendly experience, increase loyalty, establish a more relevant and valuable system, create a system that supports the user needs.

UCD sometimes called usability engineering, is a structured approach to producing a system that involves users throughout the entire design process to create a system that works properly and satisfies the users [10]. UCD involves the following techniques:

- defining user goals and objectives
- gathering requirements
- evaluating design alternatives, building and testing prototypes
- analysing usability problems, testing the system with users and proposing solutions to problems

2.4.9 The human machine interaction

There are different standards that are used as guideline or specification for any particular purpose. Most of the Human computer interaction (HCI) standards provide a detailed specification of the nature of the user interface [16]. Although standard user interfaces provide the benefit of consistency, they become out of date as technology changes, and are usually only appropriate for limited types of users and tasks [28]. Therefore almost all the international standards for the Human computer interaction focus on principles that produce an interface which meets user and task needs. The Human computer interaction (HCI) standards are mainly divided in to two. The first approach is called "top-down" approach, that is concerned with usability as main objective. It emphasizes mainly on the ability to use of a product for the required purpose. The second approach is known as a product-oriented "bottom-up" view and it deals with the user friendliness aspect of the the product. In other words it deals with the feature of the interface that makes it easier to use. The human factors affect the quality view and these standards are applied in the context of design and quality as an objective. The product oriented approach is mainly concerned with the design of specific attributes, and is mostly related to the needs of the interface designer and the role of usability in software engineering [18].

First approach

As it is mentioned above, the first view is concerned with the usability as quality objective. In ISO 9241-11 [5], usability is defined as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. These kinds of standards can support and in cooperate the standards such as, specification of overall quality and usability requirements and evaluation against these requirements (ISO 9241-11 and ISO/IEC-14598-1), incorporation of usability into a quality system (ISO 9241-11), incorporation of usability into the design process (ISO/IEC 13407).

Second approach

The second approach is the product-oriented standards. In ISO/IEC 9126 [5], usability is defined as a set of attributes of software which bear on the effort needed for use and on the individual assessment of such use by a stated or implied set of users. There are different standards that deals with usability when it come to attributes that must be designed in to the software product to make it user friendly. Some of these standards are: ISO 9241 (Ergonomics requirements), ISO/IEC 10741-1 (dialogue interaction), ISO/IEC 9126 (Software product evaluation). These standards can be used in the following ways, to specify details of the appearance and behaviour of the user interface, to provide detailed guidance on the design of user interfaces, to provide criteria for the evaluation of user interfaces. The nature of the user, task and environment affects the attributes that a product requires for usability. A product has a capability to be used for certain context, but it has no any fundamental usability.

Usability as High Level Quality Objectives(First approach)

- ISO 9241-11 Guidance on usability (1998)

ISO 9241-11 standard, is part of the ISO 9241 series, provides the definition of usability that is used in further related ergonomic standards [5]. Usability according to this standard is defined as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. When evaluating usability in terms of measures of user performance and satisfaction, ISO 9241-11 provides guidance on how to describe the context of use of the product and the measures of usability in more explicit and described way. The standard includes an explanation of how the usability of a product can be specified and evaluated. It also explains how any component of a system affects the quality of the whole system in use by measuring user performance and satisfaction. User performance is measured by the extent to which the intended goals of use are achieved thereby showing its effectiveness and the different resources such as time, money or mental effort that have to be depleted to achieve the intended goals or efficiency. Satisfaction is measured by the extent to which the user finds the product's use acceptable [5].

ISO 9241-11 is concerned with the level of usability that is achieved that depends on a particular circumstances on a particular product that is used. It also emphasis that usability is dependent on the context of use. The context of use includes mainly of the tasks, users, the physical and organizational environments which may all influence the usability of a product and equipment (hardware, software and materials)[16]. The Figure 2.4 illustrates the this relationship on

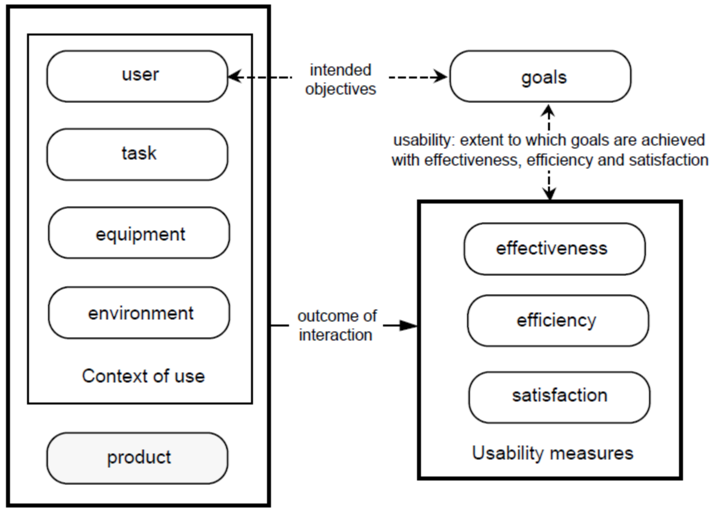


Figure 2.4: Illustrates ISO9241-11 Usability framework. [5]

the usability framework.

- Quality systems and ISO 9001

As described in ISO 9001, usability as part of a quality system for design and development of products includes the systematic identification of requirements for usability, including usability measures and verifiable descriptions of the context of use. These provides a basic stage which can be the basis for verification of the resulting design. In ISO 9001, there is a specification for what is needed for a quality system. A quality system is defined as system where a documented set of procedures intended to ensure that a product will meet initially stated requirements and needs. In order to achieve quality of the end product, a quality system is a desirable (though not sufficient) condition [31].

ISO 9241-11 explains how the usability of a product can be documented, defined, and verified as part of a quality system which adapts with ISO 9001 [5]. The overall context of use should be identified, usability requirements should be specified, usability issues should be monitored during development, and the usability achieved should be evaluated.The quality plan is shown in Figure 2.5.

Overall context of use: refers to the information about the characteristics of users, their goals and tasks and the environments in which the tasks are carried out provides important information for use in the specification of overall product requirements, prior to development

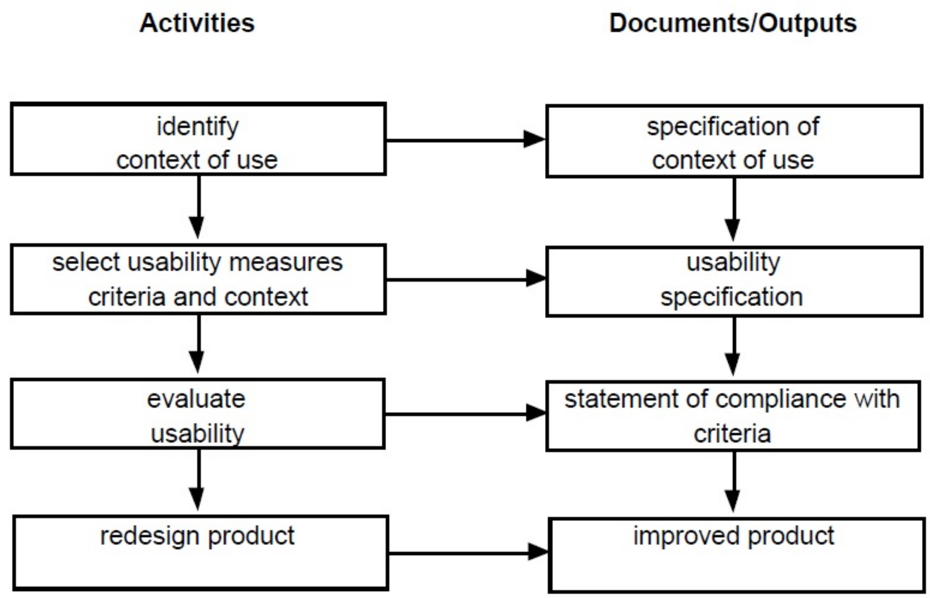


Figure 2.5: Illustrates Quality plan. [16]

of specific usability requirements [16].

Usability requirements: Prior to development of a custom system, the purchasing organization should specify the usability requirements which the system must meet and against which acceptance testing may be carried out. Specific contexts in which usability is to be measured should be identified, measures of effectiveness, efficiency and satisfaction selected, and acceptance criteria based on these measures established [16].

Monitor usability: At various stages during the development process the developer should measure the usability achieved against these targets. This information enables objective decisions to be taken about the need for design changes to enhance usability, and about trade off which may be appropriate between usability and other requirements [16].

Usability evaluation: The characteristics of the context in which a product is likely to be used need to be identified. To ensure the validity of test results the users, tasks and environments used for the evaluation should match the real context of use as closely as possible [16].

- Quality of use

For the purpose of achieving a particular job, ISO 9241-11 introduces the concept of a work system, consisting of users, equipment, tasks and a physical and social environment. Measures of user performance and satisfaction measure the quality of the work system in use. These measures provide information about the usability of that product in the particular context of use provided by the rest of the work system when a product is the focus of concern.

ISO 9241-11 defines the quality of a work system in use as: Quality of a work system in use: the extent to which specified goals can be achieved with effectiveness, efficiency and satisfaction in a specified work system [16].

The difference between usability and the quality of a work system in use is a matter of focus. When usability is evaluated, the focus is on improving a product while the other components of the work system (user, task, equipment, and environment) are treated as given. If the main goal is to improve the quality of the overall work system in use, any part of the work system may be the subject of design or evaluation. In usability evaluation, it may be appropriate to consider the amount of user training to be provided, changes in lighting, or re-organization of the task. In this case the element which is the object of design or evaluation is considered to be subject to potential variation, while the other elements of the work system are treated as constant elements.

- Software quality evaluation

ISO 8402 (Quality vocabulary) defines quality as: Quality is defined as the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs [24]. This defines quality in terms of the characteristics of a product. To the extent that user needs are well-defined and common to the intended users. In general it implies that quality is an inherent attribute of the product. The quality of the product is affected by the needs of the people(users), for example if different people(users) have different needs, then the quality(characteristics) of the product is affected accordingly.

ISO/IEC 14598-1 (Information Technology - Evaluation of Software Products - General guide) differentiates between the idea of quality as an inherent characteristic of the product, and quality of use:

☞ **Quality of use** is defined as the extent to which an entity satisfies stated and implied needs when used under stated conditions [17].

The main aim of software quality evaluation is to endure that the developed product meets the needs of the users, in other words it fulfils the quality of use. In ISO 9241-11, the definition of quality of use is similar to definitions of the quality of work system and usability. The only difference is that ISO 9241-11 specifically defines the stated conditions in terms of users, goals and environment and needs in terms of user performance.

The final software quality can be estimated by Internal software quality attributes (such as the functionality, usability and efficiency attributes defined in ISO/IEC 9126).The specific internal attributes which are relevant to final quality of use will be determined by the intended conditions of use and for an interactive product, this will rely on the needs of the final end users and the tasks.

- Human-centred design

Human-centred approach to design is very important factor to be considered to achieve objective of usability and quality of use. This is the subject of a standard under development: ISO 13407 (Human centred design process for interactive systems). This standard is expected to cover topics including: planning the usability process, incorporating human-centred design activities in interactive system development processes, and assessing the benefits of human-centred design.

To achieve the overall objective of usability and quality of use requires a human-centred approach to design. This is the subject of a standard under development: ISO 13407 (Human centred design process for interactive systems). This standard is expected to cover topics including: planning the usability process, incorporating human-centred design activities in interactive system development processes, and assessing the benefits of human-centred design [11].

Designing for usability: Product-oriented standards

Usable products may be designed by integrating product features and attributes that are known to benefit users in particular contexts of use [16]. ISO 9241 provides requirements and recommendations relating to the attributes of the hardware, software and environment which contribute to usability, and the ergonomic principles underlying them [16].

Chapter 3

Methods

In this chapter, the methods used in spectrum generation, user interface improvement and user-interface evaluation are discussed. As introduced in Chapter 1, one of the tasks in this thesis is spectrum processing and visualization. In Section 3.1, methods used for spectrum computation, further processing, visualization with corresponding axis and automatic spectrum update are discussed. Then, Section 3.2 continues by describing methods used for tablet user interface improvement which is done before evaluation. Finally, Section 3.3, discusses in detail the methods and techniques for tablet user interface evaluation.

3.1 Spectral Processing and Visualization Methods

Obtaining Doppler spectrum from raw data involves various steps. First the magnitude of the Doppler frequency components must be computed from windowed data using FFT methods. Then, the computed spectrum must be rendered in a platform that allows real-time updating. Moreover, the corresponding axes for Doppler spectrum plot must be rendered and updated accordingly. VTK is an important toolkit that has components that can be used to perform these operations. Therefore, VTK is the main method that is used to develop most of the programming code.

3.1.1 VTK: useful classes and methods

VTK has various useful classes. The most important of them that are used as a technique for the spectrum processing and visualization are discussed in this section.

vtkImageFourierFilter

vtkImageFourierFilter is an important class that contains FFT computation methods such as ExecuteFft. The inputs and output of the ExecuteFft method are instances of vtkImageComplex that supports the storage of complex data.

vtkImageComplex class has public attributes for real and imaginary data that enables to store complex (I/Q) data. For a given number of samples, the I/Q data is selected and is stored as complex data (with real and imaginary parts) and are used as input for the ExecuteFft (Fast fourier transform) execution method. The size of the input (stored I/Q data) should be same as the size of the velocity bins used to compute FFT, if the size is less, then zero padding is applied on the input until it is equal to the size of the velocity bins used. Once the size of the input complex data and the velocity bins are of equal size, the ExecuteFft function is used to compute the FFT of the array. ExecuteFft function is public member of the class vtkImageFourierFilter and it takes I/Q data as an input, and outputs complex data too. This FFT execution method is chosen because it is faster as compared to other FFT computation methods for instance when it is compared to RFFT (Reverse Fast Fourier Transform) that produces an output with zero imaginary parts and takes time to extract out the zero imaginary from the real image.

The ExecuteFft method is utilized in my implementation as follows. First the data of a given packet size (which may vary from time to time) is divided into a sequence of windows of data depending on the overlap parameter. Then the FFT of the input data is computed in a column by column (window by window) manner for a given number of samples. That is the FFT for a given window length is computed at a time and it shifts forward to compute the next FFT until the whole packet length is covered. This is also one reason why this method is faster in FFT computation. After FFT computation, the magnitude of the output of the FFT is computed, squared to obtain the power, logarithmic compression is applied before applying further spectrum processing.

vtkLookupTable

A method of gain adjustment is developed using one of the VTK class called vtkLookupTable. vtkLookupTable is an object that is used by mapper objects to map scalar values into rgba (red-green-blue-alpha transparency) color specification, or rgba into scalar values [13]. The color table is created by specifying hue, saturation, value,and generating a table. This class has a public member function called SetTableRange that provides a method to set the minimum/maximum scalar values for scalar mapping. It provides a method for gain adjustment by setting the minimum scalar values to any gain factor. For scalar values less than minimum range value are clamped to minimum range value and for scalar values greater than maximum range value are clamped to maximum range value.

vtkExtractVOI

vtkExtractVOI is a filter that can select and extract out a needed portion of an input vtkImageData. The selected portion of interest is referred to as the Volume Of Interest (VOI) and the output of the extraction is an extracted structured points of vtkImageData. The filter treats three dimensional input data (the spectrum time length in x direction, double sized velocity bin in the y direction and 1 in the z direction) and generates an output data of the same dimensions but of a desired extracted size. In order to use this filter, set the the Volume Of Interest, which is bounded by the maximum and minimum (x, y, z) coordinates, that specify a rectangular region in the data. This coordinates specify the time and velocity axes minimum and maximum values to be extracted where the third dimension, z coordinate is assumed to be a dimension of(1,1).

When the user increases/decreases the velocity or time scale range, this filter will automatically update the VOI and extract the needed spectrum with the corresponding updated velocity and time scales. Therefore this method of extraction has been implemented to extract a slice from a volume of the processed spectrum in a real time and interactive mode. Such extraction allows a user to view a needed VOI in detail depending on the scanning application.

vtkAxis and Axis Update

vtkAxis provides a method for implementing axes for the velocity time sonogram representation of the Doppler signal which is represented by time along the horizontal axis and frequency (velocity) along the vertical axis. It includes different member function and data documentation that helps to implement the axis properties. Some of the member function used to to make the axes are:

- *SetPoint1*: is used to set point 1(initial) of the (velocity/time) axis which is the origin.
- *SetPoint2*: used to set point 2 of the velocity/time axis in pixels, which is the terminal point.
- *SetRange*: used to set the range of the axis either velocity or time in plot coordinate
- *SetPosition*: to set the position of the axis to the left or right(velocity axis), bottom or top(time axis).
- *SetTickPositions*: to set the tick positions of the velocity/time axis.
- *SetTickLabels*: it sets the tick labels for the velocity/time axis.
- *Update*: it updates the geometry of the velocity/time axis and it takes care of setting up the tick mark locations and labels.
- *AutoScale*: it is used to autoscale the axes after setting the minimum and maximum values. It will cause the velocity and time axes to select the best range that enclose the minimum and maximum values, and also to select an appropriate number of tick marks automatically.

The axis update method deals with updating the axis properties such as the tick positions, labels, and the axes scales. There are two separate methods developed for time and velocity axes update. Velocity axis update controls the velocity scale changes as well as the baseline changes and the time axis update controls when there is change in time scale only. When these axes scale is adjusted, then all the axes properties mentioned above must be updated. For the tick position and label, there is a method in vtk called **Reset()** that resets the ticks and labels. When ever there is scale change, the previous ticks and labels will be erased and updated with new ones. When the axes scale changes, the desired velocity/time scale is calculated according to the updated value and the input to the extract VOI is also updated accordingly.This axis update controls these axes changes automatically and display the spectrum at the desired scale.

3.1.2 Velocity and Time scale adjustment

Velocity: The Doppler frequency shift that is the difference in frequency between transmitted and received echoes is proportional to the blood flow velocity.

$$f_{doppler} = f_{transmitted} - f_{recived} = \frac{2 f_o v \cos(\theta)}{c} \tag{3.1}$$

where f_o is the transmitted frequency, v is velocity of blood flow, θ is beam/vessel angle, c is speed of sound.

The Nyquist velocity can be calculated from the Doppler frequency shift and depends on the Pulse Repetition Frequency (PRF), speed of sound and the transmitted frequency.

$$V_{Nyquist} = \frac{c\,PRF}{4 f_o} \tag{3.2}$$

where PRF is the pulse repetition frequency. Under this Nyquist setting, velocities in the range $(-V_{Nyquist}, V_{Nyquist})$ can be measured without aliasing. If the magnitude of velocity exceeds $V_{Nyquist}$ on the other hand, aliasing will occur. To avoid such issue, spectrum stacking is used to increase the velocity scale to the range $(-2V_{Nyquist}, 2V_{Nyquist})$.

There is also a method that is developed to adjust the velocity scale to the desired values as needed and this velocity adjustment is made as a function of the baseline shift. The position of the baseline (center, bottom or top) affects the velocity scale and the corresponding spectrum that will be displayed. The default velocity range for the spectrum is made between (-VNyquist, VNyquist) which is found using equation 3.2 and this may be an aliased spectrum. Based on the stacking, the baseline shift and the velocity adjustments, the extractor will extract the spectrum corresponding to the needed range of velocity and the renderer will display the extracted spectrum. The maximum value for the velocity scale is 2*VNyquist as mentioned above the velocity scale values are restricted between (-2*VNyquist, 2*VNyquist) .

Time: In the developed programming code for the spectrum processing, there is an option for the time scale adjustment. The time scale adjustment depends on the the spectrum time length that is feed as an input for the extract VOI. By default, the time axis range is set to two seconds and this default time axis is displayed at first. When there is increase/decrease in the time scale, the spectrum time length is updated and fed to the extract VOI. Each time scale which corresponds to the spectrum time length is computed accordingly and the time axis with the time scale will be displayed with updated value automatically. The maximum spectrum time length is set to 16 seconds length which corresponds to the output buffer size and the minimum spectrum time length is set to 1 second time length and the default setting for the spectrum time length is 2 seconds time length.

3.1.3 Aliasing

There are two basic methods that are used to avoid the aliasing effect; these are base line shifting and stacking spectra.

Baseline shift: Doppler baseline shift is one technique used for manual reconstruction of aliasing. This method enables the Doppler baseline to be shifted up and down and it is done manually based on the observed aliased velocities. In the implementation, the base line variable is made to vary in the range of 0 to 4, where a base line of 2 represents the base line being set to center. The base line variable can be incremented/decremented by a value of 1. Based on the value of the base line, the velocity axis is computed. The minimum value that the base line can be lowered to 0; in this case, only positive frequencies are displayed. When the base line attains the maximum value of 4, only negative frequencies will be displayed. When the base line variable is set to 2 (which is the default setting), both positive and negative frequencies will be displayed.

Stacking spectra: The other method that is employed to avoid aliasing is stacking spectra. It is implemented by stacking aliased spectra on top of each other. This is achieved by doubling the Nyquist limit in equation 3.2 and the spectrum is plotted in the range from $-2V_{Nyquist}$ to $2V_{Nyquist}$ limit. This technique involves copying a part or all of the spectrum corresponding to positive velocities on top of the negative velocity spectrum and copying the negative spectrum on top of the positive spectrum. In effect, there will be stacked spectrum both in negative and positive velocities and this has the advantage of identifying aliased frequencies. Therefore, a double sided spectrum is obtained after spectrum stacking of the single sided spectrum.

3.1.4 Spectral filtering

There are two methods that are used to affect the temporal variation and smoothness of the spectrum after FFT computation. These methods are temporal averaging and overlap.

Temporal averaging: A temporal averaging is simple method that is implemented for filtering of the spectrum . It includes averaging overlapping segments and this method can be used for reducing speckle without loosing spatial resolution. This filtering technique has a method for adjusting the filer length. By adjusting the filter length, it is possible to control the smoothness and appearance of the spectrum. In this particular spectrum processing, a filter order of 5 is applied, only five data are taken at a time and averaged. A filter length of 1 means, there is no filtering applied.

Window Overlap: The overlapping factor depends on the window length in samples and the skip factor that determines after how much samples the next data to be taken. The percentage overlap can be given by,

$$Overlap = \frac{Window_L - skip}{Window_L} * 100 \tag{3.3}$$

where, $Window_L$ is the window length in samples. The window length in samples is computed as the ratio between the window length in seconds to the sampling time interval (time step) and the skip factor is computed as the ratio between the spectrum time step to time step, which is equal to 1/PRF. The overlap method is applied after the FFT is computed for a given window length in samples where the FFT is implemented by column by column manner. Though my implementation allows for setting any overlap, an overlap of 75 % is applied in obtaining the results. With this overlap, the spectrum appears to have good quality.

3.1.5 User controls

User controller provides method for controlling different applications that are developed. This controlling techniques provides a means for interacting the user with the developed application. In this implementation, keyboard based user interaction is used as a control method. A method called *KeypressCallbackFunction* is developed and used to handle user interactions using a keypress listener. A keypress event is sent to the event handler when keyboard input is registered. It takes the keyboard short-cuts as an input and this key board key is associated with the event to be executed. Therefore when any particular key is pressed, the desired event occurs and creates user interactivity in this way.

3.2 User Interface Improvement Methods

vesKiwiText2DRepresentation which is one of the VES class library is mainly used as a method to implement the text representation. Some of the member functions in this class are used for the text representations and these includes:
setText: Enables setting of any text properties using vtkTextProperty. It is used to set the text itself, text color, opacity, font size, font family, bold/italic/shadow styles.The most frequent properties used for the text representation are text, font size and font color.
setDisplayPosition: provides the display position of the text representation. The position can be specified as a Cartesian coordinate system (x and y), therefore it is needed to specify the two dimensions only. These display positions are calculated with respect to the screen height of the tablet. It is possible to set the one display position once based on the desired position and the other display positions are calculated based on the screen height of the tablet with reference to the previous position if more display positions for text representation are needed.
willRender: this enables continuous rendering process to occur. It is called every time when the render window is updated. Once the texts are rendered, whenever there is an update or a change from one text representation to another, then it will automatically update and continue rendering process. Therefore it keeps the updated information while rendering.
displayPosition: It fixes the positions (x-y coordinates) where the text to be displayed.

3.3 Tablet User Interface Evaluation Methods

The methods used for usability evaluation of the user interface will be discussed.

3.3.1 Usability test events

The usability evaluation of the tablet user interface was conducted by trainee midwives at at the National Center for Fetal Medicine (Nasjonalt senter for fostermedisin), Women and Children's Center, St. Olavs University Hospital, Trondheim in 2013. The test was conducted with help of Nurse-midwife/Associate Professor Eva Tegnander and with the co-operation of three pregnant women. The test was conducted in one of the laboratory rooms at the department, and it was conducted in a way that only one trainee was examining a pregnant woman at a time. In addition to that, it was not also easy to find free willing participants(pregnant women) for the testing.

According to Nielsen and Landauer [29], ten users discover about 95 % of the usability issues. Therefore ten trainee midwives have participated in the usability evaluation process. During the evaluation, each of the midwives were asked to spend 15-20 minutes on the user interface. During this time, the trainees were instructed to: complete a user background questionnaire, answer questions about their impression to the developed user interface, perform a scanning of the Umbilical Cord, answer questions about their overall satisfaction. In the begging, the trainees were told to use the help document as guidance or help for performing the task because the help document contains all the necessary steps for conducting the test. On the other hand, if they have any medical questions regarding the imaging of the umbilical cord, they were informed to ask Eva Tegnander for help, this option was made because they were new US trainees.

3.3.2 Who is tested

This section describes the users who participated in the test in terms of demographics, professional experience and special needs.

The users who participated in the usability test were new ultrasound midwife trainees. Each of the 10 trainees are from different hospitals in Norway. The education (training program) is offered by Institutt for laboratoriemedisin, barne- og kvinnesykdommer, Det medisinske fakultet, NTNU, but all the teaching takes place at the National Center for Fetal Medicine (Nasjonalt senter for fostermedisin), St. Olavs Hospital. The education is called Videreutdanning i ultralyddiagnostikk for jordmødre, or Post-graduate ultrasound education for midwives. It lasts for

1 year and gives 60 credits. The trainees were in their second phase of their training program. The trainees were trained only for four months as ultrasound midwife by the time the test was conducted. There were several criteria that are considered to get the admission to the training program:

- A geographical aspect was considered to make sure that all hospitals in Norway have a midwife with ultrasound experience.
- Being a certified midwife (3 years nursing school and 2 years midwifery school)
- At least 1 year clinical work as a midwife

The midwives were categorized based on their age, experiences as ultrasound midwives, experiences as general midwives, and other special needs. This is well described in the table for demographics, Table 3.1 and 3.2.

General description

- All trainees were females and have widely distributed age range between late 20s and early 50s and all of them have four months of experience as ultrasound midwife.
- Some of the trainees have long experience as a general midwife. However, the number of years of experience of the midwives are widely distributed as it can be seen from the table. There are experiences ranging from 2.5 years until maximum of 25 years.
- All the trainees except one have smart phones.
- Seven of the trainees doesn't own their own tablet; however, more than half of the trainees are familiar with tablet use and it's application. The trainees that have their own tablet (three trainees) had it for a time duration of 4 months to 1.5 years . Most of the trainee don't use tablet for internet access. These days the technology is advanced from the old keyboard applications to touch screen application. The fact that most of them are familiar with touch screen application has a big effect on the evaluation of the user interface.

user	age	Trainee(US midwife)	Experience as midwife	Experience as US midwife
U1	28	Yes	3 years	4 months
U2	34	Yes	7 years	4 months
U3	32	Yes	2.5 years	4 months
U4	43	Yes	17 years	4 months
U5	49	Yes	23 years	4 months
U6	47	Yes	15 years	4 months
U7	32	Yes	5 years	4 months
U8	32	Yes	5 years	4 months
U9	52	Yes	25 years	4 months
U10	37	Yes	6 years	4 months

Table 3.1: Profile Characteristics one

User	Has smart phone	Familiar with table use	Own tablet	How long time	use tablet for internet
U1	No	no	no	-	no
U2	yes	no	no	-	no
U3	yes	yes	no	-	no
U4	yes	yes	yes	1.5 years	yes
U5	yes	yes	no	-	yes
U6	yes	yes	yes	4 months	yes
U7	yes	yes	no	-	no
U8	yes	no	no	-	no
U9	yes	yes	yes	4 months	yes
U10	yes	no	no	-	no

Table 3.2: Profile Characteristics two

3.3.3 Individual interview

I conducted this individual interview with the trainee face to face before the test and during break times. I gathered as much information as I can from them that will help me understand more about them. It gave me a deep understanding of the midwives that evaluated the user interface. It was possible to probe their attitudes, beliefs, desires and experiences.

Interview with Eva Tegnander I made so many meeting and e-mail conversation with Eva Tegnander, to get the necessary information about the trainees. The midwives had very tight schedule, so it was very difficult to have time with them. Eva helped me to know so many contextual and practical information about the trainees through different session of our meeting.

3.3.4 Personas

It represents the major(end) user of the developed user interface. It Gives a clear picture of the midwives expectations and how they're likely to use the user interface. It provides a method of describing the real people with backgrounds, goals, and values. Personas development belongs at the beginning of the project, as personas can provide a method to inform the user interface functionality, help uncover gaps, or highlight new opportunities and it merely focus on the major needs of the most important user groups(the midwives).

3.3.5 Context of product use in the test

In this section the tasks that were part of the evaluation, scenarios, and conditions under which the tests were performed, and the specific configuration operated by test participants will be described.

Test facility

The usability evaluation of the tablet user interface by trainee midwives was conducted at one of the laboratory rooms at the National Center for Fetal Medicine (Nasjonalt senter for fostermedisin), St. Olavs Hospital. As can be seen in the test facility Figure 3.1 there were different equipment were used during the test. The test facilities include a web camera that is used for

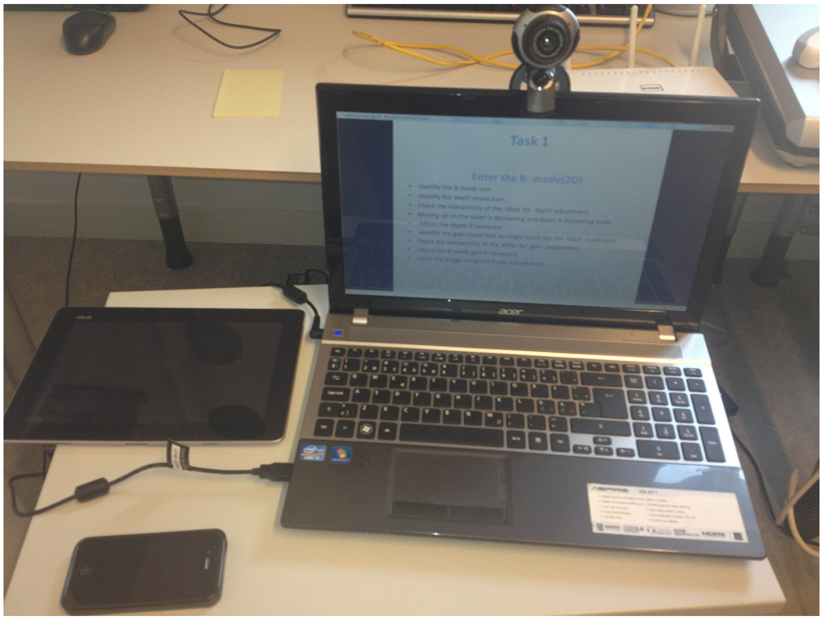


Figure 3.1: Test facility

recording videos and it was found to be very important for later reference. Audio recording system was used as an additional recording device for voice and it was used as a back up means for the video recorder. A timer application over on my iphone was used to record the completion time for the task performed by each user. Acer laptop with windows operating system was used, which was used as source of the help documentation system.

The help documentation was prepared in the form of power point presentation and was displayed on the laptop as a help document. It is prepared by gathering necessary information from Doppler ultrasound guideline for umbilical artery and the guideline is included in the appendix A.1. The help documentations was easily available, focused on the user's task, short, clear and contains list of concrete steps to be carried out in the usability task.

Tasks

The tasks that are part of the evaluation process includes:

Scenario Use cases have been used for setting up a scenario. The scenario was written in a way describing a plan set up for users in the application of the user interface for imaging of the umbilical cord. The scenario lays out the steps from the user's point of view rather than the user interface point of view.

Task(T) number	main usability test task
T1	Enter the 2D mode
T2	Adjust the gain
T3	Adjust the depth
T4	Save the image
T5	Open saved image
T6	Go to the scanning operation

Table 3.3: Tasks performed for Usability test

Evaluation(E) number	Evaluation Criteria
E1	Does the user enters the 2D mode
E2	Did the user adjust the gain
E3	Did the user adjust depth values.
E4	Can the user save the scanned image
E5	Is the user capable of opening the saved image
E6	Did the user go to the scanning operation successfully

Table 3.4: Usability evaluation criteria

Usability test task

Usability testing is used as a technique(method) used to evaluate the tablet user interface. The goal is to identify any usability problems, collect quantitative data on midwives performance (e.g., time on task, error rates), and determine the midwives satisfaction with the user interface application.

The usability test task that was conducted was a 2-dimensional (2D) imaging of the umbilical cord. During the test, the trainees tried tried to complete typical tasks while I watched, listened and took some notes. During the task, they were provided with help documentation where all the steps of the task are well described and reference images are well provided. The methods for conducting the main usability test task are shown in Table 3.3.

Usability test evaluation criteria

There are several evaluation criteria methods that are used and this methods are used to asses the tasks that are mentioned above(usability test task). The evaluation criteria are shown in Table 3.4.

Task no	Task criteria
T1	Knows 2D icon
T2	knows the depth icon
T3	Knows the interactivity of the slider
T4	Moves the slider and adjust depth
T5	Identify change icon
T6	knows the gain icon
T7	Moves the slider & adjust gain
T8	knows how to zoom
T9	knows the freeze icon
T10	knows the image save icon
T11	save the image successfully
T12	Exit the scan operation
T13	open the total command
T14	open the folder patient
T15	open the image
T16	exit the total command
T17	Go to scan mode
Success	
Completion rates(%)	
Time(min:sec)	

Table 3.5: Usability Metrics

3.3.6 Usability metrics

Different measures have been used in the evaluation metrics. The usability metrics in general are selected to measure the effectiveness, completion rate, efficiency and satisfaction of the users(trainees). The usability metrics used with the main task and sub task are summarized in Table 3.5.

Effectiveness

Effectiveness relates the goals of using the user interface to the accuracy and completeness with which these goals can be achieved. Some of the measures of effectiveness that are used in the usability metrics includes percent task completion, frequency of errors, frequency of assists to the trainee from the tester (me) and frequency of accesses to help documentation by the trainees during the tasks.

- Completion Rate: A method of task completion success rate is employed in the usability metrics. The task success rate is the number of successes divided by the number of participants completing the task. The results includes the percentage of participants who completely and correctly achieve each task goal.
  If the task is partially achieved (e.g., by incomplete or sub-optimum results) then the the average task achievement is reported, scored on a scale of 0 to 100 percent based on specified criteria related to the value of a partial result.

- Assists: When the trainees cannot proceed on a task, some times they were given some assistance that gives direct procedural help in order to allow the test to proceed. Those that are assisted are marked with 'H' symbol which stands for helped in the usability metrics table.

Efficiency

Efficiency is generally assessed by the mean time taken to achieve the usability test task. A common measure of efficiency is time spent on each task.

- Task time: is one of the method used for efficiency measure. The time taken by each trainee to complete the task is reported. The task time is described in terms of minutes and seconds accordingly(min:sec). It doesn't include a more detailed breakdown of time for instance, the time that trainee spent looking for or obtaining help (e.g., including help system or calls to the help).

Satisfaction

Satisfaction describes the trainees subjective response when using the user interface. User satisfaction may be an important factor that may affect performance of the system in some cases.

A number of questionnaires are available that are widely used user satisfaction measures. A questionnaire that is used here is System Usability Scale (SUS). It includes measurements of satisfaction, usefulness, and ease of use and it is included in the appendix A.3.

Chapter 4

Results

In this chapter, various results obtained in this thesis are shown and discussed. First, results obtained in Doppler spectrum processing and visualization are discussed in Section 4.1. Then, the results obtained form improvement of the user interface are discussed in Section 4.2. Finally, Section 4.3 contains detailed results obtained from the evaluation of the tablet user interface.

4.1 Doppler Spectral Result

Pulsed wave Doppler ultrasound is used to provide a sonogram of the artery or vein under investigation. The sonogram provides a measure of the magnitude distribution of velocities at a particular time and the temporal variation of the magnitude of each velocity component with time. Using the time-frequency Doppler spectrum plot,

- It is possible to measure blood velocities.
- It enables detailed analysis of the distribution of flow and its temporal variation
- It can be used to examine the flow wave forms and patterns

A typical time-frequency Doppler spectrum plot of a carotid artery is shown in Figure 4.1.

During the initial development, some of the spectrum processing methods were implemented in MATLAB with stored data of carotid artery. Based on that, a C++ code was developed for real time processing and visualization. The results in this section are obtained from the developed

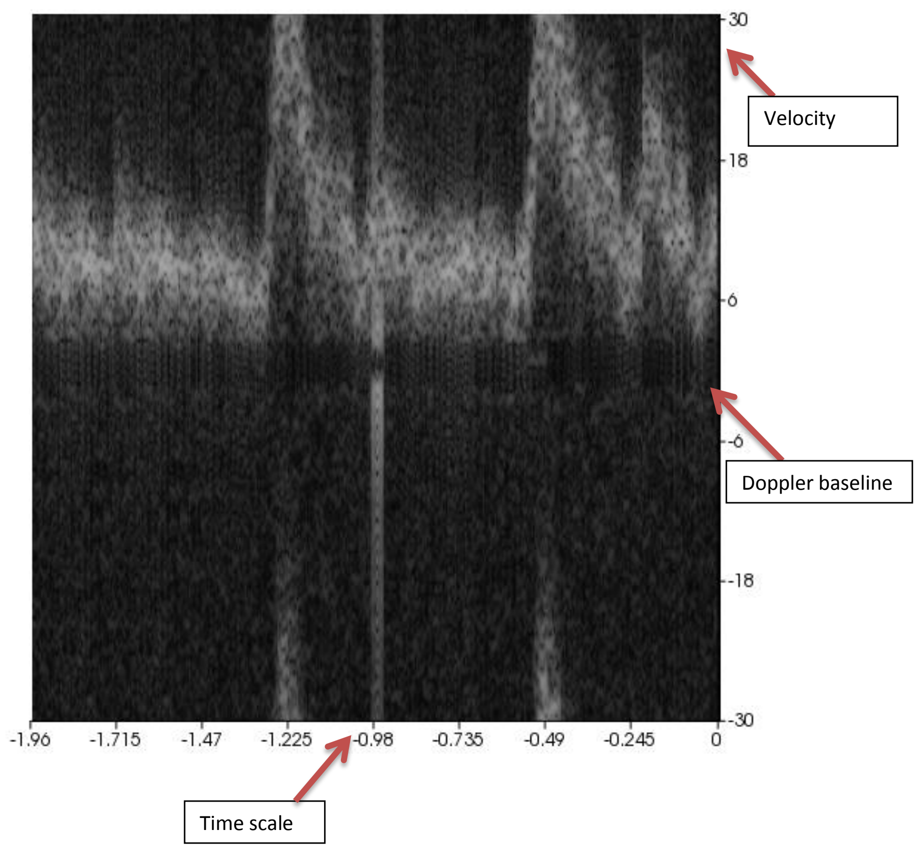
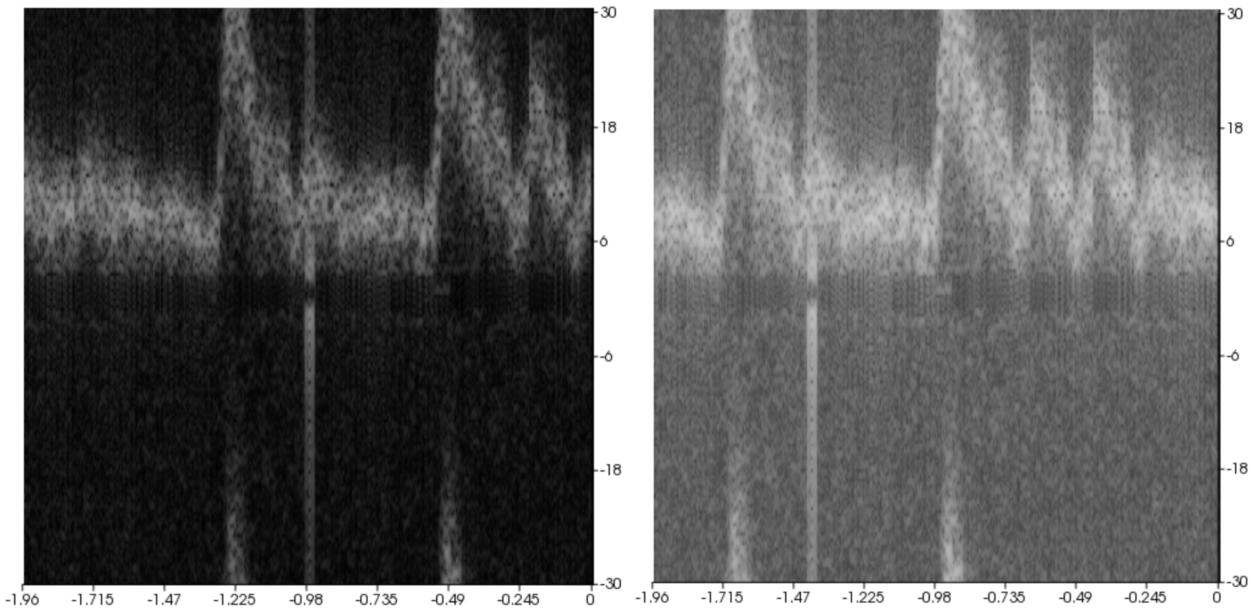


Figure 4.1: Velocity time spectrum plot of carotid artery



(a) Spectrum with gain of 20

(b) Spectrum with gain of -60

Figure 4.2: Carotid artery spectrum with different gain values

C++ code. However most of the results are compared with the corresponding results on MATLAB and found to be similar. The only difference that was observed is the difference in the brightness of the spectrum plots, which resulted due to the the difference in assigning of colormap in VTK and MATLAB.

4.1.1 Gain adjustment

Gain adjustment is important so that the sonogram is clearly visible and well distinguishable from the background noise. The spectral gain is adjusted to get a good image of the spectrum. The gain value can be adjusted to any value and it is made in the range between -70 and 20 which is a typical range for spectrum processing. The gain adjustment is made to increase by a factor of 30 and the spectrum becomes darker as the gain increases. On the other hand the gain is made to decrease by a factor of 5 and the spectrum becomes brighter when the gain is reduced. Figure 4.2 shows the spectrum obtained using two different gains of 20 and -60.

4.1.2 Velocity resolution

It possible to determine detailed analysis of the distribution of flow, low velocity flow and high velocity flow through velocity resolution. One of the parameter adjustments made in spectral Doppler mode is PRF. In the implementation of this thesis, the PRF is set to a fixed value. The effect on velocity resolution and SNR achieved by varying PRF is rather obtained by using the highest possible PRF (given by the sample volume depth) and adjusting the FFT window length to obtain the corresponding time length in milliseconds. The needed velocity scale can then be obtained by zooming the vertical axis. This is possible because,

1. The spectral resolution (in Hz) is only dependent of the time span of the window; not the number of samples

2. Decreasing the PRF will decrease the noise bandwidth, and give a proportional increase in the spectral noise level. On the other hand; the transmitted energy per pulse can be increased to obtain the same mean transmitted power. So the spectral signal to noise level will be independent of PRF.

Velocity measurement

Once the beam/flow angle is known, velocities can be calculated from the Doppler frequency as shown in the Doppler equation 3.1. It enables the vertical scale of the Doppler spectrum and the maximal detectable velocity to be modified. Velocity range directly controls the pulse repetition frequency, which is responsible for the setting of the Nyquist limit (the ability to detect maximum velocity without aliasing).

Velocity scale

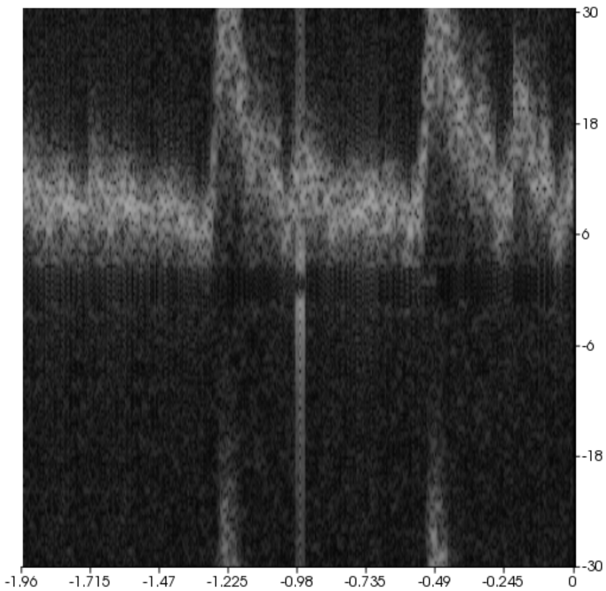
Velocity scale shows the scale of the velocity distribution and it is displayed in cm/s. The velocity scale of the Doppler spectrum is adjusted automatically based on the minimum and maximum limits set by the user and the baseline factor. Based on the position of the baseline set by the user, the corresponding velocity scale is obtained. When the velocity scale is increased or decreased, a zooming effect is observed on the spectrum. When the velocity scale is increased, the spectrum becomes zoomed out and when it is decreased the spectrum becomes zoomed in. As a consequence of this, in real time scanning, it is possible to detect high and low blood flows respectively through the zooming effect. For instance, in Figure 4.3, the modification of the velocity scale and the spectrum of the carotid artery is shown for various velocity ranges.

4.1.3 Time scale adaptation

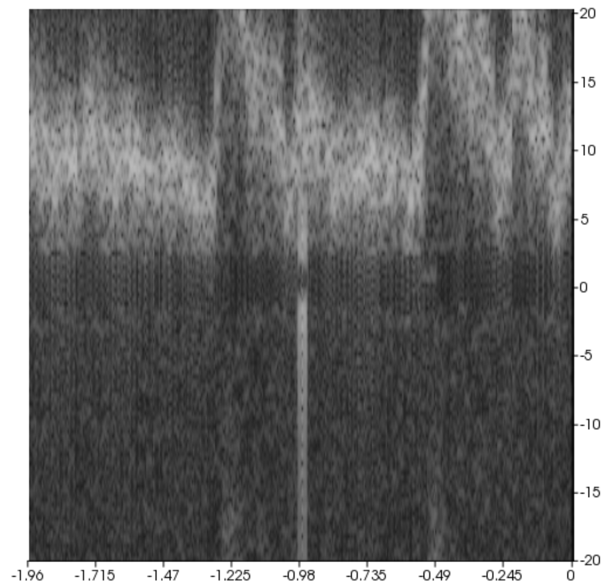
The time scale adjustment is very important factor in understanding the spectrum waveform. The time scale increases or decreases by a scale of 1 seconds and the maximum scale value is 16 seconds which corresponds to the output buffer size 4.1.8. The minimum value that time scale can be lowered to 1 sec and the default(display) setting used for the time scale that is found to be optimal in the imaging of the uterine artery is 2 seconds. The time scale can be adjusted with respect to the spectrum automatically and it is possible to observe the spectrum from a time length of 1 sec until 16 seconds. Time scale adjustment (increasing or decreasing) is made possible in both scanning mode and freeze mode. During freeze mode, it is possible to display a spectrum of fixed time buffer length (last 2 sec) or it is also made possible to adjust the time buffer length to any desired scale for displaying the spectrum. When the time scale is increased, a zoom out effect is observed until 16 seconds, whereas when it is decreased, a zoom in effect is seen with a minimum limit of 1 sec length. The spectrum with different time scale is shown in Figure 4.4.

4.1.4 Axis update

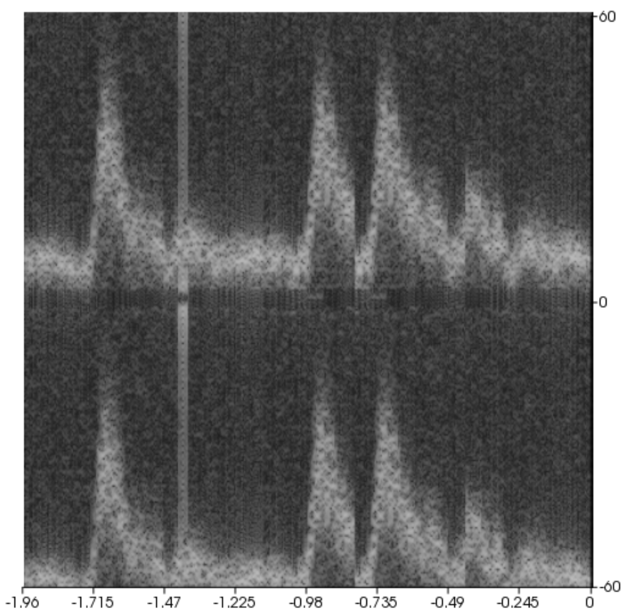
The velocity time sonogram representation of the Doppler signal is represented by time along the horizontal axis and frequency (velocity) along the vertical axis. The time and velocity axis contains the time and the velocity scales respectively. This axis update deals with updating the axis properties, the time and velocity scale to the desired (needed) value. When the velocity or time scale is changed (increased or decreased), there is a method that is developed to remove the old ticks positions and labels and replace it by the new ones. Once the tick positions and labels are updated, the desired velocity/time scale is calculated and the axis update controls this axis changes automatically and display the spectrum at the desired scale. Velocity axis update controls the velocity scale changes as well as the baseline changes and the axes update



(a) Velocity range between -30 and 30 cm/sec

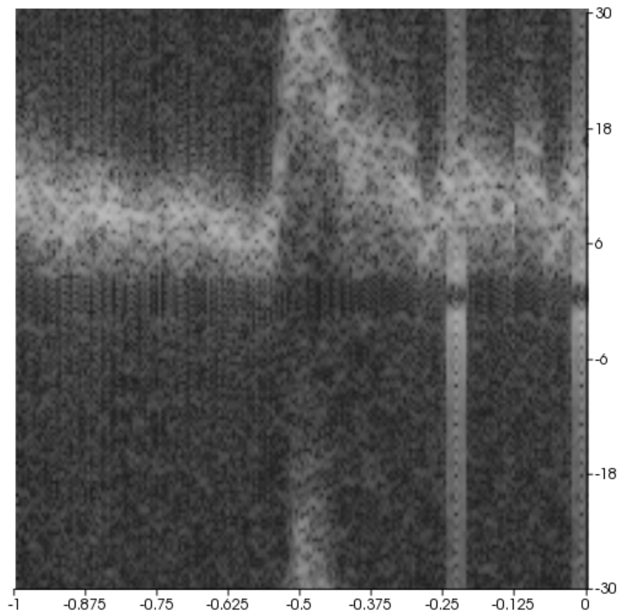


(b) Velocity range between -20 and 20 cm/sec

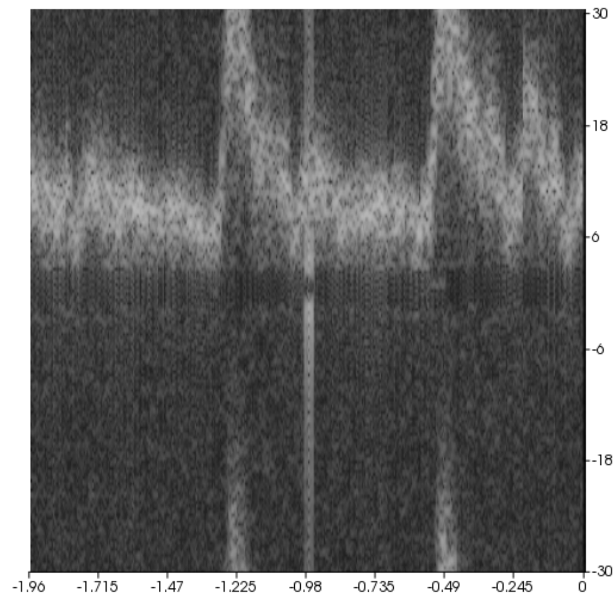


(c) Velocity range between -60 and 60 cm/sec

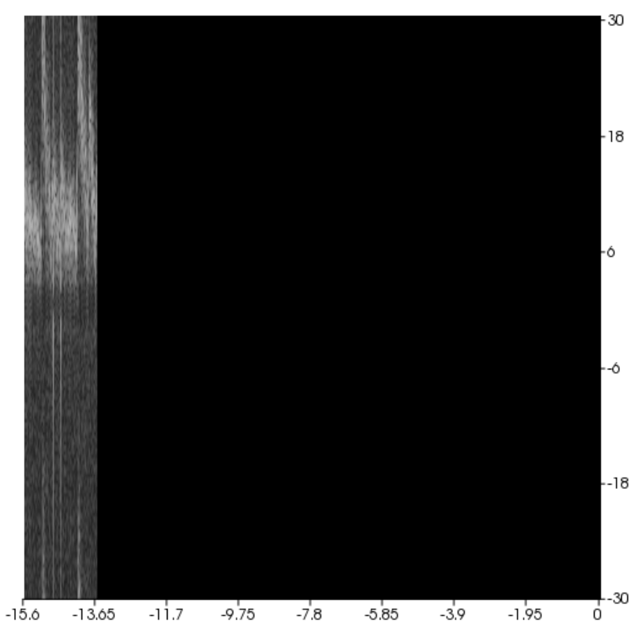
Figure 4.3: Carotid spectrum plot with different velocity scale



(a) 1 sec display



(b) 2 sec display (default setting)



(c) 16 sec display

Figure 4.4: Carotid spectrum plot with various time scale values

(both velocity and time) is possible in both scan and freeze modes. Even though it is difficult to put figures showing the update result, it is observed and tested that the axis update works as expected and updates correctly according to the different settings.

4.1.5 Aliasing

The spectrum of the carotid artery shown in Figure 4.1 is an aliased spectrum. Aliasing occurs because the maximum velocity component in the spectrum becomes greater than the Nyquist velocity for error free reconstruction of a sampled signal. According to Nyquist theorem, the maximum frequency (velocity) content f_{max} must be less than the Nyquist frequency, $f_{Nyquist}$ which is equal to half the sampling frequency. That is, $f_{max} < \frac{f_s}{2} = f_{Nyquist}$ must be satisfied. This is known as Shannon criterion for error free reconstruction of a sampled real signal.

When aliasing occurs, the positive velocities that exceed $V_{Nyquist}$ will be aliased onto the negative frequencies components that span from $-V_{Nyquist}$ towards 0. The frequencies just above $V_{Nyquist}$ will be aliased onto the frequencies just above $-V_{Nyquist}$. Similarly, when the negative frequency components exceed below $-V_{Nyquist}$, they will be aliased onto the positive frequency components starting from $V_{Nyquist}$ downward. The result of the aliased spectrum is shown in Figure 4.5. As the figure shows, it is the positive frequency components which are aliased onto the negative frequencies in this case. In order to remove this aliasing effect, the methods of Doppler baseline shifting and stacking spectra must be applied.

Stacking spectra

One of the methods that is employed to avoid aliasing is stacking spectra. It is a manual correction of aliasing. By stacking aliased spectra on top of each other, it is possible to remove a possible aliasing that may occur in the positive or negative frequency range.

The spectrum result obtained after spectrum stacking is shown in Figure 4.6. As the figure shows, a new plot having a velocity range of $\left(-2V_{Nyquist}, 2V_{Nyquist}\right)$ is obtained after spectrum stacking. The aliased spectra are now restored and can be interpreted without ambiguity.

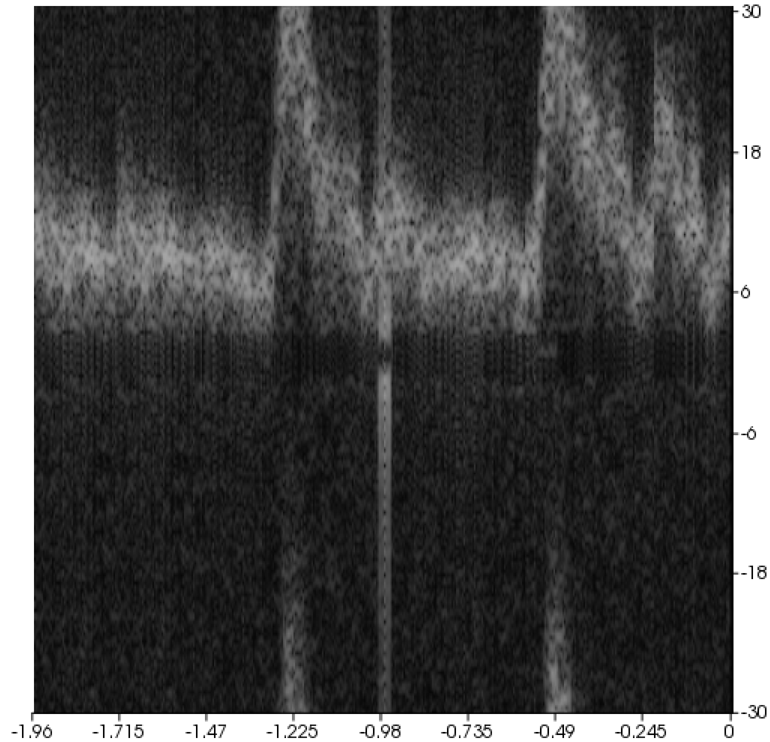


Figure 4.5: The figure illustrates aliased spectrum of Carotid artery

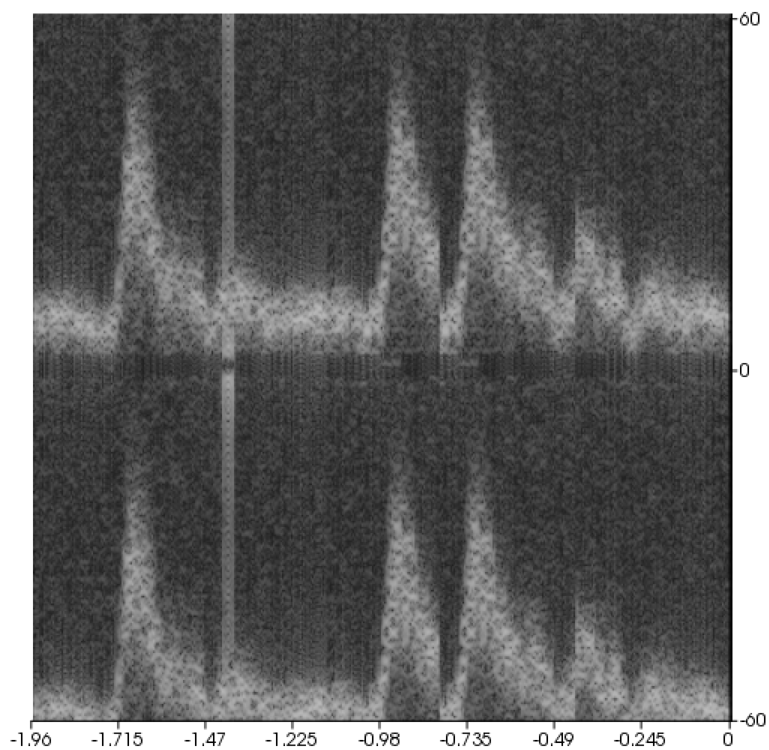


Figure 4.6: Stacked spectrum plot for carotid artery

Doppler baseline

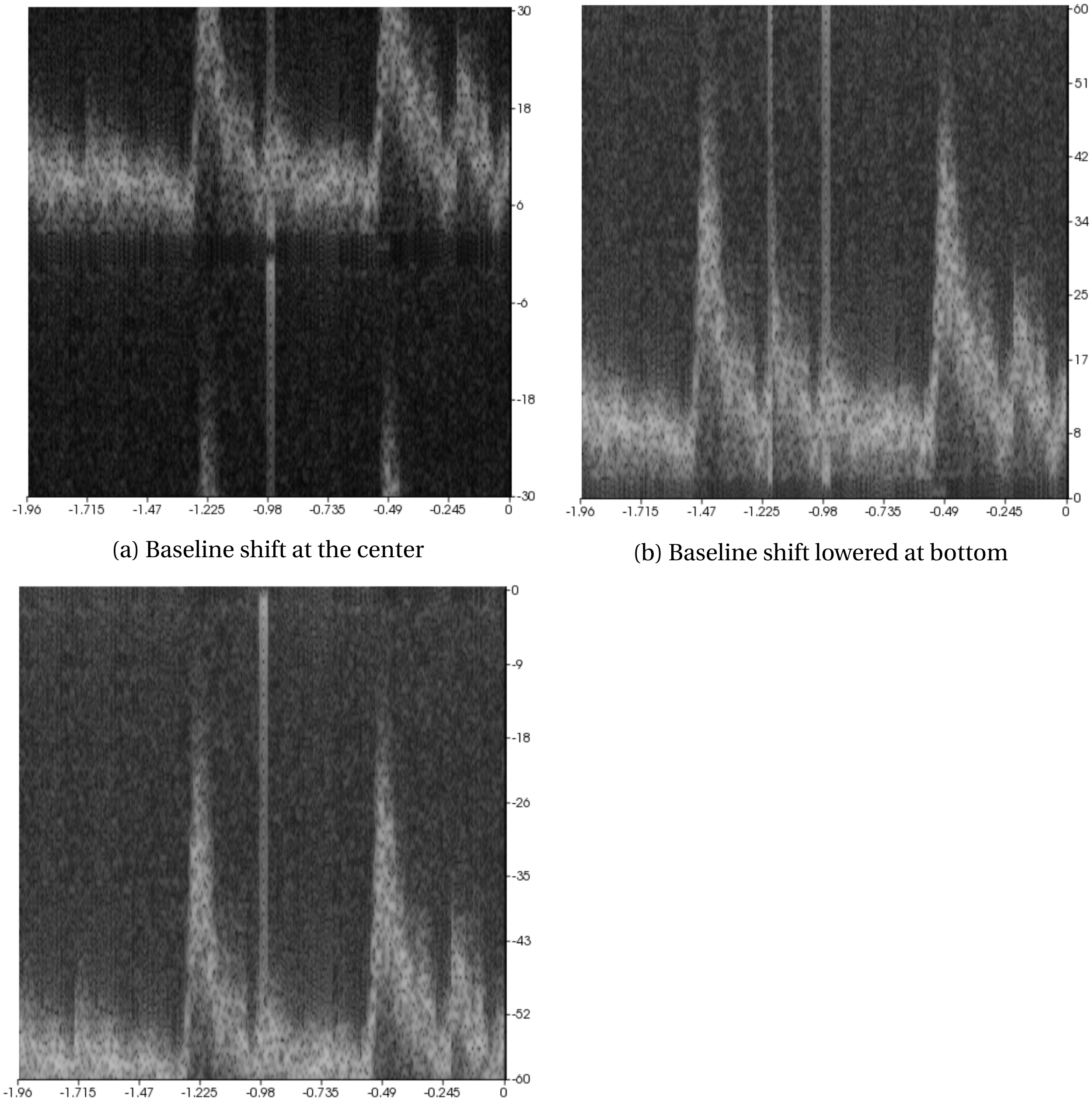
Doppler baseline shift is another technique used for manual reconstruction of aliasing. It is the shift of zero frequency line in the spectrum. Doppler baseline enables the Doppler baseline to be shifted up and down and it is done manually based on the observed aliased velocities. The default Doppler baseline is set at the center of the vertical aspect of the Doppler display, dividing evenly the flow toward and away from the probe or in other words, the negative frequencies are displayed below the baseline and positive frequencies above the baseline. It adjusts the color map to emphasize flow either toward or away from the probe. By adjusting the baseline a larger portion of the analysis is assigned to the flow direction present and baseline is available in both Live and Freeze modes.

For the aliased spectrum shown in figure 4.5, the needed section of spectrum can be obtained by adjusting the baseline. If the emphasis is on positive velocities, the baseline can be set to bottom so that only positive frequencies in the range $(0, 2V_{Nyquist})$ are shown. If the expected velocities that need to be investigated are rather negative, the baseline can be set to top so that only positive frequencies in the range $(-2V_{Nyquist}, 0)$ are shown. The different results obtained by adjusting the baseline are shown in Figure 4.7. Therefore, the requirement for error free reconstruction (unambiguous interpretation) is dependent on the range (bandwidth) of velocities expected not on the maximum velocity.

4.1.6 Overlap

The FFT is computed for a widow length of 80 samples at a time. It is implemented by column by column manner. Once the FFT is computed for the given number of samples, an overlap is applied and the next data are taken and then the spectrum processing continues.

By overlapping the segments when calculating the Periodogram, the power spectrum becomes interpolated and appears much more improved than the unoverlaped spectrum. The overlap should not be too high since this will mask the effect observed from time-varying phenomena. The overlap should not also be too low because this causes big jumps in the spectrum (non-smooth spectrum). In this case a 75 % over lap is found to be a good choice. For example, the spectrum in Figure 4.1 is obtained with a window length of 80 sample points and a 75 %



(a) Baseline shift at the center

(b) Baseline shift lowered at bottom

(c) Baseline shift raised at top

Figure 4.7: Carotid spectrum plot with various baseline values

overlap.

Frequency and time resolution

In normal FFT analysis, the spectrum time resolution and the frequency resolution are inversely related and the frequency resolution is given by

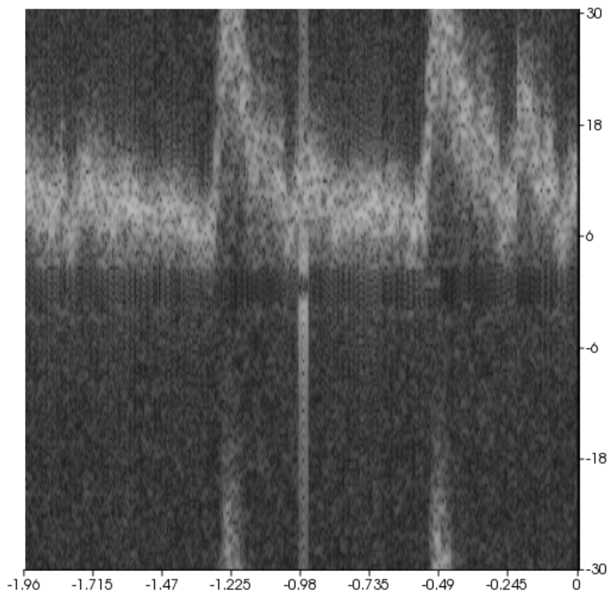
$$\triangle f = \frac{1}{T} = \frac{f_s}{N} \tag{4.1}$$

where $\triangle f$ is the frequency resolution, T is the time window length, N is sampling points and fs is sampling frequency.

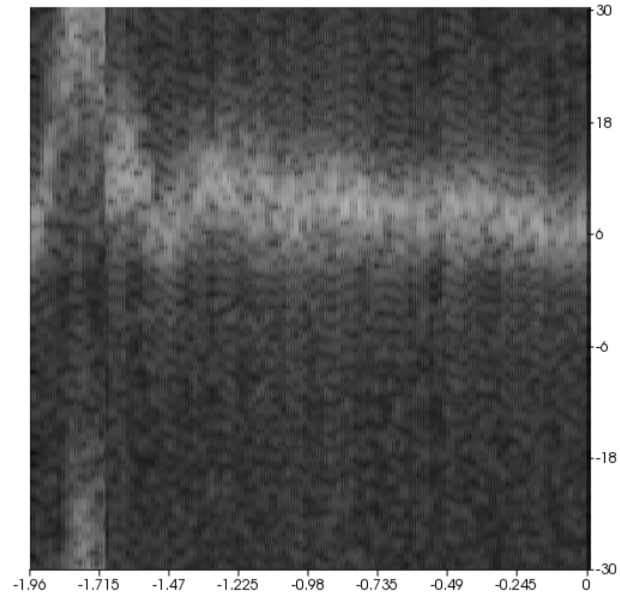
The time resolution must be increased (and the time window length reduced) in order to view instantaneous time variations in the spectrum, with a consequent deterioration in frequency resolution or for a good frequency resolution, the time window length must be increased(T) or increasing the number of sampling points N. As can be shown in the equation 4.1, the frequency resolution is dependent primarily on the number of sampling points N or window length in samples and in addition to that the spectrum time resolution and the frequency resolution are inversely related. The performance of the spectrum sonogram as a function of the window length is illustrated in figure 4.8a, 4.8b, 4.8c and 4.8d respectively. As shown in figure 4.8a, window length of 80 points has good frequency resolution and bad temporal resolution. The window length can be adjusted to any value and a value of 80 point window length is found to be optimal in this spectrum processing. In figure 4.8c, it has better temporal resolution than the window length with 80, 60 and 40 points.

4.1.7 Temporal averaging

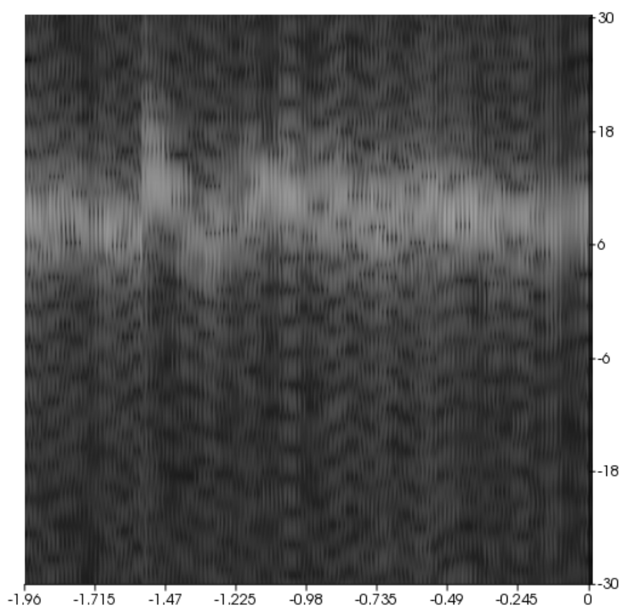
A simple method that is implemented for filtering of the spectrum is temporal averaging. By averaging overlapping segments the variance of the spectrum can be reduced or it has the advantage of reducing the speckle without loosing spatial resolution. It is a method of extracting the mean values and it is possible to average over any filter length. The spectrum with temporal averaging is more smooth as compared to the unfiltered spectrum. The optimal filter length that is applied in the spectrum processing results of this chapter is of length of 5. The spectrum



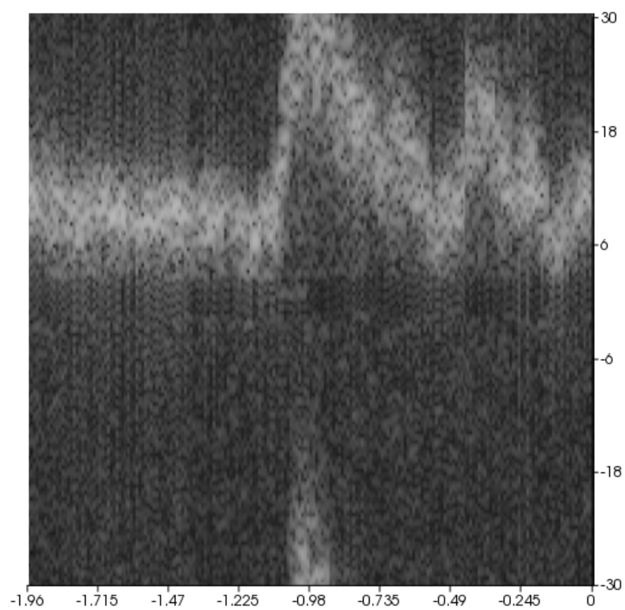
(a) Window length of 80 points



(b) Window length of 40 points

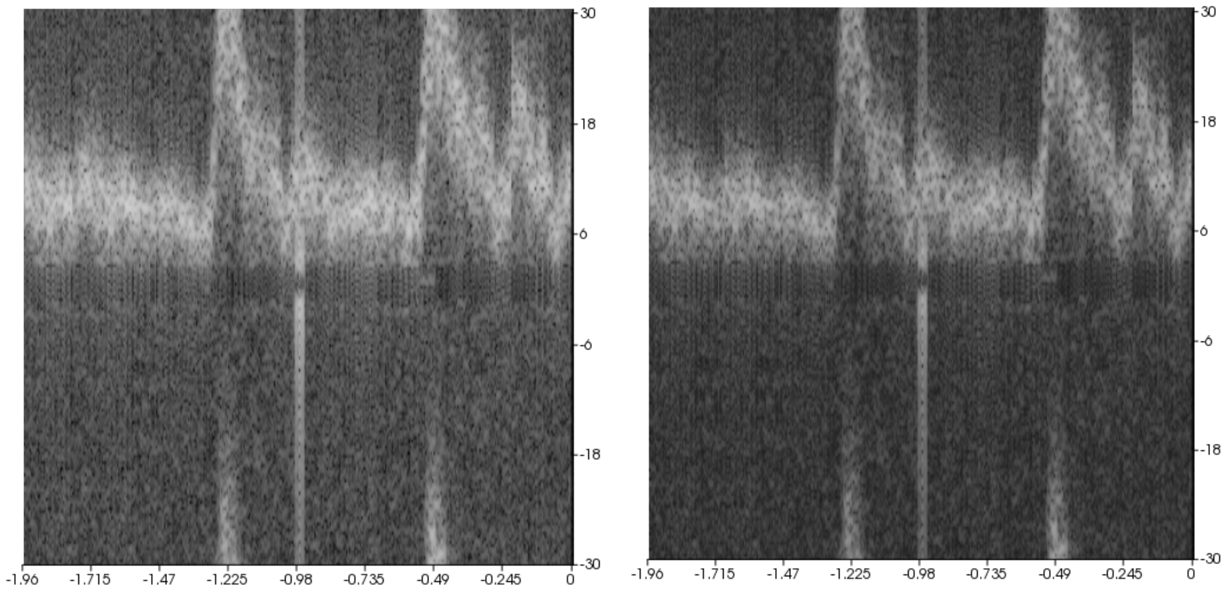


(c) Window length of 20 points



(d) Window length of 60 points

Figure 4.8: Carotid spectral plot with different window length



(a) Spectrum with no smoothing applied

(b) Spectrum with filter order 5

Figure 4.9: Carotid spectral plot with and without filter

obtained with and without filtering is shown in Figure 4.9.

Once the spectrum is averaged and then logarithmic scale is applied on it and stored in the out put buffer.

4.1.8 Output data buffer

Once the raw data is processed through FFT and smoothing, then the output of this processed data is stored in output vector. The content of the vector is stored in a circular output buffer. The maximum output buffer size is set to 16 seconds which is optimal for typical applications. Therefore the output buffer size has a capacity of holding 16 seconds buffer and if the output vector size is larger than the output buffer size, then the extra elements are calculated and erased from the output vector. The maximum size that the output vector can hold is the same as the size of the output buffer size that is 16 seconds. The processed data that is stored in the buffer can be retrieved for different application during the freeze mode because it requires to play the the stored data from the buffer. There are different application that can be performed during the freeze mode and these applications includes time scale up/down, velocity scale up/down, baseline shift and gain adjustments. Therefore all the applications that are performed in the freeze mode require the utilization of the stored data. During the scanning mode it is possible to perform all the application that are performed in the freeze mode as well. Once it is in the freeze mode, the spectrum freezes and all the applications that are mentioned above can be performed as needed. When going for new scan from freeze mode, all the stored data in the buffer is erased and replaced with new ones. Therefore for every new scan, there is method that is developed that enables the new data to be stored and the old ones to be removed.

4.1.9 Performance of Spectrum generator and it's issues

ExecuteFft, the method used for FFT computation, is implemented to compute the FFT in column by column manner (it computes one column at a time and it shifts forward to compute the next FFT until the given packet size). It is faster as compared to other FFT computation methods for instance when it is compared to RFFT(Reverse Fast Fourier Transform) that produces an output with zero imaginary parts that takes time to extract out the zero imaginary from the real image. Therefore the method of ExecuteFft has resulted in increasing the performance of the FFT computation.

As compared to the GE simulator, the speed of update both for the spectrum and axes is a bit slower. The main reason for this is the extraction process(ExtractVOI) that extracts a portion of the velocity/time spectrum. For instance, it is measured that the average processing times of ExecuteFft and ExtractVOI are approximately 1 ms and 15ms per FFT window. This shows that the extraction process is comparatively slow. In terms of quality of the image, the performance of the spectrum generator is good. For instance, with 75 % overlap, temporal averaging and window length adjustment for frequency/time resolution has resulted in a good quality image.

4.1.10 User controls

User controller provides ways for controlling different applications that are developed for the spectrum processing. In this implementation, keyboard based user interaction is made as a control method and it forms user interaction with the developed application. The various user controls includes controls for gain(up/down), velocity(increase/decrease), time(increase/decrease), baseline adjustments such as up, down. The user controls function to control the applications in both scan and freeze mode.

4.2 Improvement on the user interface

This section will emphasize on the improvements made on the user interface based on project idea and the images are taken to show mainly the improvements made, not the quality.

The modification of the user interface includes adding text representation for all the icons and modifying the image saving method. The text representation for all the icons was made to make the user interface more user friendly and understandable to the user in addition to the icons representation. The text representation was found to be very helpful and provide effective result during the evaluation process because it was easy to be understood by the trainees and it ease their work when they performed their task. The text representation doesn't only show the text representation of the icons, but it provides an information in text form on how to access the other alternative modes. The user interface with text representation is shown in Figure 4.10, 4.11 and 4.12.

In the improved image saving activity, a default file name with a name for instance "Image01" will pop out when the save icon is pressed, so the user can directly save the image or change the file name and save. The file name is developed in an iterative manner and is different for different images. Therefore the user can save as much images as possible. Based on the improved user interface, user interface evaluation was conducted and the results of the evaluation will be presented in the next section.

4.3 Main Findings of the Evaluation

4.3.1 Individual interviews

The individual interview with the trainee was conducted face to face during the test and break times. It was possible to gather as much information as possible from them and the main areas of the individual interview are listed below:

- All of the midwives have experience as general midwife for several years. But they all are

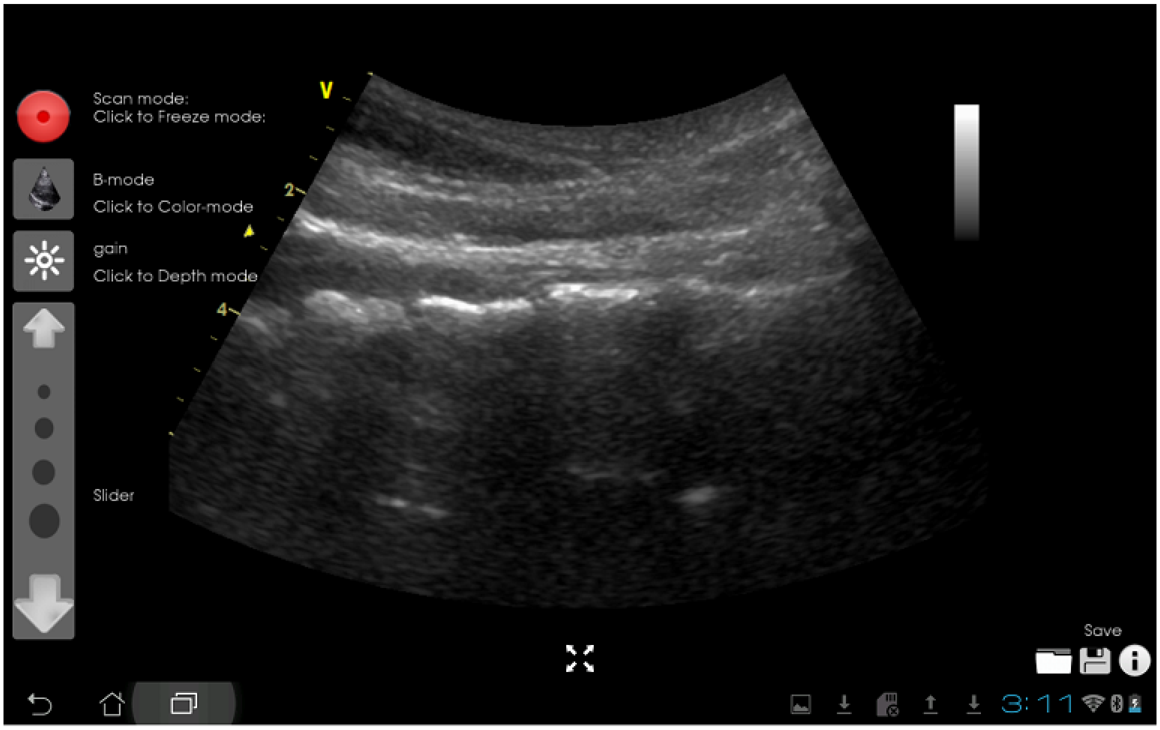


Figure 4.10: Carotid artery 2D scan with text representation

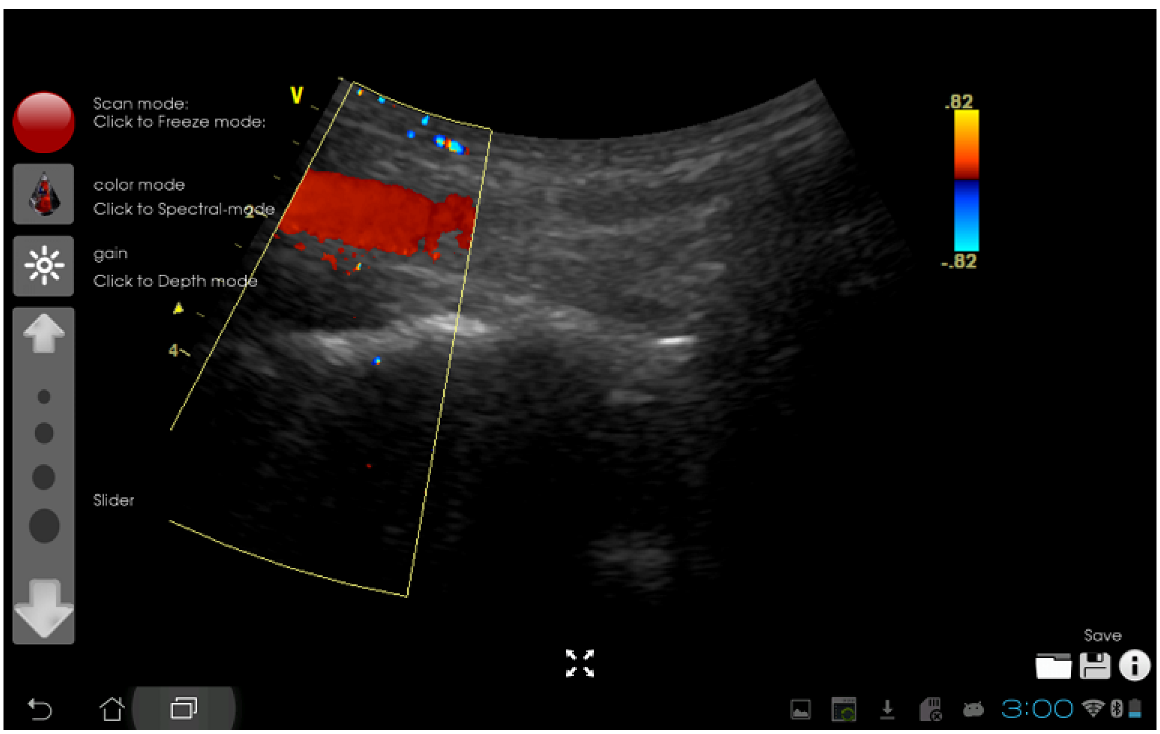


Figure 4.11: Carotid artery color mode with text representation

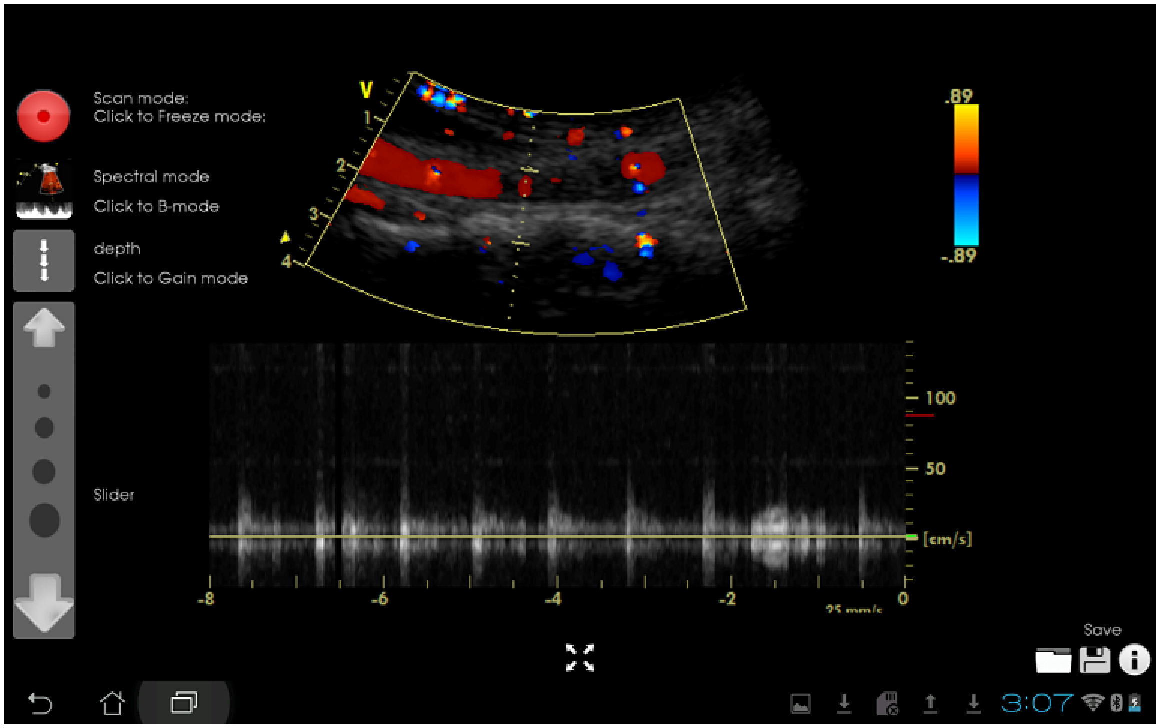


Figure 4.12: Carotid artery spectral mode with text representation

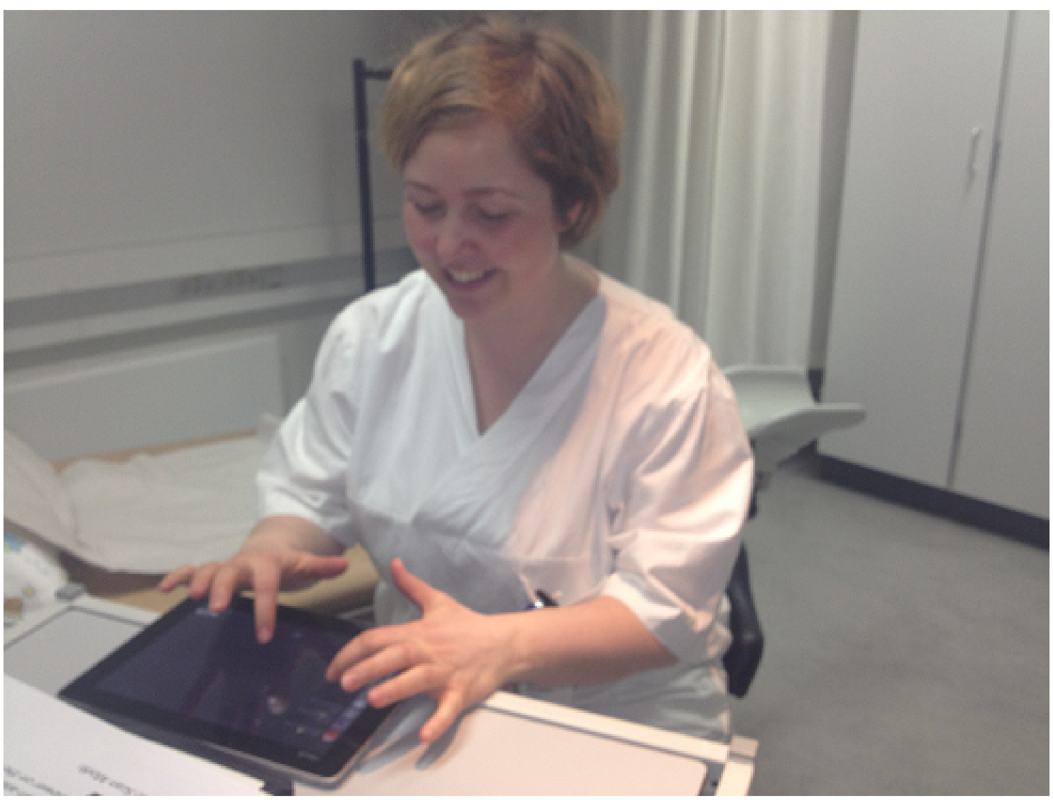


Figure 4.13: Trainee operating the Tablet user interface

new as ultrasound midwife, so all of them were new not only to the technology, but also the scanning techniques and procedures as they are trainees.

- Four of the trainees are married among the others, three of them have a partner, and three of the trainees that participated in the test are single. Those that are married are in the age of their late 40th and early 50th, older than the others. The trainees that have partner and single are in the late 20th and early 30th.

- All of the trainee have completed high school and have attended higher education.

- The connection of these trainee midwives with the technology is very strong. It is not affected by their age and status, all of the trainee midwives have access to internet and get update themselves. Most of the midwives use different system to access an internet and one thing that makes all of them similar is that, all of them use computer as means of internet access. Some of the midwives use their smart phones, computer and tablet as source of internet and some of them use only their smart phones and computer as internet source.

- Even though they are not far from technology, there were some trainee who didn't have the exposure to use a tablet before. They told me that they work mostly on computer if it is work related things and use their smart phone as for other entertainment and browsing purpose. Therefore there is no need for them to buy a tablet of their own. Despite all, most of them have exposure to tablet use before and are familiar with some of the applications.

- Most of the trainee never thought that it could be done this much on a tablet, developing this kind of ultrasound application on it, as most of them used tablet for entertainment, reading and browsing purpose.

- I asked them how they fell about this developed ultrasound system. Most of them were so curious about it when they see it for the first time and try to scan using it, but they were happy at the same time. Most of the midwives were happy and want to use it further and prefer it over the old key board application. However one trainee was confused which one of the ultrasound system she wants to use(keyboard/touch screen, tablet), and she said that there are some pros and cons with the new touch screen system even though it is a lot better than the keyboard application.

The overall individual interview is summarized in the Appendix A.2.

Interview with Eva

Before I conducted the usability test, I made an informal interview with Eva Tegnander. While discussing about the midwives, Eva informed me that the trainee can scan only in 2D mode and as a result of that they can scan only a 2D image of the the umbilical cord or umbilical artery. Initially, me and my supervisors thought that they can scan in Doppler mode. As a result of this, I modified all the questionnaire and usability test task to adapt their skills. I get to learn that all of the trainee midwives worked as general midwives for so several years and now they are 4 months since they started to be trained as ultrasound midwives.

4.3.2 Personas

Ultrasound midwife trainee

Maria Carolina

Maria is one of the trainee who participated in the usability test. She is 37 years old and she has six years of experience as general midwife. She has a partner and came from Finnmark for training as ultrasound midwife that is offered at the National Center for Fetal Medicine (Nasjonalt senter for fostermedisin), St. Olavs Hospital. She is very close to technology and like to update herself with new inventions and systems. She uses her smart phone and computer for communications, internet based applications and other purposes too. She is not familiar with tablet use or have some experience with tablet application before, but she has positive attitude towards the developed ultrasound system and she has the eagerness to learn and work on it in the future. She said that this system is a lot better than the big ultrasound machine or any ultrasound system with key board application. At the end of the test, this was the question that she asked ," When is this technology available in the market ?, " Can I take it home now ? ".

4.3.3 Scenario

During the usability test task, there can be various use cases in which the user interface is useful. Scenario set up : For instance the midwife is so busy to examine the scanned images in detail online(while scanning), rather she wants to save all the images and examine them offline before she chooses the best picture to print and give it to the patient. She can follow this procedure set up in order to act in this scenario:

1. Enter the 2D mode
2. Find and scan the umbilical cord
3. Save the image
4. Open the saved image and check.

The overview of the scenario is illustrated in Figure 4.14. During the imaging of the cord, if the midwife is inexperienced, then before she saves her image, she can go to the help document and compare with the reference image if she wants help.

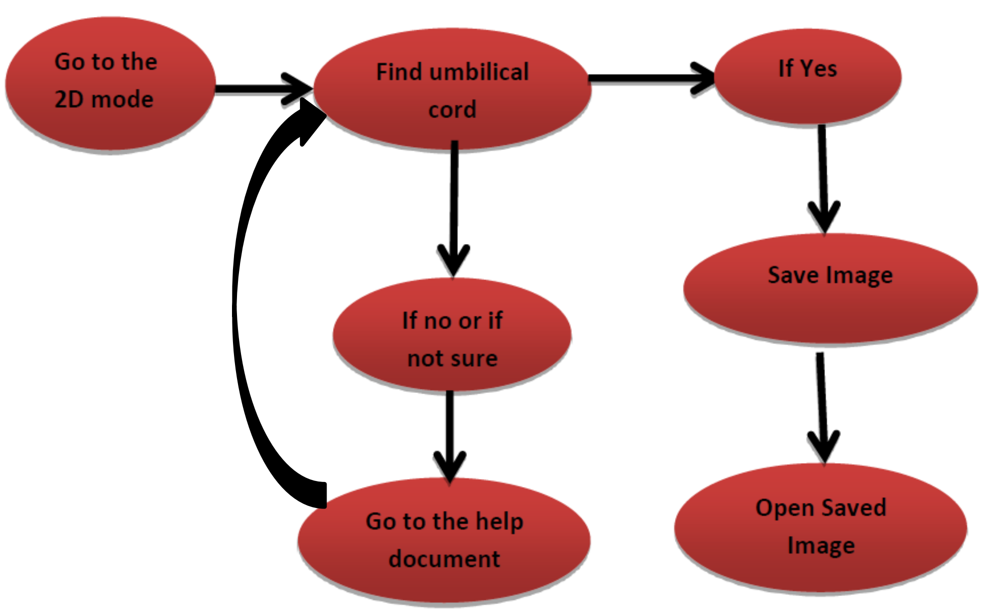


Figure 4.14: The figure illustrates Set up scenario for 2D umbilical cord imaging

4.3.4 Prototype fidelity

Fidelity considerations: The prototype fulfills the the following fidelity dimensions:

Equipment fidelity: The developed tablet user interface fulfills equipment fidelity. The tablet user interface was properly developed and used to to achieve the goals of any system including the usability task system.

Environment fidelity: The system is not affected by the environment. Even though the midwives use ultrasound gel during scanning, it was not found to be a problem to operate the touch screen application on the tablet because the midwives were scanning by their right hand and using their left hand to operate the tablet user interface.

Task fidelity : The usability test task that was given for the midwives were very precise and realistic. It enables them not only to test the user interface, but also helps them to advance themselves in fetal imaging as ultrasound midwife. In other words, it was a way of learning opportunity for them.

Functional fidelity: The tablet user interface provides high degree of reality. All sorts of scanning modes and methods can be supported based on the need. For example, as in the usability test task, 2D imaging of the umbilical cord was performed. While imaging the cord, there were so many tasks and sub-tasks that were accomplished. In each step of the task, there were so many functional buttons keys and slider application applied each with it's own functionality to image the 2D image of umbilical cord.

4.3.5 Usability test result

The usability test result includes both for the main tasks and different sub tasks, the main tasks are those tasks that generally show the usability test task 4.1 and the sub-tasks show the detailed tasks, what each user used to accomplish in the usability test. As can be seen on the table from usability test result 4.1 :

- 80 % of the midwives have accomplished the task of entering in the 2D mode.
- 90 % of them have adjusted the gain.
- All of them have managed to adjust the depth.

Task(T) no	Evaluation criteria	Percentage
T1	The user enters the 2D mode	80%
T2	The user adjust the gain	90 %
T3	The user adjust the depth	100 %
T4	The user can save the scanned image	90%
T5	The user is capable of opening the saved image	90%
T6	Did the user go to the scanning operation successfully.	80%

Table 4.1: Usability test result for main tasks

- 90 % of them saved the image.
- 90 % were able to open the saved image.
- 80 % of them go to the scan mode successfully.

The main tasks together with sub-tasks are described in the Table 4.2 and the usability test result for the main and sub-task together is shown in Table 4.3. In Table 4.3, there are various symbols used and they are defined here; Success(S which is number of successful tasks), percentage(% is task completion success rate), User number (U number), Task number (T number), Yes/correct (Y), No/wrong (N), Helped(H).

Trainee 1-5 scanned 38 weeks old fetus, Trainee 6,7 and 10 scanned 18 weeks old fetus while Trainee 8 and 9 scanned 40 weeks fetus. Based on Table 4.3, all of the midwives have successfully finished Task(T4,T6,T13,T14), less than half of the midwives have completed Task3, 90 % of the midwives have accomplished task(T5,T7,T9,T10,T11,T12,T15,T16) and 80 % have accomplished T1 and T17.

4.3.6 Usability test observations

When conducting the usability test, there were so many “Aha, wow, where am I ? , how can I find it ?” moments. All the trainee were so curious of the technology from the begging until the end. When they were told that that they are going to scan using the tablet, their face turns in to serious and stare at the tablet user interface looking at it surprisingly, partially feeling insecured. Then when I inform them that it is not them that I want to test, it is the user interface, then they start smiling and say "now it feels better". Since they are new students as ultrasound midwife, every

Task(T) no	Task
T1	Knows 2D icon
T2	knows the depth icon
T3	Knows the interactivity of the slider
T4	Moves the slider and adjust depth
T5	Identify change icon
T6	knows the gain icon
T7	Moves the slider & adjust gain
T8	knows how to zoom
T9	knows the freeze icon
T10	knows the image save icon
T11	save the image successfully
T12	Exit the scan operation
T13	open the total command
T14	open the folder patient
T15	open the image
T16	exit the total command
T17	Go to scan mode
Success(S)	
Percentage(%)	
Time(min:sec)	

Table 4.2: Main task and Sub task

Task no	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	S	%
T1	Y	Y	Y	Y	Y	Y	Y	H	H	Y	8	80
T2	H	H	H	Y	Y	H	Y	H	Y	Y	5	50
T3	H	Y	N	H	H	Y	H	Y	H	H	3	30
T4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100
T5	Y	Y	Y	Y	Y	Y	H	Y	Y	Y	9	90
T6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100
T7	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9	90
T8	Y	H	Y	Y	H	Y	Y	Y	H	H	6	60
T9	Y	H	Y	Y	Y	Y	Y	Y	Y	Y	9	90
T10	Y	Y	Y	Y	Y	Y	Y	Y	Y	H	9	90
T11	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9	90
T12	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	9	90
T13	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100
T14	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10	100
T15	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	90
T16	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	9	90
T17	Y	Y	Y	Y	Y	Y	N	Y	Y	N	8	80
S	14	14	15	16	15	16	14	14	12	12		
%	82.3	82.3	88.2	94.1	88.2	94.1	82.3	82.3	70.5	70.5		
Time(min:sec)	15: 02	13: 00	7: 03	18: 06	10: 00	12: 02	15: 05	8: 02	13: 03	9: 00		

Table 4.3: Usability test result summary

step of the test that they make was so important for them and take the usability test so seriously. Most of them were in a rush to touch and see how it works, even though I explain and provide the help document that indicates them how to conduct the test. In the begging, most of them just touch any random button and prefer to see what is going on rather than hearing what i am going to say. I just let them do that, because it was good for me to see their reaction and response, probably it could be part of their personal behavior on how they respond to new(innovative) technologies and I enjoyed most of the moments when I worked with them. Some of the trainees especially those young ones were so free when they were using the tablet for scanning, they were enjoying their time, not only focusing on getting good image, but admiring the user interface too. When they perform a task successfully they say “wow” ,”I did it”. On the other hand the other trainees especially those with a lot of experience as general midwife were serious about it and they focus on getting the test work done. At the end of each test, it was really inspiring to see when all of them smiling and so ready to welcome the new technology. Conducting the test was really fun for me, working with the midwives, seeing their reaction and every situation that occurred rather than sitting in the office and do the programming code. During the test, even some of the patients (pregnant women) were asking about the technology and wanted to see how the it works.

Some of the pregnancies were late pregnancies(40 weeks old fetus), that means there was less amniotic fluid present that has resulted in difficulties to image the cord. This has affected the quality of the image that they scanned and the time they took to find good image. The midwives that scanned normal stage of pregnancy have imaged very good quality image where as those with late pregnancy imaged fairly good image. In addition to this, they were given short time of introduction about how the tablet user interface works, but even though it was short introduction, I have observed that they were fast learners because they get used to the user interface so easily in less time. During the test, it was very difficult to find free willing participant pregnant women for the test, but with the strong help of Eva, it was possible to evaluate the user interface as planned(Umbilical cord) and all the trainees have benefited more experience in 2D imaging in addition to evaluating the user interface.

Additional observations

- Some of the trainees are curious about the scanner application, they focus more on how to use the user interface and the procedures and forgets to scan the image.

- Prefer to ask me how the interface works rather than following the guideline(help document) and scan according to the guideline.
- Confused with the vertical slider application. It was hard to adjust the depth and gain easily. I have observed that the slider is very sensitive when touched slightly .
- Some of them in the beginning just touched the freeze icon and asked for help how to get out.
- One of them prefers to follow her own guideline, for example if one has to adjust depth first and gain after according to the guideline, she do it the other way around and this made her to repeat the steeps again. May be this is due to being curious of how this new technology works and failure to read the guideline as well.
- One user touched the text not the icon or button for user interface interaction and only one user was helped to identify the change icon.
- One user briefly asked how the vertical slider relates with the a gain or depth adjustment.
- Those that have experience with touch screen application like iPad, easily managed the user interface interactivity than the inexperienced ones .
- Some of them felt insecure, even though they identify which icon to press according to the guideline, they need my confirmation to yes or no. This is normal and is due to being new to the technology.
- The fastest task time taken by a user to conduct the task was 7:03(min:sec) and the slowest time taken was 18:06(min:sec).

4.3.7 System Usability Scale(SUS)

SUS is calculated out of hundred point scale. It contains 10 questions and each item has a 5 point scale (i.e. 1 corresponds to "strongly disagree" and 5 corresponds to "strongly agree”; range of a item =[1,5]).

Trainee	SQ1	SQ2	SQ3	SQ4	SQ5	SQ6	SQ7	SQ8	SQ9	SQ10	SUS
1	4	1	5	1	4	2	5	1	4	2	87.5
2	4	2	4	2	4	2	4	1	2	2	72.5
3	3	2	4	3	3	2	4	1	4	2	70
4	4	1	5	1	4	1	4	1	4	1	90
5	3	2	4	3	4	3	4	2	3	2	65
6	4	1	4	2	4	3	3	2	3	2	70
7	3	2	5	2	4	3	5	1	2	2	72.5
8	2	2	4	1	4	2	4	2	4	2	72.5
9	3	2	4	3	3	3	4	2	3	2	70
10	3	2	4	3	4	2	4	2	4	2	70
Average	3.3	1.7	4.3	2.1	3.8	2.3	4.1	1.5	3.3	1.9	74

Table 4.4: SUS score of the trainee

According to Brooke each item contributes to the SUS scale with a range from 0 to 4 [19]. For positively worded items (1, 3, 5, 7 and 9), the score contribution is the scale position minus 1. For negatively worded items (2, 4, 6, 8 and 10),it is 5 minus the scale position. To get the overall SUS score, the sum of the item score contributions were multiplied by 2.5. Thus, SUS scores range from 0 to 100 in 2.5 point increments. The SUS score is shown in Table 4.4 and in the table SQ number stands for SUS Question number.

Regarding usability and learnability, it follows the suggestions of Lewis and Sauro [27], and calculate usability (sum of the items 1, 2, 3, 5, 6, 7, 8, and 9) and learnability (sum of the items 4 and 10) in addition to the total score of SUS. To make the usability and learnability scores comparable with the overall SUS value (ranging from 0 to 100), the summed score was multiplied by 3.125 and 12.5, respectively. The Usability and learnability are 80 and 20 point scale respectively and is shown in Table 4.5.

4.3.8 Usability issue

In the test, there were some usability problems that I observed and they are summarized and presented as in the Table 4.6.

There were several usability issues that are obtained from the usability test. There are four main issues that most of the midwives had problem with while they were conducting the test and it is shown in Table 4.6. More than half of the midwives didn't know how the vertical slider

Trainee	SUS	L&S Usability	%	L&S Learnability	%
1	87.5	60	75	17.5	87.5
2	72.5	57.5	71.8	15	75
3	70	57.5	71.8	12.5	62.5
4	90	52.5	65.6	20	100
5	65	52.5	65.6	12.5	62.5
6	70	55	68.75	15	75
7	72.5	57.5	71.8	15	75
8	72.5	55	68.75	17.5	87.5
9	70	50	62.5	12.5	62.5
10	70	57.5	71.8	12.5	62.5
Average	74	55.5		15	

Table 4.5: SUS, Learnability and Usability scores of the trainee

Issue(I)number	Issue description	Percentage
I1	User don't know 2D icon	20%
I2	User didn't find the depth icon	50%
I3	User don't know the interactivity of the slider	70%
I4	User don't know to how zoom	40%
I5	User fail to manage to enter the scan mode	20%

Table 4.6: Usability issues

works and it's interactivity, 40 % of them don't know how to zoom and half of them couldn't find the depth icon. Less than half percent of the midwives(20 %) don't know the 2D icon and to go back to scanning operation after freeze during the test.

Minor issues: Most of the midwives had difficulty to easily adjust the gain and depth values because the gain/depth scales were so sensitive, it changes so quickly. In addition to this, it was possible to observe that one midwife couldn't find the image save icon. Even though almost all of them except one mange to find it, but for some, it wasn't that easy task to do.

Chapter 5

Discussion and analysis

This chapter discusses some of the results from Chapter 4 and their possible implications. Section 5.1, discusses the results on Doppler spectrum processing and Section 5.2 discusses the results on user interface improvement and evaluation.

5.1 Doppler Spectrum Processing

In this thesis, various techniques and methods are employed in the spectrum processing that helps to obtain a good quality spectrum. In the spectrum processing implementation, there is option to make various adjustments such as gain, velocity and time scale, filter order, window length and overlap and other parameters. Based on the the scale changes, the developed code allows automatic update of the velocity/time scale and the spectrum. Even though, there is option to adjust parameters, optimal parameter values are set by default in order to obtain a good image. For instance, the window overlap is set to 75 % by default since this value is found to be optimal. Averaging over three to five consecutive data is also found to be enough to get good filtering effect in the spectrum plot. These values are based on the data from carotid artery imaging. In other imaging scenarios such as Umbilical/Uterine artery, it might be necessary to change this optimal values. The user has various controls for scanning, freezing, adjusting the time scale, adjusting the velocity scale etc. These controls are important in having an easy to manipulate and user-friendly spectrum plot system.

Spectral performance : The spectrum generation is mainly affected by the axes and spectrum extraction process. The extraction process that filters the desired velocity/time during scale changes has a bit slow effect in generating the updated spectrum and axes for display. As described in 4.1.9, the extraction process takes about 15 ms per window length. For spectrum of 2 seconds length, this extraction could take upto 6 seconds. Therefore this could be a bit far for real time display. Nevertheless, the spectrum processing and visualization tools discussed in this thesis can be used as a component block in real time streaming. The FFT computation is comparatively very fast as mentioned in 4.1.9. During the initial development of this work, the FFT was implemented by computing more than one column at a time, but it slows the update. The modification to compute one column at a time using the method described 3.1.1 has brought faster computation performance.

Integration into tablet: As stated in the introduction section 1.4.1, due to time limitation, it was not possible to integrate the developed code into the tablet application at the end. Instead, all the methods and components of the spectrum are developed with the stored data and the developed code was tested for real time streaming to make sure integration into the tablet system is possible. By importing some part of the code for instance the filtering and overlap effect in to the streamer code and it was possible to see that it can be used for real time streaming too. The initial spectrum processing is done on windows based platform because of its simplicity for trial implementation and it is easier to debug when there are errors. The developed code can similarly be integrated for real time streaming on a tablet by adding some android specific manipulations.

5.2 User Interface Evaluation

Before the user interface evaluation was conducted, user interface improvements were made. These improvements are text representation for all the icons and image saving methods 4.2. My earlier project work provides only icon representations [26].

As usability is about effectiveness(success rate), efficiency and the overall satisfaction of the user, all this goals have been measured in the usability evaluation of the user interface. The effectiveness can be measured by task completion success rate. In the usability test result 4.3, each user is assessed by the number of success, task completion success rate and task time. The highest rate is achieved by user 4 and 6 94.6 % and the lowest rate is achieved by user 9 and 10 70.5 %. The usability test task has 17 tasks, 4 of the tasks are achieved with 100 % success rate , 8 of the tasks are achieved with 90 %, 2 tasks are achieved with 80 % and 3 tasks are accomplished with 50 %, 30 %, 60 % success rates. The efficiency can be measured by task time. Most of the midwives have performed good and the fastest time(min:sec) to accomplish the task is 7:03(user 3) and the slowest time to accomplish that task is 18:06 by user 4. This is mainly affected by the fact that some pregnancy were so late, the body anatomy of the patient(one patient was over weight). As a result, it was difficult to find the cord, and also lack of experience in fetal imaging as they are new trainees but they get used to the user interface application in less time than it was expected mainly due to improvements made 4.2. The satisfaction is measured by using SUS score and it is calculated out of hundred point scale. The maximum SUS score is 90 and minimum score is 65, and this shows that most midwives agree to have the support of technical person to be able to use the user interface for ease of use and the midwives that are satisfied with the integration of the various functions in the user interface is very less. During the usability test, there were some major and minor issues that were obtained. The major issues are problems with user interface application such as the depth and 2D icons, the interactivity of the slider, zoom and entering the scan mode after freeze. More than half of the midwives didn't know how the vertical slider works. As the slider icon is two sided arrow, therefore in order to increase/decrease the depth/gain, they apply one finger single tap on the down/up arrow head, rather than applying sliding action of their finger downwards/upwards. The other issue was most of the midwives had difficulty to easily adjust the gain and depth values. The gain/depth scales were so sensitive, it changes so quickly with small sliding application on the vertical slider. In addition to this, it was possible to observe that one midwife couldn't find the image save icon. Even though almost all of them mange to find it except her, but for some, it wasn't that easy task to do.

Interview with Eva, conducted before the test, has helped me to prepare my self well for the test and gave me good understanding of the midwives. Then, the interview with the midwives makes it possible to probe their attitudes, beliefs, desires and experiences. Scenario set up provides opportunity for various cases to be utilized where the user interface can be useful.

Chapter 6

Conclusions and Future work

In most ultrasound machines, specialized hardware are used to reconstruct images from acquired raw data, which is costly. In this thesis, Doppler spectrum processing is implemented for application on a tablet ultrasound system. In order to have low cost scanner for applications in rural areas, as much real-time processing as possible should be done in the tablet. In the implementation of this thesis work, it is possible to measure velocity, time, and display the axis update. It is provided that there are methods developed to remove aliasing and it is shown that any filtering & window overlap effect can be applied. A user controller is developed that enables user interactivity for various controls like gain. The performance of the FFT computation method used is good and sufficient quality of image is obtained. The only thing that needs improvement is the extraction method which is bit slow for real time processing. Nevertheless, the spectrum processing and visualization tools discussed in this thesis can be used as a component block in real time streaming.

Usability evaluation of the tablet user interface is conducted by using usability evaluation methods. From the evaluation, it is learned that the typical usability goals are measured. It is observed that all the midwives have achieved high task completion success rate and good task completion time, which is acceptable. The level of the satisfaction that is measured shows that most of the midwives are satisfied with the application of the user interface. In addition to this, the fidelity consideration imply that all the fidelity dimensions are fulfilled and good understanding on the needs of Ultrasound midwives is obtained. Eventually, during the test, there were some usability issues that are encountered and need to be improved in the future.

6.1 Recommendations for Further Work

The functionality of the developed code with stored data is tested for real time streaming of spectrum processing based on raw data. Therefore for full functional spectrum processing, it is recommended to integrate the developed code in to GE streamer code and display the spectrum on the client side tablet.

During the usability test, there were several usability issues encountered and these issues are described in usability issues 4.3.8 and are discussed at 5.2as well. Therefore it would be great if this issues are improved (solved) in the future and conduct the usability evaluation again.

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Appendix A

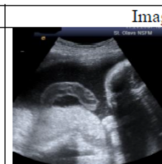
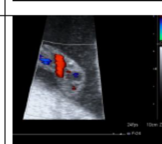
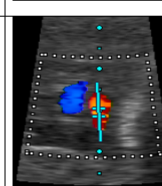
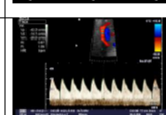
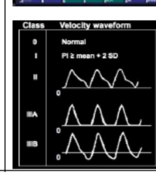
Appendices

A.1 Guidelines Doppler Ultrasound

Guidelines – Doppler Ultrasound

Lower Umolozi District War Memorial Hospital – May 2012

Umbilical artery

Method	Procedure	Image	
B-mode (2D)	• Free-floating umbilical cord • Decrease image angle • Adjust depth • Adjust focus • If necessary, decrease gain		Free-floating umbilical cord
Color Doppler	• Color box with *low* PRF/scale • Zoom image • Adjust PRF/scale • Adjust color gain • Narrow color box		Adjust angle, depth and zoom
Pulsed wave Doppler	• Sample gate to cover the vessel • Angle correction (< 60°) • Freeze color- and B-mode images		Sample gate to cover the vessel, angle correction
Spectral Doppler	• Adjust PRF/scale • Adjust gain • Low wall-filter setting • Check sweep speed • Analyze wave form	 	Adjust PRF and gain

PRF = Pulse Repetition Frequency; PI = Pulsatility Index

Figure A.1: Guidelines Doppler Ultrasound for umbilical artery

A.2 Individual Interview

Questions			U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
Q1	Marital status	Married				X	X	X			X	
		Partner		X					X			X
		single	X		X					X		
Q2	Education	Higher	X	X	X	X	X	X	X	X	X	X
		High school (videregående)										
		Elementary school (Grunnskole)										
Q3	Access to internet	Phone (smart phone)		X		X	X	X	X	X	X	X
		Computer	X	X	X	X	X	X	X	X	X	X
		Tablet				X	X	X			X	
		No access										
Q4	How often do you use a tablet	Daily				X						
		often									X	
		sometimes					X	X				
		seldom	X		X				X			
		Never		X						X		X
Q5	What do you use tablet for	Entertainment		-		X			X	-		-
		Reading				X	X	X			X	
		Browsing	X		X	X		X			X	
		other										
Q6	Do you prefer using a touch scrren application over standard keyboeard application	Yes	X			X		X		X	X	X
		No		X	X	X	X		X			

Figure A.2: Individual Interview

A.3 SUS(System Usability Scale)

The word cumbersome was given "difficult" as an equivalent meaning in terms of complexity.

System Usability Scale

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

Figure A.3: System Usability Scale

A.4 VTK based Code for Spectrum Generation and Visualization

This is the code developed for processing and displayed the Doppler spectrum.

Listing A.1: C++ Code for Spectrum Generation and Visualization

```
#ifndef __vtkGenerateDopplerSpectrum_h
#define __vtkGenerateDopplerSpectrum_h
#include <vtkImageData.h>
#include <vtkSmartPointer.h>
#include <vtkImageFourierFilter.h>
#include <cmath>// is included cos of floor function
#include <vtkTimerLog.h>
#include <vtkLookupTable.h>
#include <vtkNew.h>
#include <vtkActor.h>
#include <string>
#include <sstream>
#include <vtkAxis.h>
#include <vtkContextScene.h>
#include <vtkContextActor.h>
#include <vtkAbstractContextItem.h>
#include < vtkDoubleArray.h>
#include <vtkStringArray.h>
#include <vtkImageActor.h>
class  vtkGenerateDopplerSpectrum : public vtkObject
{
public:
        //
        ------------------------------------------------------------------------

        static  vtkGenerateDopplerSpectrum *New();
        void Clear();
        vtkSmartPointer<vtkImageData> GetSpectrumImage()// Getdoppler data is an obeject of a class vtksmartpointer that returns vtkimagedata.
        {
                return DoubleSizedSpectrumImage;// is the spectrun with its copy
        }
        vtkSmartPointer<vtkContextActor> Getactoraxis()
        {
                return actoraxis;
```

```
	}
	int GetGain()
	{
		return Gain;
	}
	int Getoffset()
	{
		return offset;
	}
	double GetVlimMin_Spec()
	{
		return VlimMin_Spec ;
	}
	double GetVlimMax_Spec()
	{
		return VlimMax_Spec ;
	}
	double Getprf()
	{
		return prf ;
	}
	int Getskip()
	{
		return skip;
	}
	int GetYMax_Spec()
	{
		return YMax_Spec;
	}

	int GetYMin_Spec()
	{
		return YMin_Spec;
	}
	double Getdt()
	{
		return dt;
	}
	int GetNs()
	{
		return Ns_Spectrum;
	}
	int GetInterval()
	{
```

```
            return Interval;
        }
        double GetTimeSpectrum()
        {
            return TimeSpectrum;
        }
        int  GetNs_buffer()
        {
            return OutputNs;
        }
        void SetDopplerData(double* PointerToReal, double* PointerToImag,int NumberOfSamples);
        void PlayBack();
        void TimeScaleUp();
        void TimeScaleDown();
        void PlayFrames();
        void Axis();
        void TimeAxisUpdate();
        void VelocityAxisUpdate();
        void clearall () ;
        void VelocityScaleUp();
        void VelocityScaleDown();
        void BaselineUp();
        void BaselineDown();
        void GainUp();
        void GainDown();
        void prfUp(),prfDown();
        void clearBuffer();
        vtkSmartPointer<vtkAxis> axesHorizontal;
        vtkNew<vtkDoubleArray> positionsX;
        vtkNew<vtkStringArray> labelsX;
protected:
        //
            ----------------------------------------------------------------------------------------

        vtkGenerateDopplerSpectrum();
        ~vtkGenerateDopplerSpectrum();
        vtkGenerateDopplerSpectrum(const vtkGenerateDopplerSpectrum&);
        vtkGenerateDopplerSpectrum& operator=(const vtkGenerateDopplerSpectrum&);
        vtkSmartPointer<vtkImageData> SpectrumImage;
        vtkSmartPointer<vtkImageData> DoubleSizedSpectrumImage;
        vtkSmartPointer<vtkContextActor> actoraxis;
        vtkSmartPointer<vtkAxis> axesVertical;
        vtkNew<vtkDoubleArray> positionsY;
        vtkNew<vtkStringArray> labelsY;
```

```
    double* data;
    double* dataDouble;
    vtkAxis* axis;
    vtkImageFourierFilter* FftCompute;
    vtkImageComplex* in;
    vtkImageComplex* out;
    std::vector<vtkImageComplex> Input;
    std::vector<double>::iterator it;
    std::vector<double> Output;
    int BufferSizeInput;
    int BufferSizeOutput;

    double VlimMin;
    double VlimMax;
    double VlimMin_Spec;
    double VlimMax_Spec;
    double VlimMin_Delta;
    double VlimMax_Delta;
    int Ns2;
    int nt;
    int YMax,YMin,YMax_Spec,YMin_Spec,YMax_Delta,YMin_Delta;
    int noVals;
    double prf;
    int skip;
    double dt;
    double dtS;
    double Tw;
    int Nv;
    int Nw1;
    int Ns;
    int c;
    int rmax;
    double vmax;
    double f0;
    int k;
    int offset;
    int Gain;
    int Ending;
    int ellNoO;
    int OutputNs;
    double TimeSpectrum;// length in time of the spectrum axis
    int Delta; //  change
    int Interval;
    int TickNumber;
```

```
        int  Increment;
        double TimeBuffer;
        int  Ns_Spectrum;
        double v[400];
        double tS[3195];
        double Line;
        double LineTotal;

        void SetVlim(double VlimMin, double VlimMax);
        void SetVlim_Spec(double VlimMin_set,double VlimMax_set);
        void SetVlim_Delta(double VlimMin_set,double VlimMax_set);
        void SetParameterf0(double f0);
        void SetParameterprf(double prf);
        void SetParameterNv( int Nv);
        void SetParameterTw( double Tw);
        void SetParameterdtS( double dtS);
};

#endif
```

Listing A.2: C++ Code for Spectrum Generation and Visualization

```
#include <vtkObjectFactory.h>
#include "vtkGenerateDopplerSpectrum.h"
#include "vtkUtil.hpp"
#include <sstream>
#include <windows.h>
#include <stdlib.h>
#include <stdio.h>
#include <algorithm>
#include <vector>
vtkStandardNewMacro(vtkGenerateDopplerSpectrum);
//
    --------------------------------------------------------------------------

vtkGenerateDopplerSpectrum::vtkGenerateDopplerSpectrum()
{       // Set the parameters
        SetParameterf0(4.6174e+06);
        SetParameterprf(4000);
        SetParameterNv(200);
        SetParameterTw(20e-3);
        SetParameterdtS(5e-3);
        SetVlim(-0.6,0.6);          // this is the maximum limit for the velocity
        SetVlim_Spec(-0.3,0.3);     // this is the default velocity limit i set
```

```
    SetVlim_Delta(-0.1,0.1);      // this is for by how much change to add or subtact the velocity scale
    Gain=-20;                     // default gain, can be increased or decreased
    LineTotal = 4;                // this is total baseline length (0-4)
    Line = LineTotal/2;           // this is the default setting for the baseline when start scaning
    // initialize the internal objects
    FftCompute = (vtkImageFourierFilter*) vtkImageFourierFilter::New();
    actoraxis = vtkSmartPointer<vtkContextActor>::New();
    axesVertical = vtkSmartPointer<vtkAxis>::New();
    axesHorizontal = vtkSmartPointer<vtkAxis>::New();

    offset = 0;
    nt = 0;
    OutputNs = 0;
    k = 0;
    c =1540;
    dt = 1/prf;
    Nw1 = floor(Tw/dt);
    std::cout<<"Nw1"<<Nw1<<endl;
    skip = floor(dtS/dt);
    vmax= 2*c*prf/(4*f0);
    std::cout<<"vmax"<<vmax<<endl;
    TimeBuffer = 16;
    Ns= (((TimeBuffer/dt)-Nw1-1)/skip);// this corresponds to 16 sec
    TimeSpectrum = 2;//2 seconds length, recommended for uterine artery also;
    Ns_Spectrum= (((TimeSpectrum/dt)-Nw1-1)/skip);
    std::cout<<"Ns"<<Ns<<"Ns_Spectrum"<<Ns_Spectrum<<endl;
    Delta= (((1/dt)-Nw1-1)/skip);// 1 sec time increment
    std::cout<<"Delta"<<Delta<<endl;

    YMin_Spec = (2*Nv-1)*(VlimMin_Spec + vmax)/(2*vmax); //minimum range to be extracted
    YMax_Spec= (2*Nv-1)*(VlimMax_Spec + vmax)/(2*vmax); //maximum range to be extracted
    Interval = ((YMax_Spec-YMin_Spec)*40)/Nv;
    std::cout<<"YMin_Spec"<<YMin_Spec<<"YMax_Spec"<<YMax_Spec<<endl<<"Interval"<<Interval<<endl;
    in = NULL;
    out = NULL;
    int SpectrumSize[3];
    SpectrumSize[0] = Ns;
    SpectrumSize[1] = Nv;
    SpectrumSize[2] = 1;
    SpectrumImage = AllocateVtkImageData(SpectrumSize, 1, VTK_DOUBLE); // creates Ns*Nv array of points and allocated by the spectrumimage

    int DoubleSpecImageSize[3]; // Double sized image
    DoubleSpecImageSize[0] = Ns;
```

```
        DoubleSpecImageSize[1] = 2*Nv;
        DoubleSpecImageSize[2] = 1;
        DoubleSizedSpectrumImage = AllocateVtkImageData(DoubleSpecImageSize, 1, VTK_DOUBLE);//this is
            vtkimagedata of the original spectrum with its copy
}
vtkGenerateDopplerSpectrum::~vtkGenerateDopplerSpectrum()
{
        Clear(); // clears everything that is initialized in clear()
}

//
    -------------------------------------------------------------------------------

//clear internal data
void vtkGenerateDopplerSpectrum::Clear()
{
        SpectrumImage = vtkSmartPointer<vtkImageData>();
        actoraxis = vtkSmartPointer<vtkContextActor>();
        axesVertical = vtkSmartPointer<vtkAxis>();
        axesHorizontal = vtkSmartPointer<vtkAxis>();
        DoubleSizedSpectrumImage = vtkSmartPointer<vtkImageData>();
        FftCompute->Delete();
        if (in) delete(in);
        in = NULL;
        if (out) delete(out);
        out = NULL;
}

void vtkGenerateDopplerSpectrum :: SetParameterf0(double f0_set)
{
        f0 = f0_set;
}
void vtkGenerateDopplerSpectrum :: SetParameterprf(double prf_set)
{
        prf = prf_set;
}
void vtkGenerateDopplerSpectrum :: SetParameterTw(double Tw_set)
{
        Tw = Tw_set;
}
void vtkGenerateDopplerSpectrum :: SetParameterdtS(double dtS_set)
{
        dtS = dtS_set;
}
```

```
void vtkGenerateDopplerSpectrum :: SetParameterNv(int Nv_set)
{
        Nv = Nv_set;
}

void vtkGenerateDopplerSpectrum :: SetVlim(double VlimMin_set,double VlimMax_set)//Myadd
{
        VlimMin = VlimMin_set;
        VlimMax = VlimMax_set;
}
void vtkGenerateDopplerSpectrum :: SetVlim_Spec(double VlimMin_set,double VlimMax_set)//Myadd
{
        VlimMin_Spec = VlimMin_set;
        VlimMax_Spec = VlimMax_set;
}
void vtkGenerateDopplerSpectrum :: SetVlim_Delta(double VlimMin_set,double VlimMax_set)//Myadd
{
        VlimMin_Delta = VlimMin_set;
        VlimMax_Delta = VlimMax_set;
}

void vtkGenerateDopplerSpectrum :: SetDopplerData(double* PointerToReal, double* PointerToImag,int NumberOfSamples)

{
        BufferSizeInput = (int) ceil(16/dt);
        BufferSizeOutput = (int) ceil(2*Nv*((16/dt)−Nw1−1)/skip);
        double magnitude =0;
        double val;
        data = (double*) SpectrumImage−>GetScalarPointer();
        dataDouble = (double*) DoubleSizedSpectrumImage−>GetScalarPointer();
        if (in) delete(in);
        in = new vtkImageComplex[Nv];
        if (out) delete(out);
        out = new vtkImageComplex[Nv];
        // ***************************************************************************

        while (Nw1−1+ nt < NumberOfSamples )// condition for calculating the columen
        {
                if ( NumberOfSamples < Nw1)
                        Nw1 = NumberOfSamples; //Nw1= 80 WINDOW LENGTH,floor(Tw/dt);
                for(int j = 0; j < Nw1; j++)
                {
                        in[j].Real = *(PointerToReal+j+nt);
```

```
            in[j].Imag = *(PointerToImag+j+nt);
            // ************************** Buffer for raw data ******************************
            Input.push_back(in[j]);
            // ****************** remove the first elements if they exceed the buffer size
            if (Input.size() > BufferSizeInput)
            {
                //number of elements to pop
                int ellNo = Input.size()-BufferSizeInput;
                //remove the elemnts
                Input.erase (Input.begin(), Input.begin()+ellNo);
            }
            // ****************************************************************************
        }
        for(int j = Nw1; j < Nv; j++)
        {
            in[j].Real = 0; // zero pad of in until length of Nv since in is < Nv, fft rule
            in[j].Imag = 0; // zero pad of in until length of Nv since in is < Nv
        }

        // ******************** FFT compute ***********************************************

        FftCompute->ExecuteFft(in, out, Nv);// fft is columen by columen.

        for(int i = 0; i< Nv; i++)
        {
            magnitude = out[i].Real*out[i].Real + out[i].Imag*out[i].Imag;
            magnitude = sqrt(magnitude);// taking the absolute
            magnitude = magnitude*magnitude;// spectrum has to be calculated for all Nv points
            data [k + i*Ns] = magnitude;// fft output is on data, that fills the spectrum image
        }
        nt = nt + skip;
        // ********* Temporal avaraging of order 3 ************************

        int filterL = 5;
        for (int i=0; i<Nv; i++)
        {
            double x =0;
            for (int j=0; j<filterL; j++)
            {
                if (j <= k)
                    x = x + data[(-j + k + i*Ns)];
            }
            data[(k+i*Ns)]= x/filterL;
            data[(k+i*Ns)] = 20*log10(data[(k+i*Ns)]);
```

```
        }

        // ******** dataDouble is data for the double size spectrum which is the copy of the single side spectrum, so i have to keep the data of single side spectrum

        for (int i= 0; i<2*Nv;i++)
        {
            if(i<Nv)
                dataDouble[(k+i*Ns)]= data[(k+ i*Ns)];
            else
                dataDouble[(k+i*Ns)]= data[(k+(i-Nv)*Ns)];
            // ***************      Buffer for image ************************************
            Output.push_back(dataDouble[k + i*Ns]);// it is a vector
            if (Output.size() > BufferSizeOutput)
            {
                // number of elements to pop
                int ellNoO = Output.size()-BufferSizeOutput;

                // remove the elemnts
                Output.erase (Output.begin(), Output.begin()+ellNoO);
            }
        }
        k = k+1;
        if (k == Ns_Spectrum)
        {
            k=0;
        }
    }
    nt = 0; // preparing for the next no of samples
    offset = offset + skip; // is used for update checking
    if (offset>7000)// offset 7000 is approximate length of the data
        offset =0;
}


void vtkGenerateDopplerSpectrum :: PlayFrames()
{
    it = Output.begin();
    OutputNs= (Output.size()/(2*Nv));
    for (int k=0;k<OutputNs;k++)// computing the columens until the output size
    {
        for (int i=0;i<2*Nv;i++)
        {
            dataDouble[k+i*Ns]= *it ;// assigns the value from the buffer
```

```
                        it= it+1;
                }
        }
}
void vtkGenerateDopplerSpectrum :: clearBuffer()
{
        it  = Output.begin();
        OutputNs= (Output.size()/(2*Nv));
        for (int k=0;k<OutputNs;k++)// computing the columens until the output size
        {
                for (int i=0;i<2*Nv;i++)
                {
                        dataDouble[k+i*Ns]= -100 ;// assigns the datadouble a very small value so that it is too black
                }
        }
        Output.clear();// this clear functions clears the previous buffer
        // intializations after clearing the buffer
        k= 0;
        nt=0;
        offset = 0;
        OutputNs = 0;
}
void vtkGenerateDopplerSpectrum :: GainUp()
{
        if (Gain < 20)
                Gain = Gain + 30;
}
void vtkGenerateDopplerSpectrum :: GainDown()
{
        if (Gain > -70)
                Gain = Gain - 5;
}
void vtkGenerateDopplerSpectrum :: TimeScaleUp()
{
        if(Ns_Spectrum+Delta <= Ns)
                Ns_Spectrum= Ns_Spectrum +Delta;
}
void vtkGenerateDopplerSpectrum :: TimeScaleDown()
{
        if(Ns_Spectrum-Delta >= Delta)
                Ns_Spectrum = Ns_Spectrum-Delta;
}
void vtkGenerateDopplerSpectrum :: VelocityScaleUp()
```

```
{

        if (VlimMin_Spec + VlimMin_Delta >= VlimMin)
                VlimMin_Spec = VlimMin_Spec + (2*Line/LineTotal)*VlimMin_Delta;

        if (VlimMax_Spec + VlimMax_Delta <= VlimMax )
                VlimMax_Spec = VlimMax_Spec + (2*(1-(Line/LineTotal)))*VlimMax_Delta;
}
void vtkGenerateDopplerSpectrum :: VelocityScaleDown()
{
        if (VlimMin_Spec-VlimMin_Delta <= (2*Line/LineTotal)*VlimMin_Delta)
                VlimMin_Spec = VlimMin_Spec-(2*Line/LineTotal)*VlimMin_Delta;

        if (VlimMax_Spec-VlimMax_Delta >= (2*(1-(Line/LineTotal)))*VlimMax_Delta)
                VlimMax_Spec = VlimMax_Spec - (2*(1-(Line/LineTotal)))*VlimMax_Delta;
}
void vtkGenerateDopplerSpectrum :: BaselineDown()//Base Line goes from 2(default) to 0
{
        double VRange = VlimMax_Spec-VlimMin_Spec;// the range between max and min
        if  (Line > 0)
        {
                Line = Line-1;
                VlimMin_Spec = VlimMin_Spec+ (1/LineTotal)*VRange ;
                VlimMax_Spec = VlimMax_Spec+ (1/LineTotal)*VRange;
                std::cout<<"LineDown"<<Line<<endl;
        }
}
void vtkGenerateDopplerSpectrum :: BaselineUp()// Base line goes until 4
{
        double VRange = VlimMax_Spec-VlimMin_Spec;
        if  (Line < LineTotal)  //BaseLineTotal in this case is  4,  in general it  can be any number
        {
                Line = Line + 1;
                VlimMin_Spec = VlimMin_Spec- (1/LineTotal)*VRange ;
                VlimMax_Spec = VlimMax_Spec- (1/LineTotal)*VRange;
                std::cout<<"LineUp"<<Line<<endl;
        }
}

void vtkGenerateDopplerSpectrum :: Axis()
{
        for  (int  n=0; n<Nv; n+= Interval)
        {
                int  t= floor((double)((Nv-1)/Interval))* Interval ;
```

```
            v[n]= floor((100*(VlimMax_Spec− n*((VlimMax_Spec−VlimMin_Spec)/(t)))));
            positionsY−>InsertNextValue(v[n]);
            std::ostringstream buff;
            buff<<v[n];
            labelsY−>InsertNextValue(buff.str());//displays axiswith the whole v[n]
        }
        axesVertical−>SetPosition( vtkAxis::RIGHT);
        actoraxis−>GetScene()−>AddItem(axesVertical);
        axesVertical−>SetRange(100*VlimMin_Spec, 100*VlimMax_Spec);
        axesVertical−>SetTickPositions(positionsY.GetPointer());
        axesVertical−>SetTickLabels(labelsY.GetPointer());
        axesVertical−>SetPoint1(vtkVector2f(1* 69 + 845, 138)); // this is for secreen resolution of 1366 X 768
        axesVertical−>SetPoint2(vtkVector2f(1* 69 + 845, 605));// it sets the initial and final points for the vertical
            axis based on the screen coordinate
        axesVertical−>Update();// displays the tick points

        // ************************ Axis horizontal **********************************************

        TickNumber = 8;
        Increment = (int) floor((double)(Ns_Spectrum/TickNumber));
        std::cout<<"Increment"<<Increment<<endl;
        int m=0;
        for (; m<=Ns_Spectrum; m+= Increment)
        {
            tS[m]= m*(skip)*dt;//calcualtes the time values until the needed spectrum length of needed interval
            std::cout<<"tS[m]"<<tS[m]<<endl;
            positionsX−>InsertNextValue(tS[m]);
            std::ostringstream buff;
            buff<<−(floor((double)(Ns_Spectrum/Increment))*Increment)*(skip)*dt+tS[m];
            labelsX−>InsertNextValue(buff.str());
        }
        axesHorizontal−>SetPosition( vtkAxis::BOTTOM);
        axesHorizontal−>SetPoint1(vtkVector2f(1 * 69 + 380, 138)); // this is // this is for secreen resolution of
            1366 X 768
        axesHorizontal−>SetPoint2(vtkVector2f(1 * 69 + 845, 138)); // it sets the initial and final points for the
            horizontal axis based on the screen coordinate
        actoraxis−>GetScene()−>AddItem(axesHorizontal);
        axesHorizontal−>SetRange(0,tS[m−Increment]);
        axesHorizontal−>SetTickPositions(positionsX.GetPointer());
        axesHorizontal−>SetTickLabels(labelsX.GetPointer());
        axesHorizontal−>Update();//it assigngs the labels
}

void vtkGenerateDopplerSpectrum :: clearall()
```

```
{    positionsX->Reset();
labelsX->Reset();
positionsY->Reset();
labelsY->Reset();
}

void vtkGenerateDopplerSpectrum :: TimeAxisUpdate()
{
        TickNumber = 8;
        Increment = (int) floor((double)(Ns_Spectrum/TickNumber));
        std::cout<<"Increment"<<Increment<<endl;
        int m=0;
        for (; m<=Ns_Spectrum; m+= Increment)
        {
                tS[m]= m*(skip)*dt;
                std::cout<<"tS[m]"<<tS[m]<<endl;
                positionsX->InsertNextValue(tS[m]);
                std::ostringstream buff;
                buff<<-(floor((double)(Ns_Spectrum/Increment))*Increment)*(skip)*dt+tS[m];
                labelsX->InsertNextValue(buff.str());
        }
        axesHorizontal->SetRange(0,tS[m-Increment]);
        axesHorizontal->SetTickPositions(positionsX.GetPointer());
        axesHorizontal->SetTickLabels(labelsX.GetPointer());
        axesHorizontal->Update();//it assigngs the labels
}
void vtkGenerateDopplerSpectrum :: VelocityAxisUpdate()
{
        YMin_Spec = (2*Nv-1)*(VlimMin_Spec + vmax)/(2*vmax); //minimum range to be extracted
        YMax_Spec= (2*Nv-1)*(VlimMax_Spec + vmax)/(2*vmax); //maximum range to be extracted
        Interval = ((YMax_Spec-YMin_Spec)*100)/Nv;
        for (int n=0; n<Nv; n+= Interval)
        {
                int t= floor((double)((Nv-1)/Interval))* Interval ;
                v[n]= ((100*(VlimMax_Spec- n*((VlimMax_Spec-VlimMin_Spec)/(t)))));
                positionsY->InsertNextValue(v[n]);
                std::ostringstream buff;
                buff<<v[n];
                if (((n/Interval)%2) == 0 || n== t ) // if even
                {
                        labelsY->InsertNextValue(buff.str());
                }
                else
                        labelsY->InsertNextValue("");
```

```
        }
        axesVertical->SetRange(100*VlimMin_Spec, 100*VlimMax_Spec);// makes it to increase proportionally
        axesVertical->SetTickPositions(positionsY.GetPointer());
        axesVertical->SetTickLabels(labelsY.GetPointer());
        axesVertical->Update();// updates the velocity values
}
```