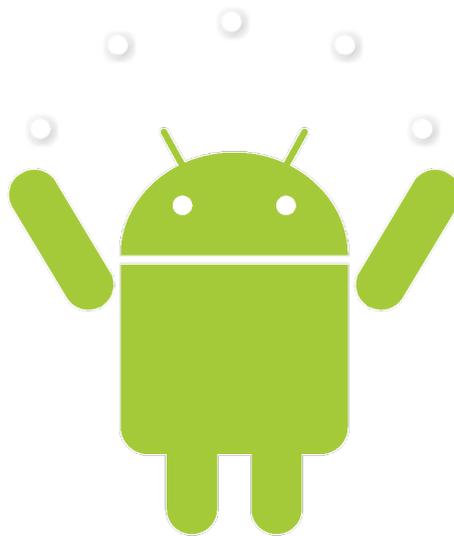


# CHALMERS



## Implementation of extended motion capture support in Android smartphones

*Master of Science Thesis in the Master Degree Programme  
Software Engineering & Technology*

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CHALMERS UNIVERSITY OF TECHNOLOGY  
Gothenburg, Sweden 2012  
Master's Thesis 2012

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## Implementation of extended motion capture support in Android smartphones

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Cover:

The Android robot juggling motion capture markers

Department of Computer Science and Engineering  
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## Abstract

This thesis is a study in smartphone applications on the Android platform that communicates with a motion capture system in real-time. The thesis covers the work in porting a C library to Android Java with NDK in order to utilize already written motion capture system communication code. Three different Android applications were developed based on this port; a remote control application, a viewfinder application and a virtual camera application. For illustration, the OpenGL library is used and hence it is also covered. Comparisons between the iOS application ditos are made and interviews were conducted in order to determine how and when the applications are useful. Throughout the project an agile like inhouse development process was utilized at the Swedish motion capture company Qualisys. At the end of this paper, some issues and suggestions on future work are brought to the surface.

**Keywords:** smartphone, android, motion capture, realtime communication

## Sammanfattning

Denna rapport är resultatet av en studie om smartphoneapplikationer som kommunicerar med ett motion capture-system i realtid. Rapporten täcker arbetet med att porta ett C-bibliotek till Android Java med hjälp av NDK för att ta vara på redan skriven kommunikationskod. Tre olika Androidapplikationer blev utvecklade baserat på denna port, en fjärrkontrollapplikation, en sökarapplikation samt en virtuell kameraapplikation. För illustration användes OpenGL-biblioteket och därmed täcks detta även av rapporten. Jämförelser med iOS applikationsditos görs samt intervjuer genomförs för att ta reda på när och hur applikationerna är användbara. Genom hela projektet användes en agil-liknande inhouse utvecklingsprocess hos det svenska motion capture företaget Qualisys. I slutet av rapporten lyfts några problem till ytan samt förslag på framtida utveckling.



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## Abbreviations

6DOF	6 Degrees Of Freedom, defines a rigid body
ADB	Android Debug Bridge
API	Application Programming Interface
IDE	Integrated Development Environment
JNI	Java Native Interface
MIT	Massachusetts Institute of Technology
NDK	Native Development Kit
QTM	Qualisys Track Manager
RT	Real-Time
UDP	User Datagram Protoco
TCP	Transmission Control Protocol
IP	Internet Protocol
VM	Virtual Machine
WLAN	Wireless Local Area Network
XML	Extensible Markup Language



# 1 Introduction

This is a master thesis written in the Software Engineering and Technology master program at Chalmers University of Technology. It is performed in conjunction with the company Qualisys AB, which provides products and services related to optical motion capture. This thesis focuses on the implementation and evaluation of a set of tools, implemented for the Android platform, for the company's system. Some of the tools have been previously developed for the iOS platform and are more or less directly translated into the Android platform, whereas one of the tools does not already exist and is designed from scratch.

## 1.1 Previous work

In 2010 a master thesis named "Implementation of motion capture support in smartphones" was carried out at Qualisys. The goal of that thesis was to implement an API for the company's Real-Time Protocol and use that to implement iOS applications for a viewfinder for seeing what the cameras of a motion capture system see and a virtual goniometer. Another goal was to investigate cross-platform development of applications for iOS and Android (Martinsson & Trost 2010).

### 1.1.1 Viewfinder

As the name suggest, the viewfinder application is meant to show what the cameras in the company's motion capture environment see. By streaming the information from a server, the application shows in real-time what is in the cameras' field of view. This is helpful when the cameras are to be mounted in a place that is hard to reach and the camera picture can be viewed in a handheld device. There are three modes of the motion capture system that the Viewfinder can show. The user can also use the viewfinder application to change some system settings (Martinsson & Trost 2010).



**Figure 1.1** The iOS Viewfinder

### 1.1.2 QTM Remote

QTM remote is an application that was developed at Qualisys by the same people who did the previously mentioned master thesis. The remote application was, however, not a part of the thesis and is therefore a separate related work. The application makes it possible for users of the Qualisys motion capture system, to trigger motion recording remotely by their handheld device and marking events on the recorded time-line. It also lets the user save the recordings to files on the computer and is also compatible with the so called batch capture, where saving happens automatically (Qualisys 2012).



**Figure 1.2** The iOS QTM Remote

## 1.2 Purpose

The purpose of this thesis is:

- To extend functionality already found in the iOS platform to the Android platform

- To explore 3D functionality of the Qualisys system by implementing a virtual camera
- To work in a realistic way with Qualisys as a customer
- To fulfill the goals specified in 1.3

The purpose also includes answering the following research questions:

- How will the portability of a handheld android device help in configuring, maneuvering and maintaining a Qualisys motion capture system?
- Will the extension to 3D handheld functionality provide any advantages to the 2D functionality?
- Are there limitations of a handheld android device when implemented in the Qualisys motion capture environment?

### 1.3 Goals

The goals of this thesis are divided in two different phases. The first phase consists of using the existing C library to develop the two previously iOS applications for the Android platform. The second phase will be an extension with a 3D implementation in the form of a so called virtual camera. Assessing the usefulness of the different applications is also a part of the goals.

### 1.4 Scope

The implementation will be the the most time-consuming part of the thesis and will include the development of the two existing iOS applications in Android as well as the 3D implementation. An evaluation will be conducted after the implementation and will be limited to the opinions of the employees at Qualisys since there will not be enough time to take the opinions of end users.

## 2 Background

Chapter two of this thesis covers background information on the different technologies and concepts that was used during the project. This is information that is important to know beforehand in order to understand the results of the thesis. The basics of motion capture is covered as well as the company Qualisys, where the thesis was housed, the Android platform and the graphics library OpenGL.

### 2.1 Motion Capture

Motion capture is the procedure of recording live motion into a digital 3D representation. This is usually done by tracking a number of landmarks on a recorded object and combining them into a viable digital presentation. The object of interest can be anything with a motion that is desirable to record. The landmarks should be the points that best represent the object's movement and links between rigid sections. When capturing, e.g. human motion, some obvious landmarks are the joints between body parts (Menache 2010).

#### 2.1.1 Purpose of motion capture

Motion capture has a number of applications, analytic like in biomechanics where tracking of motion is used e.g. as an aid in gait analysis to help in rehabilitation of injured people (Cloete & Scheffer 2008) and industrial purposes where it can be used for e.g. measuring and evaluating the efficiency of industrial robots (Qualisys 2011 *b*). There are also real-time applications, such as tracking a head-mounted display in order to show the proper information on the screen or as a tool in computer-aided surgery, where it can allow for more precise placement of hip prosthetics or tracking of probes in breast biopsies (Welch 2002).

#### 2.1.2 Motion capture basics

The tracking of the previously mentioned landmarks are done by placing markers or sensors on them and collecting the information given by them. Whether it is sensor or markers that are used depends on what type of system it is and motion capture is usually categorized into the following types: outside-in, inside-out and inside-in.

- In outside-in systems the sensors are external and placed around the measured space, collecting data from markers placed on the measured objects. One example of this is camera-based systems in which cameras receive information from reflective or light-emitting markers placed on an object.
- In contrast, inside-out systems have sensors placed on the object of interest and receive data from external sources. An example of this is electromagnetic systems, where a electromagnetic field is generated over the area and sensors placed on the object.
- Inside-in systems are systems in which both sources and sensors are placed on the object. For example, in a system based on inertial sensing used in human motion capture, accelerometers and/or gyroscopes are placed on the subject as sensors and the sources of data are the joints and movement of the subject itself (Menache 2010).

### 2.1.2.1 Optical System

Optical motion capture systems are usually outside-in system in which you mount cameras around the measured space and put markers on the subject. The markers can either reflect light hitting them, called passive markers, or actually emit light on their own, called active markers (Welch 2002). At Qualisys they mostly use passive markers. The cameras measuring are emitting infrared light from an array of diodes around the lens. The emitted light is then reflected by the markers and thus recognized by the system.

## 2.2 Qualisys

Qualisys is a company focusing on motion capture services and products, which over the years has become globally leading providers of these. Based in the port city Gothenburg, Sweden, the company has been developing their products since 1989. Fields of applications where Qualisys is active are: sport science, psychology, gait analysis & rehabilitation, neurology, mri scanner rooms, marine applications, animation and virtual reality (Qualisys 2011a).



**Figure 2.1** The Qualisys logotype

The main software of the Qualisys motion capture system is called QTM - Qualisys Track Manager. Through this software, the user is able to control, calibrate and edit

measurements. The software gives the user visual feedback about what is going on in the system in real-time. (Qualisys, 2011b) The different kinds of data that can be accessed from the cameras with QTM are:

- Marker mode - shows white dots representing markers.
- Intensity mode - see what is interpreted as markers.
- Video mode - grayscale video.

Every mode is a 2D-representation of what each camera sees. With this 2D information, QTM calculates a 3D representation of the volume. From this, it can also recognize previously defined rigid bodys which are called 6DOF. 6DOF bodies are a set of markers that are attached to the same object and therefore retain their relative position as the body moves. Besides data regarding markers, QTM can also record analog input from equipment such as pressure plates<sup>1</sup>, sound or video recordings that can be matched with the measurements. (Qualisys 2008)

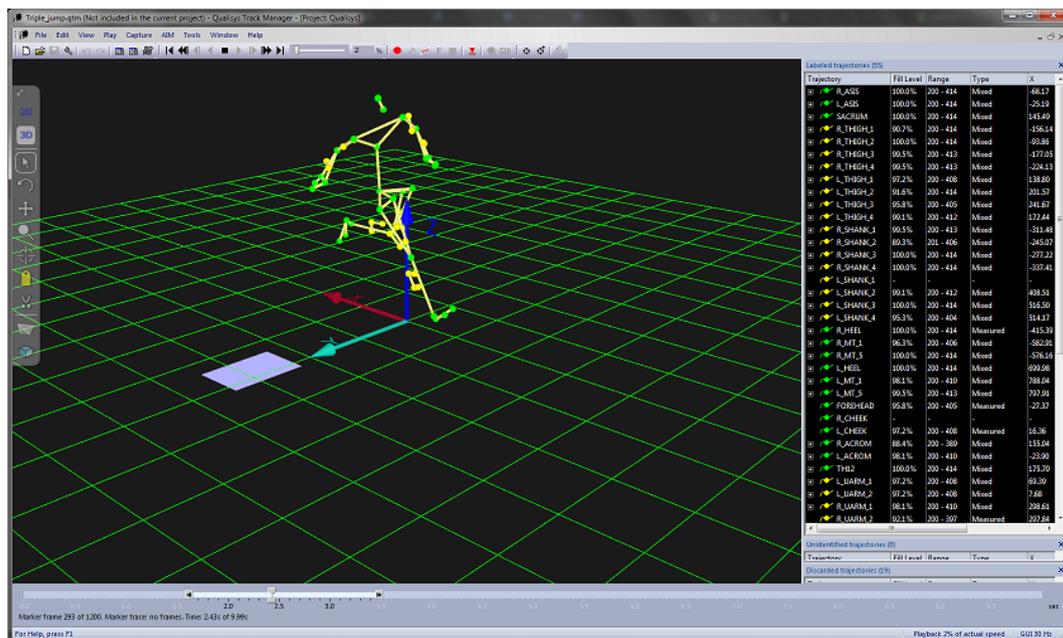


Figure 2.2 Qualisys Track Manager

The RT Protocol (Real-Time Protocol) is a part of QTM. The protocol allows for network based communication with the Qualisys motion capture system over TCP/IP or UDP/IP. Through various commands, different system settings can be set and streaming of data in real-time can be achieved. Examples of different kinds of information that can be streamed in real-time are 2d-markers, 3D-markers, video, marker intensity and 6DOF (rigid bodies). (Nilsson 2012)

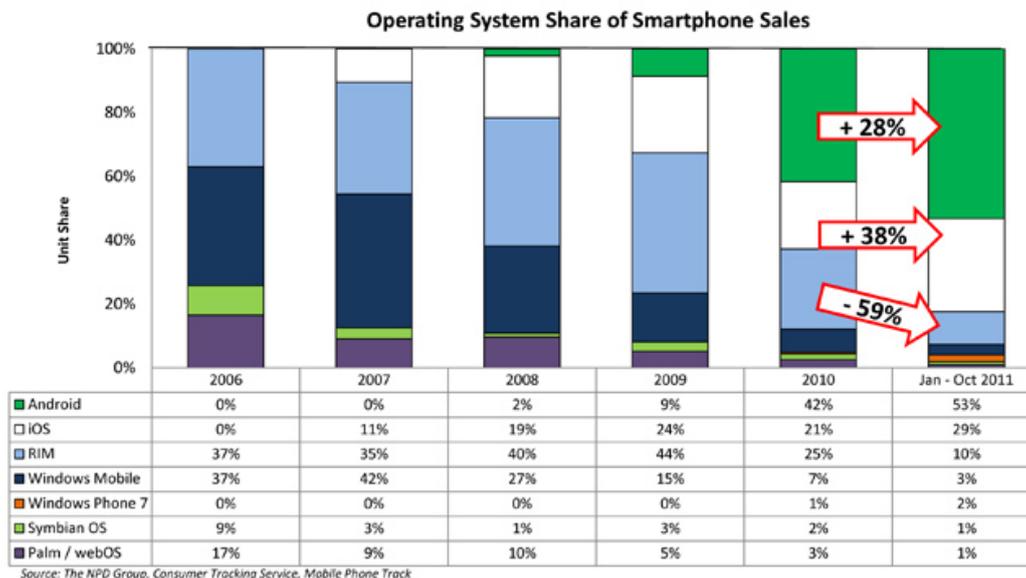
<sup>1</sup>A pressure plate records pressure, or weight.

There exists an API intended for communication with QTM through the RT Protocol and it is called QTMAPI - Qualiys Track Manager Application Programming Interface. The API was developed, in the programming language C, 2010 as a part of the iPhone application development (see 1.1). QTMAPI offers almost full functionality of version 1.9 of the RT Protocol. (Martinsson & Trost 2010)

## 2.3 Android

Android is a platform primarily developed for use on mobile devices. It is maintained by the Open Handset Alliance which consists of a number of hardware and electronics manufacturers, software companies and network operators, and is led by Google. The platform is open source under the GNU General Public License and Apache 2.0 license, which makes it available to anyone to download and make changes, but official custom releases must be approved by Google. The major releases of the platform are each designated a name of a dessert and the latest version as of this moment is Ice Cream Sandwich with the version number 4.0 (Helal, Bose & Li 2012).

Android has experienced a rapid growth during the last few years and gains more and more of the market share (see figure below). January through October 2011, Android accounted for 53% of all smartphones sold in the U.S. (NDP 2011). Since Android gets more and more widespread, developed applications for this platform reaches more customers. For a company that only provides their applications for the iOS platform, this is a strong motivation to develop them for Android as well.



**Figure 2.3** Smartphone sales in the U.S. (BGR 2011)

### 2.3.1 History

In 1999 the company Android, Inc. was founded to develop a new mobile platform. In 2005 it was acquired by Google. The development of the platform progressed and a number of other companies joined in a partnership, which in 2007 resulted in the Open Handset Alliance. The first phone running Android 1.0 came in 2008 and the platform had a very rapid growth rate much due to the quick updates and the fact that a number of partners launched their own devices, running Android, which gained popularity among users. The platform is also attractive to developers as most of it is open source and this makes it modifiable for use in a large variety of devices ranging from mobile phones to tablets and even entertainment systems in cars. The estimations of today say that there are over 250 million devices in the world that run Android and it is still growing (Helal et al. 2012).

### 2.3.2 Android development

Android applications are developed using the programming language Java and the application framework of the Android Software Development Kit. However, Android does not completely support standard Java. This is mostly due to key differences in some standard libraries, among them user interface libraries in particular. The applications are executed in Dalvik Virtual Machine which is optimized for use on mobile devices and a minimal memory footprint. All applications are run in a separate VM and kernel process, which Dalvik has been written to handle well (Android 2012).

#### 2.3.2.1 Native Development Kit

The Android Native Development Kit is a toolset created to allow developers to use native code in Android applications. When an application is written in Java, the code is compiled into bytecode which needs to be interpreted by a VM whereas native code runs directly on the processor without any need of interpretation. When native code is used, the compilation takes place in the development environment and not on the Android platform, as opposed to Java, where the Dalvik Just-In-Time compiler translates the bytecode into native code on the device. Even though it might sound as a performance boost to use only native code, in reality switching from Java to native takes time. Also, the Dalvik compiler produces effective native code, which in many cases makes it at least as good as developer written code. In short, the NDK provides a way to develop applications partly or fully in C/C++, which can be very useful if there is e.g. a pre-existing library in C/C++ that a developer needs to use in an Android application (Guihot 2012).

#### 2.3.2.2 The need for a versatile application

Devices that run Android come in a lot of different shapes and sizes and with or without certain hardware. The openness of the platform has made it possible for a lot of different manufacturers to produce their own Android device. Android is not only used in phones

but also in tablets and even in certain TVs etc. Although this diversity is good for the platform as well as device manufacturers, it might pose a slight challenge for developers. An application should be usable by as many devices as possible in order to reach a greater audience, but that also means that the developer must design it that way. In order to support devices with different screen sizes and resolutions, a developer can provide different layouts and graphical elements with different resolutions. Android will decide at runtime which of the resources that are appropriate.

In addition to devices with different screen properties, some devices might not have the required hardware for certain applications and then a developer should make sure that such devices should not be able to install the application. To provide an example; what good is a barcode scanner application that utilizes the camera on a device with no camera? The software designer should declare what features and hardware his or her application uses and in that way, the application will not be shown in the Google Play Store<sup>2</sup> to people who have devices with insufficient resources (Android 2012).

## 2.4 OpenGL

OpenGL (originally Open Graphics Library) is a library for developing 2D and 3D graphics. It was introduced in 1992 and has since then gained a lot of popularity and been adapted to many operating systems. The standard is used in many different contexts, where advanced graphics is used, like in the gaming industry. Since 2006 OpenGL has been managed by a consortium named Khronos Group which was founded in 2000 and consists of companies like NVIDIA, ATI Technologies and the original creator of OpenGL, Silicon Graphics, Inc. (Hashimi, Komatineni & MacLean 2010).

### 2.4.1 Why OpenGL?

Android offers a set of graphic libraries that can be used to render your graphics on the screen. They have advantages and disadvantages and are used in different situations: Graphics through canvases and drawables is the standard way of Android graphics. This is how all standard user interface components are drawn and is also mostly used when creating a custom component. This can also be used to draw directly onto a canvas which is mostly the case in 2D games where all drawing and updating of graphics is done “by hand”.

Canvas and drawables with hardware acceleration provides the same 2D graphics libraries as above but as of Android 3.0 hardware acceleration is available for most components, raising its performance.

OpenGL can be used to render more advanced graphics using features such as 3D. In Android it is accessed either through the regular framework API or the NDK, developing native OpenGL code. Using the framework causes some drop in performance compared to native, but is still perfectly usable, although when developing applications with heavy graphics demand, the use of the native framework should be considered. The biggest

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<sup>2</sup>Online portal for buying and downloading Android applications.

advantage is that OpenGL is well documented and accepted as a standard in many different contexts (Android 2012).

Renderscript is a form of native code for android that provides high performance 3D graphics rendering similar to NDK OpenGL, but also offers a powerful computation API. Renderscript code is compiled and cached at runtime on the device, which makes it possible to use on a variety of Android devices and thus highly portable. However, the main disadvantage of Renderscript is that it introduces completely new APIs which are not as documented as OpenGL (Android 2012).

One of the end goals of this project is to render graphics in a 3D environment, consistent with reality. For this purpose, the use of canvases and drawables is not well suited. For 3D rendering both OpenGL and Renderscript qualify, but since OpenGL is more of a standard and is more documented than Renderscript, it is the library of choice in this project.

### 2.4.2 OpenGL on Android

OpenGL ES is a version of OpenGL meant for embedded systems and is suitable for mobile devices. It is a lightweight version of regular OpenGL with a lot of convenience functions taken away. Android supports OpenGL ES 1.0 since Android version 1.0 and OpenGL ES 2.0 since Android version 2.2. OpenGL ES is closely related to standard OpenGL and also has a large supply of documentation (Android 2012).

## 3 Method & Development Process

Here the work methods that are used in the thesis in order to reach the goals are described. How the information was gathered in the initial phases is described and how the actual work was carried out. This covers literature study and how the applications was developed as well as with which tools. Finally, it also depicts how the information basis for the evaluation was collected.

### 3.1 Literature Study

In order to gather knowledge about the motion capture domain and to give a better understanding of the reasons and background of the thesis a literature study was performed. It is a summary of a variety of published documents in the area relating to this subject (Taylor 2008).

The gathering of information about the theory of motion capture and especially optical motion capture, was conducted by studying scientific papers and articles. Like in normal literature study, the material studied was organized around the research questions of the thesis and in line with the thesis' purpose (Writing 2010). As for the specific knowledge of the Qualisys system, in-house documents and specifications were studied and the staff were asked questions.

Documentation and guides on how to use the Android NDK were studied quite extensively to gain knowledge on how to use the existing C library for the real-time protocol. First party material, such as Android development guides, as well as third party documents, as e.g. developer blogs, to widen the comprehension for the subject.

As an aid in the graphical part of the development, many sources for documentation on OpenGL was used. Official, unofficial, first party and third party as well as asking experienced co-workers, all possible sources of information were used to get a better picture of the problem at hand.

### 3.2 Development

The actual development of the Android application is described in this section. Both development process and tools are discussed.

### 3.2.1 Basic agile approach

When developing the applications a simple agile approach was used with some of the basic values of agile processes. Two of the points in the agile manifesto were highlighted more than the other two during the project, namely “customer collaboration over contract negotiation” and “responding to change over following a plan”. These two points mixed with the idea of a high degree of communication both in the team and with the customer was a suitable combination since the project was carried out in house and the customer, which in this case was the supervisor at the company, was available at almost all times. This emphasis on communication and flexibility was realized through regular meetings with the supervisor, where the team reported the progress and the supervisor had his say in the development of the project (Cohen, Lindvall & Costa 2004).

A basic version of the agile notion of iterations was used throughout the thesis. Small packages of functionality ordered in logical steps were developed one at a time and slowly led to the finished products. This also adds to the ability to respond to changes and sense of flexibility in the project (Cohen et al. 2004).

#### 3.2.1.1 Requirements elicitation

The requirements for the applications that already were present for the iOS platform were taken from the actual applications. Their design and behaviour were examined and the functionality was divided in logical parts and continuously implemented for the Android applications.

However, the third application, the virtual camera, did not already exist and the requirements had to be taken from elsewhere. Meetings were held with the supervisor at the company and the basic requirements were established and informally stored.

#### 3.2.1.2 Pair Programming

During the thesis, pair programming was heavily used. Nearly all programming were carried out as a pair and that helped in increasing the understanding of the project as a whole. The team members were taking turns in being the programming part. It is argued that since pair programming is a kind of instant peer review, fewer defects are produced. It is also argued that pair programming decreases the need of competence and experience of the individuals since it provides a sort of mentoring between the parties involved (Cohen et al. 2004).

### 3.2.2 Android SDK

The Android SDK is a compilation of the all the classes and components that are used by the Android framework. The SDK is a necessity for developers to write Android applications, since all the necessary tools are included. Not only components for the actual developing is included, but also other vital tools like the Android Debug Bridge which essentially handles communications between the development machine and Android device (Android 2012). Another handy tool that is included in the SDK is the Android

Emulator. The Emulator is a virtual Android device that runs on the developers computer. It is put to good use when testing an application during or after development, when testing without using a physical device is desired. However, the Emulator has some limitations that makes it less than ideal for testing in several cases, e.g it does not support hardware sensors (Android 2012).

### 3.2.3 Eclipse

Eclipse is an open-source IDE, that was created in 2001 by IBM. Nowadays it is maintained by the Eclipse Foundation, a non-profit organisation founded in 2004. The IDE is focused on providing tools for developing, debugging, testing and providing all other sorts of tools for maintaining software throughout its life-cycle (Eclipse 2012).

Eclipse was used as the development environment through the whole thesis, due to its versatility and the fact that there exists a plugin that facilitates Android development (see 3.2.3.1).

#### 3.2.3.1 ADT

Android Development Tools is a plugin for Eclipse that presents the user with a set of tools for easier Android development. These tools enables the developer, among other things, to edit XML-files both as text and as graphical form and to edit the user interface graphically by dragging components to the right place. They also allow developers to create Android projects in an easy way and run them directly from Eclipse on an Emulator or Android device. Tools for debugging and testing in Eclipse are also provided (Android 2012).

#### 3.2.3.2 C/C++ Development tools

During the development in the thesis, a portion of the work was done in C in order to wrap the QTM API functions with the help of Android NDK to be used in Java. For the purpose of developing in C, the Eclipse plugin C/C++ Development Tools was used. C/C++ Development Tools offers functionality of a C/C++ IDE in the development platform. It offers features such as syntax highlighting, code refactoring and generation, autocompletion and other useful tools when writing C code (Eclipse 2010).

## 3.3 Interviews

After the implementation was done, some interviews were conducted in order to assess the usefulness of the applications and thereby helping to fulfill the purpose of the thesis. The questions in the interviews were designed to obtain an objective view on how the applications contribute to the system in terms of installation and maintenance. The questions were also meant to provide a view on how the 2D and 3D implementations differ. The interviewees were some people at Qualisys and, if possible, a customer of theirs. The question about the QTM Remote and the Viewfinder can be answered based

upon previous experience with the iOS versions, since they are almost identical. The derived questions are found in Appendix A.

# 4 Implementation & Result

This chapter presents the results derived from the work in the thesis. First the results from the actual development are presented which covers each application of the three. How the applications work is explained as well as how they are engineered. The general internals of the applications and behaviour of the wrapped c-library QTMAPI is also explained. Finally, the results from the interviews conducted to assess the possible benefits of the Android applications are presented

## 4.1 Deliverables

In this section the resulting products are presented and the corresponding development. The three applications produced in the development are demonstrated and their inner workings explained.

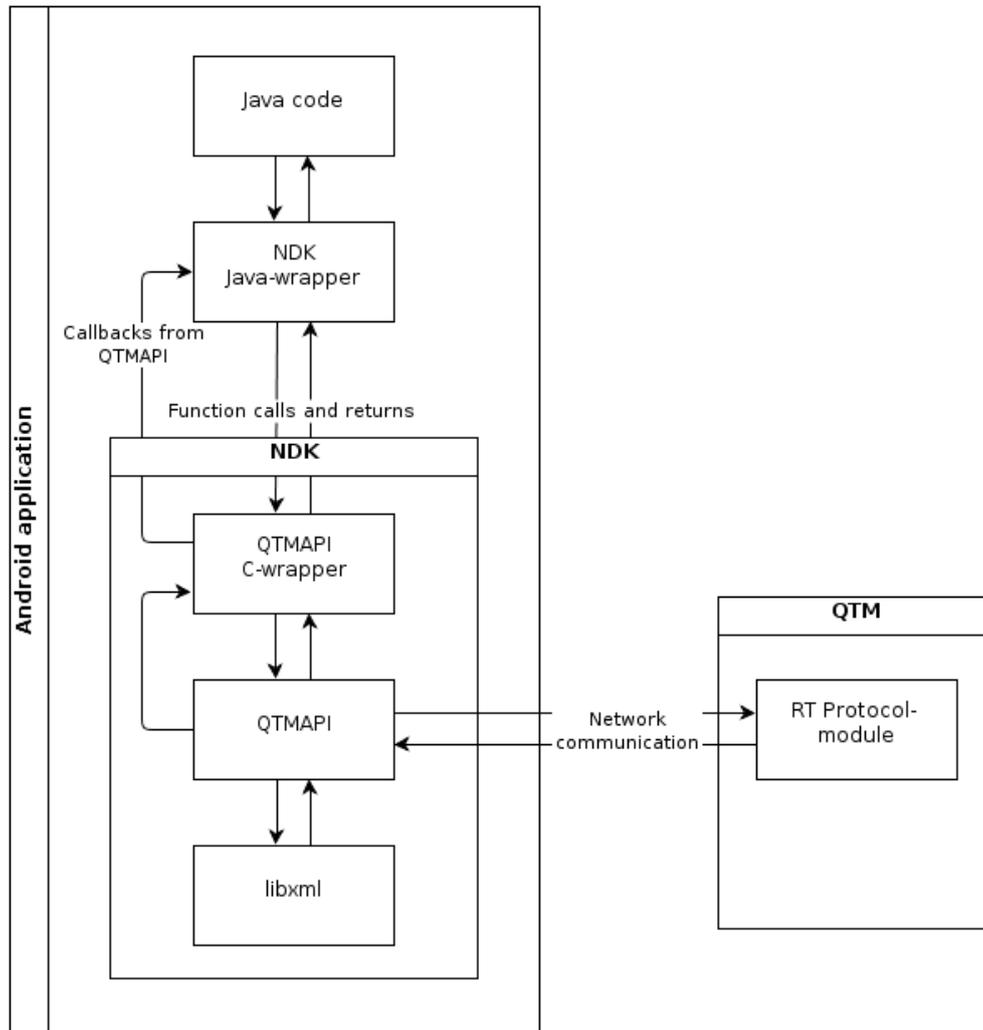
### 4.1.1 Internals

As stated before, NDK was needed in order to make use of the QTMAPI. NDK allowed for communication between Java and C through void function calls, function calls with return value and also threaded callbacks.

As an example, when initiating communication and asking QTM for version, this is done through calling a native integer method in Java. This method is then mapped to a corresponding C function. The C function makes some internal calculations and communication with QTM and returns the version number as an integer which is received in Java.

Another example is when streaming data. There, a frame handler thread is started in C which is constantly calling a specified java method (callback) with arrays containing data received, until it is told to stop.

In some cases QTMAPI was used without modification, however in most cases little to extensive rewriting had to be done. There was need for an extra layer of functions in C which was used to call the original function. This was done since data had to be altered or converted before it was sent to Java.



**Figure 4.1** Diagram depicting the interaction between Android Java, QTMAPI and QTM

As seen in the previous figure, another library had to be included; libxml, since it is a dependency of QTMAPI. Libxml is an open source library, released under the MIT license<sup>1</sup>, which have XML parsing and toolkit capabilities (xmlsoft 2009). This is used since most of the communication with QTM is XML based. Inside the Android.mk-file<sup>2</sup> it had to be specified which parts of the libxml that were to be included and how it was to be accessed. This created a hierarchy where libxml is included into the QTMAPI library which in turn had to be included as a library in our wrapper layer in C.

<sup>1</sup>A permissive free software license

<sup>2</sup>The JNI build file for NDK

### 4.1.2 QTM Remote control

The remote application provides one basic feature and that is remote controlling the captures in QTM. This is done from the main screen of the application, where the user is presented with a start button. During the capture, a progress bar shows how much time that has elapsed. The user can also add events to the timeline with the “Add event” button. Events are visualized on the progress bar as green lines and they are used to mark points of interest in time. In between captures, the user can adjust the length of captures with a seek bar.

However, if there is not an ongoing measurement in QTM when the application connects to the server, the user can start a new one by pressing the “New” button.

When a capture is complete, the user will get the opportunity to save or discard the recording. A dialog enables the user to choose a name for the capture and then desired action.

By pressing the settings button on the main screen, the application will show a settings screen where the user can search for available hosts and choose which host to connect to. From this screen, there is also an about screen available where the user can get basic help on getting started with the application.

The last feature of the remote application is called batch capture. This allows for the user to save captures automatically without having to specify a filename. This makes for fast recording with minimal downtime which comes in handy when making multiple recordings - only two buttons have to be clicked when jumping between captures. Batch capture has to be enabled in QTM.

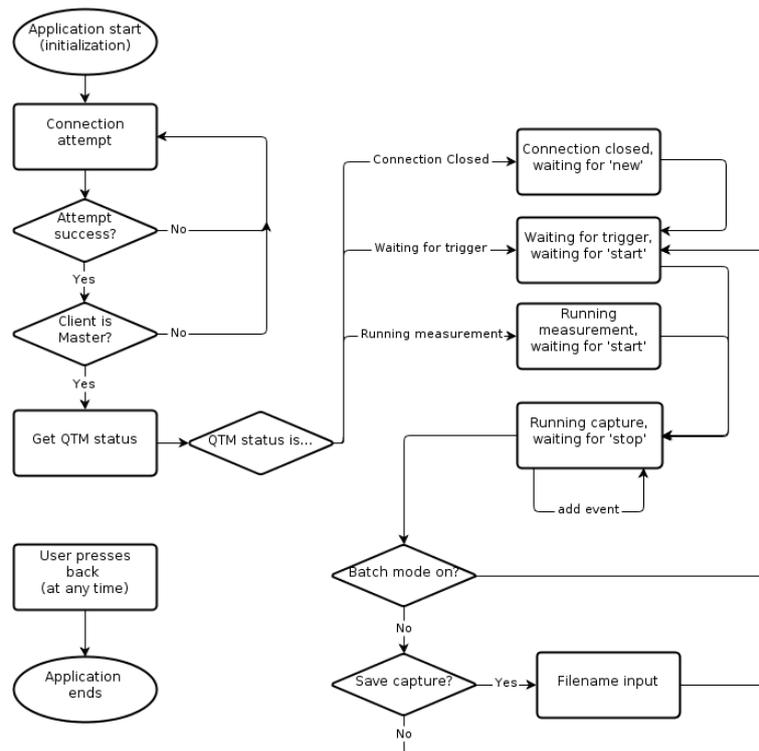


Figure 4.2 QTM Remote on the Android platform

### 4.1.2.1 Implementation

All communication with QTM in the application is done through the RT protocol by using the QTMAPI with NDK. Important commands that are used in the application when interacting with QTM are connect, version, take control, new (measurement), start, trig and save. The version command is used to specify what version of the RT protocol should be used. The take control command must be used to enable the application to change settings via the protocol. Prior to the start command, the applications sends the setting “start on trigger” to QTM, which specifies that after the start command is sent QTM should enter a waiting mode and start a capture when the trig command is received.

The discover command is also an important part of the functionality. It allows the application to discover QTM hosts in the immediate network. It works by sending a UDP packet to a pre-specified port and if an RT server is running, it will respond to this handshake and send a packet back to verify its existence. The discover command sends these packets to a range of IP addresses in the same network as itself and then returns a list of all host that answered within a certain timeout.



**Figure 4.3** Flowchart illustrating the different states of the remote application

The application is event based and the different states of the application are dependent upon what events are received from QTM. Right after the connection procedure is complete, the application sends a “get last event” command to QTM and upon receiving that, QTM resends the last event that was generated. This lets the application enter

the right state right after connecting and when further events are received, change state as appropriate.

Almost all graphical elements in the Remote application are defined using XML in contrast to using pictures. When developing the Android code, the graphical elements were defined in separate XML files and then used in the layout XML when setting background etc. to UI components just like actual pictures would be used. This is a simple way to create uncomplicated graphics using simple shapes and gradients. The settings button on the main screen, the refresh button on the settings screen and the event marker are the only components with non-standard styles that use pictures as resources instead of XML, since they are too complex for simple shapes.

### 4.1.3 QTM Viewfinder

The core features of the viewfinder application is to let the user see what the cameras see. It is to show in real-time on the Android device exactly what is in the camera's field of view. This is helpful when mounting the cameras or adjusting their focus and frees the user from the constraint of having to check on the computer whether the adjustments are right.

The connection procedure is, in contrast to the remote app, the first screen to face the user when starting the application. The user can search for hosts on the network, choose one and connect to that host by pressing a connect button.

Like the Remote application, the Viewfinder will present the user with an option to start a new measurement if there is not an active session.

When the application has successfully connected to the host, it goes into one of three modes. The modes are marker, marker intensity and video. In marker mode, the application shows everything that the camera interprets as markers and shows them as ovals on a black background. The information about the ovals exact shapes also comes from the camera.

The marker intensity mode is a kind of video streaming, where the picture is shown as a heat map. Reflective surfaces are shown as hot red and non-reflective as cold blue. This mode helps the user to know what in the picture is interpreted as markers by the cameras, since hot red or orange surfaces will be markers and everything else will not.

Video mode shows, like it sounds, video from the camera without any alterations. In this mode it is easiest to see what the camera sees and what focus it has.

The application is easy to navigate and offers a set of simple touch gestures. The user can change which camera to view by swiping horizontally or by dragging a seekbar in a panel that is shown by pressing the camera button. In any mode the user can zoom in by double tapping the screen and zoom out by tapping with two fingers. Tapping with three fingers completely resets the zoom. Zooming in and out can also be done by a pinch gesture. The modes are changed by pressing a button in the upper left corner. The modes are changed in a one way cycle and the button is changed accordingly. By pressing the camera settings button, a panel is shown that contains seekbars for adjusting the camera settings exposure time, flash time and marker threshold.

In order to be able to change the camera settings and mode the application must, just like the remote, take remote control of the QTM host. If the command succeeds the application gains master status of the RT interface and is free to do changes, but if it does not the application goes into slave mode. Since slave mode allows no camera mode or settings changes, the settings panel is inactivated and the user can only use marker mode. However if the current master of the RT interface or a QTM user on the host changes camera mode, the slave application will also make the change. Another restricted mode is the file mode. When QTM streams data from a file over the RT interface, the viewfinder enters file mode. Since the streamed data is not obtained from the cameras in real-time, there is no possibility to change the camera settings or mode.

The application features a demo mode, which is accessible from the menu in the connection screen. The demo mode is like the regular application, except that the marker information is stored within the application and is not streamed from a server. In the demo, only the marker mode is available since no image information is stored. Camera settings are for obvious reasons also not available.

A settings screen is available from the menu on the main screen. The user can change settings such as what port to use when connecting to the server, size and colors of markers and properties of the data streaming.

On the main screen a menu is accessible by pressing the menu button on devices running Android 2.3 and older. On devices that run 3.0 or higher, the menu is accessed by pressing the overflow button on the action bar.



**Figure 4.4** QTM Viewfinder on the Android platform

### 4.1.3.1 Implementation

The discovery and connection procedure of the viewfinder is almost identical to the one in the remote application. This includes the version and take control commands. If the take control command fails, it means that some other RT client is master or that the password is wrong and results in the application goes into slave mode.

Like the remote application, the viewfinder states are based on events sent from QTM. One of the events that can be sent is the event that indicates that QTM is streaming data from a file and it is that event that triggers the file mode in application.

When application is ready to start the streaming it sends a “stream frames” command to the server with arguments that specifies what kind of data to be streamed, the frequency, whether or not to use UDP and also to what host. After that QTM starts to stream the chosen data, in this case 2D markers and video images. QTMAPI delivers the marker data in C in the form of an architecture of structs, containing information about the markers the cameras see with their position and size. This information concerning the camera the user is currently looking at is put in arrays and sent to Java where it is parsed and made into marker objects that are put in a global marker set. As for the video modes, it consists of a stream of images sent from QTM. They arrive in C as byte arrays, which are directly sent to Java, where they are decoded to bitmaps and delivered to be drawn.

The drawing is made on an OpenGL surface which is placed in the camera screen of the application. The coordinates for the markers’ oval shapes are calculated when they are parsed from C by a simple loop using discrete steps of degrees and the sine and cosine functions. The drawing thread takes the marker information from the global set of markers asynchronously from the one that creates them. The drawing of the video modes is done by taking the bitmap received by the parser and making it into a texture and drawing in across the screen. The delivering of bitmaps is also done asynchronously from the drawing and when a new bitmap has arrived, it is marked as new and the drawing thread loads the new bitmap as the texture.

The demo mode is very similar to the streaming mode of the application, except that the streaming of markers is generated from a file stored in the application. The file was created by saving actual marker data, streamed from a QTM host, in a data structure and then saving that structure to a binary file. When the demo mode is launched, the structure is loaded from the file and a thread simulates a repeated marker streaming until the user quits the demo.

When the user touches the screen of the device in the camera view, a listener monitors what kind of gesture is performed. A swipe is detected by comparing the points where the gesture begins and where it ends. If they are somewhat on the same line horizontally and the gesture is performed quick enough, it is interpreted as a swipe either to the right or to the left. A double tap is easily recognizable as two touch events with short delay in between. A tap with two or three fingers is recognized by measuring the time between the first, second and third finger, making sure it is short enough. The time between the first finger touching and the last finger leaving the screen must also be sufficiently short. Pinching is done by detecting when two fingers are touching the screen and then

constantly measuring the distance between them and comparing that to the first value measured. Consider this example; if the user puts two fingers on the screen with 25 pixels between them and then moves them further away from each other. The next measured value will be somewhat bigger than 25, say 30 pixels for simplicity. The ratio between them is  $30/25 = 1.2$ , which is the scale used when zoom, i.e a zooming in action is performed. If the user continues to move the fingers apart, the zoom factor will be even greater.

The menu is implemented both as a traditional Android menu or as an action bar, depending on what version of Android the application runs on. From Android 3.0 and onward, Google decided to phase out the menu button and encourages developers to use the action bar instead (Android 2012). When targeting a device with Android version greater or equal to 3.0, Android shows a traditional menu will be automatically shown as an overflow button in the action bar. When the application starts, it will at runtime examine what version of Android is used and if it is 2.3 or less the action bar will not be shown since it is unwanted in these earlier versions. In practice this means that on a device with Android up until 2.3, the menu is accessed with the menu button and on higher versions the action bar will be used to access the menu.

#### 4.1.4 QVC

The QVC, or Qualisys Virtual Camera, was the last part of software for this thesis. This application takes the project into the 3D-world. Now, 3D markers are streamed to and interpreted by the software to in order to display a full depth, real-time picture. Rather than using the existing cameras from the environment as viewing angle the smartphone itself is used as a virtual camera. What you would expect to see in front of the device is intuitively displayed at the screen. For instance, if a user were to point the device at a body with markers, the markers will be displayed on the screen in real-time.

Rather than displaying markers with a chosen color in the device, the color is collected from QTM to enable QTM specified color on individual markers. Moreover, the user has the option to turn on and off label viewing. This means that when the user is viewing a marker, the application will display, if there is a label assigned to the marker, the according label alongside the marker itself.

Besides displaying markers and labels, the application will also draw the floor as a green grid in the plane where the x- and y-axes of origo are intersecting. The x-, y-, and z-axes of origo are displayed in the 3D-environment as well which helps the user to orient the system.

In almost exactly way manner as with the Viewfinder (4.1.3), the user is allowed to search for hosts or input the address of a host at the start screen. In the same manner there is an about screen where the user can read more about how to use the application. This screen is almost necessary since the preparations the user have to do before getting started.

QVC also features pinch-functionality as with the Viewfinder. However, the only action the user can perform is pinch-to-zoom with two fingers. Panning and moving the

camera around is simply done by physically moving the device. The zoom feature is usable when you want a closer look of an object without having to move closer to it.

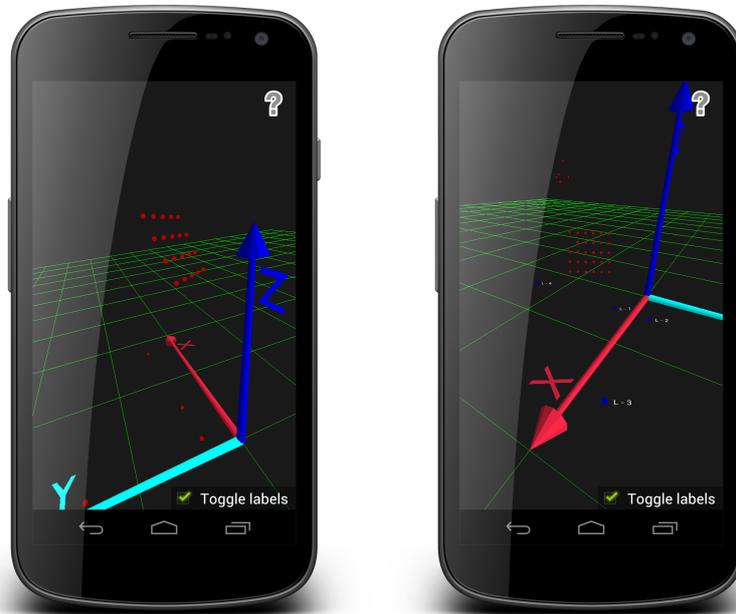


Figure 4.5 Screenshots of QVC in action

#### 4.1.4.1 Implementation

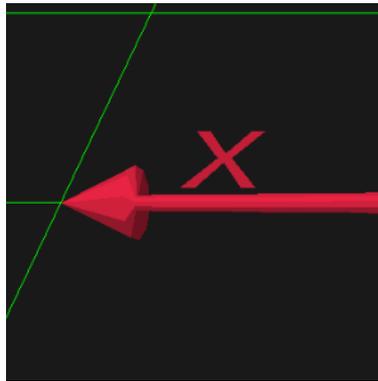
The streaming of the markers works somewhat as in the viewfinder. The QTM API and its Java layer counterpart had to be rewritten just a bit. This was mainly to cover the new aspects such as 3D-markers, colors and labels but we also had to create new functions for the rigid body (6DOF) streaming since support for this was not fully implemented in the QM API.

The largest difference in the data is that now each marker is streamed only once per frame, not once per frame and camera. Each frame that is streamed to the device contains information on each marker and its position in the system. Moreover, information about which markers have labels and if they have been assigned a special color has to be fetched alongside the frame stream. In the same manner the 6DOF information has to be streamed separately.

The reason for streaming the information separately is because how the RT protocol is defined and how QTM act to commands. Although, this implementation doesn't wait for all information from a specific frame to arrive before drawing it, it simply draws what is at hand at the moment. This may cause a latency issue when objects being drawn from different frames are intervened in one picture. However, this issue is not noticeable

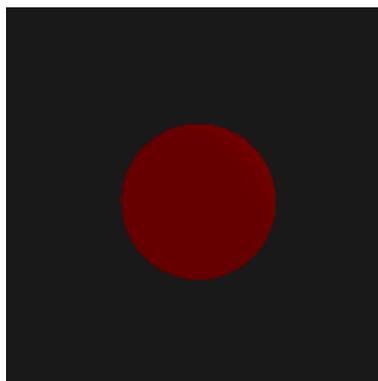
by the user since it should only be visible for a fraction of a second. If there are severe latency issues on the network the application will not work well anyhow.

Using the information streamed from QTM, the application draws a complete 3D-environment using OpenGL. Every item of the 3D-environment is measuring the same length as in real life. The ground which is drawn as a green square net is actually drawn as 0.5m\*0.5m squares, correlating to the real world. The x-, y- and z- axes are drawn with a length of 1m. However, when the floor is only consisting of lines, the axes are drawn with calculated coordinates which polygons are placed upon. This makes the axes stand out more and to make them distinguishable they are drawn in separate colors. By each axis the according letter (x, y or z) is also drawn for the users convenience.



**Figure 4.6** Close-up of the x-axis

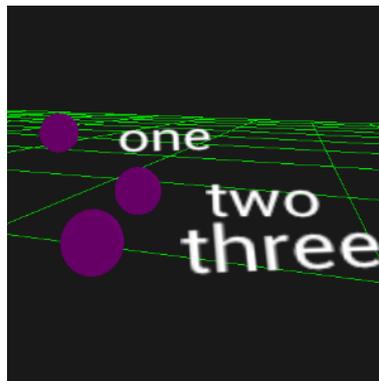
At the start of QVC, the coordinates of a sphere is calculated with the help of trigonometric functions. With these coordinates, polygons and according normals are calculated and stored for later use. This sphere is then what is used each time a marker is drawn. The normals are used in combination with a light source in order to create shading on the body of the sphere, giving the sphere 3D-look. With this, the specified color from QTM is added.



**Figure 4.7** Close-up of a marker

For each marker label, a custom texture is drawn and stored with the label name. Using this for rendering later, allows us to just place the texture with the text on a

flat object and position it alongside the according marker. In order for the label to be visible from cameras position, a technique called billboarding is used. This means that the flat side of the object containing the text always have to face towards the camera. Knowing the position of the camera, each label and which way the camera is facing, this is calculated accordingly and individually for each label.



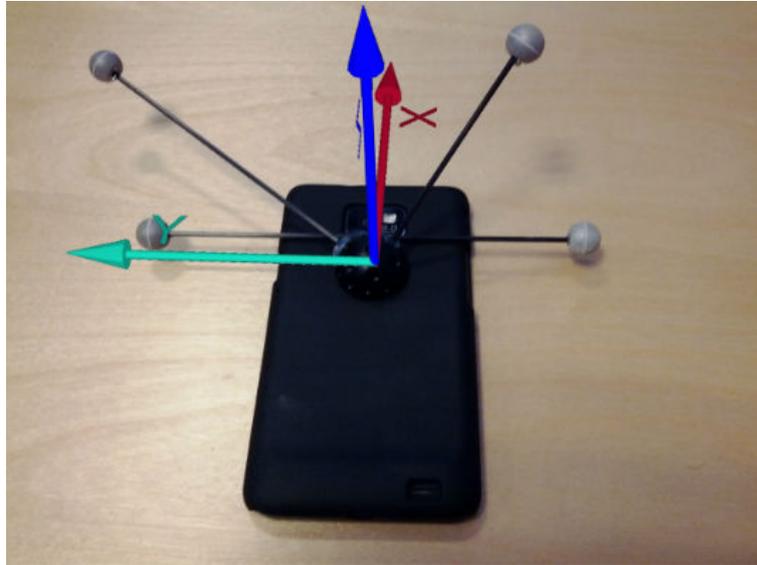
**Figure 4.8** Three markers with purple color and assigned labels

In order for the application to know where the smartphone that is to be used as virtual camera is, the smartphone has to be defined as a rigid body in QTM. This is done by fixating markers on the device itself. From a quick recording, the markers fixated to the device can be selected and named - in this case 'QVC'. Doing this will make the system identify the position and the angles of device. The device gets a center and x-, y- and z-axes. This rigid body is the last thing that has to be streamed to the application, and is called a 6DOF body. The information contained in a 6DOF body when streamed is the 3d-position of the body and a rotation matrix. The rotation matrix is used to turn the camera accordingly with the device. Here, the z-axis of the 6DOF is identified as the angle the camera is looking, the y-axis points right from the perspective of the camera and the x-axis indicates up. When this is applied the last thing to do is to position the camera according to the 6DOF information.

Regarding the recommended placement of the markers on the rigid body (see Figure 4.9), it is important to place the markers with some distance from the device. This is so that the hand holding the device will not block the markers for the cameras that easily. Further, the markers should not be placed symmetrically and absolutely not in just one plane. This is because placing markers symmetrically will allow for QTM to interpret the axes of the body in several ways. For instance, imagine that the markers are placed in the same plane consisting of four markers forming a square. This could place the x- and y-axes at four different combinations with the z-axis able to point in two directions orthogonal to the xy-plane. This makes for eight different possible interpretations of the body's coordinate system.

The reason for having four markers on the rigid body is that even if one marker is completely covered, the remaining three markers will still be enough for the cameras and QTM to recognize the position and angle of it. More markers placed on the body makes

for a more stable recognition. However, for this purpose four markers are deemed to be enough.



**Figure 4.9** A recommended configuration of a QVC rigid body with illustrated axes.

## 4.2 Interviews

The interviews showed that the remote application, like a normal external trigger is used to get closer to the measured subject. In some cases it is used to add events to the capture timeline. The application highly resembles a normal external trigger (though wireless) in many aspects except one; response time. Since the regular external trigger uses an analog signal via a connected cord, its response time is more or less constant. In the case of the application, several factors like network lag and processing time may cause a variable response time.

According to the interviews, the Viewfinder is mostly helpful when mounting cameras. It is presented to customers as a side feature and showed when the systems are installed. Customers who use portable systems have greater use for the application than other clients.

As for the QVC, the interviewees were more uncertain and speculated about it being used when checking if markers are placed correctly. It may be presented to customers as a cool feature that shows the real-time capabilities of the system. A more specific purpose may be found in the future and then the application may be used. Comparing the QVC to the Viewfinder is hard since they are complementing each other. The Viewfinder is used while setting up a system and the QVC is used in an installed and calibrated system. However there was one speculation about the QVC being helpful in the event that real-time calculations of optimal camera placement is implemented. Then you might be able to use it to see in real-time where to move the cameras.

# 5 Discussion

In the discussion some different subjects regarding the helpfulness of the handheld applications are assessed. Comparisons between the Android applications and their iOS ditos are discussed and also some the known issues and limitations. Some development discussions are made with respect to NDK and finally the thoughts on future work are presented.

## 5.1 Android adaptations of iOS applications

The Android platform and the iOS platform have some fundamental differences and therefore the applications are bound to differ somewhat. In many cases, Android devices have (mostly in earlier version) a menu button, which is used to show a menu that can contain additional alternatives and functionality than what is shown on the screen. In Android version 4.0 and forward this functionality is replaced by the action bar which offers similar functionality (Android 2012). In the Android apps, through either the menu or the action bar the menu alternatives are available, in contrast to the iOS apps where the components often are placed directly on the screen. In general, the different operating systems have a certain feel about them and that is usually transferred to their corresponding applications. In the development of the Android applications, the user interfaces were created to be more suitable for the Android environment than the interfaces in the iOS applications are. The menu adaptation is the most notable example of this.

In the viewfinder application the Android version features oval markers whereas the iOS one have only circles (even though the RT interface provides information about the diameter of the markers in both the x-axis and the y-axis). The Android application takes both diameters into consideration and produces ovals but the iOS application uses only one. In actuality this leads to a slight degradation of performance in the Android application, since the coordinates for the oval shape has to be recalculated for every marker in every frame, instead of scaling them in OpenGL. This performance issue is not noticeable on the tested devices, but whether it would affect the performance in older devices is not known. The advantage of using both diameters is that the markers in the application look like the markers in the 2D mode of QTM. This gives a higher sense of conformity to the products.

The user interface of the remote iOS application does not consist of anything that

does not fit in the Android environment. Therefore the interface for the Android version was engineered to look more or less exactly like the iOS one. However since there is a big variety of different Android devices, the interface was constructed to fit many different screens.

In conclusion, the Android applications are made to be like the iOS applications and even if there obviously is some differences in implementation, they use the same API and offer the same functionality.

## 5.2 Usefulness of the applications

### 5.2.1 QTM Remote Control

The remote application contributes a lot in maneuvering a Qualisys system, when a user wants to be able to move around while controlling the capture and adding events to the timeline. The application provides even more freedom than a regular external trigger and do not restrict the user to the computer running QTM or by a crude cable lying around. Like the interviews suggest, the application can be inadequate if a certain response time is required, but otherwise it is less restricting. Another feature not present in the regular trigger is the ability to name and save the captured data as files on the computer.

### 5.2.2 QTM Viewfinder

The Viewfinder's contribution consists of the help it provides when configuring a system. This is the purpose for its creation and is also presented to the user as such. The user of the application is not bound to the computer to see where a camera points or how it is focused but can instead look at a device in their hand. When installing a system for a client, Qualisys employees utilize the Viewfinder to mount the cameras correctly and configure their focus. By doing this, another feature of the system is shown to the customer and one can claim that this contributes to the sense of overall quality. For customers that use portable systems which they move around a lot, the application can prove to be a smart feature that simplifies their work with installing the system. The Viewfinder is not a crucial part of the motion capture system, but it is a rather useful one.

### 5.2.3 QVC

The usefulness of the QVC is much more uncertain than the two other applications. This is mainly due to the fact that the Viewfinder and remote applications have been around longer. Their advantages are already documented and they are already used in real life situations. The QVC was developed as a kind of exploration project where the 3D functionality of the real-time interface of QTM was to be used. Although the future for the QVC is unclear, the result of the interviews imply that it may be used when placing markers on a subject and making sure that they are in the right place. Another

speculation about the application's future uses, involved configuration of the system by seeing in real-time where the cameras should be moved. To summarize, even though the future of the QVC is unknown it has potential for being used while maneuvering the system and there is also a slim chance that it can be used to configure the system.

When comparing the 2D functionality of the Viewfinder to the 3D functionality of the QVC, the first observation that comes to mind is that the applications does not really overlap so the comparison itself is hard to make. The 2D functionality shows what markers the different cameras see and however useful that may be when configuring the system, it does not really reveal any information about where the markers are placed in the 3D space. In turn, the 3D functionality does not say anything about what the different cameras see. The extension to 3D presents a whole different set of features than what is available in 2D. Even though one can claim that they are more exciting, one cannot say that they present any advantages.

### 5.3 Java and NDK

As mentioned before, an existing API in C was used during this thesis for all communication with QTM. The features and functions in the API, that are used by the applications, were wrapped in Java using the NDK. The applications have some differences when using the API and because of that, some differences in the wrapping exists. The main advantage with using the QTMAPI was that all the functionality of the RT protocol was already present and usable. No work that focused on communication or low level parsing of messages had to be done and focus was instead on the functionality of the applications. The main disadvantage was the time it took to learn how to use the NDK in this environment and with the libraries needed.

To make a complete version of the API in Java would have been preferable, but that was not a part of this thesis. A complete and universal wrapping of the C library would have been very time consuming and moderately complicated. Compared to wrapping the whole C library, developing a pure Java API would have been more efficient but then the message parsing and network communication would have been necessary. In summary, even though the NDK approach consumed a lot of time in the beginning of the thesis it may have been more efficient than developing a pure Java API, since focus only lay on the necessary features. Also, there is a high uncertainty regarding what problems might have arisen during development of the communication in a pure Java API.

### 5.4 Known issues and limitations

There are some issues that affect the performance of the applications and serve as limitations in the environment. In the Viewfinder and the QVC the data is streamed in real-time from the server and this creates a problem that is out of the developers' control, namely faulty network connection. If the applications are used on an unstable network, they may produce a very deficient performance. This can be highly frustrating for the user and render the applications more or less unusable, however it is still up to the user

to prevent it. Tests have concluded that a connection to a normal WLAN is usually sufficient when running the applications, but sometimes high amounts of network traffic and insufficient range affects the performance. For the applications to perform at an absolute maximum level, an ad-hoc WLAN is recommended.

Another limitation of the applications is that handheld devices tend to be small, especially phones. In order to make the applications bearable to use, all features must be easily accessible and have a good user interface. The challenge is to get all wanted functionality into the applications and still maintaining their usability. In the Qualisys motion capture environment, there are a big variety of different features and functions that could be implemented for handheld devices so this limitation could easily be a problem, but in the case of this thesis all wanted functionality was implemented without any difficulty.

An issue that might even be called a defect in the Viewfinder occurs when changing camera modes. When the application was implemented, its behaviour was modeled after the iOS version. Because of this, when entering marker intensity or video mode all the cameras' modes are changed. This was initially considered the correct behaviour since the iOS Viewfinder behaved the same way, but has since been deemed unwanted. When working in with a system with many cameras, only one should change mode at a time. Since cameras only send marker information to QTM when in marker mode, changing from marker mode on all cameras would lead to no marker information whatsoever. In a system with many cameras, losing marker information from one is not a terrible loss but losing that information from all cameras is a problem. However this is usually only a problem when multiple users of the system wants to do several things simultaneously and one uses the application. This problem cannot cause any serious harm since the application is not able to change camera mode during capture. Although, it can cause a certain annoyance among the users.

## 5.5 Future work

As far as the remote control goes it is a remote application with all features that one could imagine for that kind of adaptation. We do not think that there is so much development that can be done in order to improve it; in its simplicity it fulfills its purpose.

As with the remote, there is not many useful features left to expand the Viewfinder with. What was noticed during the course of this thesis was the issue with the aforementioned behaviour when changing camera mode. When the mode was to be changed, all cameras was told to change mode when in reality only the camera that is active on the application is needed to be changed. Improving this feature would however imply updating the iOS dito in order to maintain coherence.

The QVC has most potential in future work. Here there is a feature which was explored during the thesis but never fully completed, namely a augmented reality feature. This means using a real-time video stream from the camera on the device itself and mapping it against the 3D representation of the space. This make markers appear with labels on actual bodies. Extending this feature further could be adding a 3D model on

the image, mapped on the body with markers, making the model move in real-time. This could be used for when recording movements in order to use them in games or movies, so that the user instantly gets feedback on what to expect from the recordings.

As mentioned before, the possibility of completely wrapping the QTMAPI into Java exists. This would be preferred if there is another Java adaptation to develop in the future. Making the wrapper more general would allow for including the exact same library in several applications, and to use it straight away. Today, features that was not used in the thesis are not represented in the Java QTMAPI counterpart and some features have to be modified in order to work in other environments.

## 6 Conclusion

In this thesis, three Android applications for Qualisys motion capture systems were developed using QTMAPI, a pre-existing C library. Two of the applications, Viewfinder and QTM Remote, already existed for the iOS platform. However, the third application, QVC, was completely new.

The viewfinder application and possibly the virtual camera can be used for configuring a system with the use of their real-time marker streaming capabilities, whereas the remote application is mainly used to maneuver the system by wirelessly controlling captures. The virtual camera was developed as means to explore the 3D functionality of the Qualisys real-time protocol and to evaluate possible advantages to the 2D functionality of the Viewfinder. The QVC and the Viewfinder turned out to be very different applications used in different contexts and therefore no advantages were identified. However the virtual camera introduces a new experience in the system and adds a new way to demonstrate its real-time capabilities. During the work with thesis, some limitations of the development were identified. The applications rely on the network performance to give an adequate experience and the full functionality of QTM would be too much to implement in an Android environment.

The future seems bright for the virtual camera, since it has big potential for further development in the form of augmented reality extensions. Perhaps even with real-time rendering of 3D models mapped to markers.

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# A Appendix: Interview Questions

These are the questions asked during interviews with the Qualisys employees.

## A.1 QTM Remote

- What is an external trigger normally used for?
- Is there any difference between the application and a normal external trigger?
- Is the remote an adequate replacement for a normal external trigger?

## A.2 Viewfinder

- What does the viewfinder contribute to the motion capture system?
- How do you present the viewfinder to customers?
- How do customers usually use the application?

## A.3 QVC

- In what ways can this application be useful to the system?
- Do you think that the application will be used in anyway in the future and how?
- What are your views on how the QVC differs from the Viewfinder and what possibilities QVC may add compared to the Viewfinder?