MASTER'S THESIS

Mobile Computing Support in Industrial Field Service Engineering

Welderufael Berhane Tesfay
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Welderufael Berhane Tesfay

Mobile Systems
Department of Computer Science, Electrical and Space Engineering
Luleå University of Technology
SE-971 87 Luleå
Sweden

Supervisors

1. **Prof. Dr. Karl Andersson, Lulea University of Technology**
   karl.andersson@ltu.se
2. **Marko Lehtola, Researcher, ABB AB Corporate Research, Vasteras, Sweden**
   marko.lehtola@se.abb.com
3. **Dr. Markus Aleksy, Research Scientist, ABB Corporate Research, Germany**
   markus.aleksy@de.abb.com

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Abstract

The increasing digitization of our daily lives is gaining a new momentum recently in what is called the post-desktop era of computing. This wide spread in digitization is made possible by the introduction of handy devices specifically of mobile phones, laptop computers, smartphones and tablets. These devices, in turn, operate on distributed systems and mobile networks, which enable mobility, ubiquity and interactivity of computers, data, software and users. This new trend in shaping up technological advancement presents new opportunities for mobile information presentation, processing and synthesis in different spheres of application such as industrial field services engineering. Industrial field service engineers execute sets of work orders on daily basis plans. These work order executions demand the availability of digital information anywhere anytime to minimize the average time required to accomplish them. In this context, the pervasiveness and ubiquity of mobile devices and smartphones creates a favorable possibility for industrial field service engineering automation. Most contemporary smartphones come out with abundant features to use for industrial field service engineering task automations and different ways of presenting information to service engineers. The objective of this thesis is, therefore, to develop a stable mobile prototype software by using Android smartphone hardware and software features to perform preparation, execution and post-processing of the work orders using latest digital technology available in smartphones, like camera, video, sound recording, annotations, maps and Augmented Reality (AR). The prototype enables service engineers to locate service fields, locate equipment, record work order events and report them for later use. The results of a usability field test carried out towards the end of the thesis work indicate that the prototype reduces the work order execution time by a considerable amount as well as giving the comfort of information presentation to service engineers. Analysis of the usability test of the project reflect that industrial field service engineers do need supportive tools based on smartphones and new technologies such as AR to assist them on daily basis works.

Key words: *Mobile computing, industrial field service, android, work orders, augmented reality, Near field communication, location based services*

Preface

This thesis work is the final project for the master degree in Computer Science and Electrical Engineering with specialization in Mobile Systems at the Department of Computer Science, Electrical and Space Engineering at Luleå University of Technology, Sweden. It amounts for 30 ECTS.

The project was conducted within the Software Architecture and Usability Group of ABB AB Corporate Research in Vasteras, Sweden in collaboration with supervision from Lulea University of Technology. ABB is a global leader in power and automation technologies. It offers an integrated portfolio of products and services for industrial automations, industrial services, pharmaceutical and biotech industries, such as process and lab analytical devices, instrumentation, drives and motors, field bus technology, process and building automation, manufacturing execution and EBR systems, and robotics. With a long track record of innovation, ABB continues to engage in R&D for energy efficiency, power systems, and smart grids,

Acknowledgements

I would like to thank my supervisors Marko Lehtola from ABB AB Corporate research in Vasteras and Dr. Karl Anderson from Lulea University of Technology for their endless support throughout the thesis work. Their guidance in narrowing down the thesis project scope, frequent follow up and comments as well as encouragements have an irreplaceable role for the successful completion of the work.

I would also like to extend my sincere thanks to Dr. Markus Aleksy, ABB Corporate Research in Germany, for his invaluable support in framing the project and thesis report.

My other thanks go to all staff members of the ABB AB Corporate Research RDAT SARU group especially to Dr. Elina Vartinen and Dr. Magnus Larson for their helpful professional comments and constructive suggestions to the thesis project.

I am indebted to my beloved parents, brothers, sisters and dearest friends and I would like to express my profound gratitude to them.

I thank you all.

List of figures

Abbreviations

AR	Augmented reality
NFC	Near field communication
GUI	Graphical user interface
UI	User interface
GPS	Global positioning system
POI	Point of interest
API	Application programming interface
HMI	Human machine interaction
ICT	Information communication technology
ADL	Activities of daily living
PDA	Personal digital assistant
LBS	Location based service
GSM	Global system for mobile
RFID	Radio frequency identification
Wi-Fi	Wireless fidelity
JSON	JavaScript object notation
ISO	International standards organization
IEC	International electro-technical commission
NDEF	NFC data exchange format

IoT	Internet of things
HCI	Human computer interaction
HMD	Head mounted display
SDK	Software development kit
XML	Extensible markup language
OS	Operating system
OHA	Open handset alliance
MVC	Model-view-control
RAM	Random access memory
HDD	Hard disk drive
SPOT	Smart personal object technology

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Scenario

For the thesis work, the following scenario was decided upon:

"Stephan is a service engineer working for Keppala waste water treatment plant. He executes a set of defined work orders every week. Typically, he does the cleaning of gas flow meter in the plant as well as exchange of the Redox meter. To successfully execute his work order, he needs to:

- ✓ Locate where the safety tools for the current work order are.
- ✓ Know the actual place of work.
- ✓ Check the cabling of the machines.
- ✓ Record and report task order events and measurements related to the work order for further analysis and use.
- ✓ Show drawings and annotate text over the drawings for clarification.

While doing the work order execution, he needs to fill in measurement data such as measure flow before and after the change in the tank. He, as well, needs to show drawings of the machines to other service engineers to figure out point of failures. There is also a need to record audio/video so as to identify the current behavior of the machines as industrial machines often exhibit different kinds of sound depending on whether the internal components are functioning well or not. In the present working scenario, he has to print out a hard copy manual, carry it to the work field, and execute the task order. This demands physically carrying manuals and redundant entry of measurement data."

Chapter 1. Introduction

This introductory chapter will present a glimpse of the overall work carried out in the thesis. It starts by stating the main research focus and objectives followed by the problem definition. It then continues to point out the contributions made, the boundary of the thesis and how the overall dissertation is organized.

In the vision of pervasive or ubiquitous computing set forward by Mark Weiser [5] information will be everywhere anytime, the physical and digital worlds interconnect, technology becomes invisible in our lives and a great number of devices and software components collaborate unobtrusively in a smart space to provide services to users. Notwithstanding the availability of the required technology, truly pervasive computing environments have not yet been realized; only prototypes and theoretical designs have been developed by the research community. Smartphones might well be the most powerful pervasive embedded device and the ideal platform to be sued for input for pervasive computing especially as future smartphones are hoped to have better processing power, battery life and memory [6].

During the past years, there has been a steady development of mobile smartphones and wireless technologies that brings forth a new paradigm of computing – mobile computing [7]. When mobile computing solutions are used to streamline the essential business processes, the resulting automation delivers reduced costs, better customer service, and administrative personnel productivity.

The growing release of feature-rich smartphone devices capable of augmenting digital information into our physical world, as well as capable of processing geographic location information to the current and emerging field of mobile and pervasive computing has stimulated the research community and business vendors to look into different application areas of the field. Smartphone device applications can also derive and utilize location information from sensors, RFID, NFC, Bluetooth, WiMax, and Wireless LANs. These systems can be used as standalone or supplement the coverage for location tracking in indoor environments such as industrial service plants.

1.1 Research focus and objective

The theme of this thesis underpins the use of mobile computing applications in the industrial field service engineering. The objective is to design and implement smartphone prototype software to showcase the possibility of using the newly emerging smartphone features such as audio/video recording, text annotation, augmented reality, and near field communication sensing capability.

1.2 Problem definition

The modern-day industrial field service engineering faces constriction in pervasively availing digital information on the go. Besides, there is an influx of aging work force in the area especially in the highly developed nations [8]. These make the challenges multidimensional. To list some of the challenges:

- ✓ Changing business environments, technological progress, and an aging workforce are some of the challenges that have to be faced in the area of industrial field service. Especially in high wage countries, some important developments can be observed that will influence the future's service organization and processes. There will be an increasing influx of non-experts into the workforce. Consequently, there will be an increased necessity to support service personnel with information and knowledge.
- ✓ Competition will increase cost-pressure on service units. Thus, service business processes must be performed more effectively and efficiently.
- ✓ Industrial products and solutions will become more complex due to technological advances such as miniaturization, wireless technologies and increasing amount of embedded software.
- ✓ Partnerships for after-sales services will increase, i.e., personnel of external firms will cover some service tasks. Since they will not necessarily be familiar with the installed products, focused information to perform service specific tasks will have to be provided on an ad-hoc basis.
- ✓ Field service engineers and trades have on-site limited information available to performing service tasks.

These challenges prognosticate for the need of digitalizing the information flow and automating the industrial work order execution processes. Broadly, the thesis questions what the newly coming out smartphone technologies got to afford to resolve the aforementioned challenges as well as doing surveys to investigate the readiness of industrial field service engineers to use new smartphone solutions.

The scope is narrowed down to two specific scenarios inquiring how Android smartphones can be utilized to develop a stable prototype:

1) Investigating problems and trouble shooting in industrial field service engineering

2) Service report and documentation for industrial field service engineering task orders.

1.3 Contributions

This thesis work tries to identify the challenges in the present-day industrial field service engineering with regard to adopting new mobile computing technology solutions from the emerging features of the smartphone eco system. In particular, it identifies the possibility of integrating smartphone features such as GPS sensing, accelerometer, audio/video recording, text input, image capturing and annotation, augmented reality to be used to develop stable solution prototype software. The contributions can be summarized as:

- ✓ Design and implementation of stable Android prototype software with features of capturing, storing and retrieving video, audio, text, and image data related to a specific work order. It also has the possibility of annotating textual descriptive information over taken pictures as well as superimposing information over virtual view of the Android camera for selected Points of Interest (POI).
- ✓ Usability test and evaluation of the developed Android prototype software by letting the volunteer target service engineers work on it live while performing their usual work orders.

1.4 Thesis boundaries

The target industrial plant where the thesis scenario was developed had no Internet connection. The absence of Internet connection influences the technology selection strategy and solution approach. There was no backend storehouse system instead the local Android smartphone memory system was exploited. Both the local Android file system, local permanent storage such as SQlite database or Sharedpreference which is specific to Android smartphones. The focus of the prototype development was more on functionality and less on Human-Computer-Interaction (HCI).

1.5 Organization of thesis

The thesis is organized as follows: Chapter 1 begins the thesis report with some introductory points to mobile computing in general and the thesis scenario in particular. Chapter 2 discusses related research areas in mobile computing, industrial field service engineering, location based services, location tracking techniques, near field communication sensors, and augmented reality. Chapter 3 continues to discuss on the research methodology followed to achieve the results while chapter 4 describes the architectural design of the developed prototype. Chapter 5 continues on the implementation methodology in the smartphone while chapter 6 discusses the experimentation and results of the thesis work. Chapter 7 brings the concluding remarks of the work, and finally chapter 8 points out the possible direction for future work followed by Appendix.

Chapter 2. Literature Review

This section reviews related research works carried out in the following fields: mobile computing application in industrial field service, mobile fall detection applications and algorithms, location based services, Near Field Communication (NFC) sensing using smartphones and augmented reality. Despite the need to fill the gap in adapting mobile computing solutions to industrial field service engineering which in most cases has a work flow a depicted in figure 1, there has not been much work done in the area except for a few research activities.

2.1 Mobile computing applications in industrial field services

As previously mentioned, Li [7] defined mobile computing the following way: "*The common definition of mobile computing is that users who carry portable devices have access to information services through a shared infrastructure, regardless of their physical location or movement behavior*" [7].

Mobile computing offers significant benefits for organizations that choose to integrate the technology into their fixed organizational information system. This is made possible by portable computer hardware, software, and communications systems that interact with a non-mobile organizational information system while away from the normal, fixed workplace. Mobile computing is a versatile and potentially strategic technology that improves information quality and accessibility, increases operational efficiency, and enhances management effectiveness [9][10].

Mobile computing is about both physical and logical computing entities that move which have three aspects communication, hardware, and mobile software [10]. Mobile computing, made possible by portable computer hardware, software, and communications systems that interact with a non-mobile organizational information system while away from the normal, fixed workplace, offers significant benefits for organizations that choose to integrate the technology into their fixed organizational information system [9].

Industrial field service can greatly benefit from the advances in information and communication technology (ICT) in increasing the speed of information flow, enhancing the efficiency and effectiveness of information communication, and reducing the cost of information transfer. In this essence, mobile computing applications promise to be of great utilization interest in the industrial field service to pervasively avail on-site information especially improved process support by providing tailored service information and presenting it in an ad-hoc manner to service engineers [11].

The contemporary industrial field service engineering faces the challenges of changing business environments, technological progress, and an aging workforce [11]. As enunciated by Aleksy et al. [3], these multidimensional challenges are more prevalent in high wage countries.

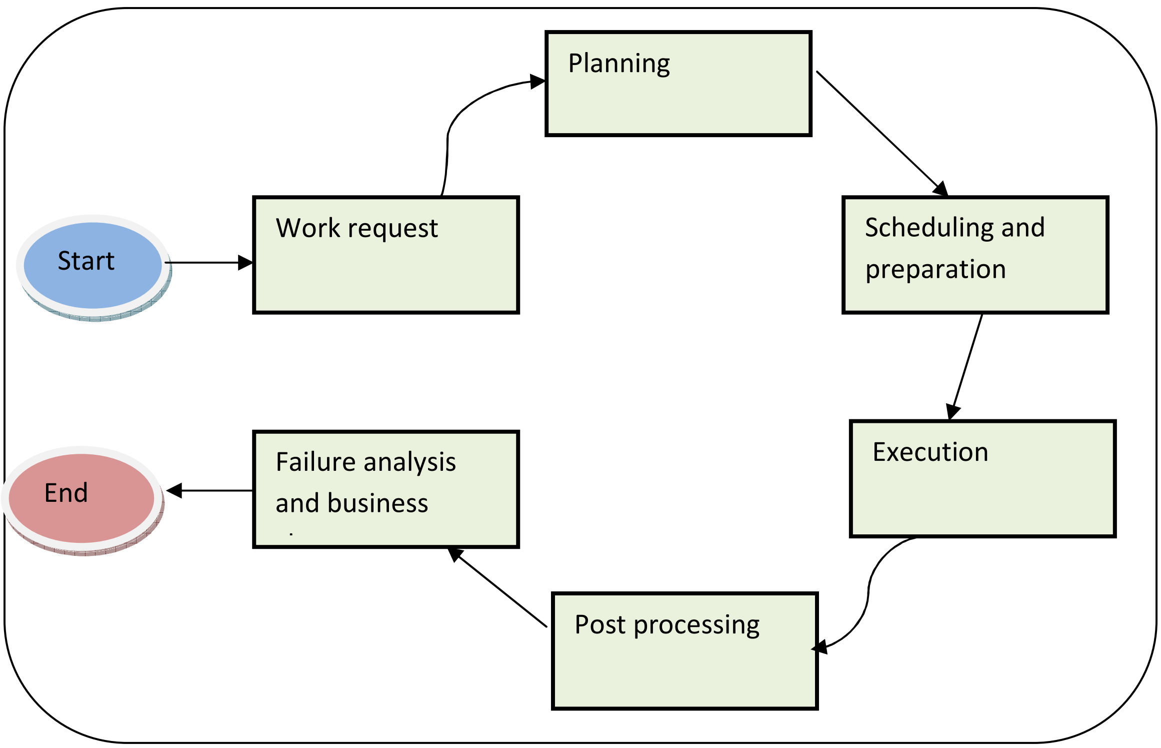

Figure 1: Basic industrial work order process

2.2 Fall detection

According to T. Zhang et al [12] unintentional fall is a very risky factor to consider especially in the elderly people's daily living. Sudden falls which are often difficult to technologically isolate from activities of daily living (ADL) are dangerous for the aged population because they can adversely damage health temporarily or permanently [13]. Therefore, many fall detection systems have been researched with due consideration of their benefits to the elderly people. Present-day fall detection techniques are broadly categorized into two: those using acceleration and others exploiting both acceleration and body orientation [13]. Fall detection technologies, however, can also be used to remotely monitor the healthy work flow of service engineers especially operating in confined working environments.

It was established that the earlier the fall is reported, the lower is the rate of morbidity-mortality. The detection of the fall is also an interesting scientific problem as it is a ill-defined process which one can approach using various methods [14]. Although the concept of a fall is in the common sense, it is difficult to describe it precisely, and thus to specify its means of detection. It can be described as the rapid change from the upright/sitting position to the reclining or almost lengthened position, but it is not a controlled movement, like lying down, for example. In 1987 the Kellogg international working group on the prevention of falls in the elderly defined a fall as "unintentionally coming to ground, or some lower level not as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" [7]. This definition has been used in many research studies, as it is general enough to be extended to include falls resulting of dizziness and syncope, consequences of an epileptic fit or cardiovascular collapses, such as postural hypotension and transient ischemic attacks [14].

2.3 Location based services

Voisard et al. [15] defined location based services the following way: "*The term location-based services (LBS) is a recent concept that denotes applications integrating geographic location (i.e., spatial coordinates) with the general notion of services. Examples of such applications include emergency services, car navigation systems, tourist tour planning, or ''yellow maps'' (combination of yellow pages and maps) information delivery*".

With the advent of Wireless networking (Wi-Fi), cellular telephone (GSM), packet radio, radio frequency identifiers (RFID), smart personal object technology (SPOT), global positioning systems (GPS), and wireless sensor networks mobile users are able to query their environment and they allow applications to monitor and track remote objects [15][16].

LBS are based on a combination of the integral location information about specific data, the location information supplied by LBS systems, requesting location-specific and otherwise customized services. The integration of location-annotated data with existing personal and public information and services creates opportunities for insightful new views on the world, and allows rich, personalized, and contextualized user experiences. One of the biggest constraints of current LBS is that most of them are essentially vertical services [17]. As the edge of the Internet becomes increasingly mobile, location-based Internet applications have taken on a much more prominent role. At the same time, though, the underlying geo-location systems that support these applications were designed with specific circumstances in mind, rather than being general to the whole Internet [18].

2.4 Near field communication (NFC) sensing

NFC is defined as a subset of the RFID technology which operates in a bidirectional point-to-point short range communication technology which allows interaction distance of approximately 5-10 cm and a maximum data rate of 424 kb/s [19]. It is an RFID deviate of 13.56 MHz frequency communication device. NFC has become a prevalent feature in most newly emerging smartphones such as the Samsung Galaxy nexus. The NFC technology in general has two major specifications: ISO/IEC 14443 and ISO/IEC 18000-3 [20].

It is estimated that NFC will be one of the widely deployed pervasive communication technology objects that will enable human beings to communicate with physical objects in their vicinity [21]. It is a new technology but it is maturing fast and finding many application areas especially by coupling it with smartphones as it is being standardized [22].

Uckelmann et al. [23] suggest that NFC is the next communication enabler to realize the Internet of Things (IoT). According to them, it has high potential for people to seamlessly identify things to access as well as contribute related information. Even though it is questionable how many mobile phone owners will use this utility technology, NFC is expected to be the next logical step for user interaction with the IoT [23].

Strommer et al. [24] studied the possibility of applying NFC to health monitoring. They claimed that NFC is, compared to other competing technologies, a high-potential technology for point-to-point connectivity between health monitoring devices and mobile terminals. They compared NFC to other short-range communication technologies such as Bluetooth and IrDA with regard to possibility of improving the usability of health monitoring devices.

2.5 Augmented reality

Augmented reality (AR) is defined as one of the latest advancements of Human Computer Interaction (HCI) technology and context-aware computing environments that allows users to view digital information superimposed onto reality with the aid of cameras, GPS, compasses and accelerometers ([2], [25], and [26]). It combines the real and the virtual worlds to assist the user in performing a task in a physical environmental typesetting by sorting and seamlessly overlaying data based on geographic locations or image processing of real world objects [27][28].

Using mobile phones for augmented reality has its own pros and cons. The ubiquity of smartphones with built-in cameras, accelerometer and magnetometers provides a good opportunity to do AR applications. On the other hand, the limited processing power, small memory access, small cache and less performance of doing real-time image processing hinders it [29]. Another challenge is that most current systems require heavy and bulky head-mounted displays (HMDs) and are based on inflexible centralized architectures for detecting service locations and superimposing AR images [25].

AR has been researched and used in different application areas for almost two decades now [30].

In their AR Computing Arena for Digital Entertainment (ARCADE) (AR environment system) Lyu et al [2] showed how the technology can be used for entertainment application development. ARCADE is a general AR platform that contains software tools, algorithms, designs, and configurations for entertainment applications [2].

Overlaying historical information onto museums' view through smartphone cameras is one of the common application areas of AR. Kang et al. [31] have developed an AR application by reconstructing historical digital photos of a city taken by community members over a long period of time. They developed an AR window application which enables users see past scenes over present view of the city using their own smartphones. Lee et al. [32] also developed an AR based museum guidance system for selected viewings. The system is capable of providing multimedia information system as well as directing users to their choice of exhibits using AR and map views.

Maintenance and operations is another potential area of application for AR. There have been research attempts to use AR in industrial and maintenance areas. Henderson et al. [33] developed a prototype that explores the benefits of AR documentation for maintenance and repair using a tracked head worn display to augment a mechanic's natural view with text, labels, arrows, and animated sequences designed to facilitate task comprehension, localization, and execution. The developed AR allowed mechanics to locate tasks more quickly than when using either baseline, and in some instances, resulted in less overall head movement. An evaluation of the qualitative survey showed that mechanics found the AR condition intuitive and satisfying for the tested sequence of tasks.

AR can also be utilized in medicine especially of medical operations. Wen et al. [34] proposed an AR robotic system equipped with intra-operative visual guidance and gesture based control interface. The proposed AR application introduced to the field of interventional medicine to assist surgeons in implementing medical operations under the augmented reality environment.

Chapter 3. Research methodology

This section discusses the methodology followed in the thesis to testify the hypothesis. Figure 2 below shows the steps undertaken to realize the project.

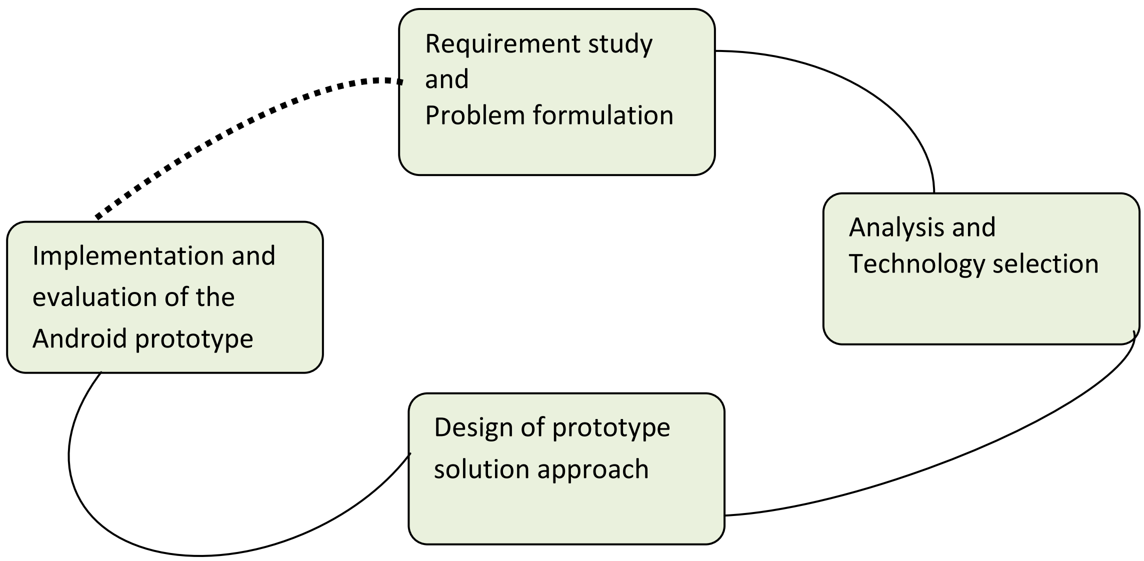

Figure 2: Research methodology procedures

3.1 Research questions

The research questions answered in this thesis are:

- ✓ How can mobile prototype software help field service engineers perform preparation, execution and post-processing of their work orders using latest digital technology available in smartphones, such as camera, video, sound recording, annotations, maps and augmented reality (AR)?
- ✓ How can the usability of the prototype software developed answer research question number one be tested and evaluated?

3.2 Hypotheses

Industrial field service equipment needs to be maintained and repaired. Field service engineers often need to execute work that requires work orders, instructions, documents, etc. written on paper. After the repair work has been finished everything needs to be documented. In this thesis, it is hypothesized that the latest digital technology available in smartphones such as camera, NFC, video, sound recording, annotations, digital maps and AR can be integrated to develop a stable functional prototype to help field service engineers facilitate their daily work order executions such as investigating problems and troubleshooting as well as service report and documentation.

3.3 Research design

The research design followed a two-step approach to materialize the thesis work. The first step accentuates on the design and implementation methodology of the Android smartphone prototype while the second one emphasizes on quantitative information gathering and analysis of the usability test of the developed prototype.

3.4 Prototype

There are different smartphone platforms of choice for the development. Some of them include: Windows Mobile, Apple iOS, webOS, Android, Brew Mobile platform, Symbian, and palmOS [35]. Out of the aforementioned platforms, Android, an open source mobile OS platform, purely based on the Linux operating system, Apache harmony, and Dalvik Virtual machine which is backed by the Open Handset Alliance (OHA) of a confederation of 50 telecoms, mobile hardware, and software companies, headed by Google, has recently gained tremendous market share and popularity among developers and end-users [36]. Given the fast growth and de facto acceptance as well as openness in its operating system and Application Programming Interfaces (APIs), it is a good choice to prototype the project on an Android platform.

The prototype is, therefore, developed in the Android platform using the object oriented Android programming paradigm and Android Software Development Kit (SDK). Activities, the special case Android classes, are used to implement the business logic while Extensible Markup Language (XML) programming is used to design and implement the user interface (UI).

A Model-View-Controller (MVC) software design pattern methodology suite which module interactions as depicted in figure 3 below was utilized. MVC abstracts the user interface (View model), which is responsible for displaying data to the user, from having a direct communication to the database [4], [37]. Instead, it uses the model module to interact with the database. It dissociates data access, business logic, and user interaction [38].

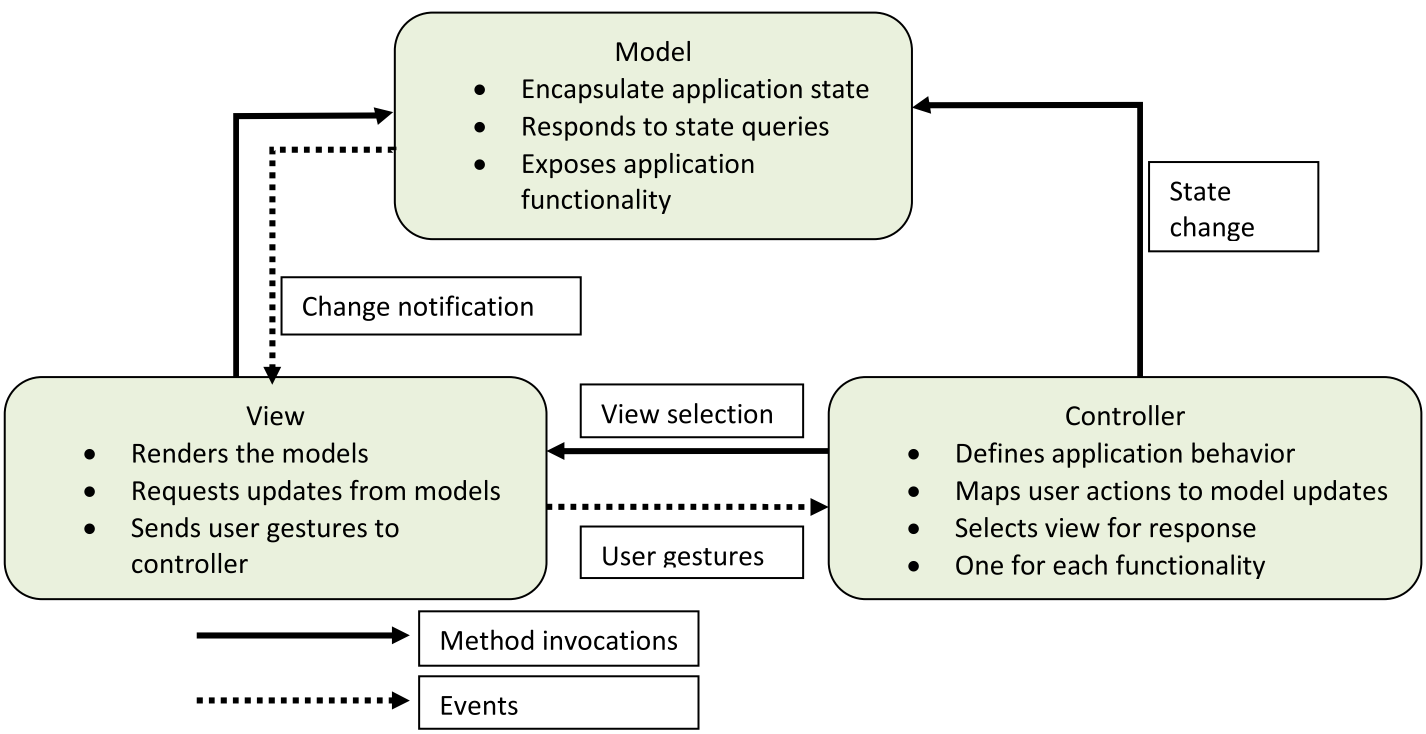

Figure 3: MVC architecture [4]

3.5 Prototype usability test

The second step of the research design emphasizes on usability test survey of the prototype by service engineers. A questionnaire was prepared and handed to the service engineers and other software usability experts within ABB Corporate Research with the intention of collecting quantitative primary data and feedback.

The collected quantitative questionnaire data results were analyzed and interpreted to identify the strengths and weaknesses of the prototype in terms of meeting its requirements. A Lickert scale suit of 1 to 5 psychometric survey methodology was used to collect the responses. The results were then fed to Microsoft Excel for graphical analysis, mean and variance calculation.

Chapter 4. System architecture and design

In this chapter, the architecture and design of the prototype is discussed.

4.1 System architecture

The general architecture of the developed prototype corresponds to an MVC variant 3-tier architecture that consists of a graphical user interface (GUI), a business logic tier, and a data storage tier as shown in figure 4 below.

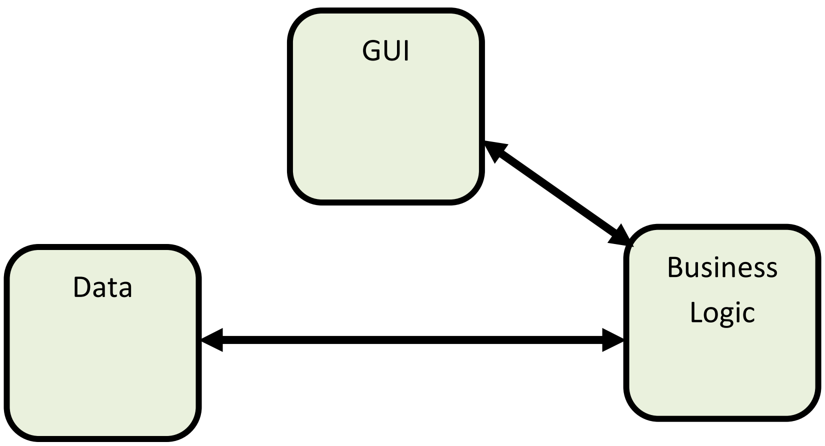

Figure 4: 3-tier architecture of the prototype mobile software

The GUI:

This is the topmost level of the application. It displays information related to the context of the service engineer's need. It communicates with other tiers by outputting results user interface.

Business logic:

Application tier (business logic, logic tier, data access tier, or middle tier)

The logical tier is pulled out from the presentation tier and, as its own layer; it controls an application's functionality by performing detailed processing and logic.

Data:

This tier consists of the Android database and file systems. In this part of the architecture, information is stored and retrieved. It keeps data neutral and independent from the application or business logic. This helps improve scalability and performance.

The prototype system components and their interactions is depicted in figure 5 below.

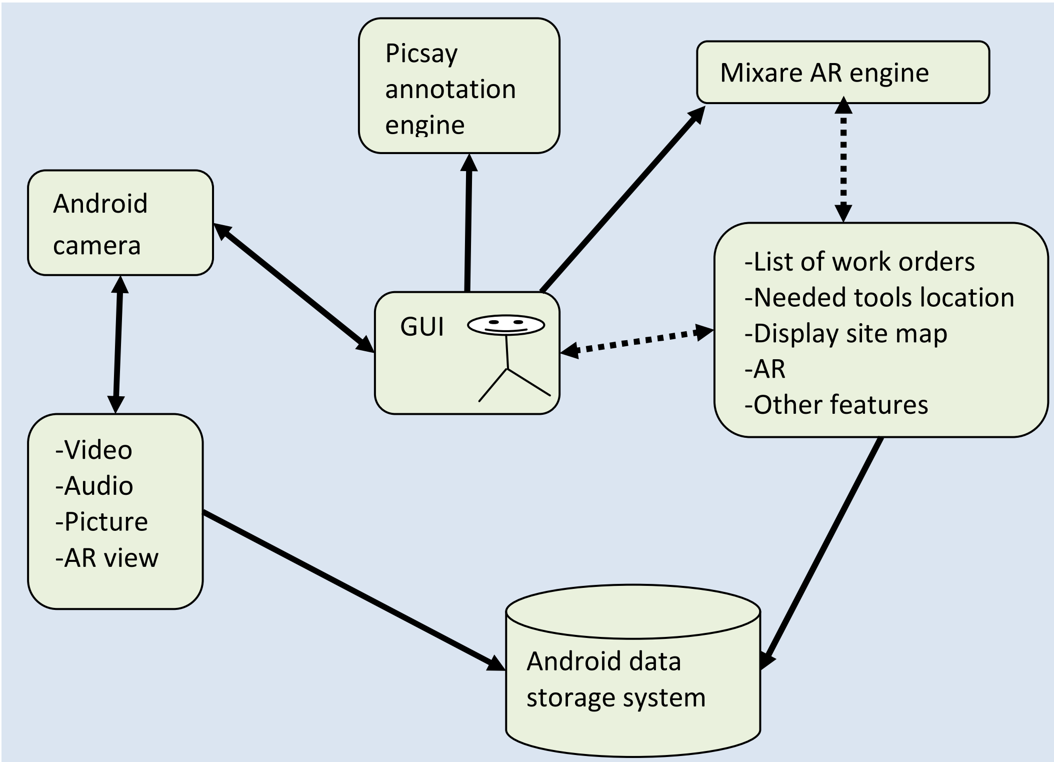

Figure 5: General high level architecture of the prototype

4.2 Prototype system design

Software design methodologies, in general, describe a proven solution to a recurring design problem, placing particular emphasis on the context and forces surrounding the problem, and the consequences and impact of the solution. Design methodology is an interdisciplinary topic, attracting researchers from miscellaneous design disciplines such as architecture, engineering and industrial design [44].

There are many deriving reasons to use software design methodologies:

- ✓ Patterns capture the static and dynamic structure and collaboration among key participants in software designs
- ✓ Reusability: When a problem recurs, there is no requirement to invent a new solution as it is possible to follow the pattern and adapt it as necessary.
- ✓ Expressiveness: Design patterns provide a common vocabulary of solutions, which can be used to express larger solutions succinctly.

MVC is mostly used for small applications such as prototypes that are easy to manage and have simple navigation interfaces [43]. MVC is also suitable for object oriented design idioms such as Android programming. Another motivation of using MVC is to make the model independent from of the views. If the model had to notify the views of changes, it would require the reintroduction of the dependency that the software developer looks to avoid. Another design choice is the Model-View-Presenter (MVP). Unlike MVC, on the other hand, MVP is introduced for test driven development and decoupling of presenter to the model by using passive view. But it is difficult to manage for multiple views.

The services described in this section are primary subcomponents of the prototype system that are designed based on the preferred MCV design model. Figure 6 presents some examples of generic components. Camera functionality, and voice / sound recording are examples of such generic components already provided by the Android platform.

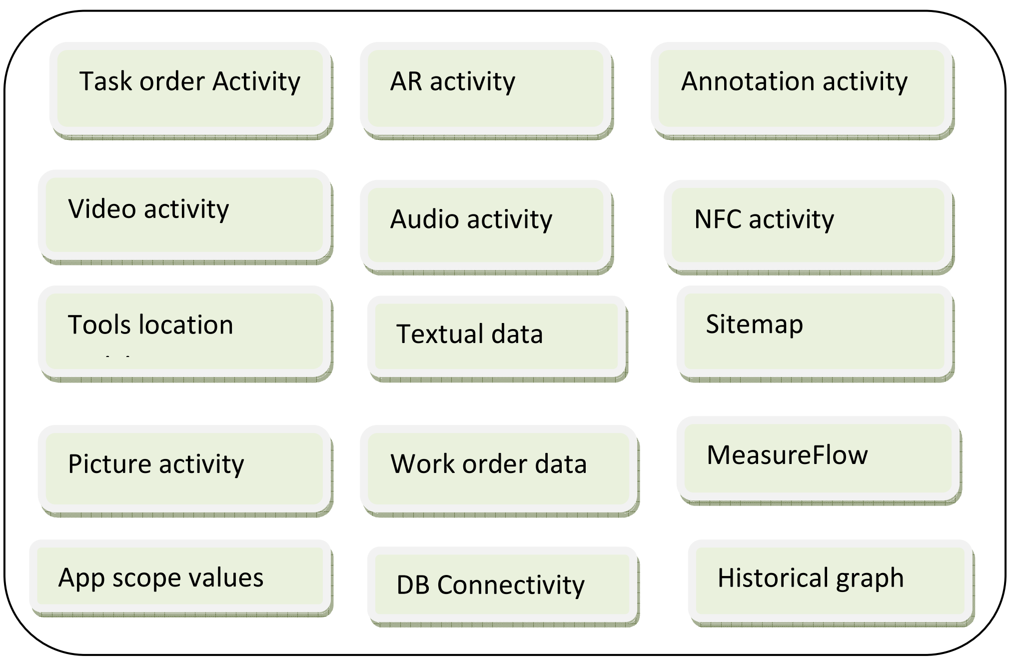

Figure 6: Generic Android activity components

After identifying the components, the proposed architecture was designed using software design methodologies. For example; figure 7 below shows the interaction and messaging sequence diagram drawn to realize the annotation and AR engine modules.

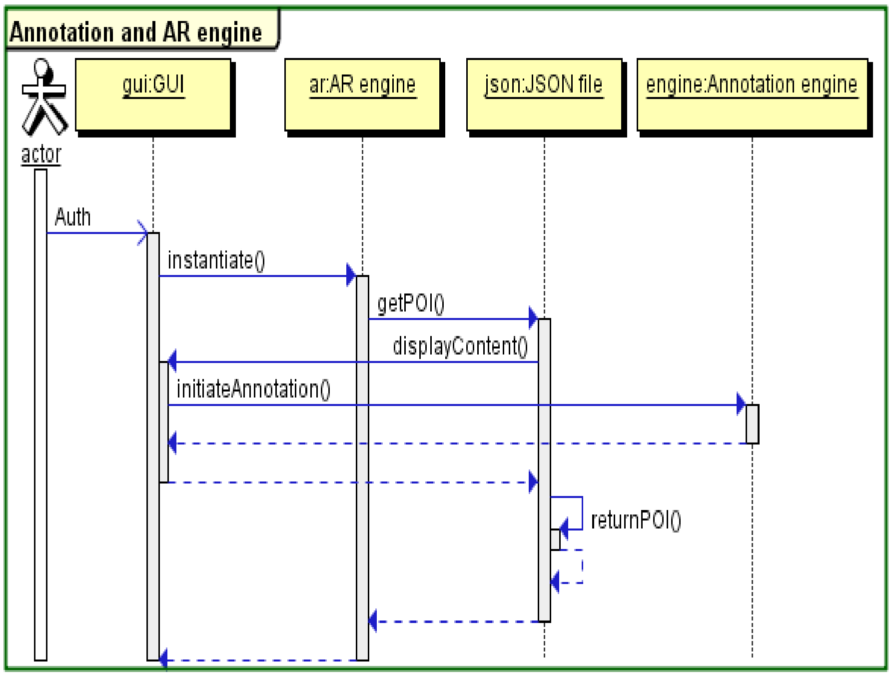

Figure 7: Sequence diagram of the Annotation and AR engine modules of the prototype

Chapter 5. Implementation

5.1 Development requirements

The prototype was developed on Android smartphone specifically the Samsung Galaxy Nexus version 4.0.2 having 16 GB of internal memory. A Satellite A305 Toshiba laptop with 4 GB RAM and 320 GB HDD was used as a development machine. The project was developed on Android version 4.0 using Eclipse Galileo edition as a development platform. Android SDK has been integrated to work with the Eclipse version beforehand.

To be able to run the project, users will need to give the file read/write, Internet, NFC, GPS and Camera permissions on their Android phone [specifically for this project]. The project makes use of an open source augmented reality platform called Mixare [39]. It is required that for the augmented reality module of the project to work properly, the system needs the pre-installation of the free augmented reality engine which can be found on [40].

The prototype uses graphs to display comparison of work order data. An open source graphing engine called AChartEngine [41] has been used to do so. Before using the graphing engine's APIs, it requires the integration of the achartengine.jar file to the project.

The prototype also has the feature of annotating textual data over pictures. For that, a trial version of a photo editing software called PicSay [42] which can be found in the Google play store has been used. This is another requirement for the Sketching part of the prototype module to work without fail.

5.2 The Android prototype features

The prototype has the following system main functionality features:

- ✓ Record and store work order events (video, picture, text notes, and audio).
- ✓ Access to the events recorded related to the work order.
- ✓ Annotate descriptive textual information over images.
- ✓ Tracking executed tasks in the work order.

- ✓ Graphical presentation of measurement data.
- ✓ Log records using time-stamps.
- ✓ Augmented reality view of selected POIs.

5.3 Implementation highlights

An Android application consists of components that are coupled together; each component can be the entry point in the application, rather than having one single entry point for everything in the application. The building blocks for the application are provided by the different components. For simplicity, the major components of the Android prototype application will be discussed in the following subsections.

5.3.1 Using the Android camera

Most of the implementation work was on instantiating the Android hardware to record, play, superimpose and display contents as well as storing the raw data for further use. The Android implementation requires the inclusion of permission in the Android manifest file to access phone features such as NFC, Camera, and SDCard access.

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
<uses-permissionandroid:name="android.permission.NFC"/> //permission to use NFC
<uses-feature android:name="android.hardware.camera" /> //permission to use camera
permissionandroid:name="android.permission.CAMERA"/>android:
name="android.permission.WRITE_EXTERNAL_STORAGE" />//permission to use the sdcard external storage
<uses-permissionandroid:name="android.permission.RECORD_AUDIO"/> //permission to //use the audio
recording feature of the android smartphone.
</manifest>
```

The Android camera can be triggered by calling it on Intent to have the camera built-in application record video and return its value. A similar implementation method can be used to activate the audio recording of the Android smartphone.

5.3.2 Mixare AR implementation in Android

In recent years, there has been exploded increase in mobile devices with GPS and an always-on Internet connection [27]. Such proliferation of smartphones favored the growth of

AR applications to seamlessly mesh rendering of synthetic over real world objects images and locations into live mobile video feeds.

Each of these devices has a multitude of sensors that effectively allow the phone's location and orientation to be pinpointed in a matter of seconds. The phone's GPS chip will find the user's coordinates on earth, and will serve as the basis for finding points of interest around the user. The phone's accelerometers will be used to determine the orientation of the phone, and at which angle it is being held. The digital compass included with Android phones will be used to find out what direction the phone is pointing in.

AR seamlessly meshes rendering of synthetic images into live video feeds through the aid of computer vision algorithms and rendering frameworks. An object can be rendered on top of a positional location indicator (often called a marker) which can relate important information about the camera's location relative to the marker through its projected representation on the video feed. AR is still a new technology, so the majority of research is focused on locating and tracking the marker with higher precision. Unfortunately, AR research doesn't often explore issues with the renderings themselves.

There are a couple of projects being carried out to implement AR features into Android phones. Mixare is one of the leading open-source projects with an active community and constant upgrades [39]. The Mixare open source augmented reality engine having org.mixare package name was installed onto the Samsung Galaxy Android smartphone beforehand. The available APIs are used to call the default Mixare engine with its own POIs and descriptive content over the POI from Wikipedia, Open street map and Twitter.

In a different implementation style, JSON file is used to define the POIs using longitude, latitude and altitude. It allows storing POIs locally on the device, thus supporting an execution of the application in an offline mode. Otherwise, an application server can be utilized to download a location-based list of POIs via JSON interface.

5.3.3 NFC implementation in Android

NFC tags are small passive NFC chips that can store data. The tag can trigger events or transfer certain data to an active NFC device, such as a smartphone. These powerless tags use a small amount of energy from the active NFC device to transfer its data. The most sophisticated tags contain operating environments, allowing complex interactions with code executing on the tag. The data stored in the tag can also be written in a variety of formats, but many of the Android framework APIs are based around a NFC Forum standard called NDEF (NFC Data Exchange Format). A typical NFC tag dispatch system looks like figure 8 below.

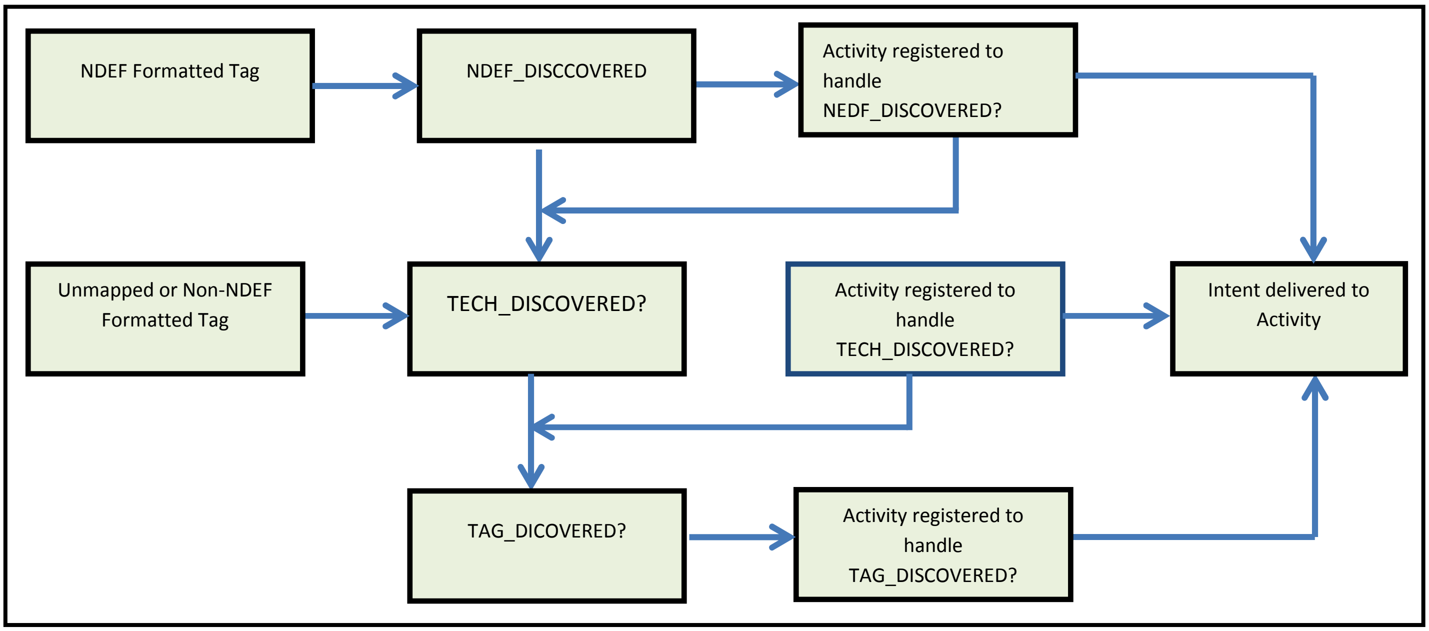

Figure 8: NFC tag dispatch system [1]

5.4 Prototype user interface

The ease or comfort during the usage of mobile computing solution systems is mainly determined by characteristics of the software product itself, such as the user interface. With this regard, the prototype user interface was designed in such a way that it has a good look and feel as seen by ordinary users. Each work order was represented with explicit text (such as the one in figure 9 below) and less ambiguous terms.

Figure 9: Screen shot of one of the work orders

AR is among the main features of the prototype. It presents information by superimposing it onto the camera view of an object or a geographic location. The following picture (figure 10) depicts an AR view of the area in the field service with adjustable radius of camera focus.

Figure 10: Screen shot of the AR view with radius of coverage extended to 20 km.

Each functional component is integrated to automate work orders as can be viewed in the screen shot below (figure 11). The prototype captures the service engineer's ID who has logged in to execute the work order. It also automatically associates this work order on which day of the week the work order such as cleaning of the gas flow meter was performed.

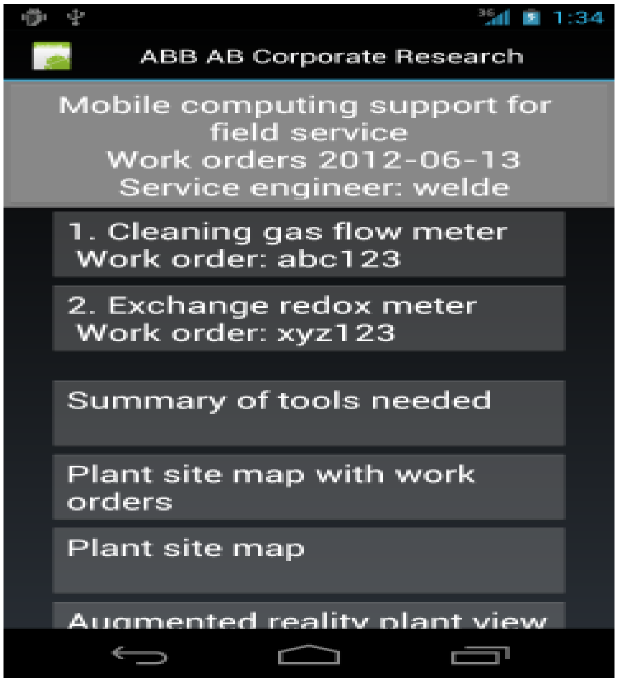

Figure 11: Screen shot of the prototype main page

One of the main features of the prototype is to help service engineers in locating their required tools and the actual work order place with respect to their present location. The following picture (figure 12) shot from the prototype depicts this requirement.

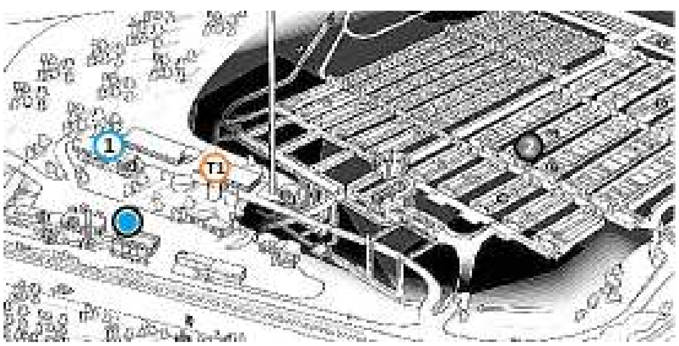

Figure 12: Screen shot of static map showing tools location, and work order location

Chapter 6. Experiments and evaluation

6.1 Experimental setup

The main goal of the experiments and performance evaluation efforts was to understand how the developed prototype fits into the demands of the target field service engineers. This creates a good opportunity to test the usability of the software with the service engineers executing their daily work orders live by following the prototype functionalities. The questionnaire was prepared with the implicit intention of achieving the following:

1. Whether the functionality of the prototype system in principle can do what is needed
2. the individual user's assessment of the extent to which the technology meets the user's high priority needs
3. Whether the system can be used for its intended purpose.
4. To assess if the completeness with which specified users can achieve specified goals in the given scenario
5. Whether industrial field service engineers have the readiness to adopt new technologies and solutions that come along the emerging smartphone eco system.
6. How comfortable and acceptable the system is to its intended users

The usability test was carried out in two different kinds of experiments.

- ✓ The service engineers at Keppala waste water treatment plant. Two service engineers who work full time for Keppala waste water treatment plant volunteered to carry out their work order for one day with the help of the Android prototype developed in this thesis project. Moreover, both of the service engineers belong to different level of smartphone users. One is a regular smartphone user and the other has never used one before.
- ✓ Software usability experts at ABB Corporate Research: Two software usability experts from ABB Corporate Research in Vasteras also volunteered to experiment on our prototype.

The average result of each question is computed and depicted below in the graph. Most of the results (refer to Appendix) except for the usability of the Annotation module score are well above four out of five.

The questionnaire was collected according to the following grading scale for each of the 35 interview questions:

5- Strongly agree

4- Agree

3- Neither agree nor disagree

2- Disagree

1- Strongly disagree

6.2 Prototype usability experiment evaluation

Usability is increasingly recognized as an important quality factor for interactive software systems, including traditional GUI style applications, web sites, and the large variety of mobile and PDA interactive services. The user interface of the prototype should be kept as simple and descriptive as possible which encourages usage of new possibilities with more ease for service engineers.

In this thesis project, a questionnaire was handed over to the service engineers and ABB software usability experts to fill in while experimenting with our prototype software. As depicted in figure 13 below, the average result of each question is calculated and drawn against the questionnaire list. The mean value of all results for one questionnaire is drawn against the given evaluation question.

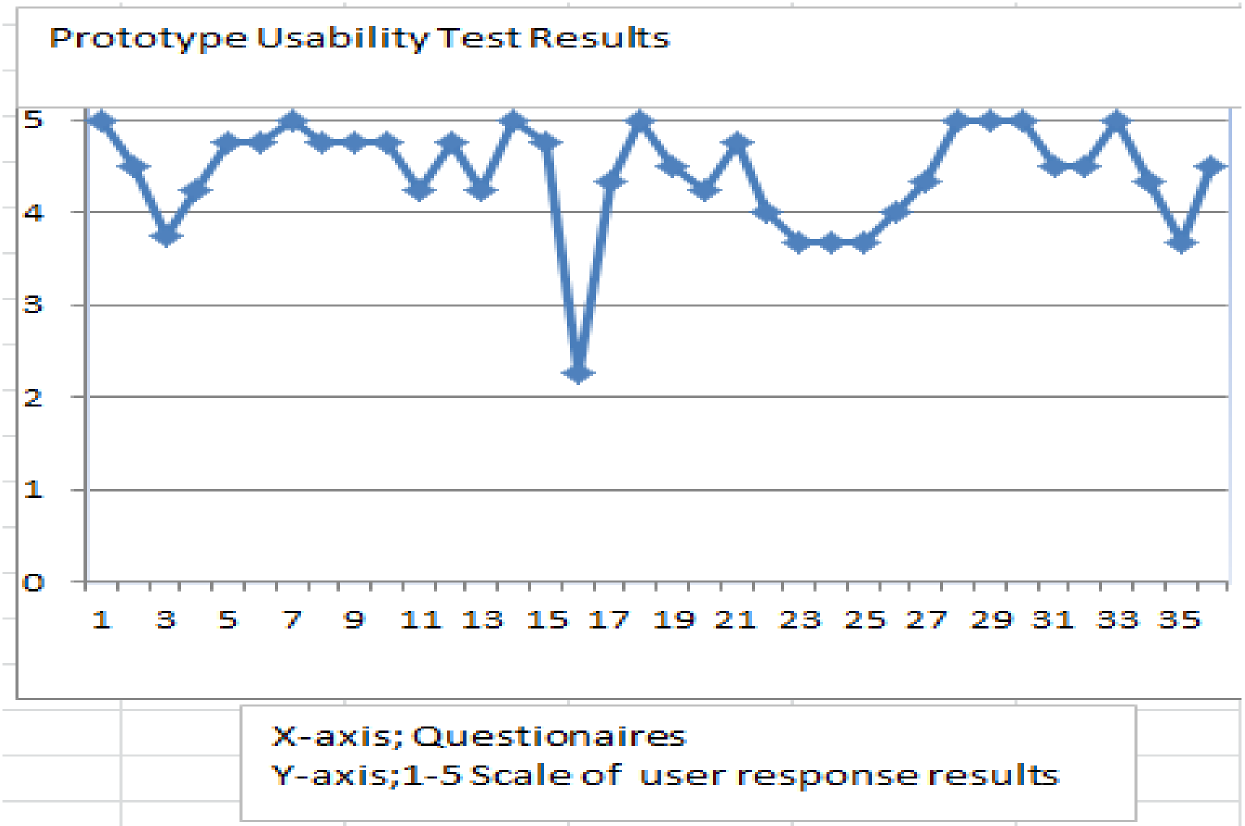

Figure 13: Usability test result graph

The mean and standard deviation of the interviewees is calculated as follows:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} = 4.42$$

Where Xi stands for the observed value

n stands for the number of observations

The higher the mean, the more satisfied the service engineers are by using the prototype software. In our experiment, the value deviates by 0.58 from the maximum achievable value of 5. The mean also indicates psychometric satisfaction measurement of the interviewees.

The standard deviation can also be computed as follows:

$$\sigma = \sqrt{\frac{\sum (x_i - m)^2}{n-1}} = 0.57$$

where Xi stands for the observed value

m stands for the mean

Xi-m calculates the deviation of each from the mean

The less the standard deviation, the more each measurement is close to the mean. This again indicates that all interviewees expressed similar opinions how satisfied they were while using our smartphone solution.

Both user feedback and quotes were collected after the field trip to the target plant where the work order executions were carried out live from the smartphone. This feedback will be part of the future works in the project. Some of the anonymous quotes about the prototype by the test service engineers while executing gas flow meter as depicted below in figure 14 include:

"*That is smart doing your homework*."

"*It couldn't have been any easier*."

"*I found it quite easy. I found it smart actually*."

"*I hope it will come soon*."

Figure 14: Textual annotation over a sample work order image during a visit to the target plant site

The questionnaire is put in appendix I for reference.

A total of four users were allowed to experiment on the prototype.

Usability experts

Two software usability experts from ABB Corporate Research did a pre-usability test on the prototype before the actual test with the service engineers. Their feedback and usability test questionnaire results were recorded and analyzed. In general, the experts didn't have problem using the prototype but they had slight difficulty matching the work flow as programmed in the prototype and the actual work order flow. The software usability experts will not be able to ascertain if the prototype satisfies points number 4 and 5 of section 6.1 hence a lower average score of for questionnaires 3, 15-17, and 35.

Service engineers

The other test targets were the service engineers. Two service engineers were allowed to do a live test of the prototype replacing their conventional paper-pencil usage for one day. More interestingly, one of them is a regular smartphone user while the other one rarely uses a smartphone. Apparently, the prototype was easy to use even for the less-experienced smartphone user. He was quoted as saying "It couldn't have been any easier." Nonetheless, both of them experienced a slight technical flow challenge especially when trying to annotate textual descriptive information over an image captured by using the prototype, resulting in a lower score at questionnaires 15-17 as depicted in the graph above. A lower scale score would mean fulfilling less of point number 6 of section 6.1.

Chapter 7. Conclusion

These days, field service engineers and trades have on-site limited information available to performing service tasks. For instance information is needed to find the right equipment on-site, to analyze the application environment, to diagnose the root-cause of the problem, and to repair the faulty equipment. Especially during site audits information must be collected to outline the current state of the installed equipment. In addition for full service or safety audits a set of tools is used to calculate and outline how the plant health and safety could be improved and guaranteed.

Mobile computing seems to hold a promising future towards implementing solutions that can alleviate the limited on-site information availability to help execute field service engineering tasks faster and more conveniently. It is even more promising with the newly emerging digital technology features available in smartphones such as camera, video, sound recording, annotations, digital maps and AR.

This thesis work has proved the possibility of integrating these latest technologies to develop a stable functional prototype to help field service engineers facilitate their daily work order executions such as investigating problems and troubleshooting as well as service report and documentation. The prototype developed with due consideration to functionality was found to meet the requirements of the target field service engineers which the thesis scenario focuses on.

An analysis of prototype usability test carried out live with the service engineers executing their daily work orders with the help of the prototype showed that the service engineers are, indeed, in need of mobile computing solutions to assist them. It indicated that solutions based on smartphones could result in higher worker productivity, improved customer service, convenient information presentation, and faster and more efficient work order resolution and reporting.

Chapter 8. Future work

As a future work, the thesis has also identified broader challenges in adopting mobile computing to the contemporary industrial field service engineering. Particular to the thesis scenario, the following ideas have been suggested as continuation work of the project.

8.1 Integration to back-end system

As described in the thesis boundaries section, the project assumes no Internet connection throughout the process. The modules are programmed to operate in offline mode. The future intention is not completed yet, when the user's device gets the chance to be connected, the recorded event files will be posted to the backend system for further processing and use.

8.2 Image recognition in conjunction with AR

The Mixare open AR platform used in this scenario works on points of interest basis. It displays the descriptive text content over a predefined geographical location identified by its latitude, longitude and altitude. The reason for choosing the Mixare AR is its capability of working offline if it is provided with JSON or XML file containing the POIs. This makes it short of recognizing images. In the future, it is recommended that another image recognition AR algorithm that runs at the backend to be integrated.

8.3 Google indoor/outdoor maps integration for finding the tools

Google maps has a good mapping technology precision for locating places. Integrating Google maps will help the service engineers find the tools needed for the work order. It can also give a good direction for locating the place of the work order itself.

8.4 Viewing live plant data

Most service engineering data need to be reported to a central server. Other tasks require live synchronization of the measurement data to a common display room where other service engineers will benefit from. The Android prototype, therefore, needs to send the measurement input data to the backend display.

8.5 Security

Security, except for basic authentication, was a low priority task during the prototype development. With the inclusion of sending event data to the backend system, in the future works, it is recommended that network and data security should also be given due emphasis.

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Appendix

1. Questionnaire used to survey the prototype usability

1. Task description	Start the main application				
	In the mobile device start the main application				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

2. Task description	Open up first work order – Cleaning of gas flow meter				
	In the main application open up the first work order - Cleaning of gas flow meter.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

3. Task description	Complete the first work order – Cleaning of gas flow meter				
	In the main application open up the first work order - Cleaning of gas flow meter and complete the steps in the work order.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5

Comments	

4. Task description	Check on required tooling for the work order				
	In the Cleaning gas flow meter click on **Required tooling** to have a look on the tools needed for the work order				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

5. Task description	Check on location to the first work order				
	In the Cleaning gas flow meter click on **Location** to have a look on the location for the work order				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

6. Task description	Add measure flow before value to the first work order				
	In the Cleaning gas flow meter click on **Measure flow before** to save the value or view history				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

7. Task description	Add measure rod length value to the first work order
	In the Cleaning gas flow meter click on **Measure rod length** to

	save the value or view history				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

8. Task description	Dismount the gas flow meter and clean				
	In the Cleaning gas flow meter click on **Dismount and clean** and **Done** when finished				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

9. Task description	Mount with rod length				
	In the Cleaning gas flow meter click on **Mount with rod length** to have a look on the data, history and **Done** when finished				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

10. Task description	Add measure flow after value to the first work order				
	In the Cleaning gas flow meter click on **Measure flow after** to save the value or view history				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

11. Task description	Add a note to the first work order				
	In the main application open up the first work order and choose **Additional notes** and complete by adding some text in there.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

12. Task description	View added notes in the first work order				
	In the main application open up the first work order and choose **Show taken notes**				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

13. Task description	Attach a new photo to a work order				
	In the main application go to the first work order and capture a new photo by clicking the **Photo** button.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

14. Task description	View taken photo in a work order				
	In the main application go to the first work order and choose **Show taken pictures.**				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

15. Task description	Attach a video to a work order				
	In the main application go to the first work order and capture a video by clicking the **Video** button..				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

16. Task description	View taken video in a work order
	In the main application go to the first work order and choose **Show taken video**

How did you experience it	Difficult				Easy
	1	2	3	4	5
Comments					

17. Task description	Annotate a picture in a work order				
	In the main application go to the first work order click on **Sketch** to annotate text or arrow pointer on a picture. Take a picture with it and add some text to a spot in the picture.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

18. Task description	Open up augmented reality view of the "plant"				
	In the main application, click on **Augmented reality view**. Stand up, hold the device like taking a picture of a distant object and turn around your axis. There should be some plant related points in the view.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

19. Task description	Open a local pdf document in a mobile device				
	In the main application, go into the **Other features** and open up a local document by clicking **Read offline document**.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

20. Task description	Open an online pdf document in a mobile device				
	In the main application, go into the **Other features** and open up a local document by clicking **Read online document**.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

21. Task description	Take a photo				
	In the main application go to the **Other features** and capture a new photo.				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5

Comments	

22. Task description	Capture a video			
	In the main application go to the **Other features** and capture a video.			
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

23. Task description	Record audio				
	In the main application go to the **Other features** and click on **Record audio**				
How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

24. Task description	Listen to recorded audios
	In the main application go to the **Other features** and click on **Listen to audios**

How did you experience it	**Difficult**				**Easy**
	1	2	3	4	5
Comments					

25. Task description	The user interface of software should be kept as simple as possible and as complicated as needed while making work pleasing.
Actors:	Service Engineer / Field Service Engineer
Testing procedure	
Test report	Record the times needed to complete this task and the comments of the service engineer.
Test result	The test is passed if the service engineer is able to utilize this kind of functionality.

1) Class diagram of one module of the prototype