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Industrial Mobile Application Design and Development

Transformer Monitoring Mobile Application

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Abstract

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This thesis shows how mobile communication and information technology can be used on power industry domain. More specifically, the goal of this thesis is to design and develop a software concept demonstrator that gives operators a better possibility to check the status on ABB high voltage products, utilizing mobile devices, such as mobile phones and tablets.
At the beginning of this thesis, user study and information gathering was conducted at ABB Corporate Research Center, Västerås, Sweden and VB Energi, Ludvika, Sweden. According to the result of interview with both transformer monitoring experts and operators, a preliminary use case of the concept demonstrator was defined. By using evolutionary prototyping, the use case was continuously refined and rewritten, and user interface was designed in from sketches to high-fidelity prototype. Finally, a fully functional prototype, which used as software concept demonstrator, was implemented on Android mobile phone platform and evaluated by both experts in ABB and end users in VB Energi.
The result of this thesis illustrates the current state-of-the art technologies on mobile device can be used in power industry to help the operators and engineers with their daily work. Usability, accuracy, interactivity are the most significant characters for this kind of industrial used software.

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IT 13 069
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Tryckt av: Reprocentralen ITC

Contents

1. Introduction

This thesis shows how mobile communication technologies and modern mobile products, i.e. smart phones and tablet PCs, can be used on power industry domain. The current state-of-the-art technology in mobile devices supports greater processing power, more vivid display, and higher efficient information collecting method, which enhances interaction possibilities between human and machines. This technology can be used not only as consumer electronics products[1], but also considered as great assistants on the industry area. The goal of this thesis is to design and develop an application which provides operators a better possibility to monitor the performance and status of ABB power transformers on their mobile devices.

1.1. Problem statement

Power transformers are indispensable components of high-voltage equipment for power generation, transmission and distribution plants (Westman, Lorin, & A.Ammann, 2010) and their correct functioning is essential to the reliable operating of the power system. An unexpected interruption of power transformers can lead to unscheduled outages and power delivery problems, resulting in severe consequences for the stability of the electric grid. Therefore, it is necessary to monitor the operating condition and performance of power transformers in order to avoid or reduce unplanned failure. It also helps to save running costs by optimizing maintenance schedules.

Power transformers are placed in various geographical positions, many being located far away from cities and centralized electric grid control center. The operators can only get access to them via either physical visits to the site or remote connection equipment in secure network. Usually, one such operator is responsible for several transformers on different locations, which are often far from the others. Remote connection to transformers is an approach for monitoring, since warnings and alarms can be handled before the transformer protection system trips the unit. However these remote monitoring systems are built mainly to be accessed from PCs, but the operators are usually sitting in their cars, travelling between different sites, therefore they are unable to access the remote monitoring information.

Transformer monitoring on mobile devices, as an extension of the current monitoring system, could provide operators an access of the transformer status anywhere and anytime. The current state-of-the-art smart phones and tablet PCs equipped with powerful processors and large storage capacity allows applications operating on its platform. Meanwhile, the support of different kinds of network communication protocols enables the access to the Internet and the local network at anywhere there is mobile phone signal or hotspot (Wi-Fi). Moreover, the multi-touch screen and integration of GPS and camera provides more features of mobile applications. Therefore, mobile devices are able to be used in power industry domain and for transformer monitoring as a specific example in this thesis.

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[1] Consumer electronics are electronic equipment intended for everyday use, most often in entertainment, communications and office productivity. http://en.wikipedia.org/wiki/Consumer_electronics (visited 2013-06-16)

1.2. The aim of this thesis

The goal of this thesis is to design and develop an application which provides operators a better possibility to monitor the performance and status of ABB power transformers on their mobile devices. To be more specific, as an extension of the current transformer monitoring system, this application should have a good consistency with it, which displays most of the significant information in a proper way. Moreover, the difference between mobile devices platform and traditional control room environment should be figured out and considered, especially when designing the user interface. The design and prototype should be based on user study, which guarantees the application comply with the real needs of operators.

1.3. Delimitation

The output of this thesis work is a functional prototype that represents abundant concepts targeting ABB power transformer monitoring system on mobile devices. Due to the complexity of transformer monitoring system itself and different secure policies in Electricity companies and ABB, Only a subset of concepts are implemented in the functional prototype. Moreover, the functional prototype is only fulfilled on Android platform, since the market study illustrates Android has and going to have more markets.

1.4. Thesis outline

Chapter 1: Introduction indicates the thesis objective, motivation for the project, the target and delimitations.

Chapter 2: Background includes the brief introduction of ABB Company, the definition of transformer monitoring, ABB transformer monitoring method, the usage of mobile application in general and technology adopted in this thesis.

Chapter 3: Method explains the methodology applied during different phases of the thesis work.

Chapter 4: Result presents the results of user study, use case building, design of user interface, implementation of the functional prototype and testing and evaluation.

Chapter 5: Conclusion and future work concludes the thesis and suggests some possible future work.

2. Background

2.1. About ABB

ABB is a multinational corporation, global leader in power and automation technologies. It has about 145,000 employees in approximately 100 countries[2].The current form of ABB Company is a merger of Allmänna Svenska Elektriska Aktiebolaget, Sweden and Brown, Boveri & Cie, Switzerland with over 120 years history.

ABB Corporate Research in Västerås is ABB's largest research center world-wide with more than 200 employees, mainly focusing on research and development of automation technology and power technology[3]. Software architecture and processes is one research under department of automation technology. This thesis work was conducted in ABB Corporate Research, Västerås, Sweden, which is a cooperation projects between power and automation technology, i.e. using IT solutions in power products domain.

2.2. Mobile application

Mobile applications are a kind of software application design and developed for mobile device platform, such as smartphone and tablet PC. Native application and web application are the two major categories of mobile applications (Charland & Leroux, 2011). Even though they are different from both developers point view and user experience, they have some common characteristics:

-small size of software package, due to the limit of mobile device storage capacity

-no heavy calculation, because of the limit of less powerful processor

-low battery consuming

-proper UI which fits the small size of screen and touch screen (phone keyboard) operation

2.3. Power Transformer

A transformer is a static electrical device that transfers energy by inductive coupling between its winding circuits. A varying current in the primary winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic flux through the secondary winding. This varying magnetic flux induces a varying electromotive force (emf) or voltage in the secondary winding[4].

In electric power system, the generation of power in the generation stations is typically at medium voltage level (11-33kV), however, efficient and effective transmission over very long distance requires much higher voltage (etc,230kV), on the other hand , distribution of power

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[2] Brief introduction of ABB Company. http://new.abb.com/about/abb-in-brief (visited 2013-06-160)

[3] ABB Corporate Research in Sweden. http://www.abb.se/cawp/seabb361/d2763491a6c93e61c1256ab800248c8f.aspx (visited 2013-06-16)

[4] Basic knowledge of transformers. http://en.wikipedia.org/wiki/Transformer (visited 2013-06-16)

take places at much lower voltage, like several kV. Thus, power transformers can provide an efficient means of shifting voltage from one level to another (Bergen & Vittal, 2005).

2.4. Transformer monitoring

Power transformers, which are often the most valuable asset in a substation or plant, are indispensable components of high-voltage equipment for power generation plants, transmission systems and large industrial plants. Unexpected failures cause major disturbances to operating systems, resulting in unscheduled outages and power delivery problems (Westman, Lorin, & A.Ammann, 2010). Such failures can be the result of poor maintenance, poor operation, poor protection, undetected faults, or even severe lightning or short circuits. Outages affect revenue, incur penalties and can cost a company its reputation and its customers.

Transformer monitoring is becoming an essential component of transformer management. It serves as an early warning system for any fault developing in the main tank and in the accessories, allowing an operator to evaluate the severity of the situation. Multiple transformers are connected to the operator’s network and can be monitored from a local control room or from remote working stations. Sensors measuring dissolved gases, moisture in oil, oil temperature, load current for each unit, and ambient temperature send data to the system via analog signals. The interface provides exact status information by generating a model of the transformer and its working condition and then comparing the measured parameters with the simulated values. Discrepancies are detected and potential malfunctions and normal wear in the transformer and its ancillaries are indicated. The monitoring system also tracks transformer alarms, recording an actual event as well as the sequence leading up to the alarm to assist operators in determining the root cause.

The benefits of monitoring are substantial. A CIGRE study has shown that transformer monitoring can reduce the risk of catastrophic failures by 50 percent. Furthermore, it has been shown that early detection of problems can reduce repair costs by 75 percent and loss of revenue by 60 percent, and that annual cost savings equal to 2 percent of the price of anew transformer – i.e., approximately $40,000 to $80,000 – can be achieved (Boss, Lorin, Viscardi, et al., 2000).

2.5. Development tools

2.5.1. Android

Android[5] is a Linux-based operating system designed primarily for touch screen mobile devices such as smartphones and tablet computers. It is an open-source software stack for mobile devices, and a corresponding open-source project led by Google[6].

The Android software development kit (SDK) is a set of libraries and developer tools for building, testing and debugging Android apps. So as to build and develop an Android

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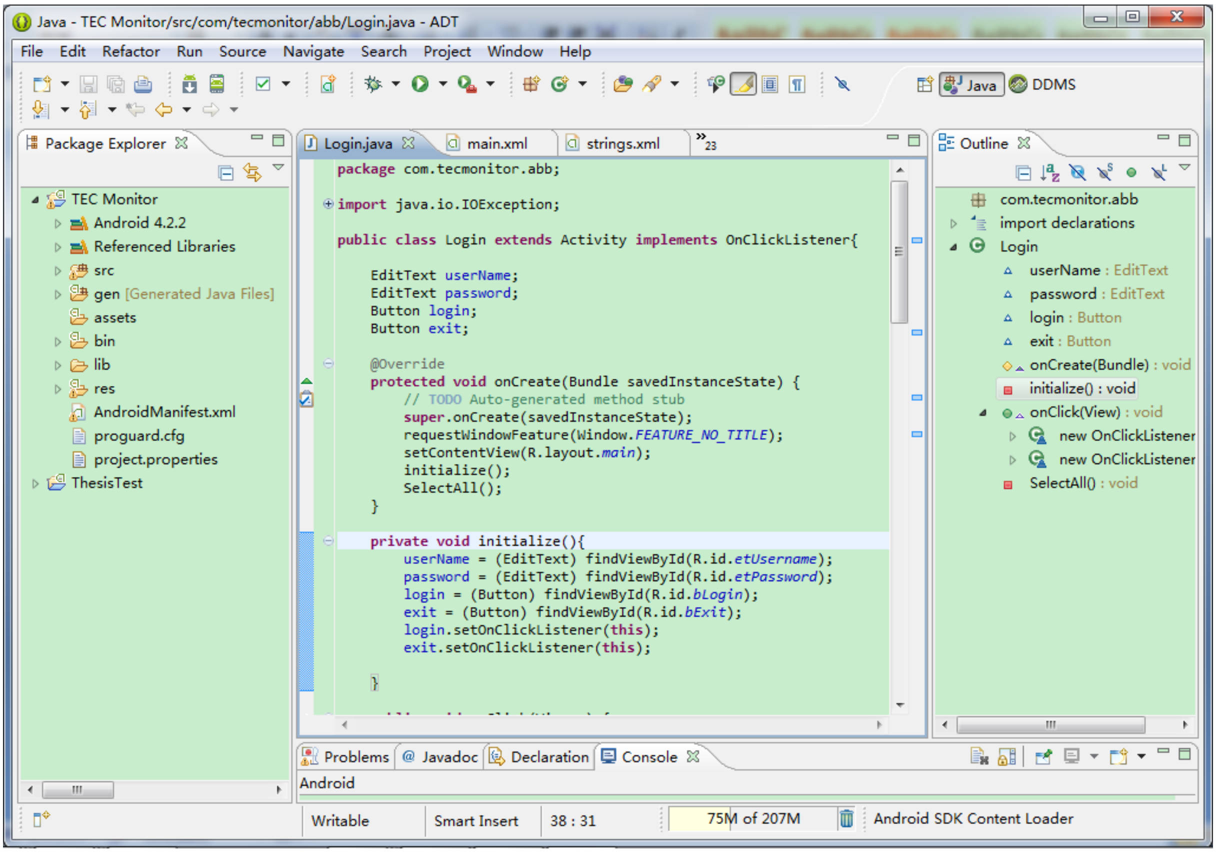
[5] Brief introduction of Android. http://en.wikipedia.org/wiki/Android_(operating_system) (visited 2013-06-16)

[6] Brief introduction of Android . http://source.android.com/ (visited 2013-06-16)

prototype, android SDK should be download and installed, and Java programming language is usually used for developing android app. (Applications are usually developed in the Java programming language using the Android Software Development Kit, but other development tools are available.)



```
package com.tecmonitor.abb;

import java.io.IOException;

public class Login extends Activity implements OnClickListener{

    EditText userName;
    EditText password;
    Button login;
    Button exit;

    @Override
    protected void onCreate(Bundle savedInstanceState) {
        // TODO Auto-generated method stub
        super.onCreate(savedInstanceState);
        requestWindowFeature(Window.FEATURE_NO_TITLE);
        setContentView(R.layout.main);
        initialize();
        SelectAll();
    }

    private void initialize(){
        userName = (EditText) findViewById(R.id.etUsername);
        password = (EditText) findViewById(R.id.etPassword);
        login = (Button) findViewById(R.id.bLogin);
        exit = (Button) findViewById(R.id.bExit);
        login.setOnClickListener(this);
        exit.setOnClickListener(this);

    }
```

Figure 1: A screenshot of Android software development kit

2.5.2. SQLite database

SQLite is light weight relational database engine, which is designed especially for embedded device[7], since only little memory is required at runtime. The same as android, the source code for SQLite is in the public domain; therefore, it's free of charge for every developer and student. Most interesting, SQLite is embedded into Android by including the SQLite database management classes into Android APIs. Importing these classes into android APP project, without any database setup or administration, the application can build and manage its own private database.

SQLite has approximately 13 years history, and the latest version is SQLite 3. Compared with the other open-source database management systems, its execution time is faster. Besides, it supports transactions and uses B-tree implementation, since SQLite 2. SQLite can run under several operating systems, e.g. Windows, Linux, Unix, usually without any graphical user

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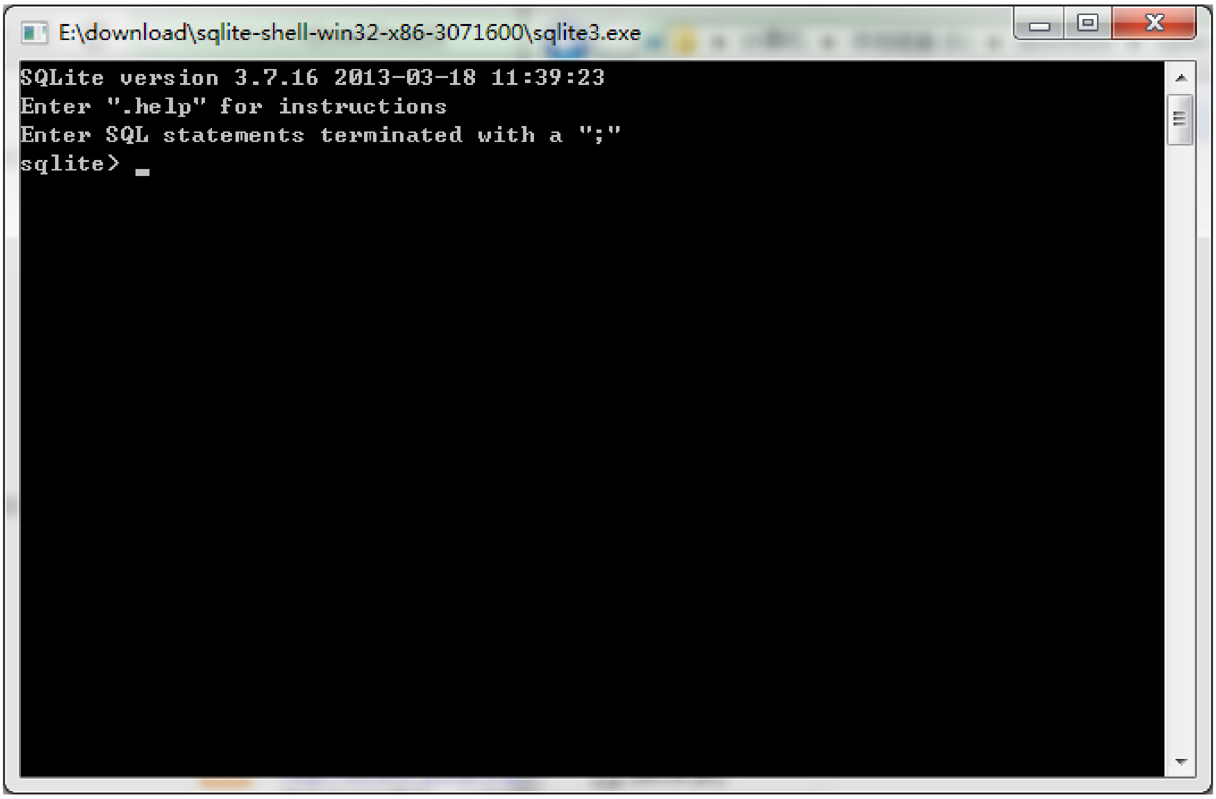
[7] Brief introduction of SQLite. http://www.sqlite.org/ (visited 2013-06-16)

interface. Some free tools for GUI are SQLite Administrator, SQLite Spy and sqlite-manager[8].



```
SQLite version 3.7.16 2013-03-18 11:39:23
Enter ".help" for instructions
Enter SQL statements terminated with a ";"
sqlite> _
```

Figure 2: A screenshot of SQLite3 command line interface (window operating system)

2.5.3. AChartEngine

AChartEngine is a charting software library for Android applications running on mobile phones, tablets and other Android devices that developed with Android SDK version 1.5 and up. Currently, more than 10 different kinds of chart are supported[9], including line chart which is used in the android prototype enclosed in this master thesis.

The reason why AChartEngine is needed here is that there is no existing java libraries for developing chart. Unlike the immediate use of SQLite APIs, a proper chart library needs either to be built or to be found for this thesis project. Since time is limited for this thesis work, and building a chart library is not an aim of this thesis work, the idea implementing a chart library was given up. After searching on the Internet and comparing several solutions of drawing charts, AChartEngine was chose for its good performance of charting display on the testing Android mobile phone for the project.

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[8] SQLite management tools. http://www.sqlite.org/cvstrac/wiki?p=ManagementTools (visited 2013-06-16)

[9] Brief introduction of AChartEngine. http://code.google.com/p/achartengine/ (visited 2013-06-16)

3. Method

This thesis was mainly organized by user-centered design method, together with software engineering principles, UML (use case), user interface design and test methodology. Specifically, different methods were selected and adopted in different phases, i.e. user study phase, design phase, implementation phase and test and evaluation phase.

3.1. User-centered design

User-centered design (USD) is a kind of design process in which the end users, who are the experts in their work, are actively participating. It is focus on usability in each link of the system life circle. According to Key Principles for User-centred Systems Design (Gulliksen, et al., 2003), some more of the key principles of user-centered design are listed here:

- Evolutionary systems development method should be used in USD;
- The design should be represented easily understood;
- Prototyping should be created and used to cooperate with the end users;
- Evaluation should be conducted in each phase of design and development;
- The design and development should be professional;
- Usability experts should also be involved.

In other words, user-centered design is cooperation between system developer and usability expert concentrating on users' need that provided by real end users during the entire design and development process incrementally. The aim is to create usable interactive systems, involving analysis, design, implementation, evaluation, etc., and thus it guarantees the users and usability are focused the entire system lifecycle.

In this thesis work, the real end users should be the operators working in electricity companies with ABB power transformers. Practically, the electrical operators from one Swedish electricity company, VB Energi, were chosen as the end user for this user-centered design. Furthermore, the people working in software architecture group, especially, my supervisor Jonas Brönmark, are the usability experts for this thesis project.

3.2. User study and information gathering

Six different approaches of information gathering were used during this diploma work, including checking user menu of ABB power transformer monitoring system, searching information on the Internet, interviewing experts in power transformer monitoring area, questionnaire survey to operators, investigating competitors and marker studying of mobile applications. The information gathered at this phase was used not only for evolving project plan, but for also software (mobile application) design, implementation, modification and evaluation.

3.2.1. Check user's menu

The user’s menu and technical guide of ABB transformer monitoring system are the written documents provided by ABB power transformer department in Sweden. The technical guide explains the hardware architecture of this monitoring system and installation guide, and the user’s menu illustrates the user interface of monitoring software, which is a website, from the user point of view.

The user’s menu of TRANSFORMER MONITORING SYSTEM is more interesting to this thesis delimitation, as the aim of this thesis work is to design and implement a mobile application with a better display of transformer status. However, as for the user’s menu, it is obvious that the user interface of current transformer monitoring system is designed for big screens, e.g. PC or monitors in control room, and mouse-based control.

Although the user’s menu is based on the design for current transformer monitoring system user interface (for big screen), it is a useful and valuable reference to this thesis work, since all the significant functionalities that need to be presented also by the mobile application are listed in this document. Nevertheless, not every feature on the website interface is necessary or can be displayed on the mobile devices, because of the limitation of these mobile devices, e.g. small size screen and touch screen. Therefore, some others approaches of information gathering are also need.

3.2.2. The Internet

In 21 century, collecting information via the Internet is one of the most efficient and effective way of comprehending knowledge that is not familiar with. Some open encyclopedias and academic thesis database are good resource helping understanding the area out of someone’s knowledge.

What is power transformer? How does it work? Why monitoring system is obliged to power transformers? ...

These questions could be unfamiliar to a person with computer science background. However, *power transformer, monitoring system and reliability* are the key words of this thesis. It is necessary to search for the definition and description of transformers with monitoring system and other related electrical devices and components.

3.2.3. Interviews

Interviews with power transformer monitoring specialists were conducted at ABB power transformer department in Ludvika, Sweden. In order to deeply investigate the architecture and functionality of current using transformer monitoring system, both hardware and information technology experts in TRANSFORMER MONITORING SYSTEM team were interviewed.

Interviews with operators in electricity company, performed at VB Energi in Ludvika, were also an indispensable part to information collection, because operators are the anticipate end user to the mobile app designed in this thesis work.

Interviews were not only conducted at the beginning, but also permeating the whole period of thesis work. The results were using for requirement analysis, new concept design, prototyping and evaluation.

3.2.4. Questionnaire

See Appendix 1.

3.2.5. Market study

The aim of market study is to select an appropriate mobile application platform for the functional prototype. The market study was carried out mainly by two methods. One is investigation of smartphone market share statistics published which is oriented global smartphone market. And the other one is market study within ABB Company and Electricity Company, in order to find out which smartphone operating system has the highest utilization among the target users.

3.3. Design phase

The design phase could be divided into two steps, i.e. use case creating and evolutionary prototyping. At the beginning, a preliminary use case was defined based on the result of user study and interview with power transformer experts, which included the common tasks of an operator's daily work.

On the next step, evolutionary prototyping[10] (Ozaki et al., 2003) was conducted to constantly refine and rebuild the use case. At the beginning of this thesis work, the understanding of the user requirements was limited, thus only the most well understood ones were built by low-fidelity prototyping. These preliminary design ideas were evaluated by user and expert to obtain feedback, modify the use case and add more features correspondingly. Moreover, this design and evaluation circle repeated during the whole design phase; accordingly, to the end of design phase, a relatively complete use case and high-fidelity prototype were accomplished, which were the base of the implementation. One advantage of evolutionary prototyping is that less time and effort was spent on ambiguous features, until them becoming clear.

3.4. Implementation phase

Due to the delimitation of thesis, the outcome of this project is a fully functional prototype of a transformer monitoring application for mobile devices that satisfies the operator's needs. The implementation phase involved in this thesis is the implementation of this functional prototype, which is separate from the user interface prototype built on design face.

Hardware selecting was conducted before the implementation phase. According to the result of market study and user interview, Android mobile phone was chosen to be the hardware platform for this functional prototype. At the end of 2011, the latest released Android phone

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[10] Brief introduction of evolutionary prototyping.

http://en.wikipedia.org/wiki/Software_prototyping#Evolutionary_prototyping (visited 2013-06-16) model was Galaxy Nexus with the first use of Android 4.0 Ice Cream Sandwich operating system and a 1280*720 high definition screen. Java programming language was used for implementation, and Eclipse with Android Developer Tools plug-in [11] was selected as Integrated Development Environment (IDE). Besides, the implementation also involved database development with SQLite database engine.

3.5. Testing and evaluation phase

In addition to the prototype evaluation and component testing during the design and implementation phase, release test and evaluation were conducted after accomplishment of the functional prototype. The aim of release test is to validate that the application meets its requirement of end user and emanate if every component of the application operates well together on the system level. Due to the limitation of time and resource, this test was first conducted by the developers, following the use case and test case accordingly. Afterwards, some transformer monitoring experts also conducted a “black-box” test on the functional prototype. Besides, scenario testing was adopted to assist the tester’s work.

A short video was recorded and projected to both end user and experts on the user evaluation phase, which presented the basic functions and brief use instructions. Moreover, an integrated scenario was also related to the user together with a demo presentation of the functional prototype. After the presentation, the user and experts were guided to think aloud in order to provide the real feeling and every detail suggestion of the application.

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[11] Android developer tools. http://developer.android.com/tools/index.html (visit 2013-06-16)

4. Result:

4.1. Results from user study

According to the user study, there are six major features that should be included to this concept of mobile application for power transformer monitoring and some additional ones that could be involved.

First of all, this application should support multiple transformers monitoring. That is to say, one operator can obtain status information of different transformers at the same time. It shows from the interview with both the transformer specialist and operators working in Electricity Company that usually one operator has the responsibility for several sites (transformer substation) within a certain area, and in one site there usually is more than one transformer. Therefore, it is necessary to have multi-monitoring solution for operator's daily work. However, due to the limitation of electrical system monitoring devices network and security issues, there is no proper communication method ready-made between the monitoring servicer side and client side. It is also can be a good discussion in this diploma work.

Secondly, dynamic data fetching should be used in the design concept of this mobile application. Power transformers are expensive electrical facilities and one significant part of the whole electrical grids. Prompt information or warning and alarm messages of the status of transformers are essential to the health of them, prolonging their service life and saving them from being destroyed in emergencies. Moreover, records or logs of historical data is also interesting to operators, as from which a skillful electrical engineer can easily diagnose the problem in one transformer. Even though, for a new operator with limited work experience, this historical data can be used to calculate by an auto-diagnostic program.

Thirdly, it should be localized to proper languages and units. Although, English is the most popular and widely used language in the world, and temperature unit Degrees Celsius is most of countries in Europe and Asia, localization of software is totally meaningless. On the contrary, it can be important and necessary to use. People can obtain more information and more quickly from the message written by their mother tongue or language they are familiar with than the same message written by a foreign language or secondary language. For another reason, not every operator has a good language skill with foreign languages, especially, when reading technical terminologies in foreign languages. Similarly, not everybody can converse Degrees Fahrenheit to Celsius. Besides, the use of appropriate language, unit and time format, can result in less pressure and relaxed feeling of operators daily work, which is good for operators health and working higher efficiently.

Next, direct communication with control room should be a valuable assistant. In typical Swedish electricity companies, control room is a core part of the whole monitoring system of power facilities. Usually, there are 3-5 operators working together in one group. And 2-3 operators are responsible for inspecting the status of transformers on site and other devices in power grid, while the other operators stay in central control room. When an operator on site or on the way to site notices some abnormal of transformer, he reports it immediately to his colleague staying in control room, before the final decision made in control room.

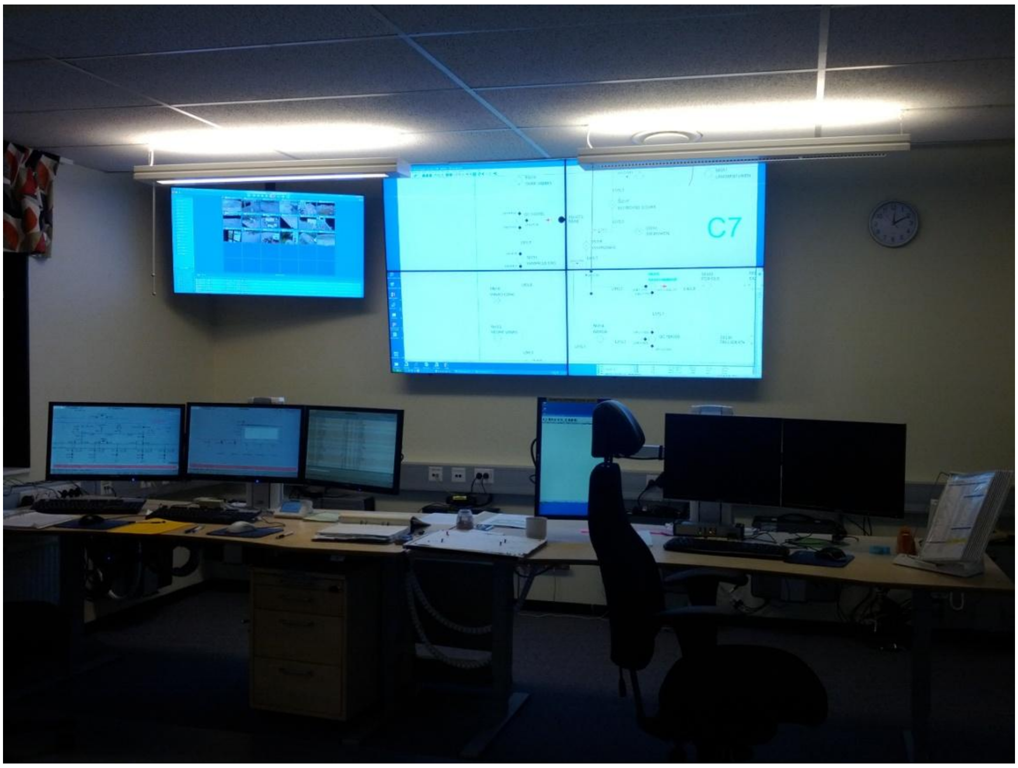


Figure 3: Photo of electricity company control room

Fifthly, user interface of transformer monitoring application should be consistent to the display of other devices monitored by operators. Taking error messages list for example, the operators are more familiar with checking error messages sorted by time descending order, because the same ordering method is used in all other devices.

Sixthly, security issue is one topic widely discussed amount all the interviewers, since power transformer is extremely critical to the whole electrical grid. In transformer monitoring system, this security is reflected in the information safety during the transmission of monitoring data. *Who can access to the monitoring database*, and *how to guarantee the authority using correctly*, are two key questions need to be taken care of and discussed when designing the monitoring application on mobile devices.

4.2. Use case

A use case describes a sequence of interaction between actors and system to accomplish a particular goal, which is widely used in system analysis to identify system requirements. The actor here can be a human user or an external system. Typically, a use case should include the following sections (Williams, 2003; Repond, Dugerdil, & Descombes, 2011):

Table 1: Sections and description of use case table

Use case ID	A numerical identifier to specific use case.
Use case name	The name of the use case, indicating user’s intention.
Use case description	Several sentences summarize the use case and explain concepts.
Pre-condition	A list of conditions that must be met before the action of the use case.
Post-condition	A list of conditions that must be reached after the action of the use case.
Basic flow	A sequence of interactions between the actor and system that follows the main logic path.
Alternate flows	An alternate logic path that could be resulted by the use case, e.g. an exception or an errors situation.
Expected result	The acceptable results of the use case.

In this case, actor is the operators and system is the mobile application. And the interaction between them shows in the UML use case diagram (Booch, Rumbaugh, & Jacobson, 1998; Ambler, 2005) below.

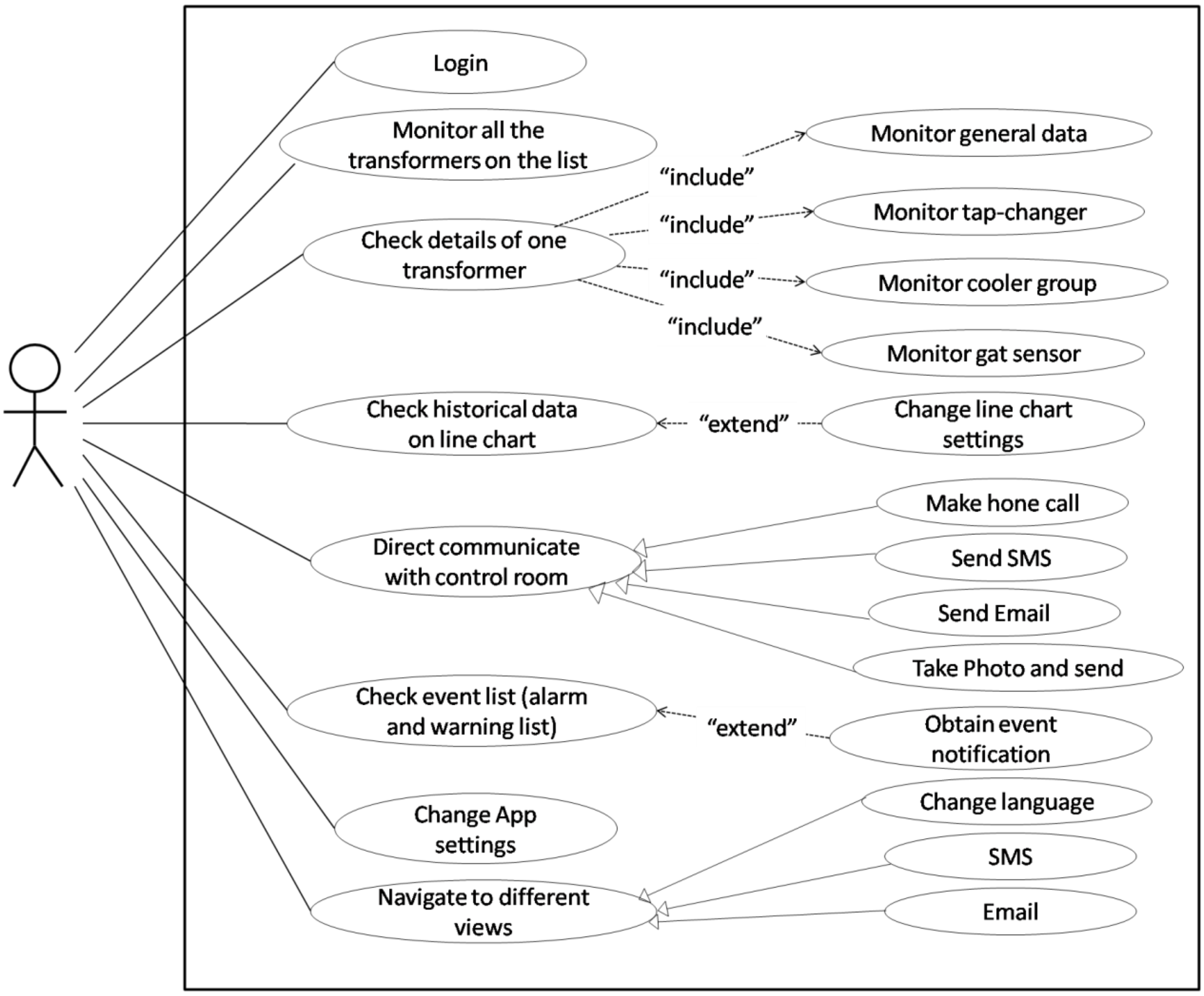

Login
Monitor all the transformers on the list
Check details of one transformer
"include"
"include"
"include"
"include"
Monitor general data
Monitor tap-changer
Monitor cooler group
Monitor gat sensor
Check historical data on line chart
"extend"
Change line chart settings
Direct communicate with control room
Make hone call
Send SMS
Send Email
Take Photo and send
Check event list (alarm and warning list)
"extend"
Obtain event notification
Change App settings
Change language
SMS
Email
Navigate to different views

Figure 4: UML use case diagram for transformer mobile monitoring system application

The information in this use case is intended for operators.

Table 2: Use case for login

Use case ID	UC-1
Use case name	Log-in on the mobile monitoring application
Use case description	An operator should be able to login on the mobile monitoring application via using his or her own user name and password. Users without any authority should not be allowed to login on this application.
Precondition	The operator has this App on his or her smart phone, before clicking on the shortcut icon of this App.
Postcondition	The operator successfully logs in on this App and start monitoring the transformers on his or her responsibility.
Basic flow	1. The operator enters his or her username and password on the login

	page. 2. The operator clicks on Sign in button
Alternate flows	3. The operator clicks on Exit button, quitting the monitoring App. 4. Username and password can be saved by marking the check box Stay signed in.
Expected result	1. The operator logs in on the App successfully with the correct user account. 2. If the username or password is not correct, login should be refused, with showing a message box. 3. If the check box is marked, the operator should not need to enter the username and password when he or she logs in next time.

Table 3: Use case for transformer overview list

Use case ID	UC-2
Use case name	Check the status of all transformers in the list
Use case description	The operator should be able to monitor several transformers categorized by several sub-stations. The identification of transformer and the current working condition should be obviously displayed to the operator.
Precondition	The operator logs in on the App.
Postcondition	After examining status of all the transformers, the operator moves on to checking detailed monitoring information for one transformer that he or she is interested in.
Basic flow	1. The operator checks all the transformers in the list. 2. The operator is navigated to one transformer directly from the transformer list by one click.
Alternate flows	3. If the list of transformer is longer than length of the smart phone, the operator should be able to check the transformer at the end of the list by sliding the transformer list. 4. The composition of this transformer list could be altered by the operator himself or herself, since different operators is responsible to different transformers.
Expected result	1. The operator obtains the working condition for each transformer.

Table 4: Use case for real-time status monitoring of one transformer

Use case ID	UC-3
Use case name	Check detailed monitoring information of one transformer
Use case description	The operator should be able to examine all the significant parameters and data from censors in power transformer, which should be dynamic and fetching from time to time automatically.
Precondition	1. There is an access to network, e.g. via 3/4G or wifi. 2. The communication with monitoring server works properly.
Postcondition	1. One or more abnormal conditions in this current transformer are discovered. (The operator could take measures on the transformer, or report it to Control Room.)
Basic flow	1. The operator enters the page presenting transformer general condition and most important temperature page. 2. The operator goes to a specific page for examining condition information of tap-changer by clicking one icon. 3. The operator moves to a specific page for examining condition information of Cooler group by clicking one icon. 4. The operator moves to a specific page for examining condition information of gas sensor by clicking one icon.
Alternate flows	5. The operator can easily go to check different groups of transformer condition data via a navigation menu or icon list.
Expected result	1. The operator could easily be navigated to appropriate condition data group and check all of them. 2. If there is an abnormal event happening, the operator could be able to find it and do some investigation.

Table 5: Use case for historical data chart

Use case ID	UC-4
Use case name	Check historical data from a chart
Use case description	The operator should be able to check the historical data of some of the most important transformer condition data, for example, the load of transformer and tap-changer temperature. The historical data should be showed in one line chart with at most two different y-axis for using two

	units, but time should always be used for x-axis, if more than one status variables associated to each other need to be displayed in the same chart.
Precondition	1. The operator checks the page of examining transformer status and monitoring data for one specific transformer.
Postcondition	1. One or more abnormal conditions in historical data for this current transformer are discovered. (The operator could take measures on the transformer, or report it to Control Room.)
Basic flow	1. The operator clicks on one icon or link displayed on monitoring information page.
Alternate flows	N/A
Expected result	After clicking on the specific icon, the page turns to the line chart presenting historical data.

Table 6: Use case for chart display setting

Use case ID	UC-5
Use case name	Change settings of the chart’s display
Use case description	The operator should be able to change the settings of the chart showing historical data for enabling or disabling the display of some status variables, changing line colors and setting time interval.
Precondition	1. The operator checks the page of historical data.
Postcondition	1. The line chart display has been altered based on the new settings.
Basic flow	1. The operator clicks on the setting icon on historical data page, before the page changing to chart setting view. 2. The operator marks the status variables that he’s interested with, and chooses line colors for each variable from the color picker. 3. The operator clicks on SAVE button to save the new setting and go back to historical data chart page.
Alternate flows	4. After step 1 and/or 2 listing in basic flow, if the operator clicks on CANCLE button, the page will go back to historical data chart without any change.
Expected result	The line chart historical data displays with the new settings which is latest set by operator.

Table 7: Use case for direct communication with control room

Use case ID	UC-6
Use case name	Direct communication with control room
Use case description	The operator should be able to communicate with control room directly inside or one part of the App, when some emergency happens or transformer routine status report. That is to say, the operator doesn’t need to quit this App before communicating with his or her colleagues working in control room. This communication can through several approaches, such as phone call, SMS, email and/or sending photos.
Precondition	1. The operator logs in to this transformer monitoring mobile App and needs to communicate with control room.
Postcondition	1. The operator contacts control room successfully, and continuously checks the other monitoring information through this App.
Basic flow	1. Clicking on the icon for direct communication, the App turns into corresponding pages. 2. As for the phone call page, the operator could choose from an embedded phone address book with all the contacts in control rooms and/or ABB after-sell service hotline. 3. In email or SMS page, the operator could write text description about the transformer status and send it to control room. 4. As for photo communication function, the operator could take a picture of transformer, and send it together with some short description to control room.
Alternate flows	N/A
Expected result	The operator contacts his colleagues successfully via direct communication through this App.

Table 8: Use case for event list (alarm and warning list)

Use case ID	UC-7
Use case name	Alarm and warning list
Use case description	The operator should be able to check all the alarm and warning information of transformer status, which is called event in transformer diagnose system saved in transformer monitoring database.

Precondition	1. The operator logs in on the mobile App. 2. There is at least one alarm or warning event happening, and recorded in the database.
Postcondition	1. A list of active events of the transformer displays to the operator. 2. Detailed event information shows, for example, event start time, event name and severity.
Basic flow	1. The operator clicks on event list icon on navigation bar or main menu of this App. It shows a list of alarm, warning and other kinds of event classified by event type in time reverse order. The events displayed here in the list are only with simple transformer identification and timing information. 2. Clicking on the event name, the App turns into a page showing event information dentally.
Alternate flows	3. The operator has another approach to enter event list page. After new event occurred, the operator could clicks on event notification displayed in the notification area at the top of the screen out side App. This is introduced in another use case *Event Notification*.
Expected result	The operator examines event list and detailed event information successfully.

Table 9: Use case for event notification

Use case ID	UC-8
Use case name	Event notification
Use case description	A notification is a kind of message that can be displayed outside App itself but in the notification area at the top of the screen. The operator could be able to obtain the notifications presenting event information when some new events happen. This notification could accompany with sound and/or vibration.
Precondition	1. This mobile transformer monitoring application should be logged in, running foreground or background.
Postcondition	1. The transformer event page is displayed to the operator.
Basic flow	1. One or more transformer event notifications appear in the notification area of the phone. 2. The operator opens the notification drawer to see details of those

	notifications, including transformer identification, serious level and short description of the events. 3. The view of App turns to *Event List* page (warning and alarm list), and event disappears from the notification area. The operator can see the new events on the event list and check more details by clicking on one specific event name.
Alternate flows	4. On notification drawer page, the operator clicks on CLEAR button, removing the notification from notification area. As for this situation, the event list view doesn't appear on the screen.
Expected result	The operator examines the status of newly happed event successfully.

Table 10: Use case for application settings and localization

Use case ID	UC-9
Use case name	Settings of the App and localization
Use case description	The operator could be able to set their preference and modify the display of some features of this mobile application, for example, changing the language to his or her native language, changing temperature unit familiar one, and changing date/time format to official one in his or her country.
Precondition	1. The operator logs in on the transformer monitoring mobile App, and turns to *Settings* view by clicking an icon for through navigation bar.
Postcondition	1. The view turns back to the previous page that the operator last checks.
Basic flow	1. The operator opens *Main Settings* page of the app, and chooses the one setting he decides to change from the list. This setting could be display language, temperature unit, time format, etc. 2. As for the language setting, the operator could choose from a list of predefined languages, usually including English and his or her native language. After saving the change, the view turns back to *Main Setting* page. 3. As for the temperature unit setting, the operator could choose between Degrees Celsius and Fahrenheit by clicking on the name of unit. After saving the change, the view turns back to *Main Setting* page. 4. As for the time format, the operator could choose amount DDMMYY, MMDDYY, YYMMDD, etc. by clicking on the format. After saving the change, the view turns back to *Main Setting* page.

Alternate flows	5. Clicking on RETURN button, the operator could turn back to other views without any setting changes.
Expected result	The operator changes application settings successfully.

Table 11: Use case for application navigation

Use case ID	CU-10
Use case name	Navigation
Use case description	The operator could be able to navigate to different views via a menu page, a navigation bar and/or buttons, e.g. back button on the phone.
Precondition	1. The operator logs in on the App.
Postcondition	1. The app display turns to corresponding view as operator requests.
Basic flow	1. The operator enters menu page by clicking on an icon or through MENU button on the phone, and sees a list of views that can be navigated directly from the main menu. 2. The operator clicks on the name or icon of the view requested.
Alternate flows	3. Clicking on CANCEL button on menu page or BACK button on the phone, the operator could turn back to the page latest visited.
Expected result	The operator navigates to the proper view he requires.

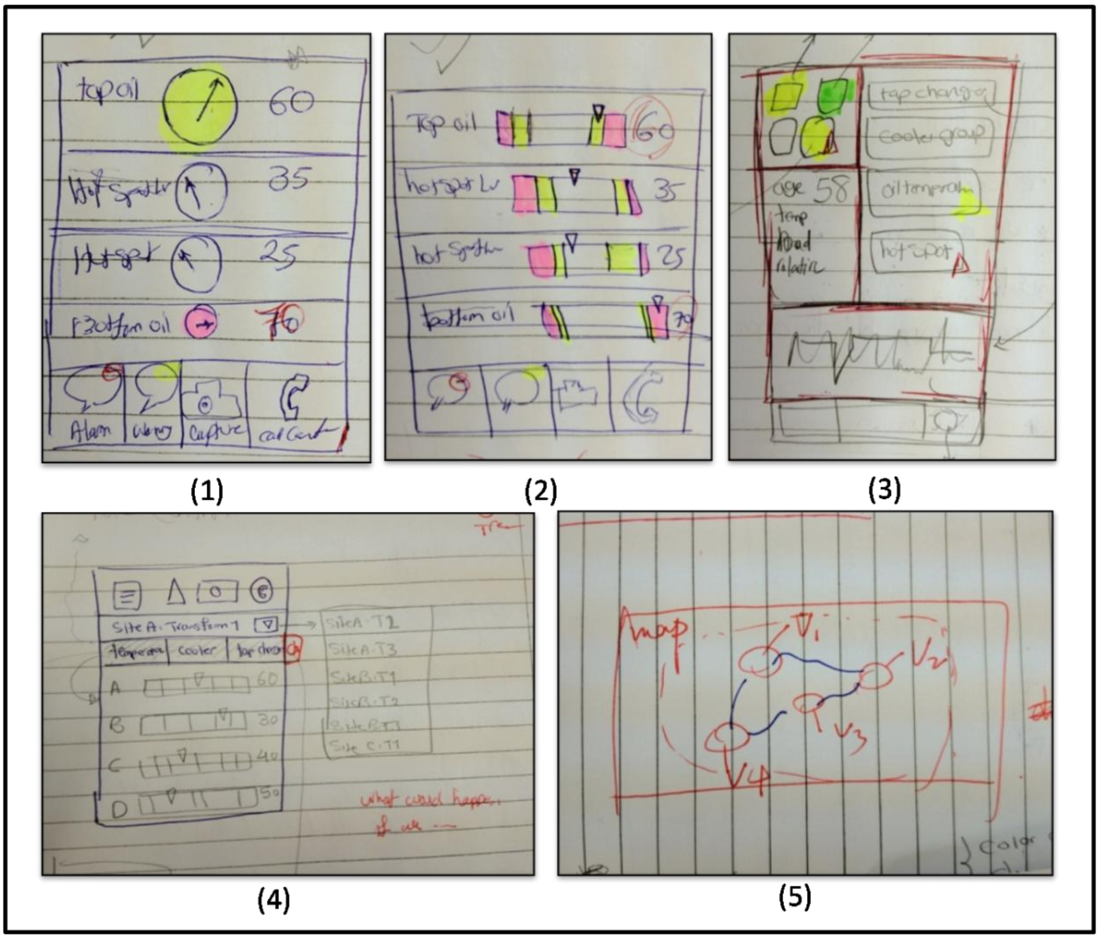
4.3. User interface design (sketches -low fidelity- high fidelity)

4.3.1. Low-fidelity prototype

After the use case definition and analyses, low-fidelity prototype was created to evaluate the usability of use case and provide the end-user, the operator, a direct experience with user interface. This low-fidelity prototyping could be divided into 2 steps, i.e. sketches and mock-up design.

The paper and pen based sketches is the simple, cheap and effective approach of prototyping (Sommerville, 2006, P382) which can be accessed without any training or special devices and software. Moreover, it is convenient for the communication between developers in the very early process.

Figure 5 shows some sketches drawn for the user interface design of this mobile application at the end of the first month. The analog meter design (1) and linear meter with 2-side limitations (2) were designed for presenting transformer status parameters, and the navigation quick bar was at the bottom of this view. In the sketch of transformer overview page (3), a transformer list, several the most significant monitoring items and a brief historical data line chart were displayed together in the same view at that time. Sketch 4 shows a design of fast navigation between different transformers monitoring pages via a dope-down menu. Besides, displaying transformers or sites geographical location on the map (5) was also a substitute of transformer list page.



(1) (2) (3)

(4) (5)

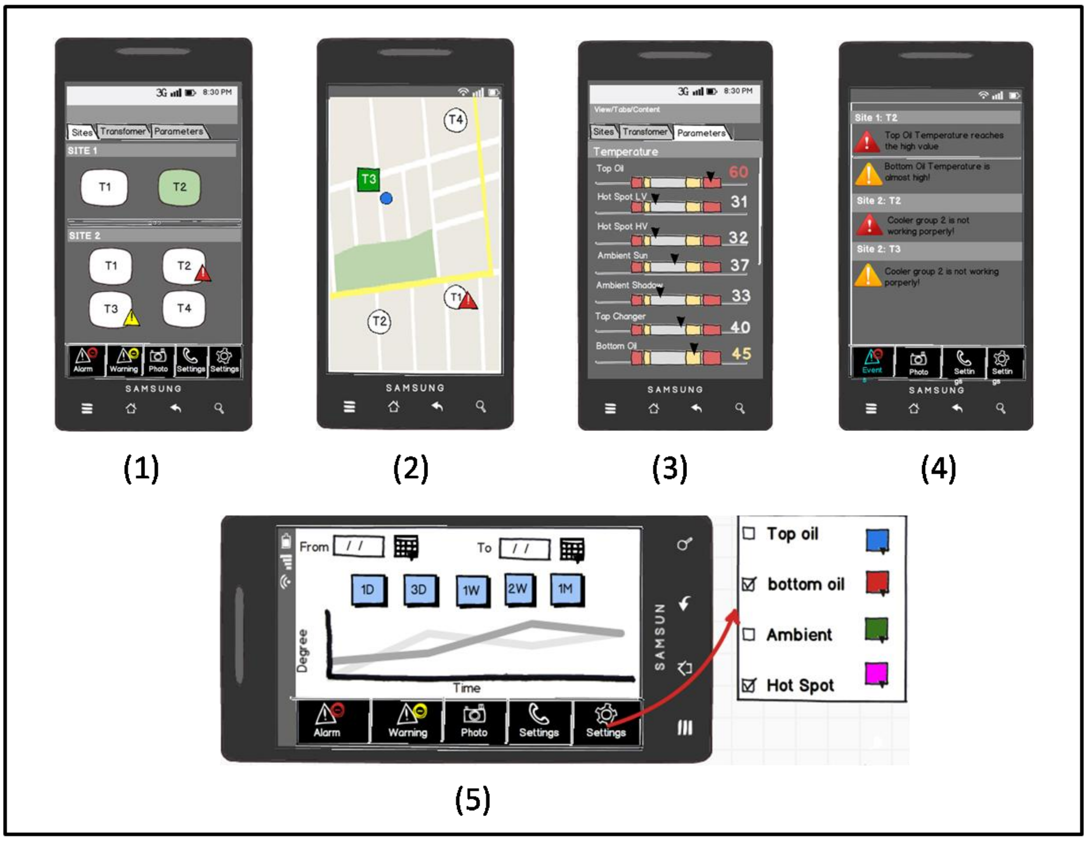
Figure 5: Paper and pen based sketches

These sketches were the first version of interface design. Although they looked very different from the functional demo presented at the end of the whole thesis work, they were significant and obligatory in the development process.

After discussing with end-user and other potential users with the sketches, some designs were changed and some other good ideas came up. For example, the analog display had been removed, since the operators though they would never use this feature due to a couple of reasons. First of all, there was no similar user interface at any part of monitoring system that they daily worked with; that is to say, analog design is inconsistent to other designs. So they were unfamiliar with reading analog meters. Moreover, because the analog icon itself took more space than the linear meter, less monitoring parameters could be displayed in the same view, which would lead more operations on touch screen for scrolling and switching pages.

Most importantly, it was difficult to present the warning and alarming limitation on analog meters, which was indispensible to monitoring display.

With those modifications and some new inspirations, the next step of low-fidelity prototype was designed via Balsamic mockups tool[12] to obtain a better view approaching a real application's user interface.



Site 1: T2

Top Oil Temperature reaches the high value

Bottom Oil Temperature is almost high!

Site 2: T2

Cooler group 2 is not working porperly!

Site 2: T3

Cooler group 2 is not working porperly!

Figure 6: low-fidelity prototype by Basalmiq mockup

Figure 6 shows some mockup screenshot for the user interface design of this transformer monitoring mobile application. Some of them inherited from the sketches with more new features, such as mockup picture (2) and (3) are from sketch (5) and (2) in figure 5. As it is shown in mockup screenshot (3), tabs were adding for switching between temperature monitoring page and other views. At the same time, more color coding signs were attached to the geography location of the transformers (2), for example, the red triangle representing for alarm situation, and tiny bull dot showing the operator's current location. In this step low-fidelity prototype, sketch (3) was spitted into two separate function page, i.e. transformer list (1) and historical data line chart (5) in figure 6, because there was too much information and the page was too crowded in the previous design. Besides, mockup picture (4) shows the warning and alarm list page for all the transformers' events.

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[12] Brief introduction of Balsamic mockups tool. http://www.balsamiq.com/ (visited 2013-06-16)

Although Basalmiq mockup pictures has a better performance presenting different features of interface design than pencil and pen based sketches in some aspects, it still has its own limitations. Therefore high-fidelity user interface prototype and functional prototype of the application were carried out in the following work.

4.3.2. GUI layout, functionality and APP components

Graphical user interface is one of the most important sections to the design of this power transformer monitoring mobile App, which goal is to display the monitoring data to operators in the proper way that is clear, simple and efficient. As the same time, the interaction between mobile App and operator should be easy to master even without any learning or reading users' manual.

Different layouts are the basic components of graphical user interface for the mobile application. As from android, there are 5 basic layouts recommend by android developers API Guides nowadays, i.e. linear layout, relative layout, web view and list view, grid view with adapter. (There were more in history, but these five are the most popular and recommend to the developers by Android guide line.) By using the combination of those layouts together with other kinds of basic UI components, more practical user interface were constructed to this mobile application. In this chapter some of the typical GUI designs would be illustrated.

4.3.2.1. Customized listview

Listview is a kind of view group displays a list of scrollable items. Using a List Adapter, the list items, usually from a source such as an array or database query, are automatically inserted to the list.[13] The simplest list is only a list of test strings. In order to develop a more attractive user interface, customized listviews were designed and implemented to this mobile application.

4.3.2.2. Listview with different icons

Adding different icons to each list items is the most common and effective customized listview. The icons can show the distinctions between items more intuitively than just text descriptions. List view with Icons is not only used in Android mobile application, but also almost everywhere on the current PC operating system and software. Two examples are the starting menu of Microsoft office operating system and menu page of Microsoft Word.

Icon listview design was used in several places of this mobile application, and here is an example of menu page. As it shows on the figure 7, there is an icon in front of each line of text, which clearly indicates what the following text represents for. All of this icon images are abstracted from the real image of according object, so the user can understand them only using his or her perception from daily life and work.

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[13] Listview. http://developer.android.com/guide/topics/ui/layout/listview.html (visited 2013-06-16)

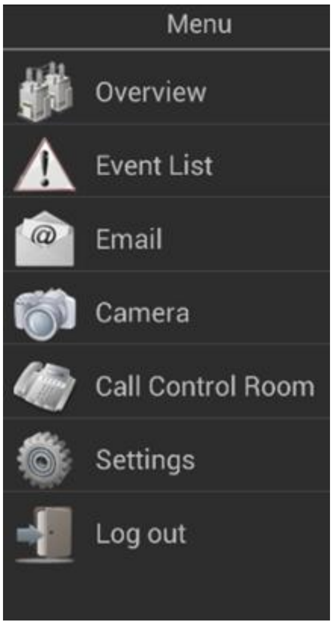

Figure 7: Listview with different icons for menu page design

4.3.2.3. Listview with separators

Although icon listview is a strongly supplement of traditional text listview, it is not sufficient in some situation, especially for some large lists. Separators could be an approach to improve the usability. Take phone address book for example, the contacts are categorized by the fist letter of their names, so that it is easier for users to find out one specific contact from thousands of them.

As for the design of this mobile application, listview with separators is also applied to many pages.

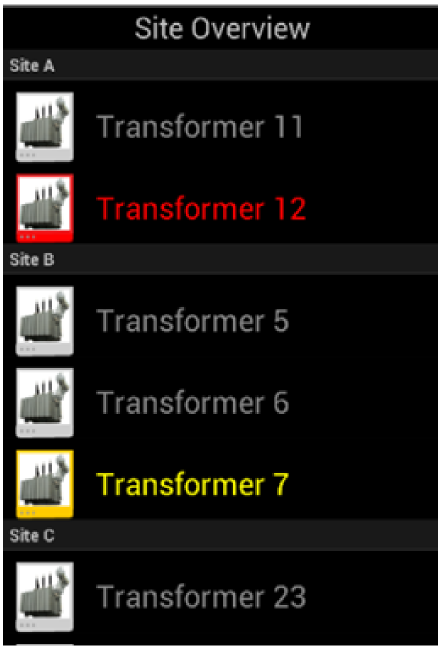

Figure 8: Listview with separators for transformer list design

According to user case UC-2, the display of power transformer should be classified by sites (transformer substation) name, since transformers belonging to one site are geographically located at the same place. It is convenient for the operator to visit them together at the same time.

4.3.2.4. Customized Seekbar

Similar as progressbar[14], Seekbar[15] can easily indicate the progress in one operation, but it has one extra draggable thumb on the bar. Usually, the draggable thumb can be touched and dragged to the left or right side of the bar to set the current progress level. However, the Seekbar can also be customized by disabling the draggable thumb, and alerting the display of the bar, in order to present more information in one Seekbar.

As shown in the figure below, the bar is divided into 3 parts, i.e. blue, gray and black, which represent 3 different state of “Hot-Spot LV temperature”, an important monitoring item of power transformer. At the same time, the thumb, which is an arrow in this picture, was disabled and only controlled by the monitoring data getting from servicer side. When the thumb lays on the blue part of the bar, it turns gray, which means this monitoring data is in the normal scope. If this monitoring temperature is higher than the alarm level, the thumb turns red and lays on the black part, accompanying with color change of the texts to red. It is a warning situation shown in this figure below.

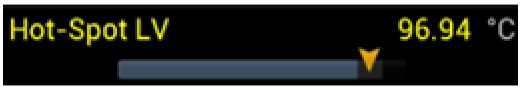

Figure 9: Customized Seekbar design

4.3.2.5. Gridview with different icon

Compared with ListView, the difference of GridView[16] is it displays items in a two-dimensional, scrollable grid instead of one-dimensional. By using similar listadaper, the grid items can be automatically inserted to the layout. This is applied in this mobile application for a color picker mentioned in use cage UC-5.

This color picker is used for setting the line color displayed in historical data chart. After clicking on one color, the App turns back to the previous page with the new color setting.

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[14] Android ProgressBar. http://developer.android.com/reference/android/widget/ProgressBar.html (visited 2013-06-16)

[15] Android SeekBar. http://developer.android.com/reference/android/widget/SeekBar.html (visited 2013-06-16)

[16] Android GridView http://developer.android.com/guide/topics/ui/layout/gridview.html (visited 2013-06-16)

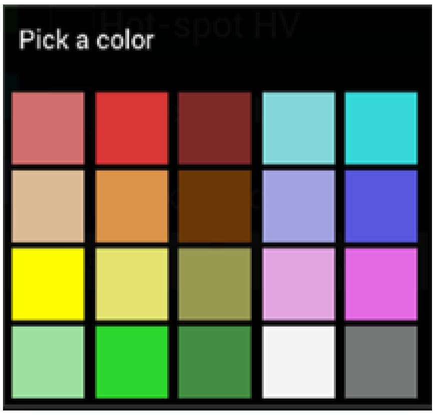


Figure 10: Gridview with different icon for color picker design

4.3.2.6. Quick bar

Another navigation measure is the shortcut of a couple of icons list in quick bar at the top of each page. Because of the limit space in the quick bar, not all of the functional activities can be navigated by an icon list, but only the most frequently used and the ones for emergency need to be added there.

As shown in figure 11 below, there are only 5 icons displaying in the quick bar, which can be divided into 3 categories. The first one is using for controlling sliding menu; and the second one represents the event list, with a small digit in a red circle showing the number of activated alarm and warning events. The remaining there are the three ways of direct communication with control room, i.e. via email, photo message and phone call. It is obvious that sliding menu button is the most frequently used and should be accessed from each view.

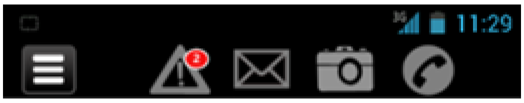


Figure 11: Quick bar design

4.3.2.7. Preference settings with images and checkbox

Some features and displays of a mobile application can be modified by setting user preference, and the new characteristic after modification should be remembered automatically and permanently. That is to say, when the application restarted, it should present the new attributes as the last setting by the user. List, check box and edit text are the most commonly used approaches for setting user preferences. However, in some situation, they do not accommodate every need, or is not optimal to present some specific features. Therefore, some customized preference settings should be designed for those needs and features, according to the specification of developing each android mobile application.

The figure below shows the setting for historical data chart. The purple square to the left side represents the line color of “Peak Load” displaying in the chart. By clicking on it, the user can choose another color from the pop-up color picker and save it as his preference to this particular line color. Meanwhile, the checkbox next to the purple square is used for setting whether this “Peak Load” line is displayed on the chart or not. In this way, two different settings regarding historical data chart are combined together in the same view, which simplifies the operational process to the user.

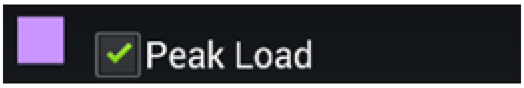


Figure 12: Customized preference settings design

4.3.2.8. Color coding and avoid using unnecessary colors

Appropriately using colors can not only promote its visual expression, but also transmit specific information to the user. For example, a black and white non-smoking poster uses a red cross on it to voice smoking is strictly forbidden here. It is obvious that the red cross is highlighted for presenting the meaning NO. However, if colors are overused, the user would miss this information among the colorful images. Avoiding unnecessary colors is one principle of user interface design.

There are only three colors are using in this application, except historical chart page. Gray represents for normal condition, while yellow and red represent for warning and alarm situation of the transformer respectively. So the abnormal events could easily be detected by the operator through this mobile application. As for the historical data chart view, the reason why more colors are needed is to display different lines in the same chart. Besides, the color used for lines are greatly different from each other and background color, so that the operator can distinguish the difference even though they use their smart in a poor lighting situation.

4.3.3. High-fidelity prototype & final design

4.3.3.1. Database

Database is used for saving user login account and transformer list with identification information for each transformer, e.g. transformer ID, sub-station ID and IP address of TRANSFORMER MONITORING SYSTEM box. The reason it needed a database in this mobile application, which was client side, was to allow multiple user login and multiple monitoring transformer. According to the user study and information gathering, one operator is responsible for at list two sites (sub-station), and in each sites usually there are more than one transformer. Moreover, there are normally several operators in one electrical cooperate; therefore, it is necessary to setup one login account for each operator.

4.3.3.2. Splash page and log-in page

The aim of using splash page in the thesis project is to inform the user that this APP is loading now, and to present company and product information by this chance. It will disappear after loading process finishing, normally 3-5 seconds. Therefore, the splash should not contain too much information, or too complicated pictures, but use the images have the identical style with the company's image and keep consistency with the other products in the same series.

This figure below is the design of splash page for this mobile app.

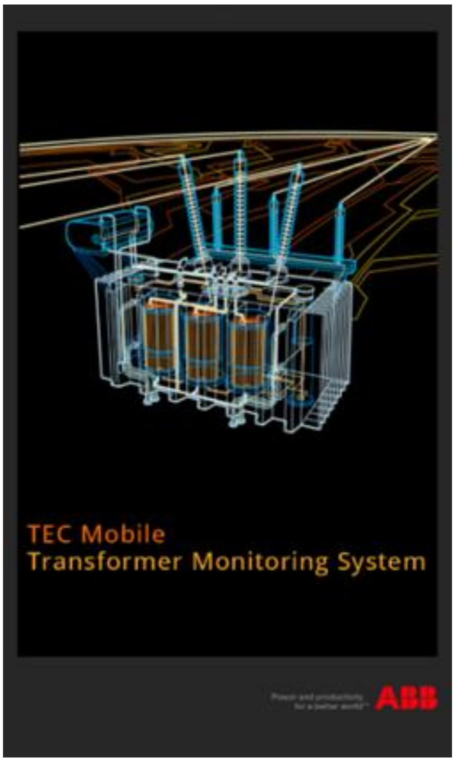


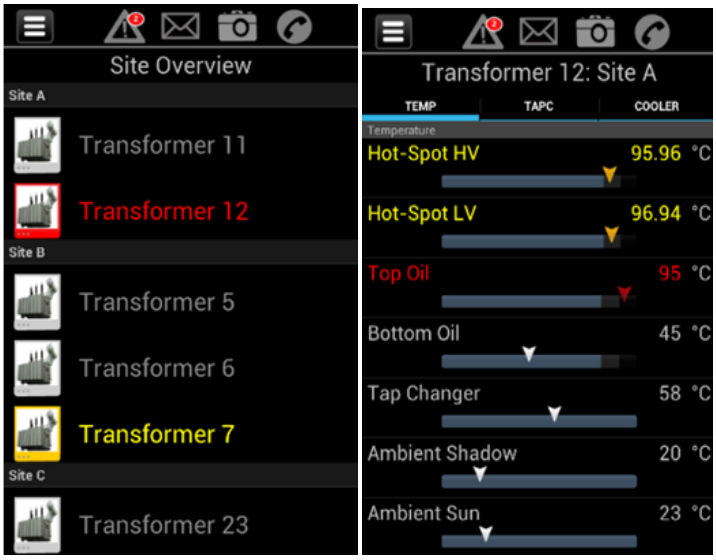
Figure 13: Splash page high-fidelity prototype design

The image used here is for ABB power transformer projects, so it is proper for this transformer monitoring mobile app. Moreover, the position, color and font are the same as the other ABB products advertisements and videos. Most important, ABB AB owns the copyright of this image, so it is free to use this commercial picture for ABB's product.

When splash page disappears, a login page shows on the screen. According to user study and information gathering, login page is needed to guarantee the data communication security, as every user could login onto the mobile app via his or her own user account.

4.3.3.3. Transformer list and multi-transformer monitoring

Transformer list page shows a list of transformers grouped by different sites where the transformer locates at. In the demo, the transformers are just named by ID number and sites are named by letters, however, they can be changed to appropriate name that user used for their power transformers and sub-station site name. What is more, the images can also be changed to the ones can easily identify each transformer in the list, for example photos of transformers. It is one of the most interesting part of this design that the use of color coding here, i.e. gray is used for normal transformer, yellow shows warning status of transformer and red shows some errors exist in that transformer. Therefore, the operator can easily find the transformer needed to check and take care of. If the list is longer than the length of smart phone screen, this list can be screw up and down.



Hot-Spot HV 95.96 °C

Hot-Spot LV 96.94 °C

Top Oil 95 °C

Bottom Oil 45 °C

Tap Changer 58 °C

Ambient Shadow 20 °C

Ambient Sun 23 °C

Figure 14: Transformer list and transformer status high-fidelity design

4.3.3.4. Transformer status and tab view

After clicking on one transformer, a list of the most essential monitoring temperatures and general information, such as aging and load of the transformer, are presented on the Transformer page “TEMP” page. On the top of this page (below quick buttons), there is the name of the current transformer the operator checking for, together with the site name where it located in. These names are the same as the ones used on transformer list page, in order to keep the consistency with each page of this mobile app. There are three tabs named “TEMP”, ”TAPC” and “COOLER” under the transformer name and its site name. “TEMP” tab is showed by default. By clicking on the names of these three tabs, the operator can easily switch among these three sub-pages and check three categories of monitoring information of one transformer. Besides “TEMP” tab, which explained above, “TAPC” tab contains the variables regarding tap-changer part of transformer, while “COOLER” tab is about the status of cooler groups of one transformer. Tap-changer and cooler group are two of the most significant components of power transformers, existing in almost all of them, and relative independence from the other parts of the transformer. Moreover, the status and variables descript these two components are indispensable for transformer monitoring. Therefore, two separated tabs other than general information tab are using on transformer page. Besides, if there are gas-censers in a power transformer, it is also need to add a new tab presenting all the information regarding gas.

4.3.3.5. Chart

Historical data chart shows the trend of important condition data, such as top oil temperature and load. A group of related trends were displayed in one chart with maximum two y-axis for two different units and an x-axis for time. Above the chart itself, there are several shortcuts, i.e. 1D, 2D, 1W, 2W and 1M, representing 1 day, 2 days, 1 week, 2 weeks and 1 month. When pressing one of these buttons, the line chart should zoom in or out to the corresponding time interval. Besides, there is a setting button on the right-bottom corner for changing line chart display settings as user's preference.

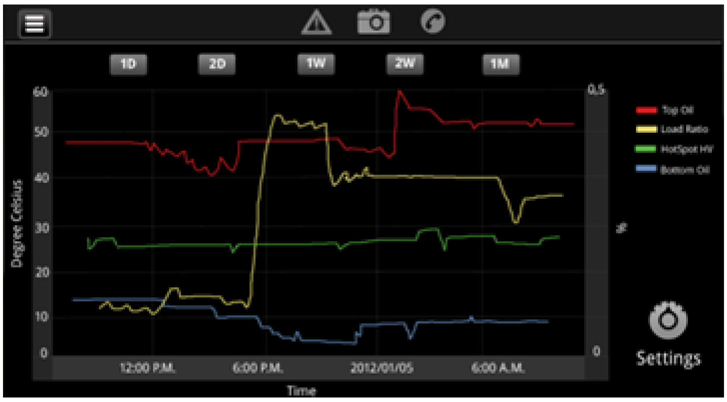
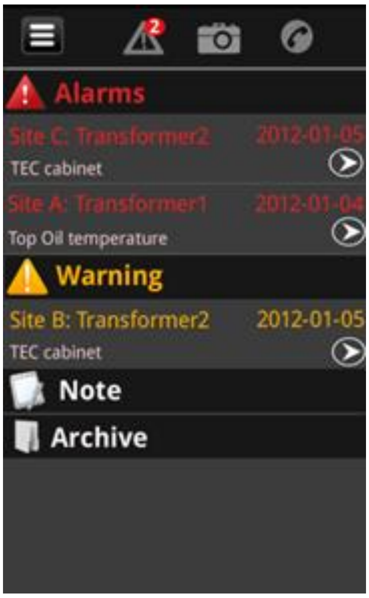


Figure 15: Historical data chart high-fidelity design

4.3.3.6. Alarm and warning list

Event list (Alarm and warning list) presents a list exception report messages collected from all the monitored transformers in different sites (transformer substation). In event list page, only the transformer ID, site ID, brief description, and start time of the currently active event are displayed. By clicking each event record, the users should turn to another page showing more detailed event information. Only three different colors are used for alarm and warning list, i.e. red for alarms, yellow for warnings and gray for other information. The event list page could be access to by clicking on the triangle sign with exclamation mark inside, and the digit at the top-right corner of the sign illustrates the number of active alarms and warnings.



Site C: Transformer2 2012-01-05
TEC cabinet

Site A: Transformer1 2012-01-04
Top Oil temperature

Site B: Transformer2 2012-01-05
TEC cabinet

Figure 16: Alarm and warning list high-fidelity design

4.3.3.7. Sliding menu

Sliding menu is increasingly popular nowadays, which is widely used in a couple of famous mobile applications such as Facebook. By clicking on the icon at the top left corner of each view of the application, the current view slides to the right part of the screen, but stops before moving outside the screen entirely, and the menu view appears on the left side of the screen. In general, it is a combination of animation and change between two different views. The benefit of sliding menu is both the menu view and apart of the previous functional page can be visible at the same time, and the switch between them just needs one click. Moreover the sliding process itself is a good interaction with users.

In this mobile application, sliding menu is also one indispensable of the whole concept design. All the functional activities can be navigated by this sliding menu.

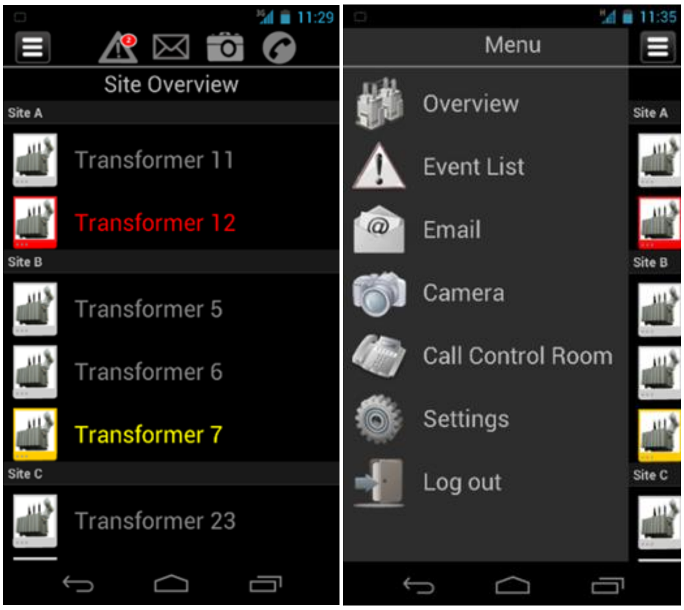
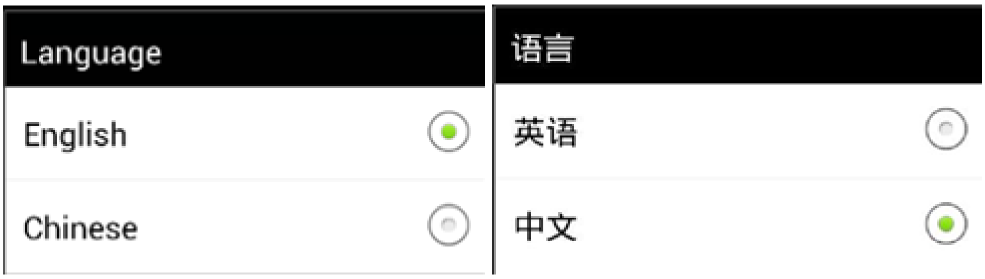


Figure 17: Sliding menu design

4.3.3.8. Settings

According to the result of user study, option settings function, especially the language localization, should be designed and developed in this transformer monitoring application. The design these settings should be as simple as possible, but some details must be handled carefully. Taking language setting for example, the operator can switching between languages by simply clicking on one radio button representing the language he prefers. Figure18 shows two screenshots under English display mode and Chinese display mode respectively, and it is obvious that any English word should be avoid appearing under English display mode.



Language

English ●

Chinese ○

语言

英语 ○

中文 ●

Figure 18: Language settings design

4.4. Implementation functional prototype demo

4.4.1. Smartphone operating system choosing

According to Gartner[17], in the 3rd quarter of 2011, Android earned 52.5% market share, leading the smartphone sales market, while the market share of Symbian, iOS were 16.9% and 15.0% in the same period[18] (Gartner, 2011). However, in the 3rd quarter of 2010, Android only had 25.5% smartphone sales to end users, showing a fast growth of Android OS market.

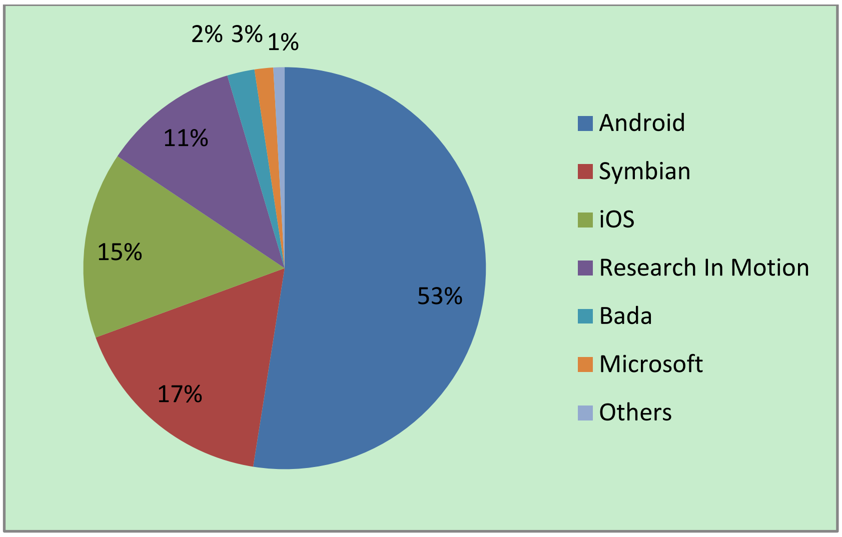


Figure 19: Worldwide mobile device sales to end users by vendor in 3Q2011, from Gartner

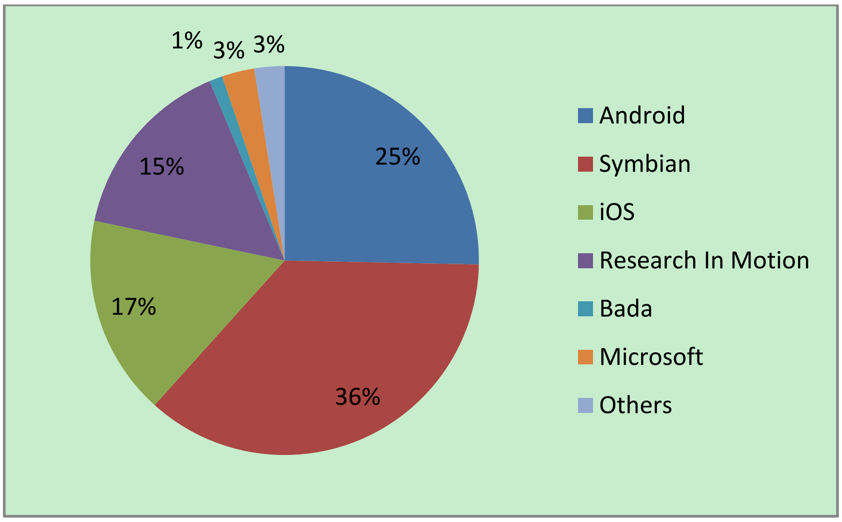


Figure 20: Worldwide mobile device sales to end users by vendor in 3Q2010, from Gartner

One reason choosing Android platform for the functional prototype is that it earns the largest market worldwide. Another reason is that based on the user survey, most of the operators in VB Energi, Ludvika and ABB transformer experts use Android phones. Therefore, the functional

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[17] An American information technology research and advisory company

[18] Source: Gartner (November 2011). http://www.gartner.com/newsroom/id/1848514 (visited 2013-06-16)

prototype can be easily installed on their smartphones for testing and user experience evaluation.

4.4.2. Android Activities

An activity is a fundamental android application component which provides user a window containing the user interface of this application[19]. Normally, one application has one or more activities that loosely bound to each other, and among them one activity is the main activity, which is the first one after launching. One activity can start another one, and only one activity can be on run mode. When the new activity starts, the previous activity is stopped. This is handled by a back stack, which always push the current running activity on the top of the stack.

Figure 21 shows the lifecycle of activity from created to destroyed.

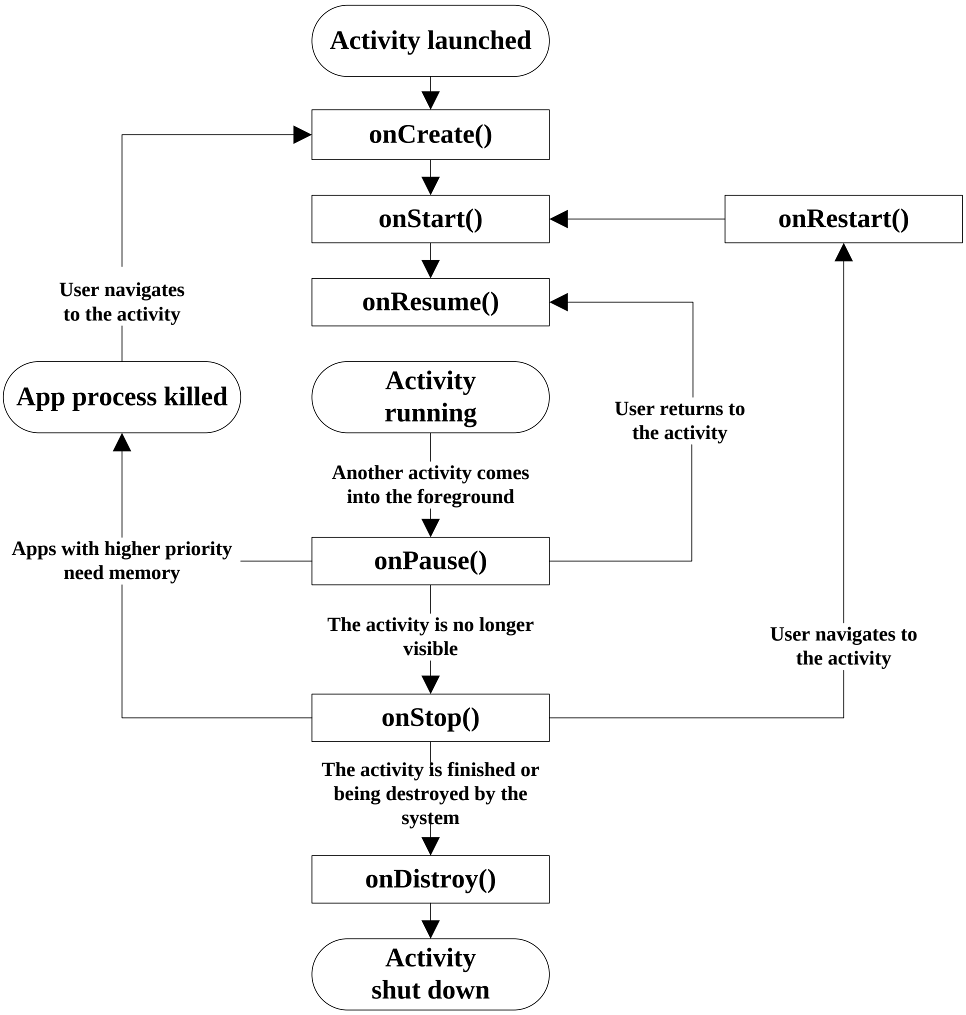
Activity launched
onCreate()
onStart()
onRestart()
User navigates to the activity
onResume()
App process killed
Activity running
User returns to the activity
Another activity comes into the foreground
Apps with higher priority need memory
onPause()
The activity is no longer visible
User navigates to the activity
onStop()
The activity is finished or being destroyed by the system
onDistroy()
Activity shut down

Figure 21: Android activity lifecycle[20], from Android

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[19] Android Actvities. http://developer.android.com/guide/components/activities.html (visited 2013-06-16)

[20] Brief introduction of Android activity. http://developer.android.com/reference/android/app/Activity.html (visited 2013-06-16)

There are more than 20 activities developed in the functional prototype. Due to the limitation of thesis space, just take the activity for user login for example to explain how activities are used in this prototype.

Create activiey:

```
protected void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        // display the activity view without application title
        requestWindowFeature(Window.FEATURE_NO_TITLE);
        // load XML layout resource to activity
             setContentView(R.layout.login);
        // initialize App widgets
        userName = (EditText) findViewById(R.id.etUsername);
        …
    }
```

Starting another activity *Transformer Overview*:

```
Intent openOverview = new Intent("com.tecmonitor.abb.OVERVIEW");
startActivity(openOverview);
```

Meanwhile, the new activity must be declared in AndroidManifest file.

```
<manifest xmlns:android=http://schemas.android.com/apk/res/android
    <application android:hardwareAccelerated="false"
        <activity
                   android:label="@string/app_name"
               android:name=".Overview"
                   android:screenOrientation="portrait"
                   android:theme="@style/CustomTheme" >
                   <intent-filter >
                         <action android:name="com.tecmonitor.abb.OVERVIEW" />
                       <category android:name="android.intent.category.DEFAULT" />
                   </intent-filter>
        </activity>
       </application>
</manifest> <!-- android:theme="@style/CustomTheme" -->
```

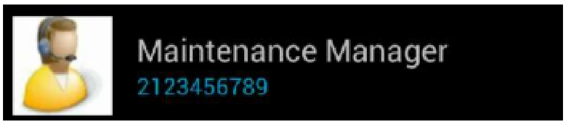
It is shown in this sample code, since activity OVERVIEW is not a main activity, category DEFAULT is used for INTENT. Moreover, this activity uses custom theme, which is specifically designed for this transformer monitoring mobile application. Besides, the screen orientation is forced to be portrait; i.e. the display won't turn to landscape, even though change the orientation of the smartphone.

Shutting down activity:

```
finish();
```

4.4.3. Layout design

The combination of many kinds of layout design is developed in this demo in order to fulfill a proper display of user interface. This section explains how multi-layout is implemented by an example which is used for one list entry of electrical company's phone book list view. And the implementation method of list view is presented in the next section.



Maintenance Manager
2123456789

Figure 22: Design of an phone book list entry

There are two methods to implement this phone book item, either using two different linear layouts from two different directions, or using relative layout. Linear layout, as its name implies, all children views are arranged in one dimension on the screen, either vertical or horizon[21]. The advantage of linear layout is that the relationship between children views is pretty obvious from both the design point of view and display point of view. It is a perfect solution of simple user interface layout. Moreover, theoretically, all complex layouts can be implemented by a combination of several linear layouts in specific orders.

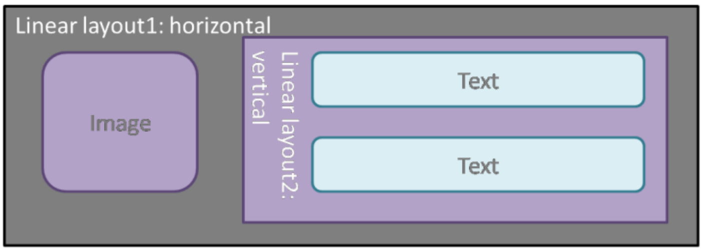


Figure 23: An example of multi-layout implementation by using multi linear layout

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[21] http://developer.android.com/guide/topics/ui/layout/linear.html

Figure 23 describes how one phone book list entry shown in figure 22 is implemented with two linear layouts. First, one horizontal linear layout is used as a container for the image view and another vertical linear layout, which are marked with purple in figure 23. Then, two text views, marked light green, are listed vertically in the second linear layout. Although, linear layout only aligns all the children views in one direction, the nesting of different linear layouts can display them in both vertical and horizontal order.

However, linear layouts also have some drawbacks of presenting user interface view. As for a complex UI, it is difficult to be divided into several children linear layout, due to a compound relationship between different UI components. Far more time and efforts are needed to implement a UI in which all children views are aligned in different directions, than a simple one, and this growth of time consuming is not disproportionate to the growth of UI complexity itself. More significantly, it could be extremely complicated to modify a multi linear layout UI, since one modification could lead a chain reaction of changes in other UI components, even those have little connections. Besides, it is hard to define the positions relative to a certain area of the screen or other UI components. As it is known, different Android mobile devices have different resolution; therefore, the user interface implemented by pure linear layout could be deformed.

As for Android layout implementation, relative layout is a powerful utility, because it can eliminate nested view groups and keep the layout hierarchy flat[22]. The children views are displayed in relative position to another element, either relative to sibling elements or to parent layout area and Many drawbacks caused by using pure linear layout can be gotten rid of in relative layout.

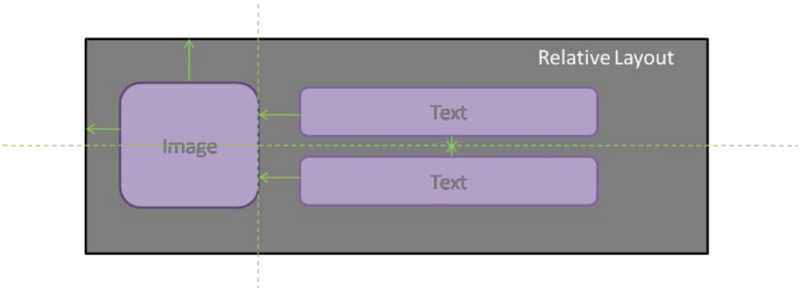


Figure 24: An example of multi-layout implementation by using relative layout

Figure 24 shows the implementation method of the same phone book list entry by using relative layout. The image view is placed relative to the top and left edge of parent relative layout with specific margins, and text views are aligned to the right edge of the image view as well as midline of the relative layout area.

4.4.4. List view and adapter (transformer list, event list)

List views are widely used in this mobile application, for example transformer list page, event list page, phone book page and main menu page. The definition of list view given by Android

---

[22] Android relative layout. http://developer.android.com/guide/topics/ui/layout/relative.html (visited 2013-06-16)

developer website is that ListView is a view group that displays a list of scrollable items[23]. There are two major features of list views. One is the list can be scrolled up and down, which expands the viewable area of one page. The other is the list entries can be imported from other sources, such as database and array list. Taking basic text list for example, texts are saving in a string array, and by using list adapter, all these strings are displayed as list entries in a predefined format (color, font, size, etc.). For the most of situations, this predefined format for each list entry is the same, so it can be designed once but repeated on every item automatically by the adapter.

Generally, there are two methods of implementing list view in one activity. First, this activity is created with extending from ListActivity, which means the activity itself is a listview; therefore without any declaration of another listview widget, *setListAdapter* function can be called directly. Here is an example of the menu page of this transformer monitoring application. The code below show how it is implemented as ListActivity.

```
public class MenuPage extends ListActivity{
    @Override
    protected void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.menu_main);
        Context ctx = getApplicationContext();
        Resources res = ctx.getResources();
        String[] texts = res.getStringArray(R.array.menu_names);
        TypedArray icons = res.obtainTypedArray(R.array.menu_icons);
        setListAdapter(new IconListAdapterMenu(ctx, R.layout.menu_item, texts,
icons));
    }
}
```

However, the limitation of this ListActivity method is that it requests the whole activity should only be a listview. If the listview is only a part of the current activity, this method could be replaced by the other method. In the second method, the activity is not extended from ListActivity, but one listview is declared in onCreate() function instead.

```
public class MenuPage extends Activity{
    @Override
    protected void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.menu_main);
        Context ctx = getApplicationContext();
```

---

[23] Android listview layout. http://developer.android.com/guide/topics/ui/layout/listview.html (visited 2013-06-16)

```
        Resources res = ctx.getResources();
        String[] texts = res.getStringArray(R.array.menu_names);
        TypedArray icons = res.obtainTypedArray(R.array.menu_icons);
        ListView listview = (ListView) findViewById(R.id.lvMenuMain);
        listview.setAdapter(new IconListAdapterMenu(ctx, R.layout.menu_item, texts,
icons));
    }
}
```

Besides, a list view layout needs to be declared in layout page, because the listview widget requires a container in which displays the list.

```
<ListView
        android:id="@+id/lvMenuMain"
        android:layout_width="fill_parent"
        android:layout_height="wrap_content" />
```

Although they are two different approaches of creating activity, the ways of using list adapter are the same. First, this adapter retrieves data from both a String array and an image array in which the texts and icons used in this menu list are stored respectively. Then, each pair of text and icon saving in the same position in their array is displayed in the corresponding position of the list with a predetermined format designed in layout file.

```
public class IconListAdapterMenu extends ArrayAdapter<String>{
    …
    @Override
    public View getView(int position, View convertView, ViewGroup parent) {
        convertView = inflater.inflate(viewResourceId, null);
        ImageView iv = (ImageView) convertView.findViewById(R.id.ivMenuIcon);
        iv.setImageDrawable(menuIcon.getDrawable(position));
        TextView tv = (TextView) convertView.findViewById(R.id.tvMenuText);
        tv.setText(menuText[position]);
        return convertView;
    }
}
```

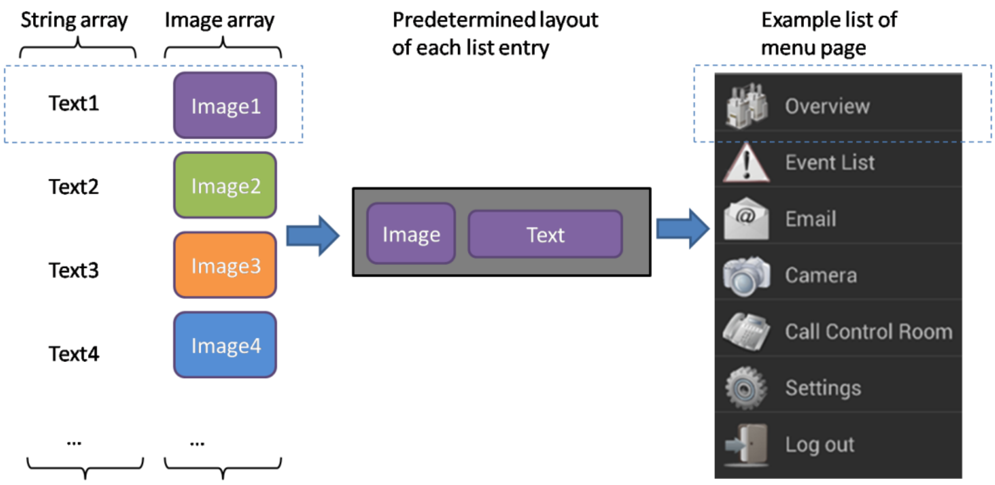


Figure 25: Example of integrating predetermined customized layout and listview adapter

4.4.5. Data fetching

In the whole transformer monitoring system, data is collected and transmitted to a monitoring server which can be connected with client side via Ethernet cable, local network or the Internet. Obviously, due to the limited time and equipment for developing this demo, it is not possible and not necessary to have a solution which supports all these kinds of communication. In this section, one solution of retrieving real time data from server side is presented based on assumption of client side fetching data through the Internet.

One common way of fetching real time from the Internet is via HTTP protocol. The first step of using HTTP protocol for an android application is to request the internet permission, which can be implemented by adding permission in AndroidManifest file.

```
<uses-permission android:name="android.permission.INTERNET" />
```

After receiving the permission, a function handling HTTP connection is built in corresponding activity. This function uses URL as input parameter, and returns one InputStream which contains the data fetched through HTTP.

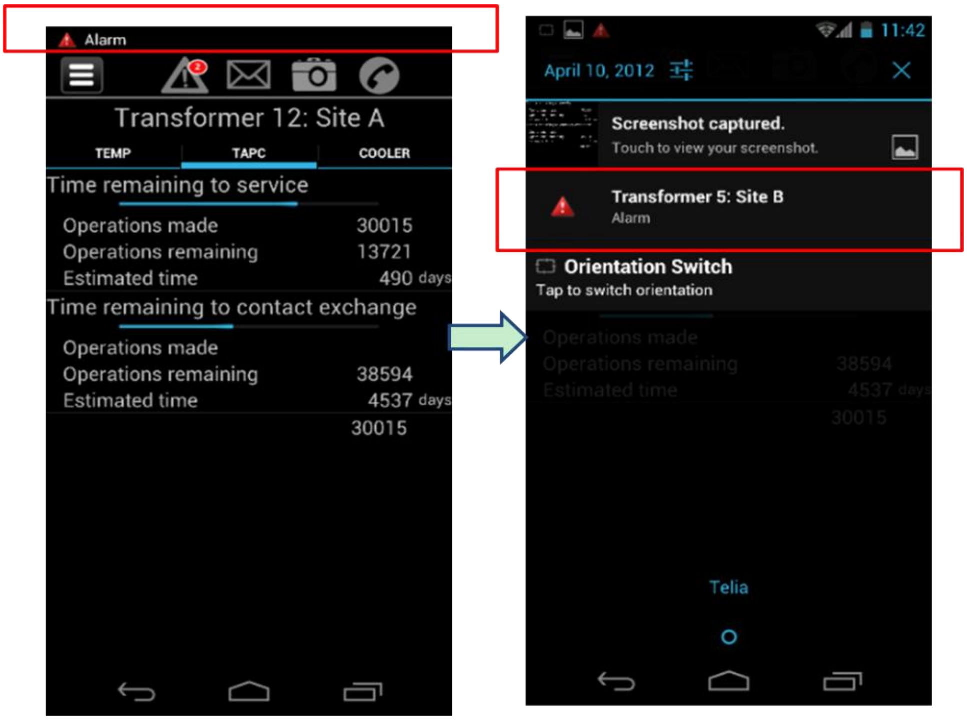
```
private InputStream OpenHttpConnection(String urlString) throws IOException {

        …

        try {

            HttpURLConnection httpConn = (HttpURLConnection) conn;

            System.setProperty("http.keepAlive", "false");

            httpConn.setAllowUserInteraction(false);

            httpConn.setInstanceFollowRedirects(true);

            httpConn.setRequestMethod("GET");

            httpConn.connect();

            response = httpConn.getResponseCode();
            if (response == HttpURLConnection.HTTP_OK) {
                in = httpConn.getInputStream();
            }
        } catch (Exception ex) {
            …
        }
        return in;
    }
```

InputStream also need to be converted to appropriate data types and displayed with certain formats on the user interface. As it shown in the following example code, the InputStream is read as a Document format, and then each element is divided from the whole Document by searching the element name.

```
InputStream in = null;
in = OpenHttpConnection(getResources().getString(urlID));
Document doc = null;
DocumentBuilderFactory dbf = DocumentBuilderFactory.newInstance();
DocumentBuilder db;
…
db = dbf.newDocumentBuilder();
doc = db.parse(in);
…
doc.getDocumentElement().normalize();
Element HotSpotHV = (Element) doc.getElementsByTagName("HotSpotHV").item(0);
        transData[0] = HotSpotHV.getTextContent().toString();
…
```

4.4.6. Popup notification

The popup notification allows this mobile transformer monitoring application to keep the operator informed about transformer alarm or warning event in time. When a new event received by the application, it first appears in the notification area at the top of the screen. After showing a quick rolling message, an icon of this notification resides in the notification area, until the operator opens the notification drawer and checks the details of this event. By clicking on the notification in the notification drawer, the page turns to the event list activity, from which the operator can checking all the active events of the current transformer.



Alarm

Transformer 12: Site A

Time remaining to service

Operations made 30015
Operations remaining 13721
Estimated time 490 days

Time remaining to contact exchange

Operations made
Operations remaining 38594
Estimated time 4537 days
30015

Screenshot captured.
Touch to view your screenshot.

Transformer 5: Site B
Alarm

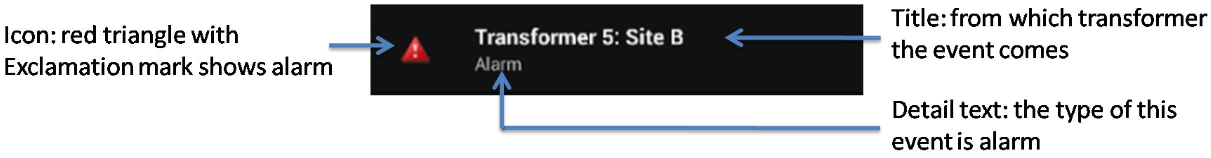
Orientation Switch
Tap to switch orientation

Figure 26: popup notification for event notification

The implementation of event notification is divided into 2 sections.

First, creating a notification and adding actions on it. The following code snippet illustrates the process, which is from notification activity of this transformer monitoring application. PendingIntent is used to set up the intent that launches an activity, which is Eventlist.class in this example. Notification creates the notification with certain notification icon, title and text message defined for its object, and setLatestEventInfo sets up the information displayed in the notification drawer.

```
Intent intent = new Intent(this, Eventlist.class);

intent.setFlags(Intent.FLAG_ACTIVITY_CLEAR_TOP|Intent.FLAG_ACTIVITY_NEW_TASK);

PendingIntent pi = PendingIntent.getActivity(this, 0, intent, 0);

Notification   n   =   new   Notification(R.drawable.ic_event_red32,   event_type,
System.currentTimeMillis());

n.setLatestEventInfo(this, trans_name, event_type, pi);

n.defaults = Notification.DEFAULT_ALL;

nm.notify(notifyID, n);
```



Icon: red triangle with Exclamation mark shows alarm

Transformer 5: Site B
Alarm

Title: from which transformer the event comes

Detail text: the type of this event is alarm

Figure 27: Description of popup notification

Besides, a notification manager is needed to manage all the notifications of this android application, which is responsible for issuing and canceling notification. Moreover the notification manager is requested when updating notification, in order to avoid creating a completely new notification for the same type of event from the same application. The following code snippet shows how the notification manager cancels the notification has been started.

```
NotificationManager nm;

nm = (NotificationManager) getSystemService(NOTIFICATION_SERVICE);

nm.cancel(notifyID);
```

4.4.7. Settings and preference

Preference APIs are used for building an interface to modify app settings. Different from drawing the UI of normal activities, the subclasses of the Preference class are used to build the UI of setting page. Most comment preferences for android applications are CheckBoxPreference, ListPreference and EditTextPreference, which are three subclasses of Preference class. In the implementation of this mobile application functional prototype, CheckBoxPreference is used for line chart settings, and Listpreference is used for language and temperature unit settings. The code snippet below indicates one example of configuring Listpreference UI for language settings page.

```
<ListPreference

    android:title="@string/sLanTitle"

    android:key="language"

    android:summary="@string/sLanSummary"

    android:entries="@array/language"

    android:entryValues="@array/langValue" />
```

The attribute android:key specifies a unique key for the value saved in a default SharedPreference file for application settings. By saving and retrieving the entry of SharedPreference marked with the key “language”, the operator’s language preference can be remembered by the application. While android:entries is an array of names of language showed on the UI, android:entryValues is an array of values actually saved in the entry of SharedPreference. For example, “English” and “Chinese” are the entries appear on the preference list, and “en_US” and “zh_CN” are saved in backstage.

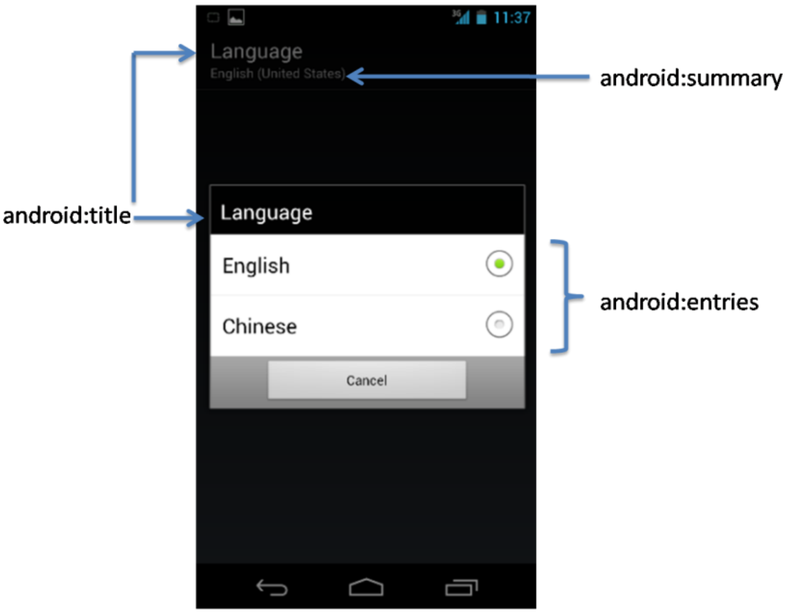


Figure 28: Description of Listpreference for language setting

4.4.8. Localization (language localization)

In the previous section, the example shows how preference settings is used for changing the language of this transformer monitoring application and how this user preference is saved in SharedPreference. The reason why this language switching can be implemented is that Android SDK supports multi-language applications, which is one branch of Android application localization. This is achieved by using different sets of resources that match the preference of users in specific region. As for adding multi-language localization, the texts in different languages are stored in different sets which are named by the abbreviations of the language.

This application project is built by Android SDK Tools, and the resources of different language texts are saving as shown in figure 29.

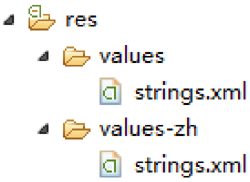


Figure 29: Directories for different language strings.xml

All the texts displayed in this demo application are stored in strings.xml files. The one under values/ subdirectory saves texts written in English, since English is the default locale of this application. The other one under values-zh/ subdirectory is using for all the same texts written in Chinese simplified.

Some sample texts on login page. /rec/values/strings.xml

```
<resources>
        <string name="sUsername">Username:</string>
        <string name="sPwd">Password:</string>
        <string name="sExit">Exit</string>
        <string name="sLogin">Sign in</string>
</resources>
```

/rec/values-zh/strings.xml

```
<resources>
    <string name="sUsername">账号：</string>
        <string name="sPwd">密码：</string>
        <string name="sExit">退出</string>
        <string name="sLogin">登陆</string>
</resources>
```

In the code snippet above, the pair of texts that have the same meaning shares the same name in those two strings.xml files. In layout files and java class files, these string resources can be referred to by using these names, e.g. “sUsername” and “sPwd”.

```
<TextView
         android:id="@+id/tvUsername"
         android:layout_width="wrap_content"
         android:layout_height="wrap_content"
        android:text="@string/sUsername" />
```

4.4.9. Three ways of communication: text, picture, phone (example phone)

Three different ways of direct communication to control room are implemented in this functional prototype, i.e. sending text email, taking and sending photos and direct phone call. Due to Android security mechanism, a basic Android application has no permission to any protected features of the device, such as internet connection, camera and phone call. Therefore, the permission of these features should be applied before using, by declaring the permit for each feature that this application needs in AndroidManifest.xml file. The following code snippet shows some of the declaration used in this prototype.

```
     <uses-permission android:name="android.permission.CALL_PHONE" />
    <uses-permission android:name="android.permission.INTERNET" />
    <uses-permission android:name="android.permission.CAMERA" />
    <uses-permission android:name="android.permission.WRITE_SMS" />
```

According to the API description of Android Manifest permission, the first permission “CALL_PHONE” allows an application to initiate a phone call without going through the Dialer user interface for the user to confirm the call being placed[24]. That is to say, with this permission, the operator is able to call the control room directly from this monitoring application, which saves much time from switching between the current application and phone dialer.

After declaring the permission in AndroidManifest.xml file, the Intent for starting phone call activity is extremely simple in the code. The code below explains how to start the phone call activity by using Intent contains the telephone number.

```
Intent incall = new Intent();

incall.setAction(Intent.ACTION_CALL);

incall.setData(Uri.parse("tel:"+controlRoomNum[0]));

startActivity(incall);
```

---

[24] Android manifest. http://developer.android.com/reference/android/Manifest.permission.html (visited 2013-06-16)

4.5. Test and evaluation

The two distinct goals of testing and evaluation are to demonstrate that the application meets its requirements and to discover faults and defects (Sommerville, 2006, P538). According to the delimitation of this thesis work, the implementation terminates with a functional prototype; therefore, the testing and evaluation is mainly based on the user interface design and the functional prototype.

4.5.1. Test at the early stage of design

Testing was conducted not only at the end of this thesis work after the accomplishment of functional prototype, but also through the whole process from the early stage of design to the final release. Three gradations of prototypes were used for user interface design, and after finishing each prototype, usability testing and/or usability inspection was conducted with the end user from VB Energi and/or several transformer monitoring experts working in ABB Corporate Research and ABB Power Transformer Department.

Results based on the early stage of prototypes, i.e. sketches and low-fidelity Balsamic mockups.

Table 12: Feedback from the early stage of prototype

ID	Feedback	Suggestions & Solution
1.	It is not necessary to display monitoring data, e.g. temperatures, via analog meter design, since even the real analog meters are no longer used in the new transformer monitoring systems. They are replaced by digital meters.	Suggestions: 1. Remove the design of analog meters, and don't put effort on the following design and implementation phase. (Solution for this thesis work) 2. Continue developing analog meters as an additional feature, but don't prioritize it.
2.	Different electricity companies in different country have different security policy on the geographical location of power transformers and sub-stations. Not all of them allow their transformers' location to be displayed on the map publicly.	Suggestions: 1. Remove the feature that is detection of transformers and operators geographical location. (Solution for this thesis work) 2. Continue developing this map design as an additional feature, and entitle the user to disable this feature according to the security policy in their company.
3.	Each operator should have his or her unique ID authentication for the mobile application, and the user account should be easy to remember. Otherwise, a	Solution: Allow the operator to use the same user ID and password as the ones for accessing his or her work computer. In case an operator

	password retrieving function should be provided in this mobile application.	forgets user name and/or password, he or she can retrieve it through the company's IT support system.
4.	The alarm and warning event can be triggered from one direction. That is to say, the monitoring data only has upper limit. Taking top-oil temperature for example, when this measurement temperature rises above 80 ℃, a warning event is triggered, but normally, no warning or alarm event would be triggered when the temperature decreases below any certain temperature under natural conditions.	Solution: Remove the lower limit calibration for event trigger on bar meter design.
5.	Avoid integrating too much information on one view, due to the limitation of phone screen size. The size of all texts displayed on the application should be large enough with high contract colors.	Solution: Divide high density information display into several views, and only present one kind of data in each view.

Since these design defects were discovered at the early stage of design, the cost of correcting them was not very expensive, and more time and efforts were concentrated on the features needed by the users at the following design and implementation phase.

4.5.2. Test during the implementation phase

After the implementation of each activity in this application, a test of this activity was conducted correspondingly. Moreover, when a use case was finished, its user interface and functionality was also tested according to the use case. The code of each activity was tested both on the emulator provided by Android Development Tools and on a real phone Samsung galaxy nexus with Android 4.0 operating system. Figure 30 shows the work flow of implementing and testing activities step by step, according to integration testing principle(Sommerville, 2006, P542).

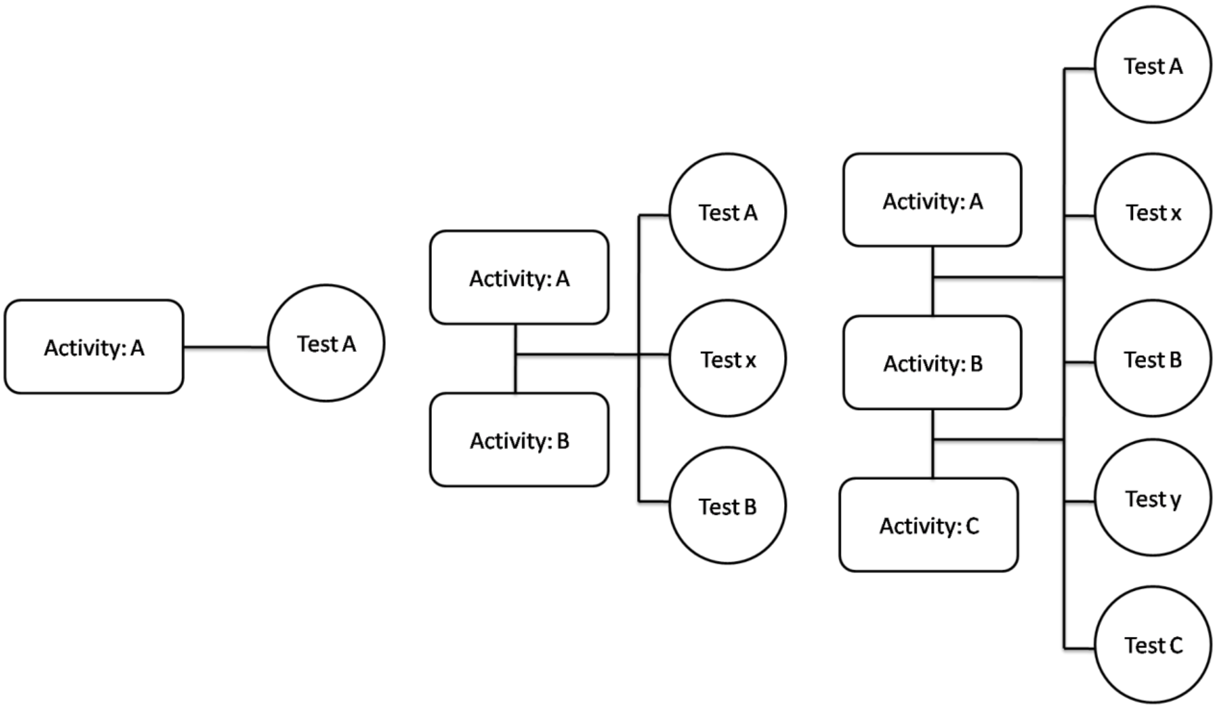
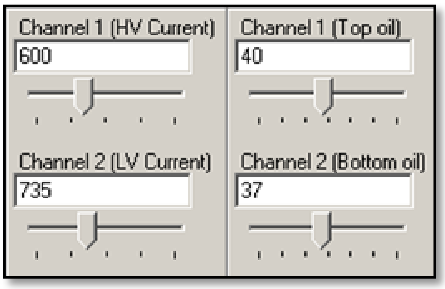


Figure 30: Incremental integration testing

According to use case UC-3, UC-4, UC-7 and UC-8, this monitoring application should be able to fetch dynamic data from one or more monitoring servers. However, due to the security issue of electricity company, retrieving data for testing this application directly from a running transformer was not available, since the monitoring data is only transmitted within electricity company's local network in most cases. Moreover, most of the transformer running under normal state, which means no alarm and little warning events would be active or triggered during the testing period; therefore, the use case UC-7, UC-8 could hardly be tested on those transformers, even though they could be accessed through some technical measures, such as VPN connection.

The solution of testing dynamic data was to retrieve data from Monitoring Demo, a simulator or virtual transformer that generates the monitoring data in real time, which was developed by ABB Power Transformer Department. The initial aim of Monitoring Demo was to test the whole transformer monitoring system and to present it to intended customer. By modifying the interface and reusing this Monitoring Demo code, one or more transformers were simulated on PC, from which the monitoring data could be set to any values as needed. For example, when testing the usability of alarm notification and event list (UC-8), an alarm signal could be triggered by setting top-oil temperature above 100 ℃.

Figure 31 shows an example of Monitoring Demo's control window, on which the input values can be controlled either by typing in the new value in the textbox, or by moving the sliding bar.


Channel 1 (HV Current)
600

Channel 1 (Top oil)
40

Channel 2 (LV Current)
735

Channel 2 (Bottom oil)
37

Figure 31: Screenshot of part of Monitoring Demo's control window

After setting input values on Monitoring Demo, the data was sent to a wireless router via Ethernet connection. Sequentially, the smart phone could access this data via the radio waves from the wireless router. This process of transmitting monitoring data from PC to smartphone is illustrated on figure 32.

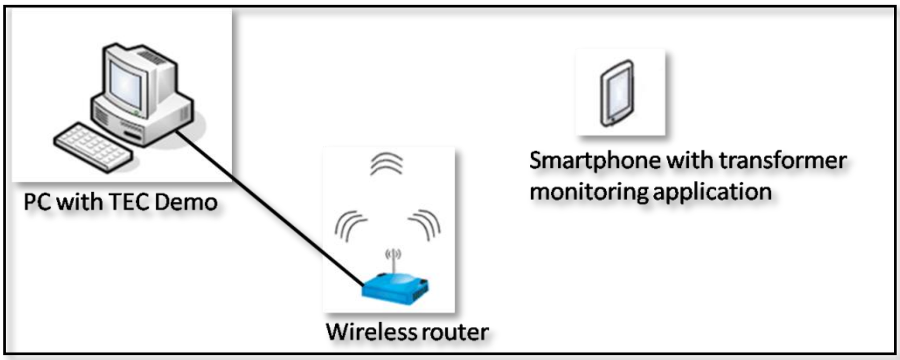


Figure 32: Data transmission form PC to smartphone

4.5.3. Evaluation

At the end of this diploma work period, evaluation were conducted base on the functional prototype amount both transformer monitoring experts and end user. Because of the time limitation, most of them were the experts working in ABB Corporate Research and Power Transformer department. The final evaluation with the real end user was also conducted ones at VB Energi later. First, they were invited to watch a short instruction video of the mobile application prototype, and then listen to a presentation with one scenario showing the most important features. Next, the participants tried the application themselves to complete some tasks, such as checking tap-changer status and calling then control room. Moreover, some of them also installed the application prototype to their work phone, and gave long term test and feedback, which was valuable to the evaluation of this thesis project. Most of the participants could manage the application without any more instructions, and used it in an efficient way for their daily work or research. They were guided to think aloud (Seman, Hussein, & Mahmud, 2010) in order to provide the real feeling and every detail suggestion of the application.

The most significant feedbacks were listed below on the table.

Table 13: Phenomenon and feedback from user evaluation

ID	Phenomenon and feedback	Severity
1	The order of events in the alarm and warning list: According to the interview result with the end user, this list should be sorted by time descending order. However, if there is more than one transformer monitored by this mobile application, whether the events should be categorized by transformer name first. Different users and experts had different point of views. Some of them considered that the list should be sorted by sites and transformers names, and then following the time descending order, while the others believed that the time descending order should be strictly complied with, even though displaying events from multiple transformers. Suggestion: Provide the user with two kinds of sorting method on event list; therefore, the user can select one based on their needs by setting user preference options.	High
2.	Refresh rate of data fetching: This refresh rate is the frequency of synchronizing with the monitoring server. If the frequency is low, for example once per hour, the new monitoring data could not be retrieved in time. However, the current refresh rate used in the prototype is too high, which leaded to high battery consumption. Suggestion: Add Settings that entitles the user could disable automatic synchronization, but synchronize manually when necessary.	High
3.	Meaningless negative numbers: Some meaningless negative numbers displayed on the functional prototype, since they were save as negative on the monitoring side, for example the recommended remaining days of changing one component. If this component wasn’t replaced in time, the calculated days could be negative, but it meaningless for the user. Suggestion: Add conditional statement to this kind of data. If the value reduces below zero, display zero instead.	Intermediate

4.	The color problem of seek bar: The seek-bar used blue for normal situation, gray for warnings, and black for alarming, while the background was also dark color. It was difficult to distinguish the edge of seek-bar. Suggestion: Modify the color of seek-bar.	Intermediate
5.	the number of decimal places: If there was no decimal of monitoring data (which is real data, like 65.00), only the integer part displayed, for example 65. However, for the real data with decimal part, two decimal places displayed, such as 65.81. This caused inconsistency of data representation. Suggestion: Fix the two decimal places for all real data.	Low

5. Conclusion and future work

5.1. Conclusion

This thesis was conducted to explore how mobile communication and information technology can be used for power transformer monitoring via smartphones and/or other mobile devices. The current power transformer monitoring method does not include any mobile monitoring access, by which the operators have to either stay in control room or visit the substation in order to examine the status of transformers. Moreover, an operator can only monitor the transformers in one substation by a visit to that specific substation, but usually he is responsible to several substations that are far from each other. Thus, not all the transformers can be monitored by this operator at the same time. Therefore, the aim for this thesis is to investigate and offer an approach to transformer monitoring on mobile devices, which provides multiple transformer monitoring and remote access to monitoring system at anytime and anyplace.

This thesis began with information gathering and user study, in order to understand the principles of transformer monitoring system and operators work. Afterwards, a mobile transformer monitoring application was designed and developed as a functional prototype for Android mobile phones. Testing and evaluation was also conducted during and at the end of thesis project by both the experts and end users.

The mobile application includes login, transformers overview (multiple transformer monitoring), real-time status monitoring, historical data chart, direct communication with control room, event list, application settings and app navigation. All of them are the core features of power transformer monitoring based on the user study. Meanwhile, the mobile application is designed to express a consistency with the current monitoring system from both functionality and user interface point of view. Moreover, as an application running on smartphones, the design and development also considers the limitation of hardware platform, such as the screen size, computation power, memory size, etc.

To be more specific, login page fulfills the requirement of information security, through which a registered operator is allowed to access to the transformers he is responsible for. Moreover, one of the most significant features is the support of multiple transformer monitoring. The users can switch among several transformers and check their status by clicking on transformer names, instead of logout one transformer and login another. Meanwhile, transformers overview list shows the general status (normal, warning or alarm) via color coding (gray, yellow or red). Therefore, less time and less process complexity is required, when monitoring multiple transformers on this mobile application. Not only can the current situation of transformers be examined through this mobile application, but also the historical data for at most 1 year can be detected in the trend diagram of each indicator. Thus, all the necessary data could be accessed within a few touches on smartphone's screen. Another two important features are the event and alarm list and notification. The former displays the events collected from each transformer, and the later sends real time alarm notification when fault happens. Accordingly, the operators could be informed of emergency situation and the current situation of transformers immediately by the mobile phone no matter where they are. This helps to make early judgment of the fault and take measures in time. Besides, the setting and localization function provides operators with their native language and familiar units. To sum up, there are notable benefits of monitoring transformers on mobile devices. Thus, transformer monitoring system could be and should be extended to mobile platform which provides no boundary monitoring at any time and any place. And the utilization of human computer interaction knowledge together with the current state-of-the-art mobile communication technology contributes to the design of application more usable and receptive to users’ need.

5.2. Future work

According to the feedback from testing and user evaluation, a couple of phenomena should be taken care of, and even modified, such as the number of decimal places and refresh rate of data fetching. And more features could be designed and implemented, such as adopting QR-code scanning for transformers identification.

More importantly, from the power industry point of view, diagnostic system of power transformers, e.g. sound recording and spectral analysis, could also be integrated to the mobile application. Furthermore, the monitoring of more electrical devices and even the whole power grid system could be considered to extend mobile platform.

References

Westman, T., Lorin, P., & A.Ammann, P. (2010.1) Fit at 50. ABB review, 63 - 69. Retrieved Jan. 2013, from http://www05.abb.com/global/scot/scot252.nsf/veritydisplay/555ce7b19930b339c12577bb003fc4aa/$file/abb_review_fit_at_50_english.pdf

Charland, A., & Leroux, B. (2011, May) Mobile application development: web vs. native. Communications of the ACM, Volume 54 Issue 5, 49 -53.

Bergen, A. R., Vittal V. (2005) Power System Analysis, Second Edition. Pearson Education Asia Limited and China Machine Press.

Boss, P., Lorin, P., Viscardi, A. et al. (2000) Economical aspects and experiences of power transformer on-line monitoring. CIGRE Session.

Gulliksen, J. et al. (2003, Nov. – Dec.) Key principles for user-centred systems design. Behaviour & Information Technology, Vol. 22, No. 6, 397-409. Retrieved Jan. 2013, from http://www.it.uu.se/edu/course/homepage/acsd/vt10/Key_principles.pdf

Ozaki, H., Ban, S., Gondow, K., Katayama, T. (2003) An environment for evolutionary prototyping Java programs based on abstract interpretation. Software Engineering Conference, 2003. Tenth Asia-Pacific, 362 - 370

Williams, A., & Rensselaer Polytechnic Institute, Troy, NY. (2003) Examining the use case as genre in software development and documentation. Proceeding SIGDOC ’03 Proceedings of the 21st annual international conference on Documentation, 12 -19.

Repond, J., Dugerdil, P., & Descombes, P. (2011) Use-case and scenario metamodeling for automated processing in a reverse engineering tool. Proceeding ISEC ’11 Proceedings of the 4th India Software Engineering Conference, 135 -144.

Booch, G., Rumbaugh, J., Jacobson, I. (1998) Unified Modeling Language User Guide. Addison-Wesley Professional

Ambler, S. W. (2005) The Elements of UML(TM) 2.0 Style. Cambridge University Press

Sommerville, I. (2006) Software Engineering, Eighth Edition. Pearson Education, China Machine Press.

Seman, E.A.A, Hussein, I., Mahmud, M. (2010) Why thinking aloud matters for usability evaluation? Computer Engineering and Applications (ICCEA), 2010 Second International Conference on (Volume:1), 462 - 466.

Gartner. (2011) Gartner says sales of Mobile devices grew 5.6 percent in third quarter of 2011: smartphone sales increased 42 percent. Retrieved Dec. 2011, from http://www.gartner.com/newsroom/id/1848514

Android. (2011) Android developers. Retrieved Dec. 2011, from http://developer.android.com/index.html

AchartEngine. (2012) Retrieved Mar. 2012, from http://www.achartengine.org/content/download.html.

SQLite. (2012) Command Line Shell For SQLite. Retrieved Mar. 2012, from http://www.sqlite.org/sqlite.html

Maguire, M. C. (1998) RESPECT User-Centred Requirements Handbook, version 3.3. HUSAT Research Institute

Lee, W. (2012) Beginning Android 4 Application Development. Wrox

Appendix A: Questionnaire

General questions:

1. How many are the operators usually working together?
2. How often do they use this application? (Every hour/ every half an hour/…)
3. What do they use it for? (Monitoring/ maintenance/…)
4. Do they use their own mobile phone or the one provided by company?
5. Does every data the monitoring web includes need to be shown on the mobile application?
6. Who can login on this application? For the security issues. (Does every operator need to login the system before using this application)
7. What is environment the operator using this application in? (hot, cold, weather; near, far, distance, inside, outside; stay in one place or move from place to place)

About the phone (mobile devices) and OS:

1. Are your mobile phone smart phones. Do you have some other tablet device? What kind of platform (operating system) do you want this application running on?
2. What is the phone OS of you smart phone. (If you don't have a smart phone now, which phone OS you would like to choose when you decide to buy one?)
3. What is the brand of your mobile phone? (the most popular brand)
4. The screen size of your smart phone.
5. Is it a touch screen one or not?
6. Would you like to try a mobile application that attends your daily work on transformer monitoring domain? (If not, why?)

About the transformer

1. How many are the transformers that one operator responsible for?
2. Is the location of transformers allowed to be displayed on mobile map server, e.g. Google map or iOS map? (Is it confidential)
3. What does the operator do when there is an alarm or error? (e.g. report it or take some measures or even turn down the transformer) Are they allowed to take any measures via mobile application?
4. What is the refresh rate dose this application need? (How often does the data be refreshed? Every 30 seconds/ every 5 minute/…)

Additional questions:

1. How many languages does this application need? (Swedish & English?)
2. Is 'help' function required?

Appendix B: A discussion about security issues

The security of transformer monitoring data transmission and presentation was widely discussed issue during the whole thesis work period. Although this problem is not the emphasis of this thesis, it is mandatory required when this kind of mobile monitoring applications becomes real product. Therefore, when this thesis carried out, security issues were also considered, discussed and suggested.

- Could the location of power transformers and substation be shown on the map?

Since power transformers are critical electricity device, different countries and different electricity companies have different rules for displaying the location publicly on the map or use online map service, the map feature could be integrated to mobile monitoring application but it should be optional and easily enabled or disabled by the operator.

- How could the mobile application get the access to the transformer monitoring system?

Nowadays, most of the electricity companies only transmit transformer monitoring data within their local network; therefore, the mobile application should be able to login to these kind of local network. Two available and mature technology approaches were discussed, i.e. VPN connection or special SIM card. Besides, a separate login for the mobile application is also considered to restrict different users.

- Is modification of event log via mobile monitoring application allowed?

Currently, any modification through mobile application is strictly forbidden, due to the secure policy of electricity companies. Mobile application only supports one way data retrieving instead of sending control signals or operating monitoring system server.