**Partial Discharge Classification using AI Techniques**

Final Report for CS39440 Major Project

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**Acknowledgements**

I am grateful to…

I’d like to thank…

**Abstract**

The aim for this project is to create an Android App, which can classify data from a test instrument, which detects Partial discharge in power distribution networks. The detection instrument will be provided by EA Technology (the industry partner for this project).  Partial discharge signatures are used in order to detect the deterioration of the insulation properties relating to cabling, switching, transformer or other components of an electrical network. Partial discharge has the effect of causing a progressive deterioration of insulating materials, which will eventually lead to complete electrical breakdown. The effects of partial discharge within high voltage cables and equipment can be very serious, ultimately leading to complete failure and very high cost of replacement. The early detection of insulation breakdown in networks therefore offers a great number of advantages.

The App proposed in this project is designed for engineers to use for high voltage asset (cabling and infrastructure network) management; the instrument will provide data to the App in order to determine if an asset (cable, transformer, switching network, etc.) is deteriorating by examining the noise signature. If time permits, additional functionality will be added such that raw audio signal can be sent to the Android device, and processed in real-time, otherwise it will use saved data. AI techniques will be used to develop a means of processing and classifying the demodulated ultrasonic (audio) waveforms.

The conclusion is the App will classify different noise signatures and be able to discriminate between Partial Discharge, background noise or other interference (i.e. transformer noise).

**Contents**

1. Background, Analysis & Process 6

1.1.1. Partial Discharge Basics 6

1.1.2. Ways of detecting Partial discharge 7

1.1.3. Classification problem within partial discharge 7

1.1.4. Android Device capabilities and limitations 8

1.1.5. Features and Artificial Intelligence Classifiers options 8

1.2. Analysis 10

1.3. Process 12

2. Design 13

2.1. Overall Architecture 13

2.2. Detailed Design 14

2.2.1. Structural View 15

2.2.2. Implementation View 15

2.2.3. Behavioural View 15

2.3. User Interface Design 15

2.4. Other Relevant Sections 18

3. Implementation 19

4. Testing 21

4.1. Overall Approach to Testing 21

4.2. Automated Testing 21

4.2.1. Unit Tests 21

4.2.2. User Interface Testing 21

4.2.3. Stress Testing 21

4.3. Integration Testing 21

4.4. User Testing 21

5. Critical Evaluation 22

6. Appendices 23

A. Third-Party Code and Libraries 23

6.1. Project Specification 23

6.1.1. Android App 23

6.2. Graph View 23

6.3. jAudio 2.0 24

6.4. libsndfile 24

6.5. Testing Tables 24

6.5.1. Load the application. 24

6.5.2. Main Menu Screen 24

6.5.3. Record screen 25

6.5.4. Save As Screens 26

6.5.5. File Chooser Screen 26

6.5.6. View Data screen 27

B. Code Samples 28

7. Annotated Bibliography 29

# Background, Analysis & Process

Partial Discharge is one of the leading causes of transformers in a power system. A transformer converts between different voltage levels, and is one of the most critical aspects of the system. While many transformers today are in service and are now past there designed life cycle, it has a strong economic impact if they can continue to run safely over many years. This is due to the fact that transformers are so expensive, and the repairs can take a very long time in relation to not supplying power to a section. This brings about a very interested party to be able to detect the condition of an asset and to plan its life in service.

A study about transformer failures carried out on transformers rated at 25 MVA or above for the period 1997 till 2001 was reported in [11]. The study shows that insulation failure is the leading cause of transformer failure.

Several methods can be used for monitoring of changes in the electrical asset; a nearly complete list of available methods is available in [12]. Conversely I will be focusing on using the ultrasonic data released by PD.

This project will be in conjunction with a company called EA Technology. EA Technology works in the electrical industry offering services and instruments to help manage the state of the High voltage/ Medium voltage assets. I worked there for my year in industry and have a job there after University.

My reading for this project has involved heavily around Partial discharge and the many forms and characteristics if can take, Cigre is a paper which has looked at the many forms of PD via an oscilloscope [14]. While this is not exactly what I will be using it provides a better understanding of how each sub groups of PD happen and their effects on electrical assets.

For the AI approach to classify the acoustic data, I looked in to Artificial Neural Networks (ANN), as these are really good classifiers with a very low computational overhead. Also I found I statistical approach to understanding the wave form [19] from this I would be able to build either a rule base classifier or depending on my findings a decision tree could be used to classify what type of partial discharge is occurring.

My motivation for this project came from my industrial year at EA Technology who are the industrial partners in this project. While there I was able to learn a lot regarding partial discharge and the effects it can have, and this is where the interest came from. I was also offered a job with EA Technology on completion of my degree scheme.

I have always had an interest in electrical and electronic engineering hold a HND in this area, and being able to further my education and research in both Artificial intelligence and electrical engineering is a big plus into doing this project.

### Partial Discharge Basics

Definition -- “A Partial Discharge is an electrical discharge or spark that bridges a small portion of the insulation between two conducting electrodes. Partial Discharge activity can occur at any point in the insulation system, where the electric field strength exceeds the breakdown strength of that portion of the insulating material”[1]

Partial discharge is a sign that the electrical asset has begun to ware and may fail. This is why it is very important to be able to detect and monitor the condition of electrical assets to better understand the ware and assess if an asset will need replacing.

PD has the deteriorating effect and over time it reduces the lifetime of an insulation system. During Partial Discharge on the surface or inside an electrical insulation, high-energy electrons or ions cause deterioration of the insulation material. This bombardment may result in chemical decomposition in the insulation material, which could finally lead to complete breakdown of the insulation.[18]

### Ways of detecting Partial discharge

**Electrical Detection**

Two types of sensors are usually used for PD measurement in transformers: capacitive and inductive coupling sensors.

Capacitive sensors work by measuring changes in an electrical property called capacitance. Capacitance describes how two conductive objects with a space between them respond to a voltage difference applied to them.

Inductive sensors operating principle is based on a coil and oscillator that creates an electromagnetic field in the close surroundings of the sensing surface. The inductive sensors are common measuring devices for rapidly varying currents.[16]

**Acoustic detection**

The acoustic wave, audible or not, is due to the expansion of gases near the discharge channel, which propagates as a pressure wave. The main frequency used for acoustic detection is between 10 kHz to 1000 kHz and usually ultra-sonic PD detectors are tuned at 40 kHz.

An advantage of acoustic detection is the ability to use multiple sensors in different positions on the transformer tank in order to localize the PD source, as well as being immune against electrical interference.

**Chemical detection**

Detection of chemical byproducts produced by PD activity is one of the simplest methods for PD detection. Partial discharges can be detected chemically because the current streamer across the void can break down the surrounding materials into different chemical components.

The two primary chemical tests employed by power companies today are dissolved gas analysis (DGA) and high performance liquid chromatography (HPLC).[17]

The main advantage of this method is that it is very well established, immune against noises and relatively easy to measure. However it cannot say much about the type of defect, location and intensity of PD, which is the main disadvantage for this method.

### Classification problem within partial discharge

Partial discharge can be split in to two main forms, internal and external. See Figure 1 -- Partial discharge form.

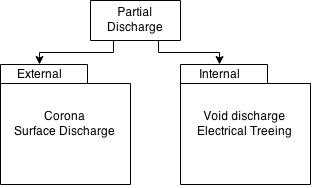


Figure -- Partial discharge form

These two sub groups of partial discharge, each have their own classifications depending on the findings, such as void discharge etc. I will mainly focus on classifying what is PD and what isn’t, however if time permitted I will try and see if I can distinguish what type of PD it is.

### Android Device capabilities and limitations

Android is the operating system that powers more than one billion smartphones and tablets. It is the choice of the customer EA Technology, they want it deployed on an Android device so that it can be mobile and on a robust operating system.

Another point to make for Android is that devices running the OS are available worldwide and via the Google Play store the app can be distributed to all our customers.

Android has been out since 2008, on version 1.0 and by 2009 it was on 1.5 and had the official name cupcake. There have been many iterations of Android in the last 7 years and currently we are on version 5.0 called Lollipop. When making an App you can make it backwards compatible and with some convocation with EA Technology we decided on making all devices running 4.4+ onwards available to download the app.

The minimum specifications for running Android 4.4 is only 512 RAM, see [22] for the full list of hardware requirements. I will be designing the app on a Samsung S4 the spec is [20]: -

* Screen - 5.0 inches
* Processor - Quad-core 1.6 GHz Cortex-A15 & quad-core 1.2 GHz Cortex-A7
* Sensors - Accelerometer, gyro, proximity, compass, barometer, temperature, humidity, gesture
* Memory 2 GB RAM, 8GB Internal storage
* Battery - Li-Ion 2600 mAh battery

### Features and Artificial Intelligence Classifiers options

With all AI techniques to classify it can all depend on what features you have, with PD there can be three types of data criteria: -

* Phased-Resolved data
* Time-Resolved data
* Data without Phase/Time information

**Phase-Resolved data** - has been captured with relation to the ac test voltage. The test voltage is a constant and the phase angle is split up to plot any PD activity within the divided phase angle. PD is active as the power builds, so we would expect to see more activity in certain places on the waveform.

**Time-Resolved data** - displays the true shapes of the individual PD pulses. The test voltage is treated as a constant like Phase-Resolved data. This data pattern has attractive advantages, since there exists some direct relationship between the physics of the defect and the shape of the PD signal.

**Data without Phase/Time information** – a typical PD pulse where time and phase data are not recorded.

**Statistical methods for feature extraction**

Each wav audio file can be represented as an array of values between 1 and -1. With this array many statistical functions can be applied at gain more information on the audio file. For example: - Where N is the number of values

Average of all the values, this can show a "measure of central tendency", meaning any statistic that in some sense represents a typical value from a data set.

The variance measures how far a set of numbers is spread out. A variance of zero indicates that all the values are identical.

Skewness is a measure of how symmetric the data is for if its tilted to one end of the array. This can show the noise of a audio file as PD can be irregular and noise if a constant.

These are a small sample of summary statistical formulas that together can make a feature vector to compare new data against.

**Signal processing tools**

Some signal processor have been used to extract features from the data, an example of these processes are, Fourier transform, wavelet transforms and Haar transforms.

A fast Fourier transform on the audio signal can show the relation between the test ac voltage and the PD activity. A limit to Fourier transforms is that it looks at the frequency and not time domain to over come this we can use wavelet transforms, while this area is still developing there is still much to learn.

**Artificial Intelligent Classifiers**

**Distance/Decision function classifiers**

These classifiers works on the data from other already classified and uses the information as a reference. The distance each data feature is from the features from the already classified features and the distance they are apart can be the decision of the classification and new data.

Examples of these classifiers are Minimum Distance, Manhattan Distance, and Nearest Neighbor.

Minimum distance classifier is the distance defined as an index of similarity so that the minimum distance is identical to the maximum similarity.

Manhattan Distance classifier, if an attribute is numeric, then the local distance function can be defined as the absolute difference of the values. Therefore the global distance is computed as the sum of these local distances, and then we refer to it as the Manhattan distance. Weighted sums and weighted averages are also possible.

Nearest Neighbour classifier, works by identifying the nearest neighbours to a query example and using those neighbours to determine the class of the query. For example the classifier assigns an instance to the class most heavily represented among it neighbours. This is based on the idea that the closer it is to another instance the more likely it is to part of the same class.

**Statistical Classifiers**

This approach is to find statistical features to separate the data and to classify the results. Statistical learning theory models this as a function estimation problem.

There are a couple of choices to use a classifier for statistical data, for example Bayes Classifier and support vector machines.

Bayes Classifier is to predict the values of features for members of that class. Examples are grouped in classes because they have common values for the features.

Support vector machines, is to find the optimal hyper plane for linear separable data. It can extend to patterns that are not linearly separable by transformations of original data.

**Neural Networks**

Artificial Neural networks have been very successful in pattern recognition and classification problems. The basic advantage of ANN over other classifiers is its ability to learn from examples. Knowledge in the training set is extracted and stored in the connection weights and neuron biases during the learning phase [23]. However once an ANN has been taught it cannot learn new instances and thus having to re teach a new ANN.

## Analysis

Taking into account the problem and what you learned from the background work, what was your analysis of the problem?

The problem is to use the saved or recorded WAV audio files, to classify if the asset the instrument have measured is showing signs of PD. There are many options to chose from for which AI technique to use, weighing up the pro and cons of each and the fact from my meeting with EA Technology the chance of having new data that will need to be classified further than just a binary classification (is or isn’t partial discharge).

To do this the feature extraction I feel is the key, from the background research done and talking with my supervisor we felt that a statistical feature extraction would be provide the best outcome. Maybe not at the first but having the ability to build upon the system and add complexity to be able to better classify the data. For example if by just checking the features we extract we could get a 80% correct classifier but then by adding on some complexity such as a fuzzy logic classifier we could make a 90+% correct classifier.

From my research there are many forms of PD and as many forms of noise that can effect the results within ultrasonic detection. Such as corona has a different thumbprint to surface discharge. This is shown in the Cigre paper and from other papers the acoustic thumbprint also differs.

Noise can play a major factor in capturing acoustic data, such as wind or other sources of sound ultrasonic or not in our audible bandwidth.

After a meeting with the domain experts at EA Technology they confirmed that they could hear a difference is the play back of the recorded difference and pointed out what they were listening out for.

In this meeting they went through how the data was captured and how they processed the raw data. The instrument uses a band pass filter to a 40KHz heterodyne process to convert the raw audio to a digital signal to save as a WAV audio file. I can use this information to process the WAV file to convert it back to the original raw data this may provide more information than the compressed data saved.

From the background reading I knew the main aspect of the work will be analysing the WAV file and being able to pick out relevant features. To do this I did some spike work into how to read in the audio file using Java. I found just normal playback was very simple in Java, however when trying to load a WAV file and convert the binary data to a double array within the Android environment was very tricky.

After the meeting with EA Technology they use a library called libsndfile, this is a C/C++ library that reads audio files of which WAV is one of the formats. As the WAV files can many different forms from sample rate to how many channels were recorded (Up to 4), finding a library that can manage this will be very beneficial as it will be fully tried and tested and have a community behind it for debugging and help on any problems.

I had to do some more spike work into getting native code running within the Android environment, there were some very good tutorials and I was able to make a small sample app, passing in string and integers from the Java classes to C files, doing the basics that I will need for the project. From this spike work using this libsndfile library is possible and makes reading the audio files much more efficient, tried and tested.

After the meeting with EA Technology I took some time trying some statistical analysis on the audio files against the classification each has to try and separate the partial discharge from the non-partial discharge. I found Skewness might be the major factor as this shows how noisy the data is.

I feel a Neural network will not be right for the job as it is more a black box and wont be beneficial later on in the project as to add a new classification you would need a new neural network to be taught. Using a Bayes network also is not right as to make a true statistical model of each electrical asset with the information needed would not be available and thus only be able to half implement the Bayes system.

An off the cuff idea was to add an image recognition approach to the plot that the audio files creates and finding similarities. However the processing power needed for this would be very high, and not viable across the Android mobile range.

The customer EA Technology and I discussed the goals of the project and what would both want to see as the final outcome. EA Technology were very interested in the feature extraction and classifier a lot more so than the Android device, and offered resources so that I was not limited to the power of the device such as a server to process the features on.

In 6.1 Project Specification there are the aspects of the project that need to be delivered.

This section is what I will be comparing and evaluating myself self come the end of the project.

The main aspects I can see from the specification are:

* Feature extraction
* A classifier to classify new data
  + Split the data provided into training/testing sets, so we can test the classifier
* This deployed on an android device running 4.4+
  + The app will record and save the audio
  + Load and classify the data
  + Classify real-time data
* Unit test and test tables to show the app fully tested

From this specification provided I was able to make it clear that the time left I would not be able to have all these goals achieved, and while I understood that the main area they are interested in is the classifier, I made this my priority as well. I was able to say that out of the main points of the specification the real-time classification will be the hardest and would be best as a sub goal only if time permits.

## Process

EA Technology use waterfall model to keep track of and help deliver the projects they use. With this knowledge I created a Gantt chart (SEE APPENDIX) to help them and myself plan what will be needed and when certain data or information will need to be ready by.

While having all the dates set for EA Technology will help them prepare the documents and data needed for myself to do the project. It also keeps myself on track knowing what needs to be done by when, for the programming aspect I want to use a template from extreme program (XP). XP offers a lot on how to deliver a project on time and while certain practices are not relevant to me like pair programming others is like iterative planning and constant testing.

Waterfall model is a sequential template where from the requirements you make the design etc. I can use this for my timings in the project, such as for my background reading, on to then needing the data to find what features to extract. Having this as an overall plan is generally what I am used to and fell most confortable with.

For the overall picture some criteria will have to be met/understood before I could move on for example there is no point in me having the data is I had no plan or idea of how to pick out the features. However once I am starting to program the Android app I know I estimate it will take a few weeks but being able to have iterations to show the customer and receive feedback will be invaluable.

This is where XP will come in using its iterative approach and constant testing practices, and allows for an ever-changing requirement specification.

In XP it uses stories created by the customer with the developers, to make use of this I am working off the points in the specification, for example:

* Recording, the engineer will need to be able to record and save the audio data either via the built in mic or plugging in a mic via the headphone jack.

Using this as a story I will be able to plan iterations of the software I am going to create, and get feedback at each stage. The main advantage for this is getting the user interface right for the end users, as my knowledge of the situations is limited having a feedback loop will be needed. I believe a hybrid of the two models will be a success.

# Design

You should concentrate on the more important aspects of the design. It is essential that an overview is presented before going into detail. As well as describing the design adopted it must also explain what other designs were considered and why they were rejected.

The design should describe what you expected to do, and might also explain areas that you had to revise after some investigation.

**Typically, for an object-oriented design, the discussion will focus on the choice of objects and classes and the allocation of methods to classes**.

The use made of reusable components should be described and their source referenced. **Particularly important decisions concerning data structures usually affect the architecture of a system and so should be described here**.

How much material you include on detailed design and implementation will depend very much on the nature of the project. It should not be padded out. Think about the significant aspects of your system.

## Overall Architecture

Android is the operating system the application will be built in. The main language used for Android apps is Java. Android is also capable if supports native C/C++ code compiling it for the operating system and using it as an external library.

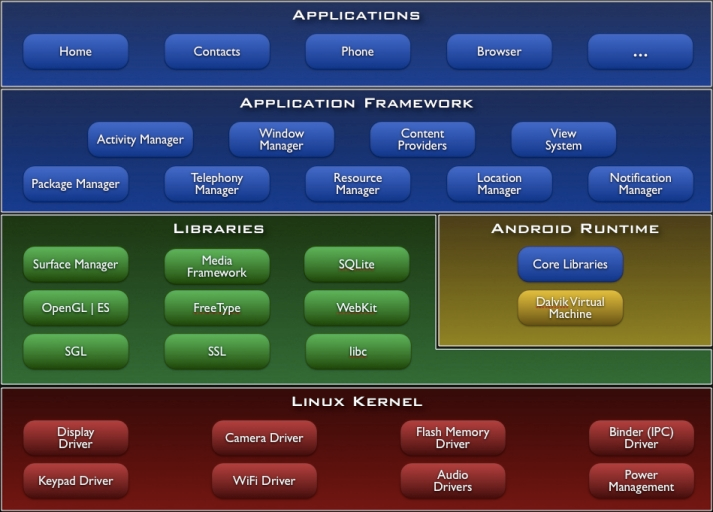


Figure -- from http://theworkshop.screeneros.com/android-source-code-under-miscroscope/ is showing the full architecture of the Android operating system

Figure 2 is showing the overview of the Android operating system, the application I will create will be in the Applications section. The app will be using a lot of the Application framework and my own C library for the reading of WAV files. This library is compiled using the NDK and saved as part of the app but is loaded as a library from the Libraries section.

Google the creators of Android have created their own IDE call Android Studio, this is where I will be creating, building and debugging the app. Android Studio does not come with the native compiler and will be downloaded and deployed within the structure of the IDE so that it will be able to compile all code at once. There were other choices for IDE such as Eclipse or (ASK MADGE), I didn’t decide to use this IDE’s as I have had experience using Android Studio and knew how to quickly and efficiently create an app.

## Detailed Design

Overview Description

User View

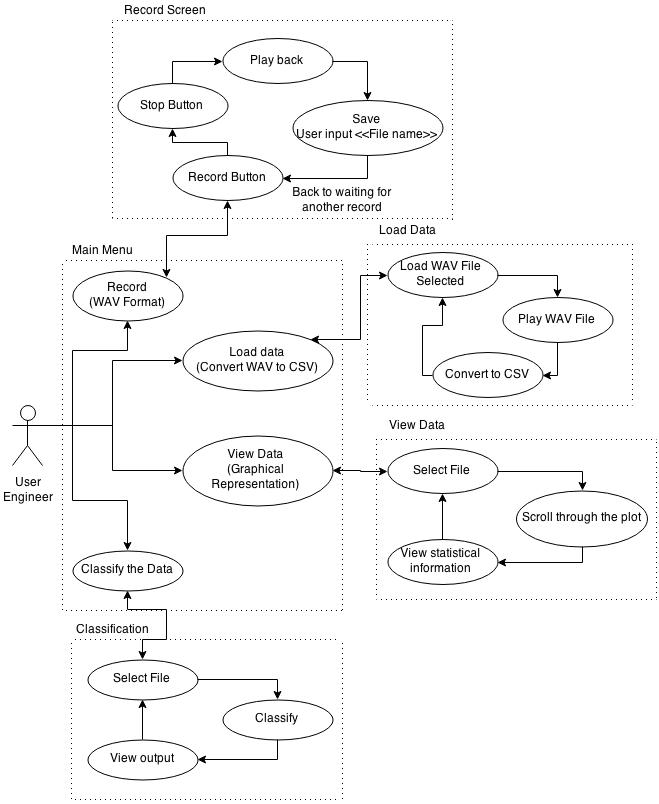
Use Case Diagram 

Figure -- Use case displaying how an engineer will be using the App

The use case above (Figure 3) is showing how an engineer will be using the App. The app will have 4 main sections, Record, Load/convert, view the data and classify, while the main aspect of the app is to classify the audio data coming in the other sections will be needed.

If the user wants to record he/she need to make sure the EA Instrument is plugged in and ready, once the recording has started and the user clicks stop they will need to input the file name. The location of the file is automatic as the new regulations in android means an app can only have access to its own folder. Once the file has been saved, the app will be waiting for the next record.

Load/convert the data, I have kept this separate as to show the different functions and for testing. This screen will search for the files in the app folder, allow the user to scroll through them, hear the recorded audio to make sure that it is the correct one and convert to a CSV format. The conversion will move and create the files to another location with in a new folder.

View Data, allows the user to view the converted data is a graphical format and see the statistical data created for each audio file. If the audio file has already been classified this will also be shown here.

Classify data will have the same select file system as the previous two screens and be able to process the data and return with an confirmation of it the audio file is showing signs of partial discharge or not.

### Structural View

Class Diagram

Object Diagram

### Implementation View

Component Diagram

### Behavioural View

Sequence Diagram

Activity Diagram

State chart

## User Interface Design

Screen shots

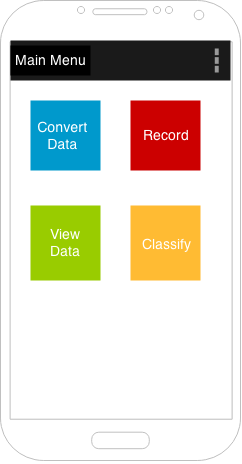


Figure - Mock screen shot of the main menu

Figure 4 showing the mock main menu of the app, had to be clean and simple as the end user will be an engineer will be in the field. The engineer will be in full health and safety gear one of which will be gloves this is the reasoning for the big clear colour coded buttons.

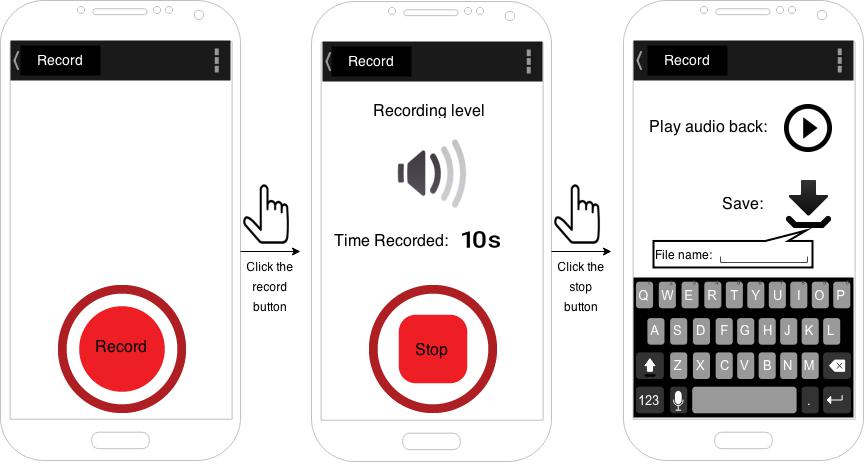


Figure - Mock screen of the recording process

Figure 5 shows the flow of screens to record the audio. The record button is as big as it can be on the android screen. By having the speaker once the user has clicked record it allows a feedback to the user of the volume level of the recording.

After some iteration when implementing this screen and feedback from the customer, the speaker got changed to a real-time graph showing the changing in the recording volume input. Once finished the 10-second recording it will not automatically take the user to save the file but rather allow the user to decide if they would like to save it.

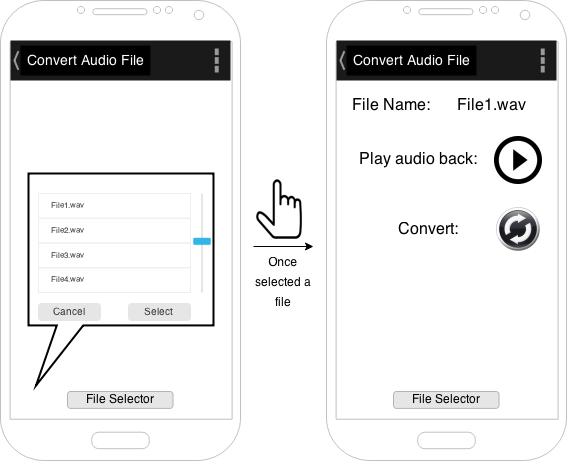


Figure – Mock Convert Audio file to data Screen

Figure 6 is showing how the user can convert the data from the audio WAV format to a CSV file. The file selector screen will be the same across all screens and will provide the user with the list of files save on the device.

Once the user has selected the file it takes them to the convert screen that allows the user to playback the audio file or convert it.

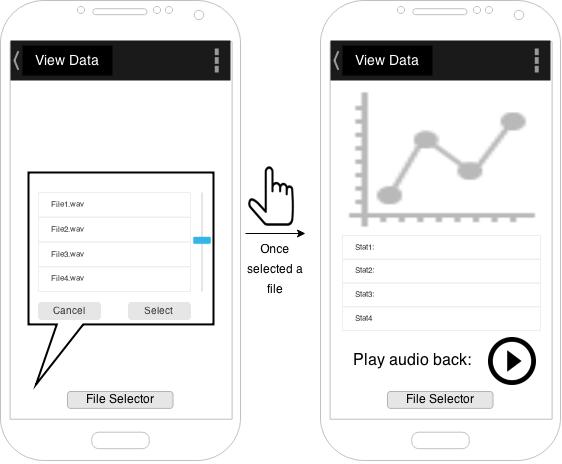


Figure - View data screen

Figure 7 is how to show the data once converted. The select file window will only show the converted data

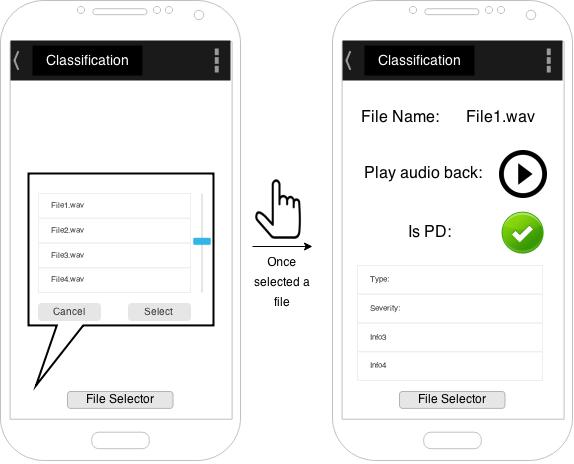


Figure - Classification screen

## Other Relevant Sections

Data storing

Data structures

# Implementation

The implementation should look at any issues you encountered as you tried to implement your design.

Spike work

App in general to know the differences in the new API

However I still worked on android 4.4 onwards so I didn’t need to worry too much

New rules on reading directories, not to hard to understand and made a new class to read/write files in java

Feature extraction

Started with using scilab to convert the wav file to a csv file

Did this so I could try and find my own features to extract

I found this very difficult as at this point I only had one wav file to use and was not sure if what I was finding was of any relevance.

I thought I had found a very good feature as the one wav file had very clear spikes so I worked on finding the spike and features from this.

Finally getting data from (Late March) EA Technology now having 20 files to classify and to pick features.

The spike work I had done on the previous file had to relevance to the new data

Some work into reading a wav file in java on android, failed and after a meeting with EA they use a C library that meant I had to add C support into the android app

During the work, you might have found that elements of your design were unnecessary or overly complex;

UI changed massively and I incorporated many of the functions into one,

So left with record and classify the data.

Perhaps third party libraries were available that simplified some of the functions that you intended to implement.

The C lib for loading a wav files

Used a open source jAudio 2.0 to extract the features as I was running out of time and the previous features was not very helpful.

If things were easier in some areas, then how did you adapt your project to take account of your findings?

With the restrictions on the read write accessibility on Android now loading the file in File Chooser function was a lot easier than first thought.

Using an automated feature extractor in the end to gain the features to classify the data was very easy it took a long time finding a program that worked and came with appropriate amount of features to be able to select what I want to find.

It came with all the source code and trying to integrate the java code into the android app is very difficult

It is more likely that things were more complex than you first thought. In particular, were there any problems or difficulties that you found during implementation that you had to address? Did such problems simply delay you or were they more significant?

I never would of guessed that having a CDA signed between a company and a University would of taken so long.

Not knowing that I needed to add native C support to the android app was not part of the plan and while was a small bump in the road it delayed some of plan however, the delay was nothing in the long run and I ended up with new added functionality with the C lib able to load any wav format and using an external Lib it means it is fully tested with a large community resource for any issues I may have using it (With examples).

You can conclude this section by reviewing the end of the implementation stage against the planned requirements.

Recording works

I know hoe to classify each audio file

Not enough time to complete the coding of it with fully understanding of the calculus behind each feature

Upon further investigation I found that I did not need to convert the audio file and save it in a different format, and if this is the case I could also classify the data on loading it.

After this I will only need two options from the main menu screen, ‘Record‘ and ‘Classify’. This will cut half the program as I no long have to convert, save and read CSV files, it also makes the load time a lot quicker as being able to read an wav file which is binary data rather than a CSV file, which is read as string then converted to a double.

# Testing

Detailed descriptions of every test case are definitely not what is required here. What is important is to show that you adopted a sensible strategy that was, in principle, capable of testing the system adequately even if you did not have the time to test the system fully.

Have you tested your system on ’real users’? For example, if your system is supposed to solve a problem for a business, then it would be appropriate to present your approach to involve the users in the testing process and to record the results that you obtained. Depending on the level of detail, it is likely that you would put any detailed results in an appendix.

The following sections indicate some areas you might include. Other sections may be more appropriate to your project.

## Overall Approach to Testing

As using java main testing is all automated

## Automated Testing

### Unit Tests

Check

TODO show screen shot of tests completed.

### User Interface Testing

Check for each screen part of the unit testing on android

Didn’t use third party testing suits and felt it was not needed

### Stress Testing

Can test this to well as not all android devices are the same and I really don’t have the data to do this. As well however I have testing incase of missing data

## Integration Testing

After refactors running the unit tests

Shows the whole system working

Test table here

## User Testing

Test Table

# Critical Evaluation

Examiners expect to find in your dissertation a section addressing such questions as:

* Were the requirements correctly identified?
* Were the design decisions correct?
* Could a more suitable set of tools have been chosen?
* How well did the software meet the needs of those who were expecting to use it?
* How well were any other project aims achieved?
* If you were starting again, what would you do differently?

Such material is regarded as an important part of the dissertation; it should demonstrate that you are capable not only of carrying out a piece of work but also of thinking critically about how you did it and how you might have done it better. This is seen as an important part of an honors degree.

There will be good things and room for improvement with any project. As you write this section, identify and discuss the parts of the work that went well and also consider ways in which the work could be improved.

Review the discussion on the Evaluation section from the lectures. A recording is available on Blackboard.

# Appendices

* 1. Third-Party Code and Libraries

If you have made use of any third party code or software libraries, i.e. any code that you have not designed and written yourself, then you must include this appendix.

As has been said in lectures, it is acceptable and likely that you will make use of third-party code and software libraries. The key requirement is that we understand what is your original work and what work is based on that of other people.

Therefore, you need to clearly state what you have used and where the original material can be found. Also, if you have made any changes to the original versions, you must explain what you have changed.

## Project Specification

For the data, I will need to decide which features are important and decide how they will impact on the required functionality of the App. As stated by Sahoo and Salama, “The first step in any recognition process is to consider the problem of what discriminatory features to select and how to extract these features from the patterns.”[4] I will use this as my starting point. In order to do this, I will need to process the data into a more relevant and more manageable form, I will need to do some additional research in order to fully understand how to accomplish this in the most straightforward manner.

In order to design a compact classifier it will be best to use data mining tools (e.g. WEKA) to extract rules based on the training data. This rule base could then hard-coded in the App and used to classify new data.

### Android App

* The Android app will work on Android 4.4+ upwards
* It will be able to record audio given
* Javadoc *“Javadoc is a tool for generating API documentation in HTML format from doc comments in source code”.*
* Working executable *APK files are a type of archive file, specifically in zip format packages based on the JAR file format, with .apk as the filename extension.*
* Testing *“The Android testing framework, an integral part of the development environment, provides an architecture and powerful tools that help you test every aspect of your application at every level from unit to framework.”*
* Test Tables for UI While I can use some testing already built into the Android API and testing tools there will be some aspects of the Application that cannot be tested and will need a table.

## Graph View

The project is a library for Android to programmatically create  
flexible diagrams. Version 4.0.0 is the latest instalment created by Jonas Gehring, is open source under the GNU general public license, version 2, June 1991. The GNU license see [8]. Full website for more information see [7]. I used the .jar file and incorporated into the final Android app.

## jAudio 2.0

jAudio is a software package for extracting features from audio files as well as for iteratively developing and sharing new features. These extracted features can then be used in many areas of music information retrieval (MIR) research, often via processing with machine learning frameworks. Authors Daniel McEnnis and Cory McKay, I used jAudio 2.0 to do some feature extraction from the data provided. TODO – add more information on how and where I used this software and on licensing

## libsndfile

Libsndfile is a C library for reading and writing files containing sampled sound (such as MS Windows WAV and the Apple/SGI AIFF format) through one standard library interface. It is released in source code format under the [Gnu Lesser General Public License](http://www.gnu.org/copyleft/lesser.html). I used this library to be able to read wav audio files on the android application, all the code was copied in to the jni folder.

libsndfile has the following main features :

* Ability to read and write a large number of file formats.
* A simple, elegant and easy to use Applications Programming Interface.
* Usable on Unix, Win32, MacOS and others.
* On the fly format conversion, including endian-ness swapping, type conversion and bitwidth scaling.
* Optional normalisation when reading floating-point data from files containing integer data.
* Ability to open files in read/write mode.
* The ability to write the file header without closing the file (only on files open for write or read/write).
* Ability to query the library about all supported formats and retrieve text strings describing each format.

The code used was from <https://github.com/michaelwu/libsndfile>

Recording Wav in java <http://i-liger.com/article/android-wav-audio-recording>

## Testing Tables

Setup:-

* Have an android device running Android 4.4+
* Have the app installed on the android device.
* Load over the test audio file into the apps folder on the internal storage at:
  + “/storage/emulated/0/Android/data/com.cs294.jas38.pdultrasonicclassification/files”

### Load the application.

Setup: -

* Find the Application with the Apps section.

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Is the Apps name “PD Ultrasonic Classification” | Yes |  |
| Once clicked on the icon, does the app load. | Yes | The main menu screen is loaded. |
| Is the Icon the EA Technology Android logo. | No | It is the default Android icon |

### Main Menu Screen

Setup: -

* Orientation - portrait

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Is the title “Main Menu” | Yes |  |
| “File Chooser” button is present | Yes | Big clear and green |
| “Record” button is present | Yes | Big clear and red |

Setup: -

* Orientation - landscape

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Is the title “Main Menu” | Yes |  |
| “File Chooser” button is present | Yes | Big clear and green |
| “Record” button is present | Yes | Big clear and red |

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| “File Chooser” button is clicked | Yes | A new screen is loaded. A list of files appears. |
| “Record” button is clicked | Yes | The “Record” screen in loaded |
| Click the android back button. | Yes | It takes the screen back to the devices home screen. |

### Record screen

Setup: -

* Click on the “Record” button from the home screen.
* Orientation – portrait

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| The title says “Record” | Yes |  |
| Has label “Count down: ” | Yes |  |
| Has number of 10 next to it | Yes |  |
| Under the label and count is a graph with a title of “Volume Input” | Yes | Title is present however the graph does not show until record starts. |
| A playback button is present | Yes |  |
| A Save as… button is present | Yes |  |
| A record button is present | Yes |  |

Setup: -

* Orientation – landscape

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| The title says “Record” | Yes |  |
| Has label “Count down: ” | Yes |  |
| Has number of 10 next to it | Yes |  |
| Under the label and count is a graph with a title of “Volume Input” | Yes | Title is present however the graph does not show until record starts. |
| A playback button is present | Yes |  |
| A Save as… button is present | Yes |  |
| A record button is present | Yes |  |

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Click the button record | Yes | The count down value counts down in 0.1 increments.  The graph shows the sound volume input over time.  After the count hits zero and the graph stops moving along and the count resets. |
| Click on Play back button | Yes | The Audio is played. |
| Click on the Save as button | Yes | Loads the Save as screen. |

### Save As Screens

Setup: -

* Make sure there is a recorded audio tmp file.

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Reference label is present | Yes |  |
| Edit text input is present | Yes |  |
| Date label is present | Yes |  |
| The current date is shown in the format YYYY\_MM\_DD | Yes |  |
| Save button is present | Yes |  |
| Enter txt in the edit text aspect, test max length is 15 characters | Yes | Limits text to 15 characters |
| Only [a-z A-Z 0-9 \_-] characters can be used | Yes | Can press other characters however nothing is inputted |
| Enter “Testing” into the edit text and click the save button | Yes | Takes you back to the Record screen and a pop up saying saved file “Testing”. |
| Check the file store and see if the file has been saved Testing\_YYYY\_MM\_DD.wav | Yes |  |

### File Chooser Screen

Setup: -

* Load the app and click the File Chooser button
* Have the test.wav file loaded within the apps folder or record some audio within the record screen.

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Can see a list of files on screen | Yes |  |
| Test.wav file is an option | Yes |  |
| If you change orientation all the same files exist | Yes |  |
| There is a scroll bar to the right, while this may not move anything if the user has many files it will be needed | Yes | It does nothing with only one .wav file in the folder. |
| Each file shown is clickable | Yes | Clicked on test.wav file and it loads View data screen. |
| Click the Android back button | Yes | Takes me back to the main menu. |
| After clicking the test.wav file and the new screen loads click the Android back button. | Yes | Takes me back to the list of files. |

### View Data screen

Setup: -

* From the main menu click File chooser, click the test.wav file
* Make sure the volume is turned up to an audible level
* Have in portrait

|  |  |  |
| --- | --- | --- |
| **Test** | **Successful** | **Comments/ Outcome** |
| Title is View Data: test.wav | Yes | The title is the file that was clicked from the previous screen |
| There is a plot present of the audio file | Yes |  |
| The plot y-axis = 1 to -1 | Yes |  |
| The plots x-axis is from 0 to 250 | Yes |  |
| Move your thumb from right to left along the plot. Does the X-axis move along? | Yes | Very responsive. |
| Pinch together over the plot and the X scale will change | Yes | It went from 0-250 to 0-2000. Though the load time of this was very high and after the moving of the plot was very delayed. |
| Under the plot there is a label called Sample rate | Yes |  |
| To the right of Sample rate is the number that is the sample rate it should be one of these values: {44100, 22050, 11025, 8000}; | Yes | The value was 8000 |
| A label situated under the sample rate called “Classification”, the label will be in larger text | Yes |  |
| The value next to the Classification label will be the classification of the Audio file, either PD or Non-PD. For the ‘test.wav file’ the classification will be PD | Yes |  |
| Each Classification comes with a certainty percentage, the one present for the test.wav file will be 95% | Yes |  |
| Button called ‘Play Audio File’ is present? | Yes |  |
| Click on the button ‘Play Audio File’, does the file play? | Yes |  |
| When tilting to a landscape orientation, all labels, buttons and plot still present with the same values? | Yes |  |

* 1. Code Samples

This is an example appendix. Include as many appendices as you need. The appendices do not count towards the overall word count for the report.

# Annotated Bibliography

This final section should list all relevant resources that you have consulted in researching your project. Each reference should also include a brief annotation.

1. The PD Academy is an online resource for sharing knowledge on Partial Discharge. Link: <http://www.partial-discharge-academy.com/what-is-partial-discharge>
2. Sinan Si Alhir, UML in a nutshell – A quick reference, First Edition. 1998 O’Reilly & Associates. ISBN 1-56592-448-7   
     
   I used this book for a reference for the UML diagrams used is this report. I found the overall organization of the Diagrams and which ones to put where most helpful.
3. Apache Software Foundation (2004) “Apache License, Version 2.0” (Online) Available at: <http://www.apache.org/licenses/LICENSE-2.0> Accessed: 14th March 2014.
4. Graph View - open source graph plotting library for Android. Version 4.0.0 – Available at: <http://www.android-graphview.org/> Accessed: 28th February 2015
5. GNU General Public License, link - <http://www.gnu.org/copyleft/gpl.html> Accessed: 28th February 2015.
6. Adding native support to the Android app. Link -- <http://www.javaworld.com/article/2077513/learn-java/java-tip-17--integrating-java-with-c--.html>

This is a tutorial I used to be able to understand how to set up the environment and utilise the C/C++ code. It gives an example and very clear diagrams on how issues can arise when using native code in the Android environment.

1. YouTube tutorial Available at <https://www.youtube.com/watch?v=kFtxo7rr2HQ>

Building NDK apps with Android studio is the tutorial title. I used this to help understand how to implement support of native code into the android app. While the tutorial is for an older version of Android it is still relevant.

1. Android NDK Available at <https://developer.android.com/tools/sdk/ndk/index.html>

Here is the NDK to build and compile the C/C++ code. It has instructions on how to install and implement it into the Android SDK.

1. Java Sound Resource Available at <http://www.jsresources.org/>

I used this website for further information into how to record and read wav formatted files. I found this very insightful and in depth regarding how java can handle audio data.

1. Audio file C library used in my Android app <http://www.mega-nerd.com/libsndfile/>

The libsndfile C library is used to read WAV format audio files. I used this library to read the audio file in and process it to a double array. I also got the sample rate from the file as it is needed for the feature extraction. This has been released under the GNU license.

1. H. William, P. E. Bartley, “Analysis of Transformer Failures”, International Association of Engineering Insurers 36th Annual Conference – Stockholm, 2003. Link -- <https://www.hsb.com/TheLocomotive/AnAnalysisOfInternationalTransformerFailuresPart1.aspx>

I used part one and part 2 for information on how transformers fail. It has all the stats and was very helpful in understanding how transformers fail and knowing that insulation failure

1. *Service handbook for transformers-3rd edition*, published by ABB.

I only read chapter 9.3 as this section was on monitoring. This game me an extensive list on how high and low level monitoring of electrical assests.

1. <http://www.fftw.org/index.html>

FFTW is a C subroutine library for computing the discrete Fourier transform (DFT) in one or more dimensions, of arbitrary input size, and of both real and complex data (as well as of even/odd data, i.e. the discrete cosine/sine transforms or DCT/DST). FFTW, which is [free software](http://www.fftw.org/faq/section1.html#isfftwfree) under the GNU General Public License.

1. Cigre - Recognition of Discharges, Electra No 11 page 61-98.

This paper goes through the types of partial discharge that can occur on high voltage assets. It shows the observed discharge and its characteristics of any unwanted disturbances, and some means of diagnosing them. It is not a complete list and all results are shown on an oscilloscope.

1. Android developer website, <http://developer.android.com/index.html>. Accessed through out the project.

The Android developer website has a lot of information regarding the design, the development and the finishing touches on how to create an Android app.

1. PD Electrical sensors, <http://www.fargocontrols.com/sensors/>

I used this website for a further insight into how both capacitive and inductive sensors work.

1. Partial Discharge Detection and Localization in High Voltage Transformers Using an Optical Acoustic Sensor by Alison K. Lazarevich.

This paper has a better understanding of the ways PD can be detected. I used this for an in-depth background into chemical, electrical and acoustic detection of Partial Discharge.

1. Partial Discharge Signatures of Defects in Insulation Systems Consisting of Oil and Oil-impregnated Paper by Mohamad Ghaffarian Niasar, 2012

This paper has an in-depth knowledge into partial discharge and its many forms. I have used this paper to refer to the definitions of the many types of PD and detection methods.

1. Partial Discharge Pattern Recognition of Transformer Based on Electric Signal and Ultrasonic Comprehensive Analysis, by Shutao Zhao, Baoshu Li and Yong Wang.

Abstract - According to the characteristics and disadvantages of PD electrical analysis method, an electro-acoustic and ultrasound combination partial discharge (PD) pattern recognition method is proposed.

I used this paper to see what statistical features can be found from the waveforms.

1. The hardware specification for the Samsung S4 - <http://www.gsmarena.com/samsung_i9500_galaxy_s4-5125.php>
2. History of Android, <http://en.wikipedia.org/wiki/Android_version_history#Android_1.5_Cupcake_.28API_level_3.29>

Accessed: 21th February 2015. I used this for the background on Android.

1. Android 4.4 compatibility pdf file, <https://static.googleusercontent.com/media/source.android.com/en//compatibility/4.4/android-4.4-cdd.pdf>

This document has all the information on the needed hardware and specification of any mobile device running Android 4.4. I only used the hardware section 7, for the storage information on the minimum requirements.

1. Trends in Partial Discharge Pattern Classification: A Survey, by N.C. Sahoo, M.M.A. Salama and R. Bartnikas

Abstract - Partial discharge (PD) detection, measurement and classification constitute an important tool for quality assessment of insulation systems utilized in HV power apparatus and cables.

This paper describes some of the tools used to extract features and compare how different AI approaches perform.