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MASTER THESIS

TITLE: Vuforia v1.5 SDK: Analysis and evaluation of capabilities

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Overview

This thesis goes into the augmented reality world and, being more specific in Vuforia uses, searching as an achievement the analysis of its characteristics.

The first objective of this thesis is make a short explanation of what is understood by augmented reality and the actual different varieties of AR applications, and then the SDK's features and its architecture and elements. In other hand, to understand the basis of the detection process realized by the Vuforia's library is important to explain the approach to the considerations of image recognition, because it is the way in which Vuforia recognizes the different patterns.

Another objective has been the exposition of the possible fields of applications using this library and a brief of the main steps to create an implementation always using Unity3D, due to Vuforia is only a SDK not an IDE. The reason to choose this way is due to the facilities that are provided by Unity3D when creating the application itself, because it already has implemented all necessary to access the hardware of the smartphone, as well as those that control the Vuforia's elements.

In other way, the Vuforia's version used during the thesis has been the 1.5, but two months ago Qualcomm was launched the new 2.0 version, that it is not intended to form part of this study, although some of the most significant new capabilities are explained.

Finally, the last and perhaps the most important objective have been the test and the results, where they have used three different smartphones to compare the values. Following this methodology has been possible to conclude which part of the results are due to the features and capabilities of the different smartphones and which part depends only of the Vuforia's library.

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Resum

Aquest projecte s'endinsa al món de la realitat augmentada, més concretament a l'anàlisi de les característiques y funcionalitats del SDK Vuforia.

En primer objectiu serà posar en perspectiva el que s'entén per realitat augmentada i de les variants existents avui dia d'aplicacions que fan ús de la RA. A continuació es mencionen les característiques d'aquest SDK, la seva arquitectura i els seus elements. En aquesta part també s'han tingut en compte les consideracions de reconeixement d'imatge, ja que es la manera en la qual Vuforia realitza el reconeixement dels diferents patrons.

El següent pas es tractar d'exposar els possibles camps d'aplicació d'aquesta llibreria, i una breu explicació dels principals passos per crear una aplicació sota Unity3D, tenint en compte sempre que Vuforia es només un SDK i no un IDE. La raó per escollir aquest entorn es degut a les ventatges que ofereix Unity3D a l'hora de crear l'aplicació, degut a que ja disposa de tot el necessari per accedir tant al hardware del propi dispositiu mòbil com a els propis elements que integren Vuforia.

D'altra banda, la versió de Vuforia utilitzada durant el projecte ha sigut la 1.5, encara que fa poc més de dos mesos Qualcomm va alliberar la nova versió 2.0, la qual no forma part dels objectius d'aquest projecte, encara que una part de les noves funcionalitats més significatives s'exposen breument.

Finalment, es conclourà amb els tests i resultats obtinguts. Per realitzar totes aquestes proves s'han utilitzat tres terminals diferents per poder comparar valors. A més, utilitzant aquest mètode, ha sigut possible concloure quina part dels resultats obtinguts es deuen a les característiques i capacitats dels diferents terminals i quina part depèn exclusivament de la pròpia llibreria Vuforia.

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INTRODUCTION

The following Master thesis is the study of the Qualcomm's newest AR[1] SDK[2] for smartphones called Vuforia 1.5.

Vuforia 1.5 is focus on possibility to move AR applications into a real time video obtained from mobile devices. This software uses the capabilities of the Computer Vision Technology to recognize and make the individually tracking of the objects captured by the video camera in real time.

The initial objective pretended to fulfill in this thesis aims to identify the elements which are part of the Vuforia's architecture. Along the document these elements were analyzed and described.

Another objective of this thesis is to show how to fit the library under Unity 3D development tool, analyzing Vuforia's main functionalities: detection and tracking. Unity 3D software is a fully integrated game engine that reduces development time and cost. Is for that reason that high programming knowledge is not required. Moreover single project supports iOS and Android.

Finally the thesis aims to evaluate the library's robustness in detection and trackability in front of physical and spatial changes. To asses this, there has been a set of tests by altering Image Targets position and colour shades. All the test have been performed using three different kinds of mobile devices (HTC, Samsung Galaxy S I and Samsung Galaxy Note II) with different characteristics The objective of these tests is to establish Vuforia's recognition and tracking limitations and also set its more suitable usage environment depending on the used device. Furthermore, aims to identify device's hardware restrictions using the SDK.

In spite of application implementation was not one of the thesis goals during it is development an AR application has been created. This application is based on Vuforia's SDK under Unity extension due to its simplicity. Vuforia's attributes configuration are correctly explained along the document. The created application has also been improved by adding new features based on scripts.

At the end of the year 2012 Qualcomm announced the development of a new release, Vuforia 2.0. Due to there has been tremendous interest from developers all over the world, Qualcomm Vuforia's documentation page has been improved including extended useful information which was not present at 1.5. SDK's newest version includes significant new features too. Although these features are not deeply evaluated were taken into account. In addition, it has been developed an application using v2.0's Video Playback feature.

[1] Augmented Reality

[2] Software Development Kit

CHAPTER 1 AUGMENTED REALITY AND IMAGE RECOGNITION

The following chapter will describe the concept of image pattern recognition and AR. The objective is to familiarize the readers with these both ideas.

1.1 Introduction

AR is a term used for a wide range of technologies aimed at the virtual integration of content and live data with real-time media. The idea is to mix the AR which is not really there with what is as smoothly as possible and to present users with an improved screen or augmented the world around them. The nature of the increase could be anything from a textual display of the data overlaid on real scenes or objects for interactive 3D scenes complete, integrated graphics in real.

AR depends crucially on hardware that is able to capture information about the real world, such as video data, location data, guidance and potentially other data forms, and also is capable of playing a multimedia presentation that mixes live with content in a virtual way that is meaningful and useful for users.

With the recent ubiquity of smartphones, almost everyone now has in his pocket an exciting potential for AR. This has led to an explosion of interest in the development of AR. With the widespread use of webcams on laptops and desktops, AR based browser for marketing and creative is booming. Cheap cameras and screens also make it possible to create in situ installations AR cheaply and easily, as LEGO did with his brilliant marketing campaign based on AR-AR that stations were installed at toy stores for customers to have a box up the camera and see the full 3D model on the screen, fully integrated into the live video camera.

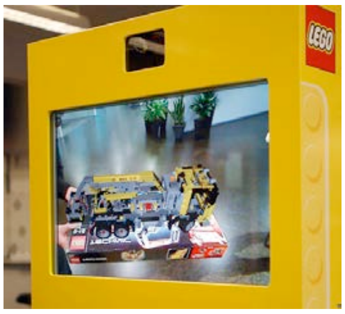


Figure 1.1 LEGO AR system

There are several main varieties of AR, and each is a huge subject in itself. The books available today about mobile AR mainly focus on using the location (GPS) and orientation (accelerometer) data from a mobile device to record the content or integrate into a living landscape. These applications know your smartphone camera is watching because they know where you stand and what direction you are pointing your smartphone. Based on these data, the entries are loaded either a centralized or other users can be overlaid on the scene camera.

Another, but by no means exclusive, AR approach is to use the content of the actual image captured by a camera to determine what you are seeing. This technology is known as computer vision, for obvious reasons. The computer processes each pixel of each video frame, evaluating the relationship of each pixel with the neighbouring pixels over time and space, and identifies patterns. Among other things, the current state of the art computer vision includes exact algorithms for face recognition, identification of moving objects in the video, and the ability to recognize known markers or visual patterns are specific to the algorithm previously identified in a robust manner.

AR-based computer vision can be used in both contexts and non-mobile contexts. It can be used to improve the location and orientation methods based on AR, and can also be used to create AR applications that are not linked in any way to a specific location. The computer-vision algorithm can be made to do pattern recognition on packages, products, clothing, artwork, or any number of other contexts.

1.2 Augmented Reality on Smartphones

The first versions of augmented reality are already here on some smartphones. Smartphone owners can download an application called Layar[3] that uses the phone's camera and GPS capabilities to gather information about the surrounding area. Layar app allows you to scan the public streets for vital information, entertainment news, or networking possibilities. The program essentially 'layers' the information about the landmarks and businesses on a particular street.

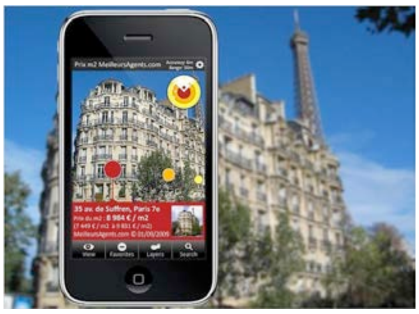


Figure 1.2 Layar app

Another example is Google Sky Map[4]. This Android app will appeal to stargazers and astronomers of all varieties. Simply point your phone at the sky and identify a legion of constellations, stars and planets. If you move the camera around, the information will change in accordance with the coordinates. Excellent for recreational or educational use, Google Sky Map is a simple

[3] Browser that allows users to find various items based upon augmented reality technology

[4] Online sky/outer space viewer

application of augmented reality used for complex tracking purposes. People used to get paid annual salaries to do what this app can do in seconds.

1.3 Image or pattern recognition

Image recognition is the process of identifying and detecting an object or a feature in a digital image or video. In machine learning, image or pattern recognition is the assignment of a label to a given input value. However, pattern recognition is a more general problem that encompasses other types of output as well. Pattern recognition algorithms generally aim to provide a reasonable answer for all possible inputs and to do "fuzzy" matching of inputs.

Pattern recognition is generally categorized according to the type of learning procedure used to generate the output value. *Supervised learning* assumes that a set of *training data* (the training set) has been provided, consisting of a set of instances that have been properly labeled by hand with the correct output. Unsupervised learning, on the other hand, assumes training data that has not been hand-labeled, and attempts to find inherent patterns in the data that can then be used to determine the correct output value for new data instances. A combination of the two that has recently been explored is semi-supervised learning, which uses a combination of labeled and unlabeled data (typically a small set of labeled data combined with a large amount of unlabeled data).

CHAPTER 2 VUFORIA AUGMENTED REALITY SDK

In this chapter it will be explained Vuforia's SDK architecture and its main elements. In addition it will be described the features of this new SDK in front of its predecessor. The chapter will also show the library's algorithm basics to guarantee minimum recognition.

2.1 Introduction

Vuforia[5] is an AR SDK for smartphones or other similar mobile device that allows executes AR applications into a real time video obtained from these devices. This software uses the capabilities of the computer vision technology to recognize and make the individually tracking of the objects captured by the video camera in real time. On the other hand, not all the objects will be detected, and only a few detected objects may be tracked due mainly to the mobile's CPU and GPU. In this project the used version of Vuforia SDK will be the last available, in this case the 1.5 version.

The capability of Vuforia to image registration enables developers to position and orient in the space the virtual objects, mainly 3D objects or other type of media, in relation to real world images or video when these are viewed through the camera of a smartphone. The virtual object then can track the position and orientation of the real image in real time, so that the viewer's perspective on the object corresponds with their perspective on the real world target. In this way, the virtual object or objects appears as if from another real world object.

The Vuforia SDK supports different types of targets, both 2D and 3D, including multi-target configurations, marker less image targets and frame markers. The SDK have another additional features like localized occlusion detections using virtual buttons, image target selection in real time and the ability to reconfigure and create target sets depending on the scenario.

But these not only will be made with Vuforia SDK to create AR applications. In fact, Vuforia provides an API[6] in Java, C++ and .Net languages through an extension to the Unity3D[7] game engine. Unity is an integrated authoring tool for creating 3D video games or other interactive content such as architectural visualizations or real-time 3D animations. Unity consists of both an editor for developing/designing content and a game engine for executing the final product.

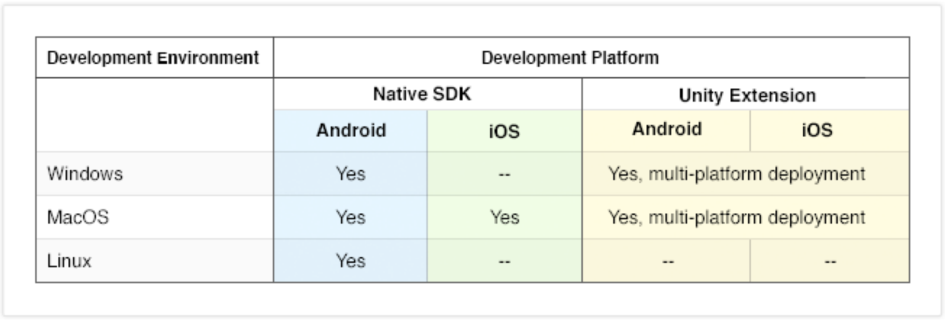
In this way, the SDK supports both native development for iOS and Android, while also enabling the development of AR applications in Unity that are easily portable to both platforms. AR applications developed using Vuforia are

[5] AR SDK for mobile devices

[6] Application Programming Interface

[7] Cross-platform game engine with a built-in IDE

therefore compatible with a broad range of mobile devices including the iPhone (4, 4S and 5), iPad, and Android phones and tablets running Android OSversion 2.2 or greater and an ARM[8]v6 or 7 processor with FPU[9] processing capabilities.



Development Environment	Development Platform			
	Native SDK		Unity Extension	
	Android	iOS	Android	iOS
Windows	Yes	--	Yes, multi-platform deployment	
MacOS	Yes	Yes	Yes, multi-platform deployment	
Linux	Yes	--	--	--

Figure 2.1 Development platforms

2.2 Architecture

The following section describes the main components in an application based on Vuforia's SDK. These components are:

2.2.1 Camera

The camera singleton ensures that every preview frame is captured and passed efficiently to the tracker. The developer only has to tell the camera singleton when capture should start and stop. The camera frame is automatically delivered in a device dependent image format and size.

2.2.2 Image Converter

The pixel format converter singleton converts between the camera format to a format suitable for OpenGL ES[10] rendering and for tracking (e.g. luminance). This conversion also includes down-sampling to have the camera image in different resolutions available in the converted frame stack.

2.2.3 Tracker

The tracker singleton contains the computer vision algorithms that detect and track real world objects in camera video frames. Based on the camera image, different algorithms take care of detecting new targets or markers, and evaluating virtual buttons. The results are stored in a state object that is used by the video background renderer and can be accessed from application code. The tracker can load multiple datasets, but only one can be active at a time.

[8] Acorn RISC Machine

[9] Floating-Point Unit

[10] OpenGL for Embedded Systems

2.2.4 Video Background Renderer

The video background renderer singleton renders the camera image stored in the state object. The performance of the background video rendering is optimized for specific devices.

2.2.5 Application Code

Application developers must initialize all the above components and perform three key steps in the application code. For each processed frame, the state object is updated and the applications render method is called. The application developer must:

- Query the state object for newly detected targets, markers or updated states of these elements
- Update the application logic with the new input data
- Render the augmented graphics overlay

2.2.6 Target Resources

Target resources are created using the on-line Target Management System. The downloaded dataset contain an XML[11] configuration file that allows the developer to configure certain trackable features and a binary file that contains the trackable database. These assets are compiled by the application developer into the app installer package and used at run-time by the Vuforia SDK.

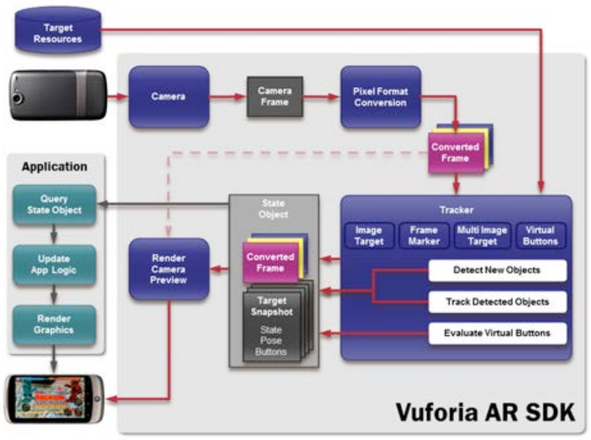


Figure 2.2 Data flow diagram of the Vuforia SDK in application environment

2.3 Features

The Vuforia SDK 1.5 supports Android devices running on Android 2.2 and above, including Android ICS 4.0 and Jelly Bean 4.1.

[11] eXtensible Markup Language

Improved Features in Vuforia 1.5 over Vuforia 1.0	
Improved detection performance	The required detection time has been reduced by up to 40% in the image targets. Normally enough with a second.
Improved tracking performance	The new SDK features several enhancements that reduce jitter in the augmentations, speed up recovery from tracking failures, detect targets at steeper angles and track over longer distances.
Better tracking occlusion handling	Frame markers can now be partially occluded allowing them to be picked up and used as game pieces during the AR experience.
Improved maximum simultaneous image targets	This feature depends basically on the device hardware. At the time of the 1.5 release (February 2012), the most advanced GPU was the Adreno 220 and dual cores CPU. With this hardware configuration, the limit was improved until 5 maximum. Today is still better, and with the Adreno 320 this number rises until 10 with any kind of problems.
New Features in Vuforia 1.5	
Video background texture access	The SDK now provides a simple and streamlined way of accessing the video background texture. The colour and video plane both image target as scene can be changed or distorted in real time.
Runtime dataset swap	If the app needs to augment more than 60 images, now the SDK can create multiple datasets using the web-based target management system and load the appropriate dataset at runtime. Now is not necessary to upgrade the app to change the target dataset.

Table 2.1 Features in different versions

2.4 Trackables

Trackable is the main class that represents all real world objects followed in six degrees of freedom by Vuforia’s SDK. Each object when is detected and tracked has a set of parameters. These parameters are: type, name, ID, status, and pose information.

Trackable type

Defines the type of the trackable:

UNKNOWN_TYPE - A trackable of unknown type.

IMAGE_TARGET - A trackable of ImageTarget type.

MULTI_TARGET - A trackable of MultiTarget type.

MARKER - A trackable of Marker type.

Trackable name / identifier

A twenty five character length string that identifies the trackable within the database. Character set is composed by a-z, A-Z, 0-9,[- _]

Trackable status

Each trackable has status information associated with it in the State object. This object is updated when each camera frame is processed. The status is characterized by an enum:

UNKNOWN - The state of the trackable is unknown. This is usually returned before tracker initialization.

UNDEFINED - The state of the trackable is not defined.

NOT_FOUND - The trackable was not found

DETECTED - The trackable was detected in this frame.

TRACKED - The trackable was tracked in this frame.

Trackable pose

Current valid pose of a *DETECTED* or *TRACKED* trackable is returned as a 3x4 matrix in row-major order. The Vuforia SDK provides simple tool functions to convert the Vuforia pose matrix into a GL model-view matrix and to project 3D points from the 3D scene to the device screen.

The Vuforia SDK uses right-handed coordinate systems. Each Image Target and Frame Marker defines a local coordinate system with (0,0,0) in the centre (middle) of the target. +X goes to the right, +Y goes up and +Z points out of the trackable (into the direction from which it can be seen).

The origin of the local coordinate system of a Multi Target is defined by its components. Image Target parts are transformed relative to this origin. The reported pose of the Multi Target is the position of this origin, independent from which individual part is tracked within the Multi Target. This feature allows a geometric object (Ex. a box) to be tracked continuously with the same coordinates, even if other Image Target parts are visible in the camera view

Vuforia represents three types of trackables that inherit properties from its base class. These trackables are image targets, multi targets and frame markers.

Each trackable is updated when its frames are processed and the results are passed onto the app into an object called the State object. For a more complete understanding of the data flow between the app and the SDK please take a look at the Vuforia Architecture represented in Figure 2.2.

2.4.1 Image targets

Image Targets, are images that the Vuforia SDK can detect and track. These images do not need special black and white regions or codes to be recognized. The Vuforia SDK uses a set of algorithms to detect and track the features that are present into an image recognizing them by comparing these features against a database known object. Once is detected, Vuforia will track the image along the camera's field of view.

Image targets are created on-line with the TMS[12] from JPG or PNG input images. Features extracted from these images are stored in a database and used for run-time comparisons.

The Vuforia SDK can detect and track up to five targets simultaneously depending on the load on the processor and GPU. The Vuforia SDK can hold approximately fifty Image Targets in its resource database. The Vuforia SDK can also swap datasets at run time so your application can hold many more targets.

2.4.1.1 Datasets

A dataset is set of trackables downloaded from the target management system. The SDK allows an app to load, activate, disable and unload groups of datasets at runtime. Datasets can contain both Image Targets and Multi Targets.

With SDK version 1.5 it is necessary to load the dataset from the SD[13] Card or download it from the Internet at application runtime. Note that only one dataset can be active. This active dataset is used by the `ImageTracker` to find and track targets in the camera's field of view.

Dataset loading requires some time and therefore it is recommended background loading.

Prior to Vuforia SDK v1.5 the old QCAR SDK was limited to only one Dataset that was statically compiled with the app. The Dataset configuration was stored in the `config.xml` file.

[12] Target Management System

[13] Secure Digital

2.4.1.2 Parameters

Target size

Target size is the actual size of the image target in 3D scene units. A developer must specify this during the on-line creation of the trackable or in the dataset configuration XML file. The TMS generates the dataset configuration XML file, but it can be modified. The size parameter is very important, as the pose information returned during tracking will be in the same scale.

Virtual Buttons

Image targets can have one or more virtual buttons. The developer can query the target for the number of associated buttons, cycle through a list accessing each individual virtual button and check their associated status. Virtual buttons can be dynamically added and deleted at run-time.

2.4.2 Multi targets

A multi target consists of multiple image targets that have a spatial relationship. When the camera detects one of the parts of a multi target, all the others can be tracked if their relative position and orientation is known. Completely field of view of multi-image is not needed in Vuforia to track it if one of its parts is partially visible. The difference between multiple individual image targets and multi targets is that the second one performs one single trackable with one pose information.

The image targets that make up a multi target are created with the TMS from JPG or PNG. Input features extracted from these images are stored in a database and used for run-time comparisons. The spatial relationship of the individual parts is stored in the dataset configuration XML file using simple transformations.

Multi targets can be created in two ways:

I. Directly with the on-line TMS

II. At run time through a well-defined set of APIs. Parts can be added or removed, and their spatial configuration can be changed.

2.4.2.1 Parameters

Parts of a multi target are transformed in a common coordinate system. At run-time the origin of this coordinate system within the multi target is returned as pose information. Thus all individual image target parts are placed with translation and rotation within this system.

Multi image target parts have the following parameters:

Part name / identifier

A twenty five character length string that identifies the part within the multiple. This name must be identical to one image target definition within the same target dataset target. Character set is composed by a-z, A-Z, 0-9,[- _]

Translation

This parameter translates the origin of an image target part by the defined scene units along the x,y,z axes.

- (x,y,z) translation in scene units measured along the three spatial axes.

Rotation

This parameter rotates the origin of an image target part by the defined angle. Rotations are defined as a series of axis and angle pairs that are applied in order. Several formats to define the rotations are allowed:

- (x,y,z, angle deg) rotation in decimal degrees along an axis defined by the vector (x,y,z).
- (x,y,z, angle rad) - rotation in radians along an axis defined by the vector (x,y,z)
- (qx,qy,qz,qw) - quaternion to define rotation

2.4.3 Frame Marker

The Vuforia SDK can track a special type of marker called frame marker. The ID of a frame marker is encoded into a binary pattern along the border of the marker image. The Vuforia SDK requires the frame and the binary pattern to be almost entirely visible in the camera field of view during the recognizing process.

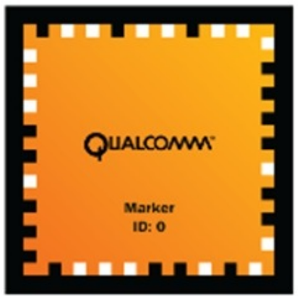


Figure 2.3 Frame Marker

The TMS does not generate frame markers. All 512 are distributed as an archive within the assets folder of the Vuforia SDK.

Due to the relatively low processing power required to decode the marker ID, all 512 frame markers can be used in an application, and about five can be detected and tracked simultaneously.

2.4.3.1 Parameters

Frame marker has the following parameters:

Marker size

Target size is the actual size of the marker in 3D scene units. A developer needs to specify this upon creation. The size parameter is important, as the pose information returned during tracking will relate to the same scale. For example, if the marker is one unit wide, moving the camera from the left border of the target to the right border of the marker will change the returned position by one unit along the x-axis.

- (x,y) size of the marker in scene units measured along the horizontal and vertical axis of the marker.

Marker ID

Each frame marker encodes an ID in the binary pattern along the border. This ID is in the range of [0-511] yielding 512 possible different markers and 3D augmented objects associated with them.

- ID [0-511] - encoded marker id.

Marker type

Enumerator defining the type of the marker, one of:

- *INVALID* - A marker of invalid type.
- *ID_FRAME* - An id-encoded marker that stores the id in the frame.

2.5 Virtual Buttons

Virtual buttons are developer-defined rectangular regions on image targets that when touched or occluded in the camera view, trigger an event. Virtual buttons can be used to implement events such as a button press or to detect if specific areas of the image target are covered by an object. Virtual buttons are only evaluated if the button area is in the camera view and the camera is steady. Evaluation of virtual buttons is disabled during fast camera movements.

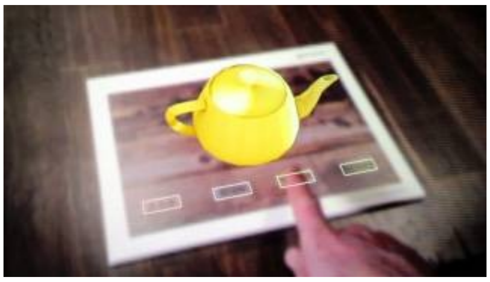


Figure 2.4 Virtual button example

Virtual buttons can be created for any of the two functions by defining them in the dataset configuration XML file as a property of image targets, or they are added and destroyed at application run-time through a set of well-defined APIs.

Each virtual button has the following parameters:

Button name / identifier

A string that uniquely identifies the button within the target.

Max string length: 25 characters

Character set: a-z, A-Z, 0-9, [- _ .]

Button coordinates

Buttons are defined as rectangular regions. A developer needs to specify:

- (x,y) of the top left corner of the rectangle
- (x,y) of the bottom right corner of the rectangle. Note that the units for the button area in 3D scene units. The origin of this coordinate system is in the middle of the Image Target.

Button sensitivity

'Sensitivity' refers to the 'responsiveness' of the button.

- *HIGH* - Fast detection of the occlusion event, button will be very 'responsive' but may trigger some false positives.
- *MEDIUM* - Balanced between fast response and robust detection.
- *LOW* - The button needs to be occluded longer for an event to be generated.

The Vuforia SDK allows adding and deleting virtual buttons to an image target at runtime. Using this feature parts of the target become responsive to user interaction, based on the applications needs. Virtual buttons are always defined by a rectangle and a name.

It is important to note that adding, removing or modifying a virtual button is a change to the state. The Vuforia SDK provides a callback that is executed every frame after the tracker finished processing. The recommended way to make modifications to trackables is to register a callback using the QCAR::registerCallback() function and perform any modifications to the virtual buttons configuration in QCAR_onUpdate().

2.6 Target management system

Image recognition augmented reality apps built with the Vuforia SDK must have a known target dataset that can be used to match targets captured with camera device. Qualcomm's TMS offers a convenient web-based tool for Vuforia SDK developers to create this known dataset from input images. This dataset is then packaged and distributed with the application.

To access to the on-line TMS it is necessary to follow this link http://ar.qualcomm.at/. Registration is required. Once log in, the server will present the workspace. This page will contain all the projects.

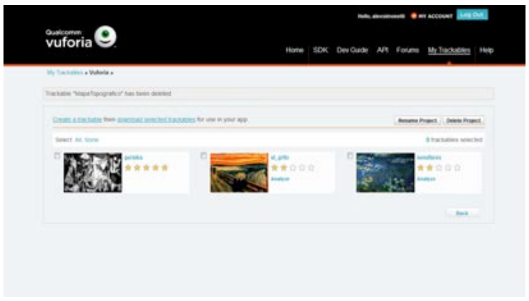


Figure 2.5 Vuforia's target management system workspace

A target is the computed result of the natural features processed from an input image. Feature sets used in the runtime application consist of one or more targets. Projects contain a set of targets that can be combined to create target resources for download. The runtime application will only accept one target resource file, which may have multiple targets that can be detected and tracked by the Vuforia's SDK.

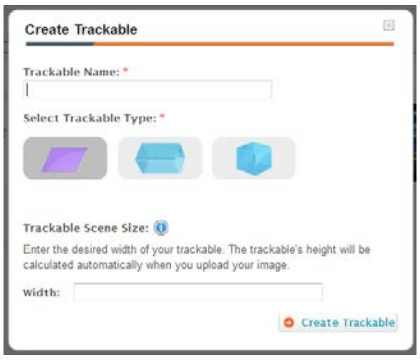
New project is created for every new application and its dataset is composed by a set of uploaded images. Once has been decided which images is wanted to include in the target resource, it must be pick it up and download it as a merged natural feature dataset. There are two formats to download the trackable assets package depending on the development interface: Unity Editor or SDK. Unity package was chosen in this case due to Unity3D is the development IDE.

Downloaded package contains the dataset configuration XML file, that allows configuring certain trackable features, and a binary file, holding the trackable database. If a multi target is created using the web tool, it will automatically include the appropriate definitions into the XML.

2.6.1 Create Image Target

Select "New Project" and provide a name for it. This name will also be used to name the downloaded archive containing the target resources.

Select "Create a trackable" and choose "Single Image" as Trackable Type. Provide a name for the resulting target. The name chosen here will be used in the application to identify the target during detection and tracking.


Create Trackable

Trackable Name: *

Select Trackable Type: *

Trackable Scene Size:

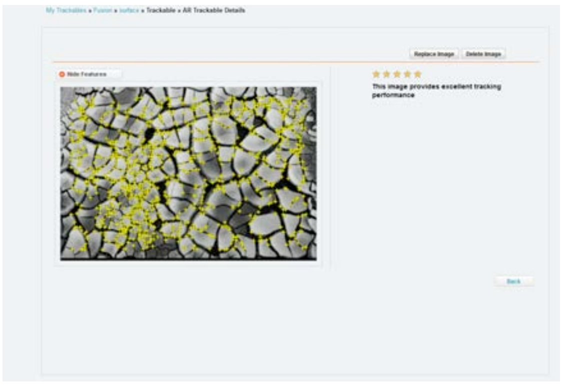
Enter the desired width of your trackable. The trackable's height will be calculated automatically when you upload your image.

Width:

Create Trackable

Figure 2.6 Create trackable

Enter the trackable name `"surface"` using the `surface.jpg` file. Also note that the maximum length of the name is 25 characters.Finally must also define the trackable width.


My Trackables » Fusion » surface » Trackable » All Trackable Details
Replace Image
Delete Image
Hide Features
Back

This image provides excellent tracking performance

Figure 2.7 TMS tool

Once image target is uploaded it is possible to download it into a .zip or .unitypackage extension and load it into the project source.

2.7 Image recognition considerations

As has been said before, one of the main purposes of Vuforia is the interaction between real and virtual elements. To manage the virtual elements, Vuforia uses a series of traces and patterns to distinguish the elements generated by the online tool and the elements not generated by the TMS tool. Next it has been explained the method used by Vuforia to recognise these different types of elements, the image targets and the frame markers.

The TMS assigns a star rating for each image that is uploaded to the system. The star rating reflects how well the image can be detected and tracked. The star rating can vary among 0 to 5 for any given image. The higher rating of an image target, the stronger the detection and tracking ability it contains. A rating of zero would result in a target that would not be tracked at all by the AR system. An image given a rating of 5 would be easily tracked by the AR system.

The developers recommend to only using image targets that result in 3 stars or higher when submitted to the TMS system.

Enhancing the uploaded image target to yield higher feature count, while not applying the same enhancements to the real target, will result in lower quality detection and tracking. Any change made to the uploaded image target should also be applied to the physical image target.

Image targets are created online with the TMS tool from jpeg or png input images. Submitting an image target to TMS that has transparent regions is not recommended because until now the system does not work properly with that, in fact, only RGB image are supported. The targets created using this tool allow the system to compute a digital fingerprint, allowing the client application to identify the target in the real world. This fingerprint is composed by a series of distinctive features, or unique details in the image usually composed by areas of high contrast.

In the next images, these features can be seen as yellow crossings. For example, the square would contain 4 features for each one of its corners. The circle would contain no features as it contains no sharp detail. Basically, each corner has a unique feature.

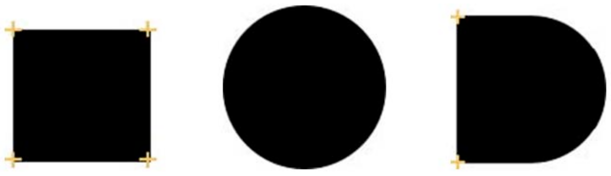


Figure 2.8 features recognition

Visually determining a good vs. a bad image target may seem difficult at first, but once the process has been understood some of the basic principles is relatively simple. A person can quickly identify good and bad image target prior to uploading it to the TMS. Next can be seen an example of an excellent image target full of unique features.

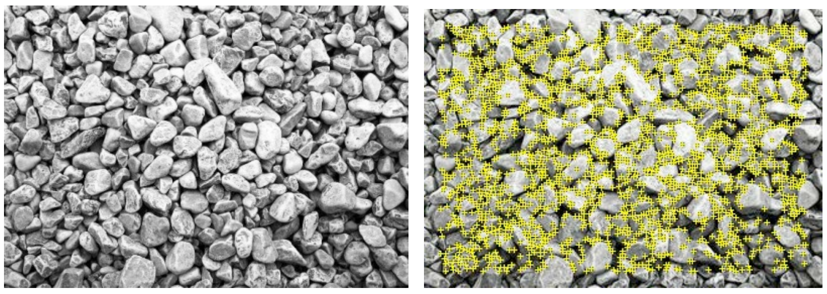


Figure 2.9 image target with & without visible features

With a high balanced distribution of the features in the image, the AR app will quickly and accurately track the image in the camera's view. A method of cutting areas with low feature count can create an image that will receive a higher star count by the TMS. This is due to the fact that the resulting (smaller) image might have a more even feature distribution. Better feature distribution will enable the AR camera to track the target across a wide range angles and zoom levels.

Like has been said before, is important to avoid cylindrical shapes, because it have soft or round details containing blurred or highly compressed aspects do not provide enough detail to be detected and tracked properly or not at all. They suffer from low feature count.

Although some images contain enough features and good contrast, repetitive patterns interfere with detection performance. For best results, choose an image without repeated motifs or strong rotational symmetry. A checkerboard is an example of repeated pattern that probably cannot be detected.

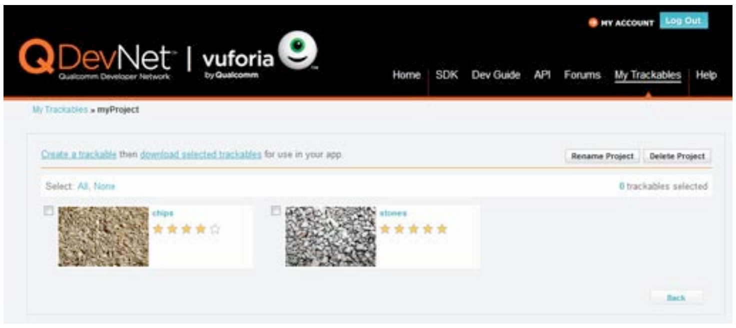


Figure 2.10 TMS tool

The other method to use a various image target is the multi target. This element joins different image targets in only one.

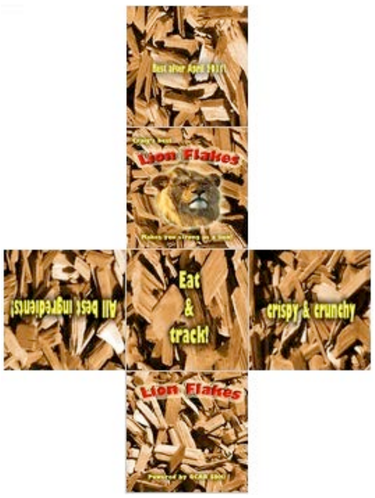


Figure 2.11 Multi target example

To design properly a multi target element, these recommendations should been followed. The depth is recommended to be at least around half of the width of the front side. Since multi targets are detected and tracked as shapes, it is important to highlight that the Vuforia SDK needs to find a certain amount of features on the side of the multi target when the object is rotated.

Any kind of box in general is good for using as a multi target element. Since multi targets are tracked as a single trackable as opposed to tracking multiple single image targets simultaneously, performance is substantially improved.

The last element is the frame marker that allows any image to be placed within a predefined border that is bundled within the SDK. Unlike image targets, frame markers are not generated by the online TMS. The number of built-in and predefined frame markers is 512, representing frame marker IDs of 0 - 511.

The main use of these frame markers is as targets, because they are unique and very simple to recognize by Vuforia. The marker consists of four areas, where each has its specific function.

Vuforia requires the frame and the binary pattern to be entirely visible in the camera image for recognition. Once the frame marker is detected, one may partially occlude the frame and the pattern. In actual usage, the frame or binary pattern a good design of the frame marker printout can help to prevent partial obstruction. Thus this guarantees the marker working properly. Below are some examples of physical designs for markers that minimize occlusions by the user.

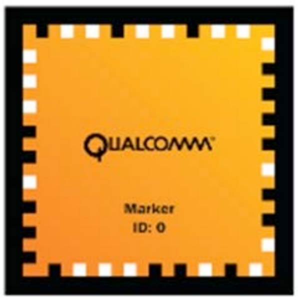


Figure 2.12 Frame Marker

An area around the black frame of the marker must be left free of graphical elements. The black frame is used to recognize the marker in the environment as seen by the camera during run-time. The ID area inside the frame encodes the ID of the marker in a binary pattern. The design area is free to carry any design. This area of the marker is not evaluated by the Vuforia SDK

CHAPTER 3 VUFORIA FIELD OF APPLICATIONS

The following chapter describes Vuforia's field of applications and its common used scenario.

3.1 Vuforia field of applications

At first, when it was decided to study the Vuforia library, the thought was that one of the main attractions was the automatic recognition of everyday objects such as trees, tables, cars, etc. The ability to use the cloud, where objects could be stored for later recognition, suggested that the user community help that soon many objects were analysed and available remotely.

Once started the first tests, clearly became apparent the actual capacities and needs of the library for recognition, which was actually for patterns and not for objects. Given this feature, should think again about new applications that could make use of this library, and how they should be used in these applications.

Currently, the main areas of use of augmented reality applications using the SDK Vuforia are education, instructional, gaming and media & advertising. In most of these areas, the applications obviously will be different, but they are perfect scenarios to use an augmented reality application.

In the field of **education**, the possible scenarios can be augmented reality apps in museums, for example to letting visitors see the unseen in the artworks or view information of the artist. Another field can be the children's books; using an AR app they can come to life with a new way of story-telling. Maybe the best scenario is the scientific text book, because in this area the augmented reality app can show 3D visualizations to help to understand concepts or ideas like can be seen in the right image. This example show a palaeontologist book with a T-Rex illustration and a 3D model of T-Rex in AR, using this technic the process of understanding if much more natural.

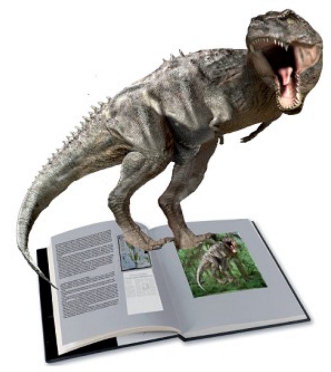


Figure 3.1 Educational example

In the **instructional** field of application the most important applications are the step-by-step instructions to assemble or troubleshoot a product. This feature can be more useful when somebody is trying to assemble a product. In Figure 3.2 can be seen an example. Other applications are the interactive product manuals and guided AR tutorials, where the instructions are augmented on the actual product.

Figure 3.2 Instructional example

Maybe the most used environment is **gaming**, because many of the applications are games. This fact is because there are a lot of different games like shooters, strategy, virtual pets, puzzles, action, sports simulation, etc. In games the only that needs the user is the image target, like can be seen in Figure 3.3, and the “standard” game starts.

The advantage of this is the multiplayer interconnection using the same image target. In fact, there is a library dedicated almost exclusively to game development.

Figure 3.3 Gaming example

The last group of field applications is the **media & advertising**, and this is also one of the biggest environment applications made for. The main augmented reality apps are in the catalogues of big companies with engaging or fun content. A very good example of this can be seen in Figure 3.4, this company uses a series of sticks to help their customers to see in their own home the chosen furniture. Other examples can be seen in magazines or readers book, putting the extended content like “behind the scenes”, treasure hunts and coupon redemption

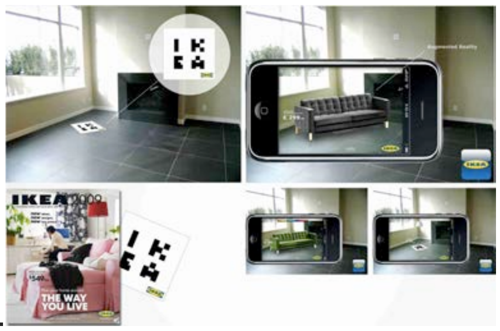


Figure 3.4 IKEA AR app

3.2 Common Target Usage Scenarios

Reaching into the real world to manipulate an object that only exists in the augmented world can be a magical experience.

The experience of direct manipulation can be fascinating, but can also be quite confusing for the final user. Must be taken in account that a user only has two hands and one of them is usually occupied by holding a mobile device. Hand-eye coordination is also crucial – remember if a user's focus is on a device, any interaction with a free hand is blind interaction. Trying to coordinate both hands can feel like use a body that is not yours. Tangible interaction can be a very pleasant and intuitive method of interaction if it is done simply and usefully but it also presents many user experience challenges.

Different targets can have different uses and have different advantages depending on the situations in which they are used. *Near-field AR applications* that aim at augmenting the immediate surroundings of the user can be largely divided into the following usage situations:

3.2.1 Handheld Targets

Handheld targets like business cards, beer mats, and playing cards are very good for use with mobile AR when the navigate pan and zoom functionality is required for looking at an object. They are simple to manipulate and allow for very accurate small movements. They can also be used as a controller for a menu or list due to their ease of maneuverability. Business cards or playing card sized targets are also well suited for tangible viewing and interaction in mobile AR applications.

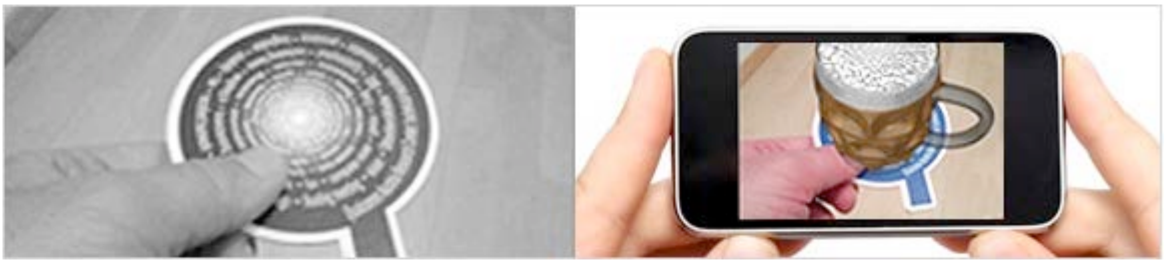


Figure 3.5 Handheld example

3.2.2 Tabletop/Floor Targets

Table top or floor targets (games, rugs, or floor-based advertising) are very good targets for use in mobile AR, as this allows the user to take a much more comfortable to hold the device. The screen remains horizontal or nearly horizontal at a convenient angle and the camera is pointing downwards, making the experience more comfortable.

These targets work very well for group tangible interaction, such as in a home (board) gaming environment, and also act as a discreet passive experience where no tangible interaction is required. A floor target can also be mounted on a tilting platform, which can be controlled by the feet when the application required a more accused control.

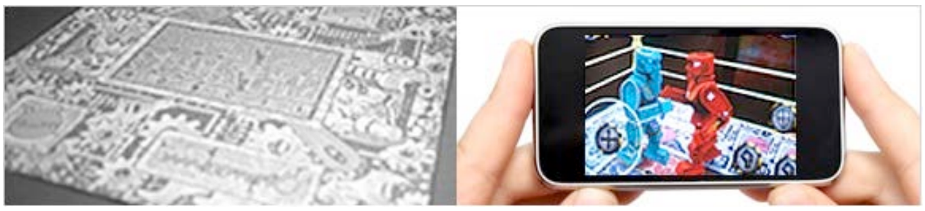


Figure 3.6 Tabletop/Floor example

3.2.3 Wall Targets

The wall target uses a big advantage in their environment, and that extends the interaction with the prospective client, offering a new experience around the posters and billboards. Tangible interaction is very challenging with wall targets, but on-screen interaction works well and is intuitive. Interactions with a wall target can get tiring when pointing the phone at the wall for a long time.

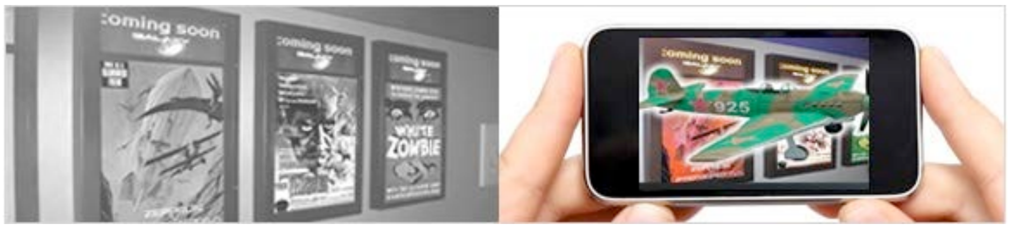


Figure 3.7 Wall example

3.2.4 Retail Shelf Targets

Store racks and shelves have labels, price tags, and other product collateral that can be used as image targets to augment the shopping experience. Product packaging on the shelf such as board games, and toys can be used as image targets. These images work well, are usually already part of a product, and can tie the in-store product to the online experience.

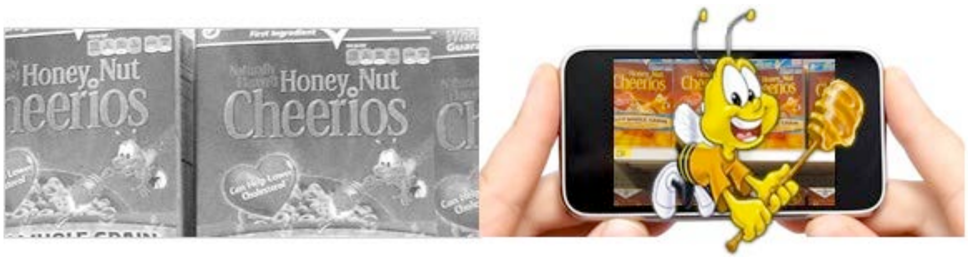


Figure 3.8 retail shelf example

CHAPTER 4 APPLICATION DEVELOPMENT

The following chapter shows how to easily create AR applications based on recognition patterns using Vuforia's Unity extension. The created application has also been improved by adding new features based on scripts.

The chapter also shows the required considerations to guarantee application usability.

4.1 Necessary software

Vuforia is an augmented reality SDK for mobile devices, and for this reason is useless by itself, needs a software development environment or an IDE[14] like Eclipse, Unity, etc. In this case, the environment selected is Unity engine, because is the easiest and compatible with the Vuforia library and with the Android and iOS systems. The app developed in this project is only for Android devices and it will be only used as a tool to test.

During the development of the augmented reality application, different elements will be needed and normally there will be modeled in 3D. Obviously Unity can manage 3D elements, but the tool that has been chosen is Blender 3D due to its simplicity.

In conclusion, as mentioned, the app is going to be made using **Vuforia Android SDK** under ***Unity3D*** IDE. Either one App 3D models are built using ***Blender*** 3D software tool.

4.1.1 Unity3D

Unity is a fully integrated development engine that provides rich out-of-the-box functionality to create games and other interactive 3D content. Unity can be used to assemble art and assets into scenes and environments; add lighting, audio, special effects, physics and animation; simultaneously play test and edit games, and when ready, publish to your chosen platforms, such as desktop computers, iOS, Android, etc. In the other hand, the Vuforia extension for Unity enables detection and tracking functionality in the Unity IDE and allows to easily creating AR applications and games.

Before start to use Vuforia is necessary to install Unity, because as mentioned above Vuforia is only a library. For the Unity installation simply follow the steps in the install file. In this case, the OS for the development has been Windows and the url that can be used to download the program is http://unity3d.com/unity/download/download-windows. Unity requirements are described in the following table:

[14] Integrated Development Environment

System	Microsoft Windows XP SP2 or later
	Java Development Kit JDK
	Android SDK
Mobile Device	Android OS 2.0 or later
	Device powered by an ARMv7 CPU
	GPU support for OpenGL 2.0

Table 4.1 Unity requirements

Vuforia unity extension

Once Unity is installed in the system, the next step is importing the Vuforia libraries to Unity. Vuforia can work both in Android as in iOS, but for the purposes of this project, the mobile OS will be only Android.

To do this, first download the Vuforia Android extension for Unity in this url https://ar.qualcomm.at/user?&platform=Android&sdk_type=Unity&sys_name=windows&file_name=vuforia-unity-android-1-5-10.exe. The version used at the time of writing this project is 1.5.

Once is downloaded the Vuforia extension, the next step is import the libraries to Unity. To make this, simply open the navigation bar -> Menu -> Assets and click in Import Package -> Custom Package. A new window will be open, go to the Vuforia folder and select all the files inside. Now all the augmented reality elements are available in Unity.

4.1.2 Blender 3D

Blender is a free and open-source 3D computer graphics software product used for creating animated films, visual effects, interactive 3D applications or video games.

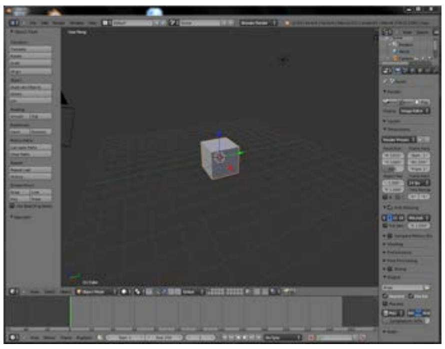


Figure 4.1 Blender environment

Blender provides a broad spectrum of modeling, texturing, lighting, animation and video post-processing functionality in one package. Through its open architecture, Blender provides cross-platform interoperability, extensibility, an incredibly small footprint, and a tightly integrated workflow. Blender is one of the most popular open source 3D graphics applications in the world.

Blender can be used to create 3D visualizations, stills as well as broadcast and cinema quality videos, while the incorporation of a real-time 3D engine allows for the creation of 3D interactive content for stand-alone playback.

The link to download the latest version of Blender http://www.blender.org/download/get-blender/ and the user manual http://wiki.blender.org/index.php/Doc:2.6/Manual

Blender unity export

Unity natively imports Blender files. This works only using the Blender FBX exporter, which was added to Blender in version 2.45. For this reason, you must update to Blender 2.45 or later. To get started, save the .blend file in the project's Assets folder. When switch back into Unity, the file is imported automatically and will show up in the Project View. To see the imported model in Unity, drag it from the project view into the scene view. If you modify your .blend file, Unity will automatically update whenever you save.

4.2 How to create AR applications

As mention, the software used to develop AR Android apps was Unity 3D. Vuforia's Unity extension allows inexperienced developers to easily create AR applications due to its fully integrated game engine reducing time and cost. Moreover Unity 3D provides flexibility in project's developing supporting iOS and Android OS.

After Unity 3D is open, the project must be created selecting create new project from menu bar file. It is indispensable to build the project importing all the necessary assets first to guarantee image recognition and trackability in order that the application works properly under Vuforia AR environment. It is for that reason that the Vuforia Unity extension package is required. The installation of this package is properly explained in 4.1.1**.** When the packages are imported, it is possible to use all the characteristics of the Vuforia is SDK and the application is able to recognise 2D and 3D objects.

4.2.1 Project Scenes

Once the project is created, Unity structures it into scenes. Every scene is like a game level and is loaded when required. Think of each unique Scene file as a unique level. In each Scene, you will place your environments, obstacles, and decorations, essentially designing and building your application in pieces Application menu is considered a scene too and its function is to manage the application different scenes. Scenes that use device's camera as AR camera launch the capture process, define the tracker and execute its renderization. AR Cameras are the eyes of the application. Everything the player will see is through AR camera. You can position, rotate, and parent camera just like any other GameObject.

4.2.2 UI: Main Menu Scene

The following point will show developers how to create a menu scene manager

As said, application main menu handles the screen button events at GUI[15] and manages the different scenes.

In order to build it is necessary to create a GUI Skin into the scene. GUI Skins are a collection of GUI Styles that can be applied to your GUI. Each control type has its own style definition. Skins are intended to allow the user to apply style to an entire UI, instead of a single Control by itself.

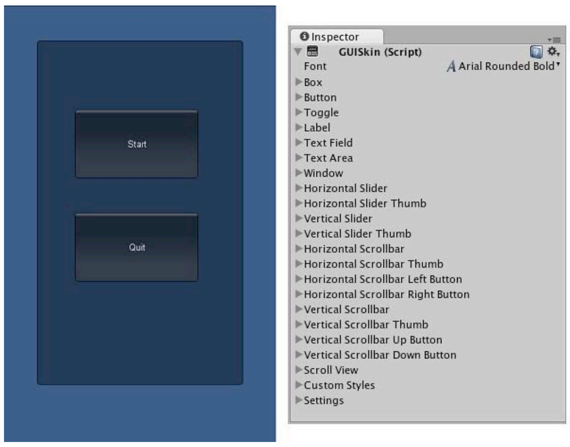


Figure 4.2 UI Main menu

To create a GUI Skin, select Assets->Create->GUI Skin from the menu bar.

GUI Skins are part of the Unity GUI system. For more detailed information about Unity GUI, please take a look at the GUI Scripting Guide http://docs.unity3d.com/Documentation/Components/GUIScriptingGuide.html.

The script that handles the menu is called "*MainMenuScript*"and has to be place in the main camera component.

```
var newSkin : GUISkin;
var logoTexture : Texture2D;

function theFirstMenu() {
    GUI.BeginGroup(Rect(Screen.width / 2 - 150, 50, 400, 600));
    if(GUI.Button(Rect(55, 100, 180, 80), "Start")) {

    Application.LoadLevel("teapot_fire");

    }
    if(GUI.Button(Rect(55, 350, 180, 80), "Quit")) {
    Application.Quit();
    }
    GUI.EndGroup();
}
function OnGUI () {
    GUI.skin = newSkin;
    theFirstMenu();
}
    theFirstMenu();
}
```

[15] Graphical User Interface

Function OnGUI is executed once the application is launching and executes menu's construction *theFirstMenu().*

The menu is composed by two buttons. Quit button ends the application and kills its process. Start button executes the AR scene. In this case, as example, the launched scene was "teapot_fire".

4.2.3 Scenes based on Image Targets

As said, every Unity project is set of scenes and it is operation is similar to a game level. Will be explained how to create Image Target based scenes It is known that Image Targets are images that Vuforia SDK can detect and track.

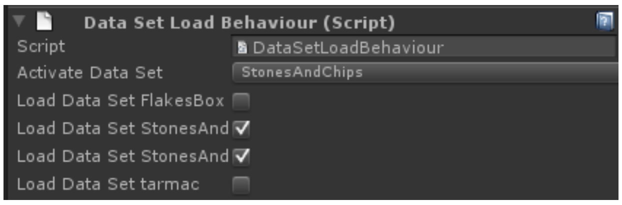
AR interaction

Vuforia in its Unity extension allows developers to create applications composed by items that had AR world featured. These attributes, set using scripting, let users to interact freely with the modelled 3d items without any mobile touch interaction. The features achieved using scripting are described below.

Scene I Teapot&Fire

Teapot&Fire scene contains all the necessary objects that perform an AR environment. The application is composed by two Image targets and one AR camera.

AR camera is the object responsible of the detection and tracking of the image targets. Is for that reason that is absolutely necessary to define the datasets that will be load in the "*DataSetLoadBehaviour*" script or the image targets will not be interpreted. In this case "Stones and chips".



Data Set Load Behaviour (Script)

Script	DataSetLoadBehaviour
Activate Data Set	StonesAndChips
Load Data Set FlakesBox	☐
Load Data Set StonesAnd	✓
Load Data Set StonesAnd	✓
Load Data Set tarmac	☐

Figure 4.3 Data Set Load selection

Data Set includes the image targets and the algorithm to recognise them when the application is executed.

Image target creation description process is shown in **2.6.1 Create Image target.** At the end, the app contains two image targets, "stones" and "chips".

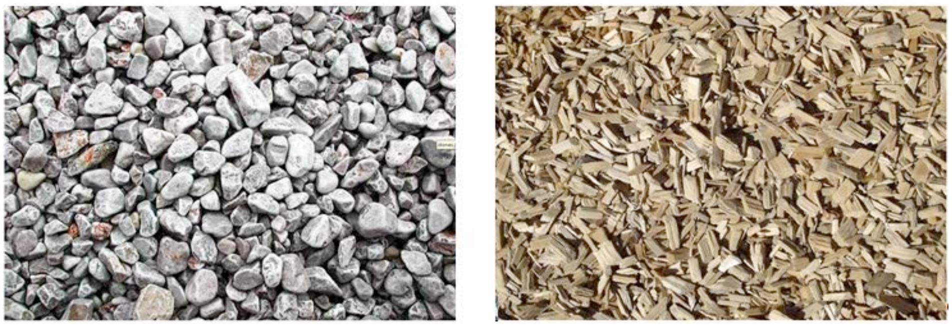
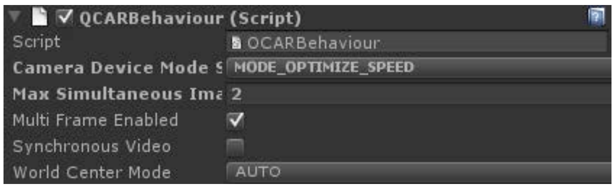


Figure 4.4 Stones and Chips image targets

The number of simultaneous targets that will be tracked must be defined too and depends on mobile device GPU specifications shown in **2.3.3 Features.**

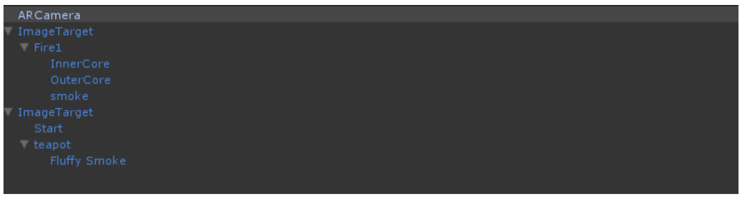


QCARBehaviour (Script)

Script	QCARBehaviour
Camera Device Mode S	MODE_OPTIMIZE_SPEED
Max Simultaneous Ima	2
Multi Frame Enabled	✓
Synchronous Video	
World Center Mode	AUTO

Figure 4.5 Number of max simultaneous targets

Once AR camera is configured 3D objects insertion is required importing it from Blender, if it is necessary, to the convenient Image Target. Insertion is simple by dragging the object to the target.



```
ARCamera
▼ ImageTarget
  ▼ Fire1
      InnerCore
      OuterCore
      smoke
▼ ImageTarget
    Start
  ▼ teapot
      Fluffy Smoke
```

Figure 4.6 figure dragging

Last figure shows our project's hierarchy. Both image targets are parents of two GameObjects(Fire1 and teapot).

The texture of the image targets depends on the image target created. Once it is done the AR camera will be able to detect and interpret the targets representing a fire in the case of the image target chips, and a teapot in case of stones. As said before, these images are considered trackables and are manage by "TrackableBehaviour" script that controls when an image target is detected or lost, and able to follow it.

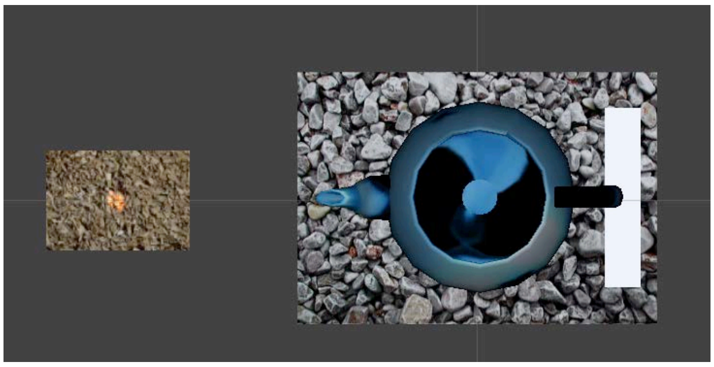


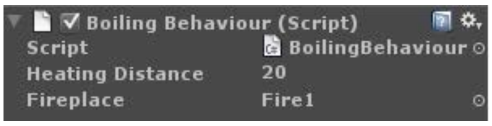
Figure 4.7 teapot application example

Previously is described how to configure the necessary assets to recognise an image target and display it is corresponding 3D object element. These elements can be manipulated to alter their physical and spatial characteristics or cause some events that were handled by scripts.

A. Proximity event

Image targets proximity events interaction can be handled using scripting. For example, two different image target, once detected, can interact between them and produce some alteration in its 3D modelled items. In this application when the distance between stones and chips image targets is less than 20 world units triggers an event script that produces steam.

Remembering project’s hierarchy teapot object has as a child a particle emitter called “Fluffy Smoke” The script responsible of the steams emission “Bolingbehaviour.cs” has to be placed at this emitter. It is very important to define at Unity Inspector window script attributes.



Boiling Behaviour (Script)

Script	BoilingBehaviour
Heating Distance	20
Fireplace	Fire1

Figure 4.8 script attributes

Heating distance defines the minimum distance required in world units. (20) from the teapot and Fireplace is the GameObject (Fire1) which interacts

```
using UnityEngine;
using System.Collections;

[RequireComponent(typeof(ParticleEmitter))]
public class BoilingBehaviour : MonoBehaviour
{
    public float heatingDistance = 0.0f;  // set in inspector
    public GameObject m_Fireplace = null;  // set in inspector
    private GameObject m_Teapot = null;

    void Start ()
    {m_Teapot = this.transform.root.gameObject;}
    void Update ()
    {
float   teapotToFireDistance   =   Vector2.Distance(new   Vector2(m_Teapot.transform.position.x,
m_Teapot.transform.position.z),
                                                      new
Vector2(m_Fireplace.transform.position.x, m_Fireplace.transform.position.z));
```

```
        Debug.Log ("Distancia: "+teapotToFireDistance);
                if (teapotToFireDistance < heatingDistance)
        {
            this.particleEmitter.emit = true;
        }
        else
        {
            this.particleEmitter.emit = false;
        }}}
```

B. Virtual button event

As said before in 2.5 Virtual Buttons are developer-defined rectangular regions on Image Targets that when touched or occluded in the camera view, trigger an event. In this application, there is a large virtual button that produces the steam emission when is pressed. The script that controls the emission is called "VirtualButtonEventHandler.cs" and has to be placed at "Stones." Image Target. The Virtual button is called "Start" and is a child of "Stones" too. All the possible actions that can be done with the virtual button are refered at SDK's script "VirtualButtonBehaviour".

```
using UnityEngine;

public class VirtualButtonEventHandler :    MonoBehaviour,
                                            IVirtualButtonEventHandler
{    private ParticleEmitter mSteamEmitter = null;
    void Start()
    {
        VirtualButtonBehaviour[] vbs = GetComponentsInChildren<VirtualButtonBehaviour>();
        for (int i = 0; i < vbs.Length; ++i)
        {
            vbs[i].RegisterEventHandler(this);
        }
        mSteamEmitter = GetComponentInChildren<ParticleEmitter>();

        if (mSteamEmitter)
            mSteamEmitter.emit = false;
    }
    public void OnButtonPressed(VirtualButtonBehaviour vb)
    {int i=0;
        if (mSteamEmitter)

            mSteamEmitter.emit = true;
            }
    public void OnButtonReleased(VirtualButtonBehaviour vb)
    {
        if (mSteamEmitter)
            mSteamEmitter.emit = false;
    }
```

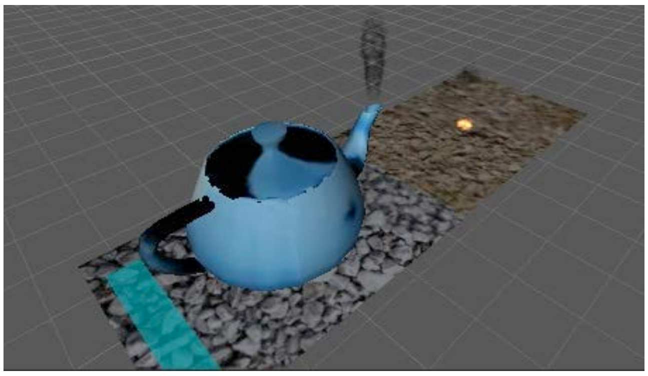


Figure 4.9 Virtual button app

Device or Real World Interaction

As seen, AR world interactions are possible using Vuforia is SDK allowing users to manage Vuforia applications without touching mobile device interface .It is logical to think then that devices interaction is summarized in application is GUI navigation once the camera is launched. However the interaction with the 3D models from device is screen is possible in camera is capture time, using scripts again. 3D objects normally are previously set to image targets during the application development and their spatial coordinates are static and referred to world but these items can created or altered in runtime from mobile screen.

Application scene II Draggable Ball

As said before create an Image Target based scene is very simple. The process to create the scene is similar to the previously described. The main difference is that now only “Stones” Image Target is set and contains as child one GameObject textured as a Ball. The scene hierarchy is showed in the following figure:

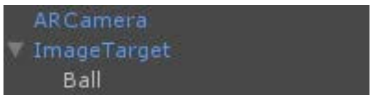

ARCamera
▼ ImageTarget
Ball

Figure 4.10 hierarchy of app

Now when the “Stones” are detected a football appears into the scene.

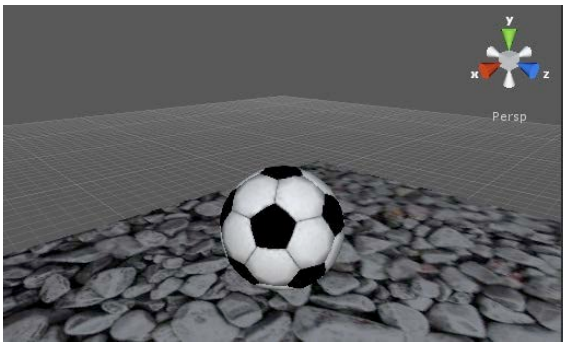


Figure 4.11 Draggable example app

C. Dragging objects

New scene contains a GameObject which coordinates could be modified from the mobile device. Only is necessary screen touching and drag the football. To achieve this GameObject has to be defined as movable containing the script “MovableObject.sc”.

```
using UnityEngine;
using System.Collections;

public class MovableObject : MonoBehaviour
{
}
```

To perceive this interaction camera has to contain another script called “InputHandle”.

```
using UnityEngine;
using System.Collections;
public class InputHandler : MonoBehaviour
{
 private Ray m_Ray;
 private RaycastHit m_RayCastHit;
 private MovableObject m_CurrentMovableObject;
        private float   m_MovementMultipier = 10f;
 void Update ()
 {
    if(Input.touches.Length == 1)
    {
    Touch touchedFinger = Input.touches[0];
    switch(touchedFinger.phase)
    {
    case TouchPhase.Began:
    m_Ray = Camera.mainCamera.ScreenPointToRay(touchedFinger.position);
    if(Physics.Raycast(m_Ray.origin, m_Ray.direction, out m_RayCastHit, Mathf.Infinity))
    {
       MovableObject                                movableObj                                 =
m_RayCastHit.collider.gameObject.GetComponent<MovableObject>();
       if(movableObj)
       {
          m_CurrentMovableObject = movableObj;
       }
    }
    break;
    case TouchPhase.Moved:
        if(m_CurrentMovableObject)
       {
          m_CurrentMovableObject.gameObject.transform.Translate(Time.deltaTime                *
m_MovementMultipier        *        new        Vector3(touchedFinger.deltaPosition.x,        0,
touchedFinger.deltaPosition.y));
       }
    break;
    case TouchPhase.Ended:
       m_CurrentMovableObject = null;
       break;
    default:
       break;
    } } }}
```

Application scene III. DynamicBall

Previously sections described that Vuforia platform enables augmented reality (AR) app experiences. These experiences reach across most real world environments, giving mobile apps the power to see. Image recognition allows to our mobile device process and recognizes images and showing a set of AR prefabs (game objects, virtual buttons, etc.) in AR world. As seen, these elements normally are static, linked to a trackable and are shown when image target is detected. But prefabs can be loaded and destroyed dynamically at runtime optimizing memory usage. For example, the following example describes how to create AR elements at runtime at a given position.

D. Creating elements at runtime.

First of all the environment has to be set. As explained before, the trackable used into the scene was Stones Image Target but this time does not contain any GameObject, as conclusion nothing was modelled when detected. To create elements at runtime is necessary script intervention.

Instantiating Prefabs

Prefabs come in very handy when you want to instantiate complicated game objects at runtime. The alternative to instantiating Prefabs is to create game objects from scratch using code. Instantiating Prefabs has many advantages over the alternative approach: A Prefab can be instantiate from one line of code, with complete functionality. Creating equivalent game objects from code takes an average of five lines of code, but likely more. It can be set up, tested, and modified quickly and easily in the Scene and Inspector. Prefabs can be changed without changing the code that instantiates it. In order to transform GameObjects to Prefab create a new Prefab in Unity (Right click in project window-->create Prefab) and drag GameObject to the create prefab

Once the prefab is created is necessary to define the script that allows to instantiate elements at runtime at AR camera object.

```
using UnityEngine;
using System.Collections;
public class InputHandler : MonoBehaviour
{
public GameObject bola;
        float xw=0;
        float zw=0;
        void Update ()
 {
    if(Input.touches.Length == 1)
    {
    Touch touchedFinger = Input.touches[0];
    switch(touchedFinger.phase)
    {
    case TouchPhase.Began:

        float x=touchedFinger.position.x;
        float y=touchedFinger.position.y;
        Debug.Log("Posicion de pantalla x: " +x);

        Debug.Log("Posicion de pantalla y: " +y);
        if(x>300){
                                xw=50;  }
        if((x<300)&&(x>150)){
                                xw=0;   }
        if(x<150){
                                xw=-50; }

        if(y<266.6){
                                zw=35;  }
        if((y<533.3)&&(y>266.6)){
                                zw=0;   }
        if(y>533.3){
                                zw=-35; }

        Debug.Log ("Posicion en el mundo ("+xw+","+zw+")");
        GameObject b = (GameObject)Instantiate (bola,new Vector3(zw,0,xw),Quaternion.identity);
        ImageTargetBehaviour itb = GetComponent<ImageTargetBehaviour>();
        b.transform.parent=itb.transform;
        ImageTargetBehaviour.CreateVirtualButton("boton",new Vector2(0,0),b);
    break;

    case TouchPhase.Ended:

       break;
    default:
       break;
    }} }}
```

It is necessary to define GameObject (bola) as attribute

Creating and deleting virtual buttons at runtime

Virtual buttons can be created at runtime too

I. Create a new virtual button for a given image target at runtime by calling the CreateVirtualButton member function on the corresponding instance of your ImageTargetBehaviour.
II. Destroy a virtual button by calling DestroyVirtualButton, which is also defined in ImageTargetBehaviour.

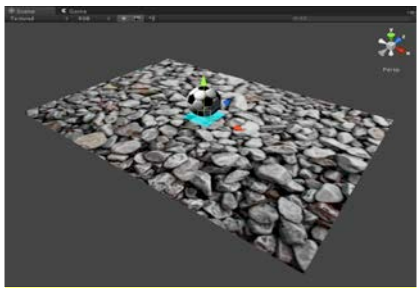


Figure 4.12 Virtual button example app

Previous script uses dynamic virtual creation at the following line:

```
ImageTargetBehaviour.CreateVirtualButton("boton",new Vector2(0,0),b);
```

4.2.4 Scenes based on Frame Markers

In order to use the frame markers objects in Unity it must be taken in account only the ID of the image. As it been said before, there are 512 different schematic (ID 0 to ID 511) in the frame markers, every one with a different marker ID. The marker ID is the identifier for Vuforia, and the final user can choose the marker ID number for every different schematic. The only condition is to avoid the duplicate marker ID's.

At the moment of make and build the app, it has been keep in mind the relation between the ID and the schematics, that is to say, make sure the combination between a certain marker ID with its schematic.

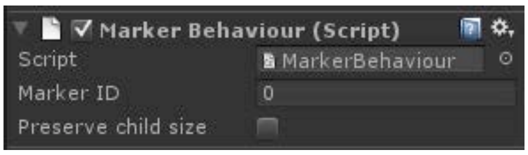

Marker Behaviour (Script)
Script MarkerBehaviour
Marker ID 0
Preserve child size

Figure 4.13 Define marker ID

Finally, to use the frame marker, simply print the desired schematic and view it with the device camera. The app will show the AR element above the printed image.

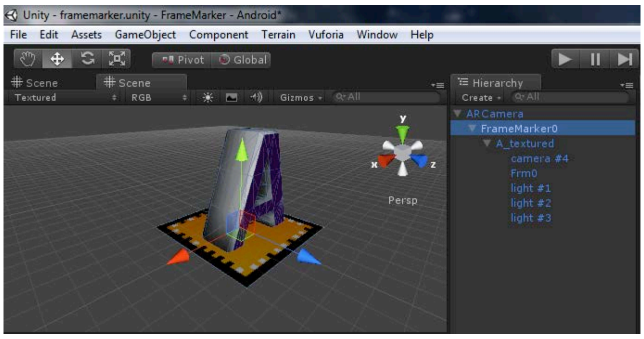
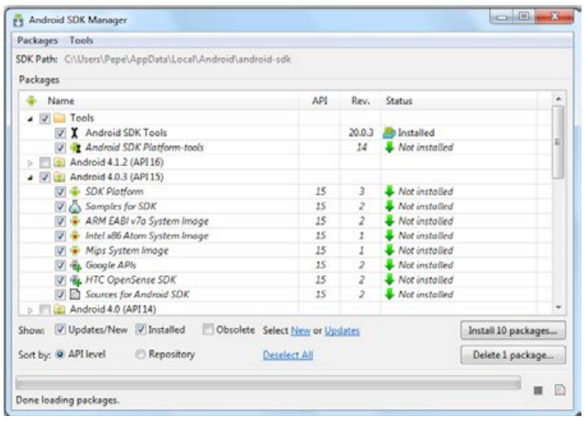


Figure 4.14 Example of use

4.2.5 Build and run

In this step, and if it does not do before, the Android SDK must be installed in the machine. If not, unity is not able to generate the application. When installing the Android SDK can choose several APIs, but in this case you should choose the API 4.0.3 or higher using the SDK Manager.


Android SDK Manager

Packages Tools

SDK Path: C:\Users\Pepe\AppData\Local\Android\android-sdk

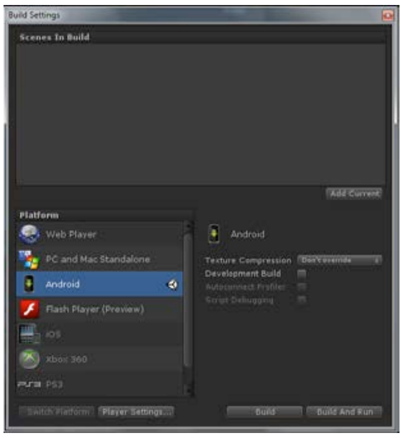
Packages

Name	API	Rev.	Status
Tools			
Android SDK Tools		20.0.3	Installed
Android SDK Platform-tools		14	Not installed
Android 4.1.2 (API16)			
Android 4.0.3 (API15)			
SDK Platform	15	3	Not installed
Samples for SDK	15	2	Not installed
ARM EABI v7a System Image	15	2	Not installed
Intel x86 Atom System Image	15	1	Not installed
Mips System Image	15	1	Not installed
Google APIs	15	2	Not installed
HTC OpenSense SDK	15	2	Not installed
Sources for Android SDK	15	2	Not installed
Android 4.0 (API14)			

Show: [✓ Updates/New] [✓ Installed] Obsolete Select New or Updates — Install 10 packages...

Sort by: [✓ API level] Repository Deselect All — Delete 1 package...

Done loading packages.


Build Settings

Scenes In Build

Add Current

Platform: Web Player, PC and Mac Standalone, [✓ Android], Flash Player (Preview), iOS, Xbox 360, PS3

Android

Texture Compression: Don't override

Development Build

Autoconnect Profiler

Script Debugging

Switch Platform | Player Settings... | Build | Build And Run

Figure 4.15 Android SDK Manager

Figure 4.16 Build settings

Now, is time to test the application connecting the smartphone to PC via USB. Unity recognises the device and automatically install and launch the application. Only need to choose the operating system of the target device and click in Build and Run.

4.2.6 Applications logs & debug

When any mobile application is being developed is need to be tested, and for this is essential to read the interaction between the device and the app. In this point, and talking about Vuforia for Unity there is a problem, Vuforia does not able to make this interaction at the current version. During the realization of this project, several e-mails have been exchanged between the authors and the Vuforia's developers and the answer is clear, this functionality will be launched with the 2.0 version (actually the last version is 1.5).

As is says before, this functionality is crucial, and the solution is explained thereupon.

The solution adopted was as follows; use the ADT plugin for Eclipse mobile developers to read the different logs and messages from the smartphone. ADT plugin extends the capabilities of Eclipse to quickly set up new Android projects, create an application UI, add packages based on the Android Framework API and debug applications using the Android SDK tools. This last part is the main advantage to be exploited.

The main steps to install the necessary software are the next:

1 – Install the Java Development Kit if necessary

2 – Install Eclipse Mobile Developers

3 – Install the ADT plugin for Eclipse

4 – Update Android SDK if necessary.

4.3 Vuforia license

For the developers it is very important to know the license that use Vuforia, if there are any. In this case, the Vuforia SDKs are all free, there are not licensing fees. Even if the purpose is the commercial use for applications under Android or/and iOS platforms, the cost of it is free. In the other hand is important to remark that Vuforia or any other Qualcomm software is subject to the terms of the GPL, AGPL, LGPL, EUPL, APSL, CDDL, IPL, EPL, MPL, or such other open source license.

But there are some conditions for this free use, and all are detailed explain in the License agreement that can be found in https://developer.vuforia.com/legal/license. The most important parts in the license agreement is the part 8 (the mandatory end-user license agreement clause) and the part 2.2 (use restrictions). Furthermore, the application only can contain the logo, the name or any kind of reference to Vuforia with the explicit permission of Qualcomm, due to the rules for these cases of Qualcomm.

There is only need to pay for the use of cloud storage, because this service is property of Qualcomm and should be used by legal engagement.

4.4 Best Practices for Well-Created Apps

The following point describes how users should interact with an AR application made with Vuforia to get the best performance and considerations that must be taken into account during the application development to made it usable. Vuforia user interface allows free method for viewing 3D objects, which promotes natural interactions and the possibility of incorporating movement into the interaction of either hand or the whole body.

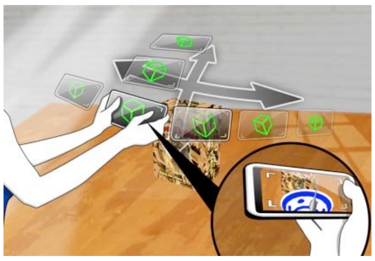


Figure 4.17 3D free enviroment

3D objects are better than 2D objects when using Mobile AR. When viewing 3D objects in 3D space is better to have a moveable device as an open window to this space instead of fixed viewpoint so more dimensions were opened to the user. Users can move freely around the targeted image, the mobile device can be tilted and is allowed to move the object. The movement of the user in relation to the target is the big differentiator in mobile AR

When an AR application starts it is important taking into account a set of considerations. It is necessary to provide clear graphical instructions on screen to help the users during the application execution, for example informing how to orientate the Image Target towards the camera. In addition, it is necessary to provide outline or some visual information that pop-ups when detecting a target.

Developed applications do not inhibit user's normal behavior. Safety of the users must be taken into account in every situation (e.g., walking through a busy street looking through a mobile device may cause a user to walk into people or traffic unintentionally).

Considering how the user will grasp and hold the device must be considered planning for the appropriate pose for the appropriate situation. Different poses might fit different purposes and types of interactions. When using AR applications, the arms of the user can feel tired very quickly when holding up the device. Often the pose required is similar to taking a picture with a camera. Longer periods of interaction suit the 'console-style' hold, while short interactions suit the 'camera-style' hold.

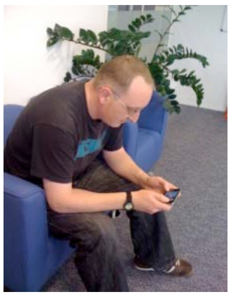


Figure 4.18 Looking down

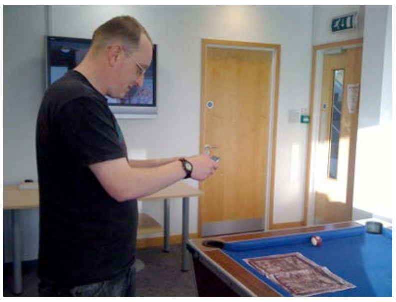


Figure 4.19 Standing over table

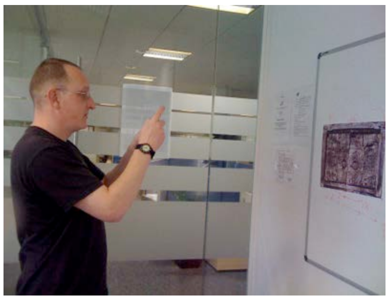


Figure 4.20 Standing on wall

Targets on the floor provide a comfortable holding position for the device. Suggesting the use of device holder or recommending users to rest their arms on something probably relax them. Targets on the wall required camera-like holds which long term exposures provide arm fatigue. Is for that reason the use of such applications should be brief.

To provide an optimal experience, the augmentation should be visible to the user. Losing a target is one of the most irritating issues when using an AR app but can be easily compensated if it is considered from the start giving some indications to users that have lost the target.

Image Target prints can be easily obtained by the user if the application is not designed around an existing object or product, for example providing a link to the target in app description text

Reaching into the real world to manipulate an object that only exists in the AR world can be a magical experience. Direct manipulation can be fascinating, but can also be quite confusing for the user. User only has two hands and one of them is usually occupied by holding a mobile device. Hand-eye coordination is also crucial. Tangible interaction can be a very pleasant and intuitive method of interaction if it is done simply and usefully. It is required to use small targets with simple one-handed operation moving one at a time. On the other hand, it is not recommended to mix tangible and on-screen interactions due to can be confusing.

On screen interaction is the most obvious, useful, intuitive, and simple method for normal or functional tasks. Is for that reason that onscreen user interface should be clear and simple.

Virtual buttons are usable with mobile AR and work well in simple tasks such as changing color. Virtual buttons provide a nice delightful surprising interaction when understood by the user.

CHAPTER 5 INMEDIATE INCOMING FUTURE 2.0

As seen during the development of this project Vuforia SDK brings to users an incredible AR experience that allows to them see and interact to the unseen. The 1.5 libraries had improved detection and trackability robustness of its predecessor. At the end of the year 2012 Qualcomm announced the development of a new release, Vuforia 2.0 SDK, from Qualcomm's Austria Research Center GmbH. The platform leverages the power of the cloud and delivers enhanced features and toolsets that enable the creation of richer, more relevant and more engaging AR experiences.

This 2.0 commercial release includes the following features:

- Cloud Recognition - image recognition against databases containing over one million images
- User-defined Targets - empowers users to define their own image targets to launch the app experience using everyday images
- Video playback
- Support for Play Mode in Unity – enables developers to code, test and debug in real time using a webcam to simulate the AR experience
- Support for using the front camera
- Support for multiple active device databases
- Improved tracking robustness
- Combined iOS and Android plugins in the Vuforia Extension for Unity

5.1 Developer Workflow. Local database vs. Cloud database

After creating an account in the TMS, the developer is presented with a choice: use device based databases or, new 2.0 feature, cloud based databases. Developers will not be able to convert a database to the other type later on, so it is absolutely necessary to be clear on which capabilities app needs.

Device databases provide Vuforia applications with a locally accessible database of image targets.

If it is known what the application will be expected “see”, and the target set of images is less than 100 images, then a local device database is the right solution. Device database use cases include promotional campaigns for a specific set of products or print material, anything that will be identified and scanned with a lower set of images. Device databases will receive more immediate responses since the images are stored locally.

Cloud databases provide Vuforia applications with a large number of targets. Cloud databases are stored in the Internet and support over a million image targets.

If the application supports a retail or catalogue use case where there are more than 100 images or the images are being updated frequently, then a cloud database is the right solution for you. Cloud image targets may take a little longer to be identified (depending on network connectivity), but provides a strong image recognition capability.

To aid with this decision, consider the following table:

Device Database	Cloud Database
Limited to 100 targets per downloaded device target database	>1 million targets in the cloud database
Allows downloading targets in different combinations	One database with all images and metadata
Downloaded targets only for detection, no metadata support	Targets retrieved by cloud recognition can carry up to 150kB of metadata
Network connection on end user device not required for detection	Network connection on end user device required for recognition, network traffic for cloud recognition
Run-time detection response time within 2-3 frames	Response time up to 3 seconds, depending on network connectivity
Multiple databases can be active (each with maximum 100 targets)	Recognition on maximum 1 million targets active at any time
Free	Free and Paid, depending on usage

Table 5.1 databases comparison

Once you have decided between the two methods, then the following chart will guide you in the creation of your Vuforia Augmented Reality application.

5.2 User-Defined Targets

The User-Defined Targets application demonstrates how to create a target directly on a device from within an application. End users are now able to display augmentations without the need for a predefined physical target. The sample shows how to capture a target and augment a teapot on top of the image

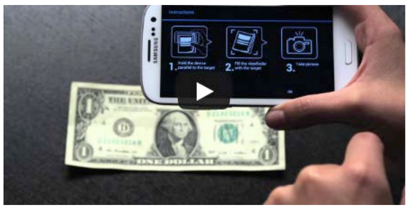


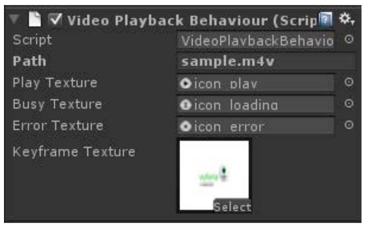
Figure 5.1 user defined target

5.3 Video Playback

One of the newest characteristics of the 2.0 SDK is the video playback. This feature allows users embed any h264 video into the application, but this video will be only visible when the AR camera detects the chose image target. This is very interesting, because it allows the developer to hide the video and play it only just above the target, resize in real time according to the user's position and the target image.

This sample application shows how to play a video in AR mode. Devices that support video on texture can play the video directly on the image target. Other devices will play the video in full screen mode.

The process to create the example is like that made before, but in this case adding a new characteristic into the image target (video). After, it should be added the script VideoPlaybackBehaviour.cs, and in it can be found the path for the video to show and the image with the play icon (Keyframe Texture).



Video Playback Behaviour (Scrip

Script	VideoPlavbackBehavio
Path	**sample.m4v**
Play Texture	icon play
Busy Texture	icon loading
Error Texture	icon error
Keyframe Texture	Select

Figure 5.2 video script configuration

Once is done, the application in the smartphone shows above the image target chosed (in this case stones) the image added in the Keyframe Texture with the play icon. If play button is pressed, the video starts and can track the image target.

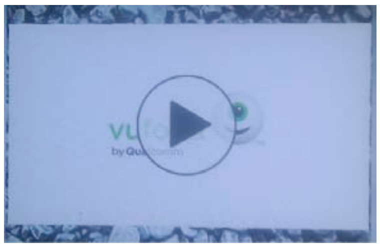


Figure 5.3 Video playback example

5.4 Unity Play Feature

Augmented scenes created for a Vuforia app can be tested in the Unity Pro IDE using Play mode. Play mode functions as it would for any application developed in Unity, allowing rapid editing and testing of your app. No special action to enable Vuforia in Play mode is required.

Play mode is intended to be only an approximation of the actual on-device experience.It is not an emulator and should not replace on-device testing during development.In particular, tracking and rendering performance are likely to differ from that seen on the device.

Using Play mode

1. To use Play mode with Vuforia, connect a webcam to your computer.
2. Select your AR scene from the Unity Project Browser.
3. [Optional] Click on the ARCamera object in the Hierarchy.
4. [Optional] In the WebcamBehaviour section of the Inspector, select the camera you wish to use.
5. Start Play mode.

Now it can be seen the camera feed from the webcam in the Unity IDE.Placing an AR target in the field of view of the camera causes detection and tracking to occur as it does on a physical Android or iOS device. Once detected, the augmentation rendered in the scene can be viewed.

CHAPTER 6 TEST AND RESULTS

Chapter 6 will show the limitations of Vuforia's SDK on image detection process. The chapter is formed by a set of different tests that will determine the robustness of the library. Before that, let is review the considerations that are based on the SDK to set up an optimal testing environment.

6.1 Initial testing environment considerations

Before trying to understand the process must take into account the mode used by the online tool to scan the image. The process starts with the first pixel in the upper left of the image, analysing all the pixels row by row until the last.

6.1.1 Image target design making off

As has been said before, image targets are images that Vuforia's SDK can detect and track. Unlike traditional markers, data matrix codes and QR codes, image targets do not need special black and white regions or codes to be recognized. The SDK uses algorithms to detect and track the features that are naturally found in the image itself. This part will show how to make off the best image target design taking into account the shapes that is composed.

The features of an image target determine the number of stars in the online tool Target Manager, highest number of stars better track and recognition. According to the developer portal, these features must have a high density and uniform distribution with high local contrast using no repetitive patterns. Taking this into account, the first tests will determine the best shape.

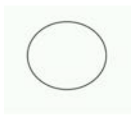
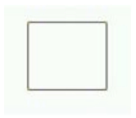
	Number of features	**Number of Stars**	**High feature density**	**Uniform feature distribution**	**High local contrast**
	0	0	✗	✗	✓
	4	0	✗	✓	✓
	15	0	✗	✓	✓

Table 6.1 shapes comparison

As can be seen in the previous table, the maximum number of features is obtained with the star shape; taking into account the number of corners. With this test can show that the more corners have the image more features detect the target manager.

It can be seen that how many corners is the most suitable, but not of sufficient quality for the lack of features in density distribution. To increase the quality of recognition of the image need to multiply the number of ways (star) within the image. It will follow a repetitive pattern in the same way multiply your number of features.

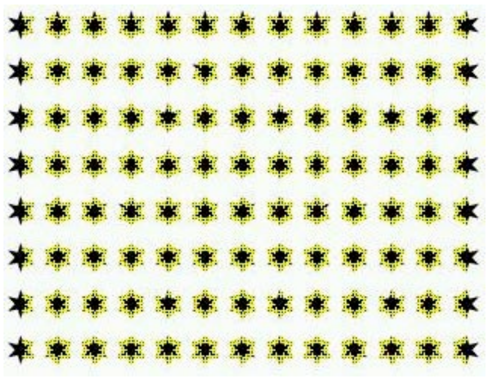


Figure 6.1 IT with repetitive pattern features

$$Nf \times Ne = NfeaturesT$$

☆☆☆☆☆

High Local Contrast	Uniform Feature Distribution	High Feature Density	Repetitive Pattern
✓	✓	✓	✓

Table 6.2 repetitive pattern behavior

As shown in Table 6.2 the number of features (Nf) have been multiplied by a factor of Ne. Surprisingly, the quality of image target has not been increased. The reason for this fact is that the recognition algorithm avoids repetitive patterns. So, creation of an image target with enough features and highly distributed is imperative. Said this, next logical step is to create an image composed with different star shapes and without a repeated pattern.

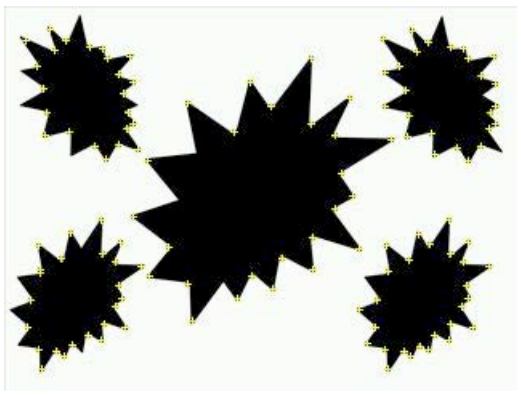


Figure 6.2 IT with custom shape

$$\sum_{i=0}^{n} NixNif = NfeaturesT$$

☆☆☆☆☆

High Local Contrast	Uniform Feature Distribution	High Feature Density	Repetitive Pattern
✓	✗	✗	✓

Table 6.3 star shape behavior

In the Table 6.3 you can see perfectly the image previously mentioned but the quality level still in zero stars. The reason is the density and the distribution of it is features that are not enough dispersed and the number of features is poor. In order to increase the number of features of Figure 6.2 alteration of it is line shape or texture is required.

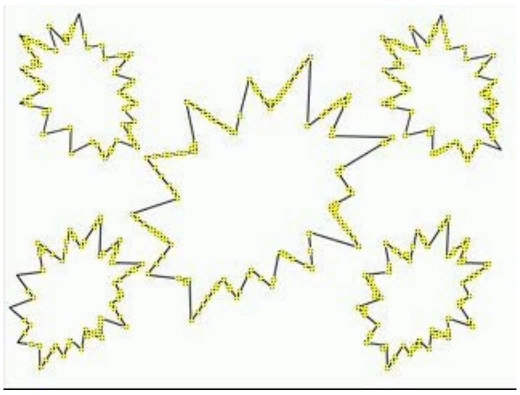


Figure 6.3 IT with custom shape

$$\sum_{i=0}^{n} NixNif = NfeaturesT$$

☆☆☆☆☆

High Local Contrast	Uniform Feature Distribution	High Feature Density	Repetitive Pattern
✓	✗	✗	✗

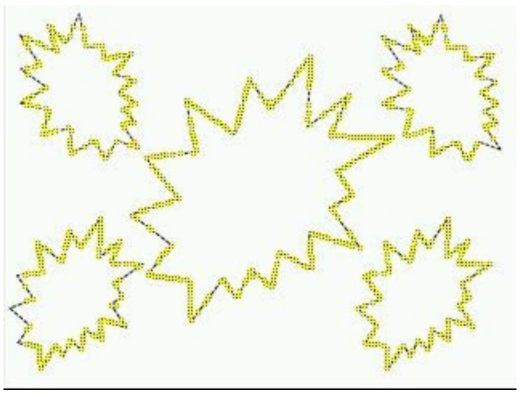


Figure 6.4 IT with custom shape improved

$$\sum_{i=0}^{n} NixNif = NfeaturesT$$

★☆☆☆☆

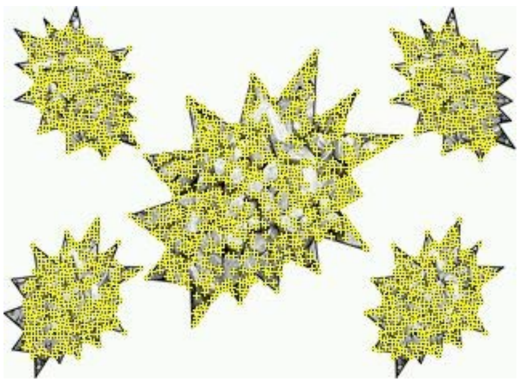
High Local Contrast	**Uniform Feature Distribution**	**High Feature Density**	**Repetitive Pattern**
✓	✗	✓	✗
 **Figure 6.5 IT with texture background**			$\sum_{i=0}^{n} NixNif = NfeaturesT$
			★★★★☆
High Local Contrast	**Uniform Feature Distribution**	**High Feature Density**	**Repetitive Pattern**
✓	✓	✓	✗

Table 6.4 improving shapes

For example, Figure 6.5 shows the rise of quality in star level by increasing the number of features of Figure 6.3 and Figure 6.4 for example, increases this level only modifying texture background. It is important to notice that the improvement was reached only using a white background instead of black. The reason is higher contrast. Recognition algorithm, as said before, executes a horizontal sweep from left to right, and changes in image shades enhance this process. Figure 6.5 improves the number of features in line shaping using dotted line instead of continuous. But image stills not getting distribution and features enough. Using an appropriate texture with a lot of shades like Figure 6.5 considerably raises it is rate in target management system because now is provided with a good distribution and a high number of features.

As conclusion, target management system is mainly based in three properties: shaping, shading and uniform feature distribution. Taking these conclusions into account, next table shows the best trackable image targets designs.

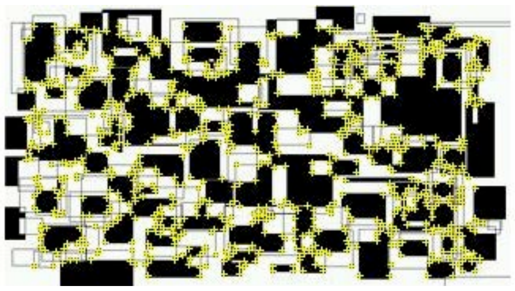


Figure 6.6 IT with 5 stars square shape

★★★★★

High Local Contrast	Uniform Feature Distribution	High Feature Density	Repetitive Pattern
✓	✓	✓	✓

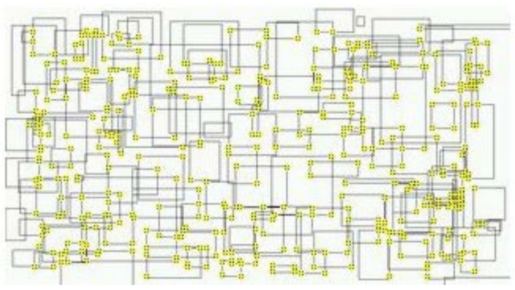


Figure 6.7 IT with 4 stars square shape

★★★★☆

High Local Contrast	Uniform Feature Distribution	High Feature Density	Repetitive Pattern
✓	✓	✓	✓

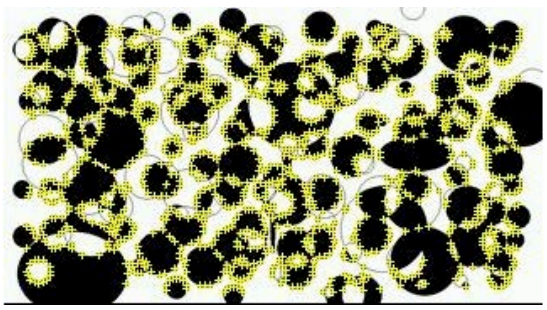


Figure 6.8 IT with 4 stars ball shape

★★★★☆

High Local Contrast	Uniform Feature Distribution	High Feature Density	Repetitive Pattern
✓	✓	✓	✓

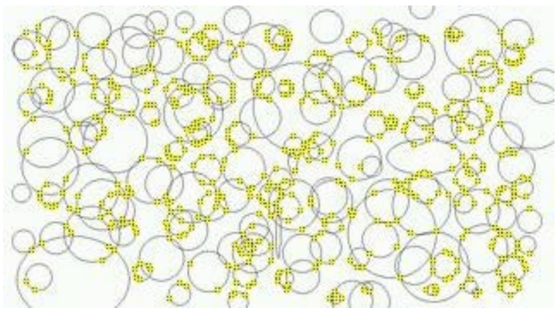
 **Figure 6.9 IT with 1 star ball shape**		★☆☆☆☆	
High Local Contrast	**Uniform Feature Distribution**	**High Feature Density**	**Repetitive Pattern**
✓	✓	✗	✓

Table 6.5 finding the best shape

As shown in the Table 6.5, when an image has highly contrasting tones the shapes which is composed are not so important due to the high density and it is great feature distribution.

In conclusion, image shading determines the number of features that can detect Vuforia in a well-done image.

6.1.2 Analysing and determining image tones

Last chapter describes the most appropriate images targets required to guarantee good trackability. Main image features that provide good scoring at target management system were high density and uniform feature distribution. It is important to mention that the number of features gets increased in pictures with a high tonal variation on it is pixels. To analyse how this variation determines image target trackability an image histogram representation was done.

An image histogram is a type of histogram that acts as a graphical representation of the tonal distribution in a digital image. It plots the number of pixels for each tonal value. By looking at the histogram for a specific image, a viewer will be able to judge the entire tonal distribution at a glance. The horizontal axis of the graph represents the tonal variations, while the vertical axis represents the number of pixels in that particular tone. The left side of the horizontal axis represents the black and dark areas, the middle represents medium grey and the right side represents light and pure white areas. The vertical axis represents the size of the area that is captured in each one of these zones. Thus, the histogram for a very dark image will have the majority of its data points on the left side and centre of the graph. Conversely, the histogram for a very bright image with few dark areas and/or shadows will have most of its data points on the right side and centre of the graph.

The following images represent different tonal distributions histograms.

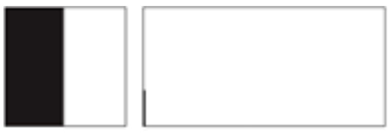


Figure 6.10 bitonal histogram

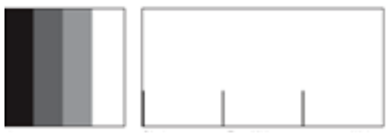


Figure 6.11 4 tones histogram

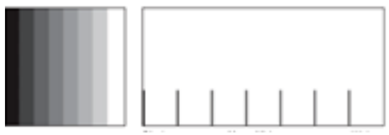


Figure 6.12 8 tones histogram

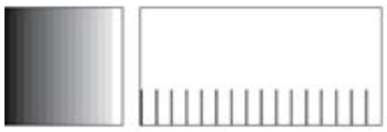


Figure 6.13 16 tones histogram

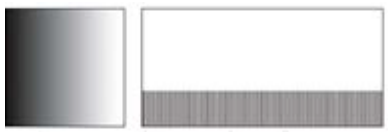


Figure 6.14 256 tones histogram

It is important to remember that Vuforia image recognition algorithm is based on grey-scale tones, so colour chroma is not so important, only shading. Every image is managed using its grey-scale information during the process.

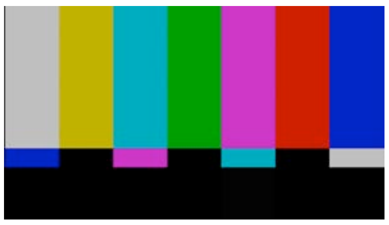


Figure 6.15 colour test pattern

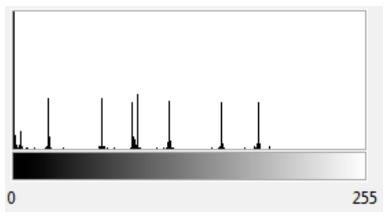


Figure 6.16 histogram with colour

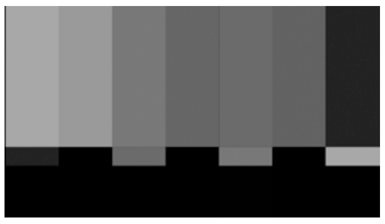


Figure 6.17 b&w test pattern

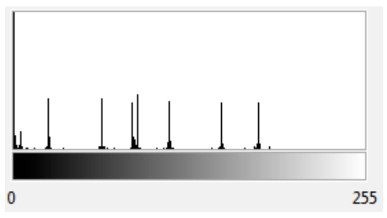
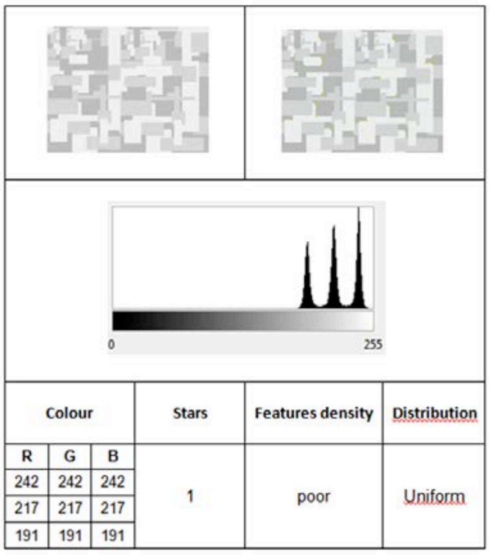
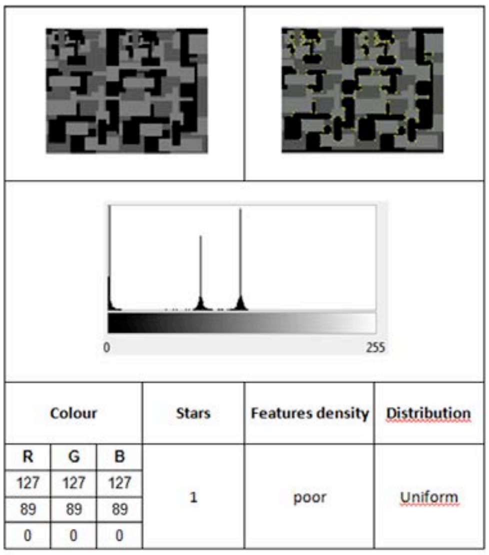


Figure 6.18 histogram without color

As is seen, the same image in colour or grey-scales gives identical grey-scale histogram. But which are the best tones to detect and track? Focusing on tonal contrast, the aim is determine the most convenient shades for this purpose: pitch blacked or highlighted ones. The result was obtained analysing an image target composed with squared in three tones forms on it and comparing the results in the target management system when the shades are altered.



Colour			Stars	Features density	Distribution
R	G	B	1	poor	Uniform
242	242	242			
217	217	217			
191	191	191			



Colour			Stars	Features density	Distribution
R	G	B	1	poor	Uniform
127	127	127			
89	89	89			
0	0	0			

Table 6.6 and Table 6.7

As seen Table 6.6 and Table 6.7, shadow black tones seems to be better to detect and track that light pure whites. In spite of this, not every tonal variation was spotted. Mid tones changing were not perceived at all. If the making off of the image target is performed using as a configuration three widely spaced tones like Table 6.8 shows the score at target management system become increased.

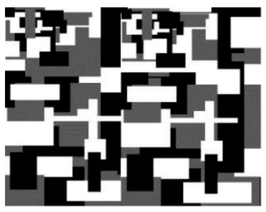
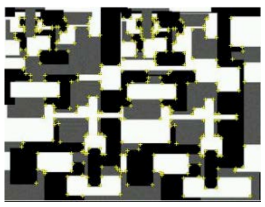
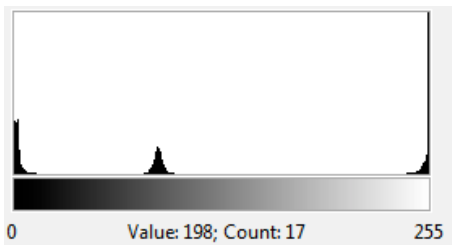
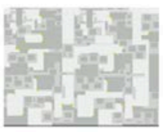
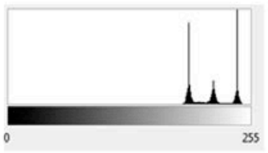
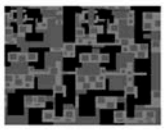
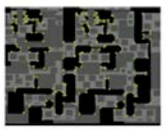
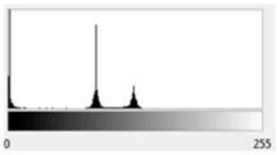
Colour			Stars	Features density	Distribution
					
					
R	G	B	2	normal	uniform
255	255	255			
89	89	89			
0	0	0			

Table 6.8

Increase features quantity and distribution to raise stars number score is possible using more shapes with high contrast between them. For example, following tables have an image target that was altered adding more square elements on it. As seen, the squares added in Table 6.10 are clearly identified. On the other hand newer elements in Table 6.9 and 6.10 are themselves better camouflaged. The reason is the lower tone range between them.

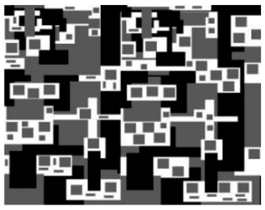
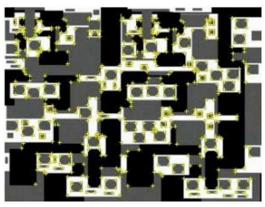
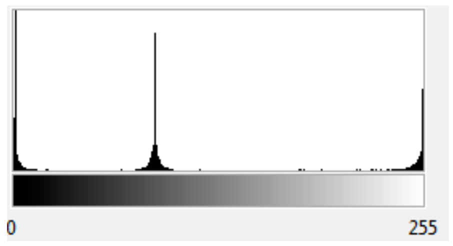



Colour			Stars	Features density	Distribution
R	G	B	1	Very poor	Uniform
242	242	242			
217	217	217			
191	191	191			

Colour			Stars	Features density	Distribution
R	G	B	1	Poor	Uniform
127	127	127			
89	89	89			
0	0	0			

Table 6.9 and 6.10

Colour			Stars	Features density	Distribution
R	G	B	4	rich	Uniform
242	242	242			
89	89	89			
0	0	0			

Table 6.10

As a result, Table 6.10 is richer in features than the other two and consequently high rated. But what is the minimal gamma range used at TMS to spot a shade change? Is the same range for dark and light tones? To determine both minimal ranges, two different images were processed at TMS. First one is composed by a set of squares with shades that belongs to dark region over a pitch-black background (0,0,0). Every square jumps ten tones from previous one situated at its left. The same idea occurs at the second one but this time squares decrease ten tones from light region over clear white background (255,255,255).

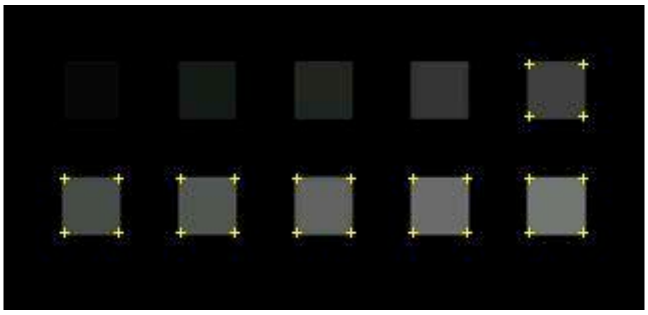


Figure 6.19 Min. dark tone range detection

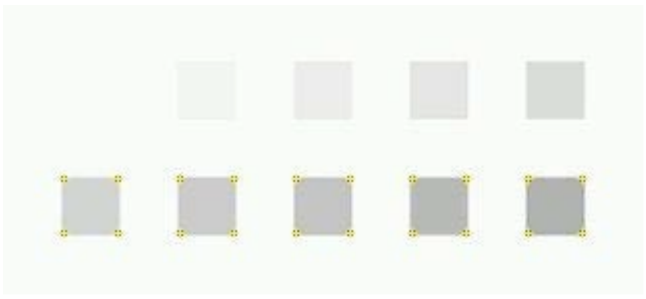


Figure 6.20 Min. light tone range detection

As seen in the two above figures dark tones had less detection window (50) than clear ones (60) at TMS, in conclusion are more accurate at pitch changes. Dark detection

Image manipulation and histograms

Image editors typically have provisions to create a histogram of the image being edited. Algorithms in the digital editor allow the user to visually adjust the brightness value of each pixel and to dynamically display the results as adjustments are made. Improvements in picture brightness and contrast can thus be obtained.

6.1.3 Detection algorithm minimum requirements

Until now the underlying features of Vuforia is TMS were described to guarantee good detection and trackability. This algorithm, as mentioned before, is basically based on shapes with corners and tone changes, been the last one the most important feature. When these conditions are spotted the algorithm puts a marker on it. But this is done in each pixel? Is known that the sweep done by the algorithm is from top to bottom and left to right, so is not unreasonable think that horizontal tone changes were spotted and marked on every pixel of an image with vertical black and white pixel lines but the result was unfavourable. The same occurs for a horizontal black and white pixel lines image. In conclusion, the algorithm needs both sweeps to determine line corners and mark image features. But in practice, using an image formed by the fusion of last both images no features were marked.

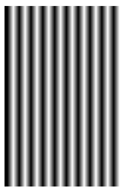


Figure 6.21 1 pixel stripes

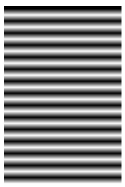


Figure 6.22 1 pixel stripes

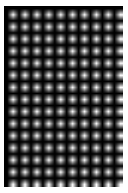


Figure 6.23 1 pixel squares

One pixel tone changes does not contain enough information to determine image features. Minimum pitch changes in groups of two pixels are required to mark image features which are randomly set .If the algorithm processes Image Targets composed by a groups in same color and size 15x15 pixels then features marks positioning are more predictable and clearly identified at corners

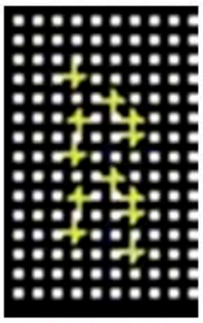


Figure 6.24 2 pixel squares

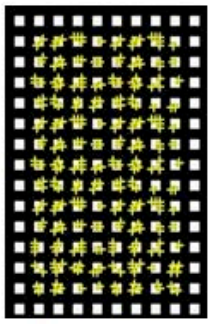


Figure 6.25 5 pixel squares

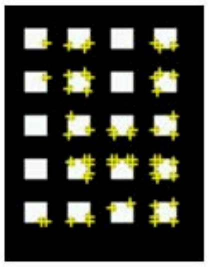


Figure 6.26 10 pixel squares

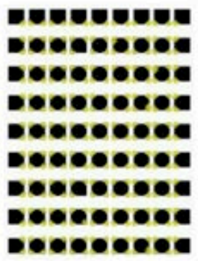


Figure 6.27 15 pixel squares

As can be seen algorithm has a 15 pixel frame around the image were features are not marked.

6.2 Disposable devices to test

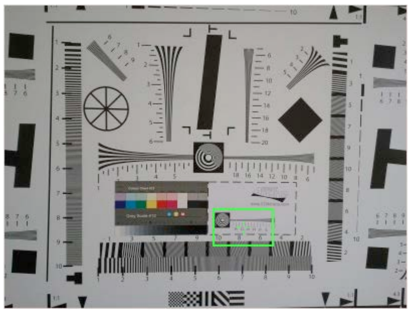
As it been said before, the performance of the same application varies depending on the hardware of the device used to test. Taking this into account, the best way to test the applications is use different devices to compare the throughput. Table 6.11 shows the main specifications of the test devices.

	Samsung Galaxy Note II	Samsung Galaxy S	HTC Desire
CPU	Exynos 4 Quad 4412 1,5GHz	Exynos 3110 1Ghz	Snapdragon QSD8250 1GHz
GPU	Mali 400 MP (quadcore)	PowerVR SGX 540	AMD Z430
RAM	2 GB	512 MB	512 MB
Android	4.1.1	2.3.6	2.2
Display	S-AMOLED 5,5” 720x1280	S-AMOLED 4” 480x800	AMOLED 3,7” 480x800
Camera	8 Megapixels	5 Megapixels	5 Megapixels

Table 6.11 Specification comparison

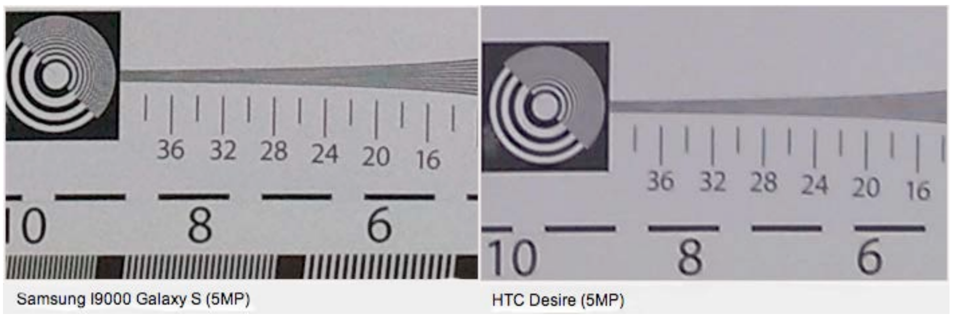
In the Table 6.11 can be clearly seen the deep similarities between two terminals (Samsung Galaxy S and HTC Desire) both CPU and GPU are similar in their capacity and performance. In the other hand, there is a last generation smartphone with a quad core CPU and GPU with a massive improve of performance in relation with the other two. In the two similar devices, the amount of available RAM is the same and the Android version is not the same, but has a common basis. Moreover, the amount of RAM in the Galaxy Note II is four times greater and the Android version is almost the last launched version. In a few words, the difference between smartphone technologies is huge.

With respect to the camera, and being the most important section, it can be seen that they have two with the same resolution, but this does not mean they have the same definition. To test the optics of the both cameras the idea is make a common experiment.



Then we see a real comparative between the two smartphone cameras, using a pattern normally used to check the quality of the lenses. In this case is used an image from ISO 12233. The idea is to take a picture at the same resolution, at the same point of the image using two cameras to check the actual quality of the optics.

The idea is compare the two different images obtained from the both cameras, viewing if one is more defined or clear than the other one. Normally, never 2 cameras are equal although both can have the same maximal resolution. Next can be seen the images made by every camera, and can be seen clearly the difference between their quality.



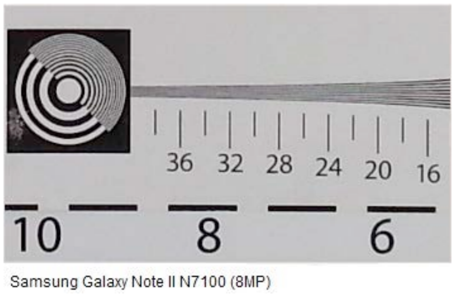


Figure 6.24 ISO 12233 camera comparison

In Figure 6.24 can be seen the difference between the two optical lenses, being more defined in the Samsung Galaxy S. This should be reflected in a better performance of the camera in the following tests, although probably the results are quite similar the main times.

6.3 Tests results

Before start testing it is important to determine the difference between Vuforia is two main characteristics: detection and tracking. Detection is the action of the app to find the image target, recognize them and make the desired function (in this series of test put a tridimensional AR square). On the other hand, the tracking is understood only when the detection was made, the only function of tracking is to follow the image target and try to not lose it.

Taking this into account, all the experiments in this group of test must be separated into two different ways, the tracking mode and the detection mode. In the detection mode the application should be stopped and killed of the memory every time, due to the temporal memory of the application. In the tracking mode, it is enough to stop focusing the image for 10 seconds, and focus again to view for example the time to retracking.

Every test was repeated ten times, and the final result was the arithmetic mean of these. Taking these into account, in all the graphics and tables in this chapter the results always are the mean of the measured values. Also when standard deviation is a fact that offers new information will be explained; understanding that if not mentioned in a given test is because there are no remarkable differences. The entire tests were performed using as image target trackables “Stones” or “Chips”. The features of this image target are described below:

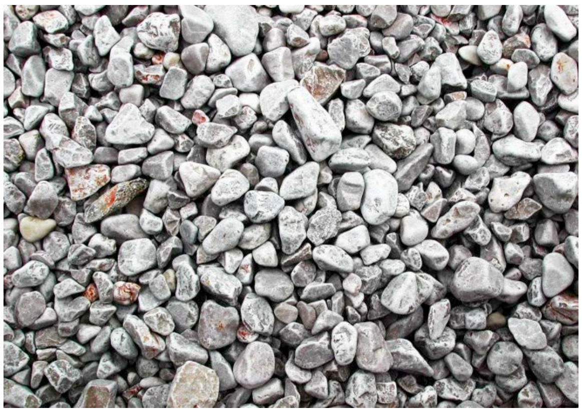
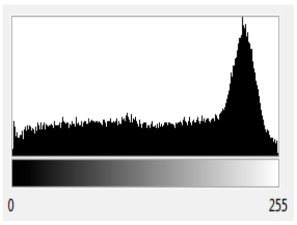
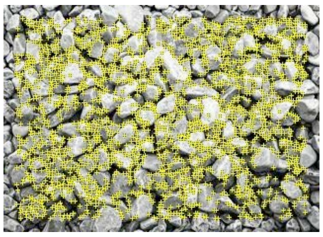
	**Stars**	★★★★★
	Histogram	
	Features	
	Size	24x15cm

Table 6.12 stones image target analysis

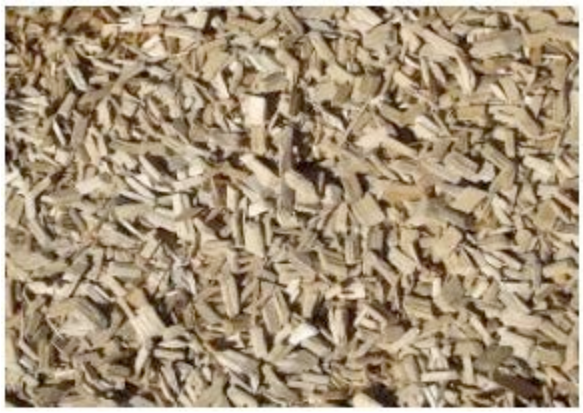
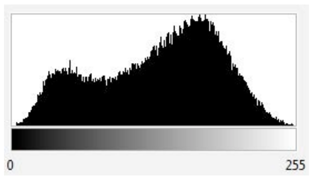
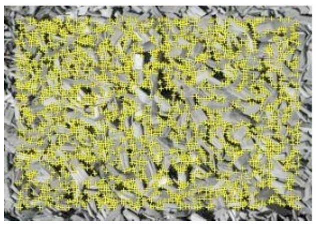
	**Stars**	★★★★★
	Histogram	
	Features	
	Size	24x16cm

Table 6.13 chips image target analysis

Another goal pretended to fulfill with these tests is to compare efficiencies obtained using as a trackable an image target or a frame marker. Is for that reason the entire tests were performed using also frame markers. The used frame markers features are described below:

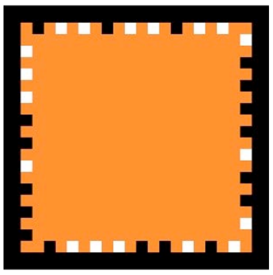
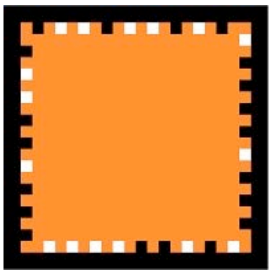
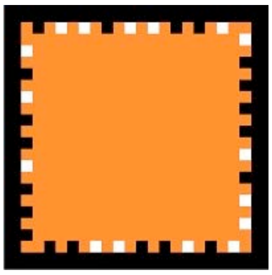
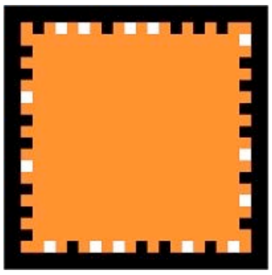
 ID = 0	 ID = 1	 ID = 2	 ID = 3
Size = 55 x 55 mm			

Table 6.14 example of frame markers

Next you can see the different tests done, with the results of each of them and the relevant conclusions.

6.3.1 Detection

The purpose for the following detection tests is to determine the minimum requirements to recognize image targets.

6.3.1.1 Mean response time and Maximum targets recognition

First test will determine the required mean processing time before detecting an image target and render it is correspondent 3D object model. This time is a decisive factor in AR applications usage because if high is not considered acceptable for detection.

Device	Time
Samsung Galaxy SI	<1sec
HTC	<1sec

Table 6.15

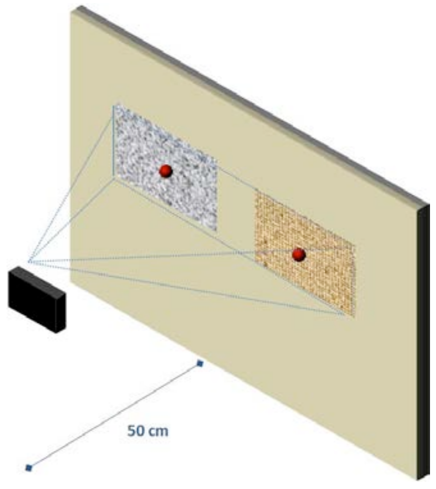


Figure 6.25 mean response time

This test was reproduced using the three different mobile devices mentioned in chapter **6.2** to compare results. The number of image targets was also increasing in order to determine how affects simultaneous recognition of elements in detection and establish, if exists, is maximum number.

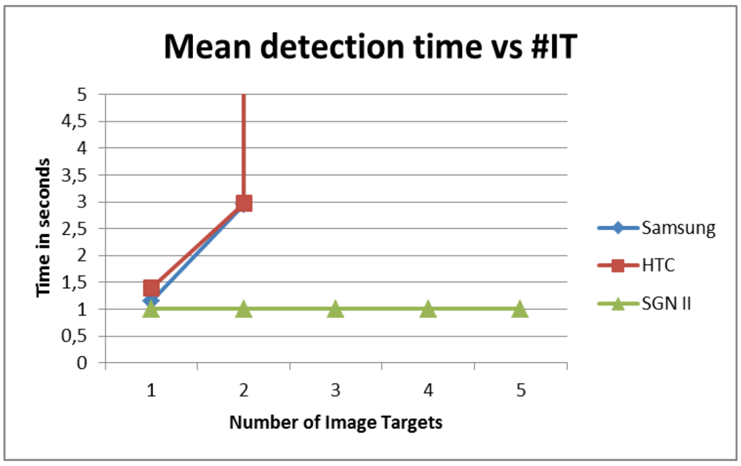


Figure 6.26 mean detection time

As can be seen in Figure 6.26 both devices with similar features had similar detection times. Detection time is about one second in the case of one image target being increased to three seconds when aiming to detect two targets, considering acceptable both cases. If the number of Image Targets is more than two, detection is not appreciated. This is due to CPU devices limitations. On the other hand, if comparing last results with the obtained using as a device Samsung Galaxy Note II the number of simultaneous Image Targets is getting increase considerably without raising required detection time. In conclusion application usability is getting increased.

Now proceed to repeat the detection test done before but using this time a Frame Marker as a trackable.

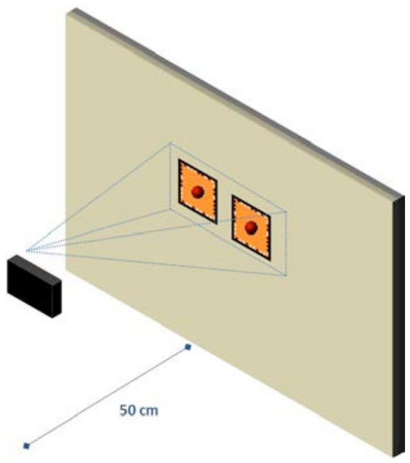


Figure 6.27 detection test

The major advantage of using frame markers instead of image target is it is short processing time. Frame markers are instantly identified (≈ms) because only nine bits binary decode is required.

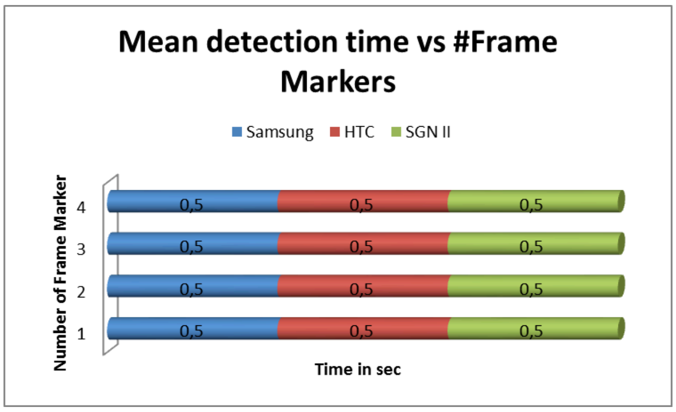


Figure 6.28 mean detection time using frame markers

Due to CPU lightly loaded devices CPU performance is not so important and a high number of simultaneous frame markers can be detected.

6.3.1.2 Minimum distance

The following test pretends to determine the minimum detection distance in order to establish the boundaries of the desired scenario.

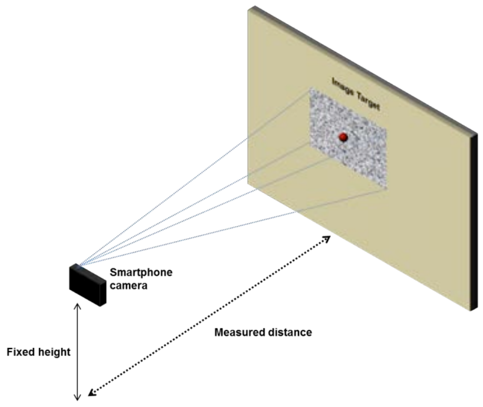


Figure 6.29 minimum distance test

To make this experiment is necessary to put the device so far away from the image source to make impossible the detection. Once the device is placed at the desired distance, the idea is gradually approaching it to the image target until it is detected. As said before, the test was repeated ten times and these results are the mean. The standard deviation is not relevant in this case.

Device	Mean (in cm)
Samsung Galaxy SI	87,73
HTC	72,4
Samsung Galaxy Note II	130,5

Table 6.16 minimum mean distance

As can be seen in the Table 6.16, the camera of the Samsung device is more sensible and detects the image target better than the HTC's camera.

Image's size increasing alters the results listed above. Using this time 37x25 centimeters image (925 cm^2 of area) the obtained results are the following:

Device	Mean (in cm)
Samsung	**131,73**
HTC	**106,8**
Samsung Galaxy Note II	**151,5**

Table 6.17

By comparing both results, distance is directly proportional to image size increments. In conclusion, camera's lens quality can be compensated expanding image target size. Obviously there is a distance limit that cannot be established in these tests in which no detection is possible. Now proceed to repeat the test done before but using this time a frame marker as a trackable.

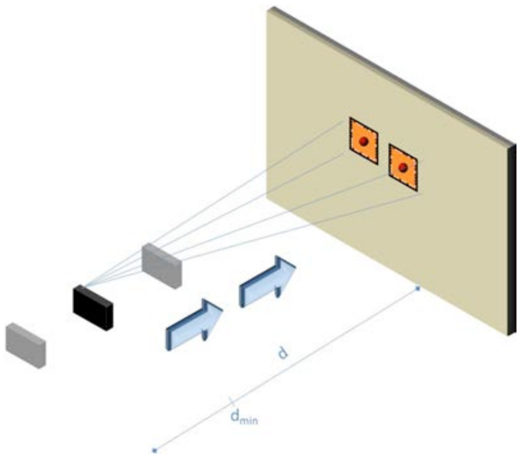


Figure 6.30 tracking test

Device	Mean (in cm)
Samsung	**169**
HTC	**121**

Table 6.18 maximum tracking distance

Table 6.18 proves that frame markers are quickly identified. As said before frame markers are composed using four binary codes (9bits) through their edges. The combination of those codes allows to easily identify the frame marker and it is position. Owning to binary codification uses the most contrasted shades in histogram as bits (black and white), frame markers are clearly identified due to their simplified format, consequently the minimum distance of detection increases.

6.3.1.3 Maximum occlusion

This third test will determine the required image percentage to guarantee detection. As seen in previous chapters, to recognize an image Vuforia processes its features and compares the results to the database contained in the application's chosen dataset. If the results match, then the image is considered to have been recognized. Therefore, if image features are not clearly perceived, no detection is possible.

To make this experiment and considering that features are not equally distributed image target was occluded in the following four ways:

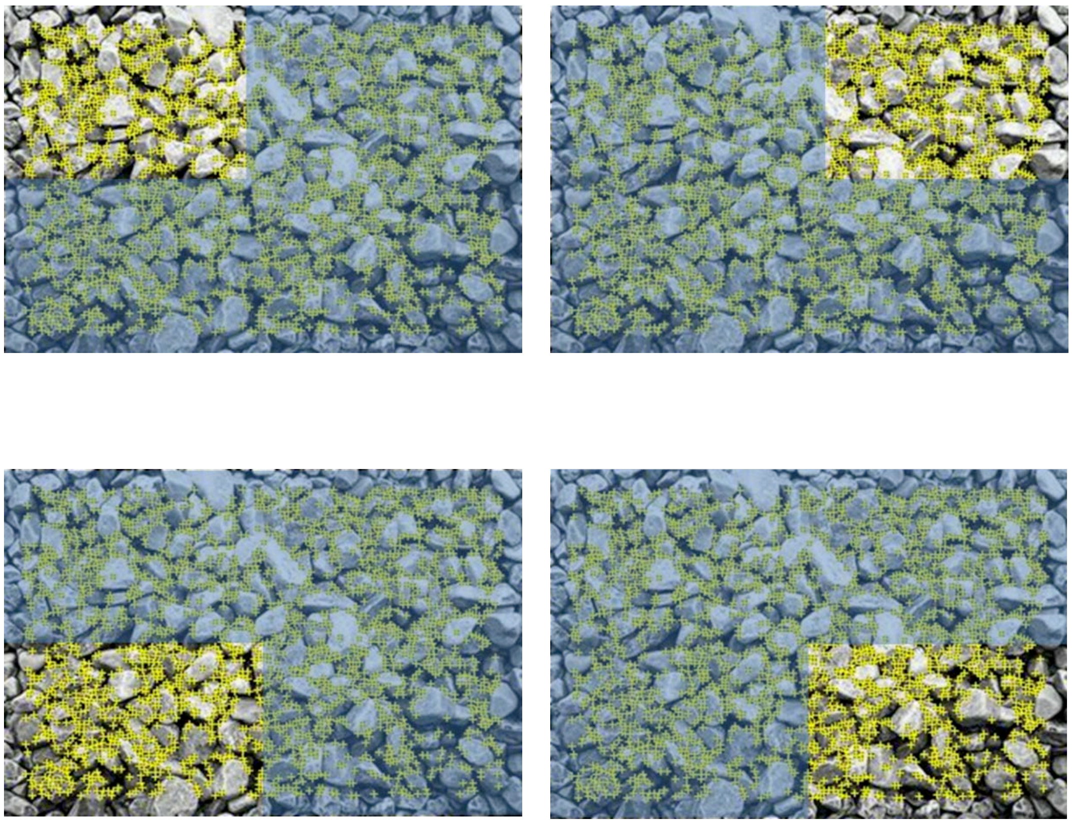


Figure 6.31 maximum occlusion test

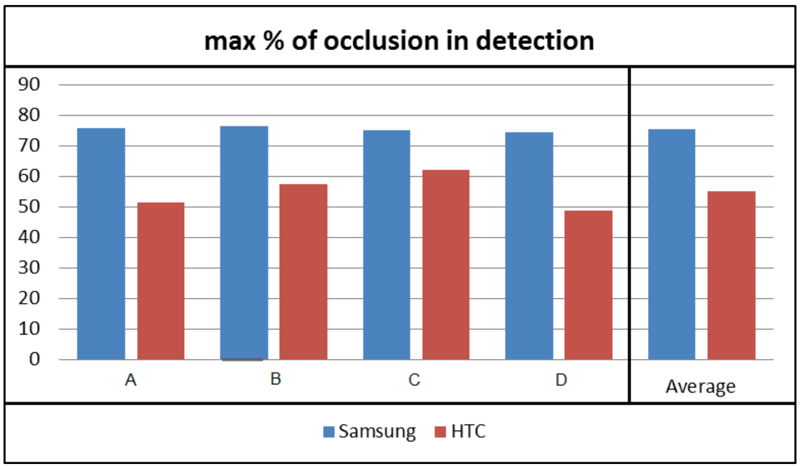


Figure 6.32 maximum occlusion test

As seen in Figure 6.31 Vuforia not required a great image percentage to guarantee detection. Only about 75% in case of Samsung mobile device and 55% in case of HTC. These results are explained, as said, due to the difference between camera's lens quality in both devices.

Image detection not only depends on the visible image's percentage. Theoretically recognition algorithm selects a set of points called, as said before features, and compares it is distribution with the stored one at dataset. If this information matches image targets corresponding object was modelled. Features density in a visible area will determine if the target is detected or not. A high features density in a visible area does not imply that this area is smaller than other with lower density. It is believed that "overfeatured" zones will be averaged. If frame marker is used as a trackable in application with cannot cover any of is it pixels otherwise no detection is possible.

6.3.1.4 Minimum angle

The latest detection test is similar to previously done because both determine the minimum useful image data to detect. All tests that have been done before had direct view from the camera to the target image, being considered that the ideal scenario. But in real world these circumstances are rarely given. In practice, when no direct view is possible, an angle of incidence (α_i) between camera and target is needed to span image size; otherwise much information is lost or considered not useful to detection. For example, imagine a wall image target situated in an elevated position. Probably the field of view of the camera is not enough to capture complete images dimensions. Only about 30% of image is required to detect it, but supposing that camera is focusing image centre and it is total dimensions are span which is the minimum required incidence angle to detect.

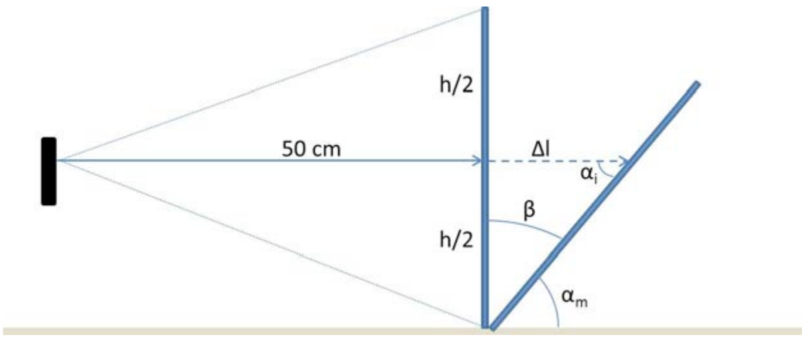


Figure 6.33 angle of incidence

$$\alpha i + 90° + \beta = 180°$$

$$90° - \beta = \alpha m$$

$$\alpha i = \alpha m$$

As shown in Figure 6.33 to realize this final test the image target position angle (α_m) was increasing from zero degrees to ninety in order to identify its minimum incidence angle (α_i) of detection. As ever, the results are the mean of the ten measured values.

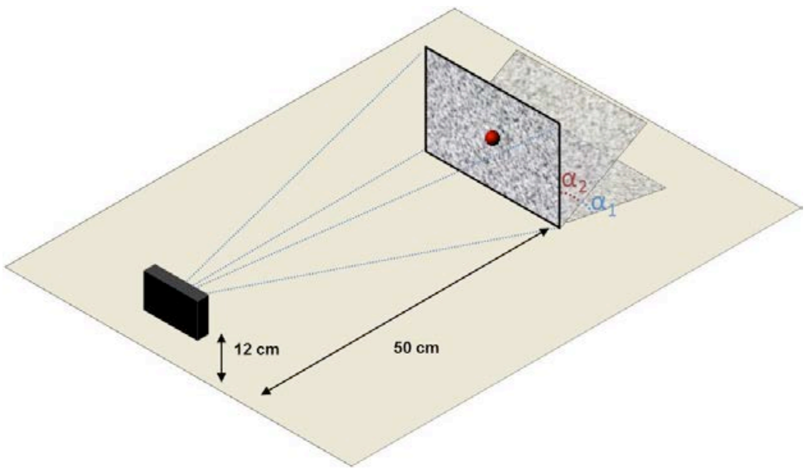


Figure 6.34 angle of incidence test

Device	α_i
Samsung	**43º**
HTC	**52º**

Table 6.19 minimum detection angle

6.3.2 Trackability

6.3.2.1 Maximum distance

The following test pretends to determine the maximum tracking distance once image target is detected in order to establish the trackability limits.

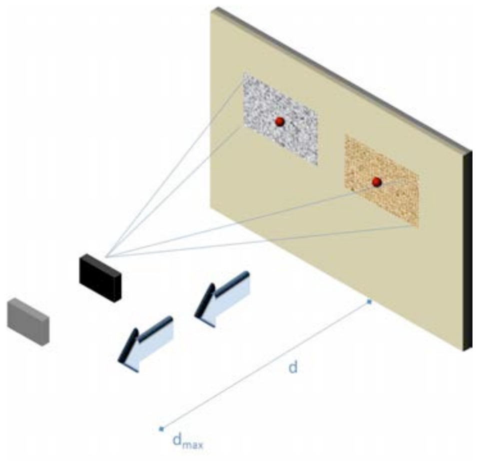


Figure 6.35 tracking test

To make this experiment is necessary to put the device at minimum distance of detection. Once the device is placed at the desired distance, the idea is gradually away from image source until it is lost.

Device	Max distance (in cm)
Samsung GSI	278
HTC	251
Samsung GN II	276

Table 6.20 maximum mean distance

As seen, once image target is detected tracking maximum distance widely overcomes minimum distance of detection. The explanation is that in tracking mode image features are not as important as where in detection mode. Image target is tracked as long as a clear contrast exists between image and environment. This factor is determined by cameras lens quality

6.3.2.2 Maximum movement speed

The following test pretends to determine the trackable maximum displacement speed in kinetical objects, just before the camera loses its source. Although in most cases AR environments are set using as a trackable source static images is possible to provide them certain mobility. This test will determine Vuforia's SDK trackability limits in terms of velocity.

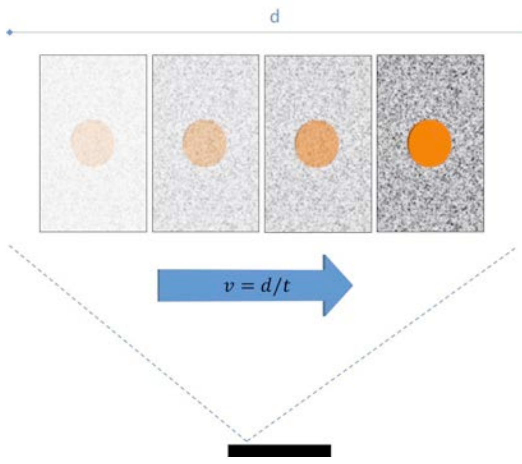


Figure 6.36 velocity test

To perform this experiment is necessary to set devices camera in a fixed position. Once the camera is set and its field of view covers a well-known distance (d) the image target will shift through it at constant speed (v) repeating this experiment until lost image target's rendered object. Each test impact on a speed increase.

Device	Max velocity (in m/s)
Samsung	0,5
HTC	0,5

Table 6.21 maximum mean velocity

6.3.2.3 Maximum occlusion

This test will determine the maximum percentage of image target occlusion necessary to lose trackability.

$$\frac{Aocclusion}{Atotal} \times 100 = \%occlusion$$

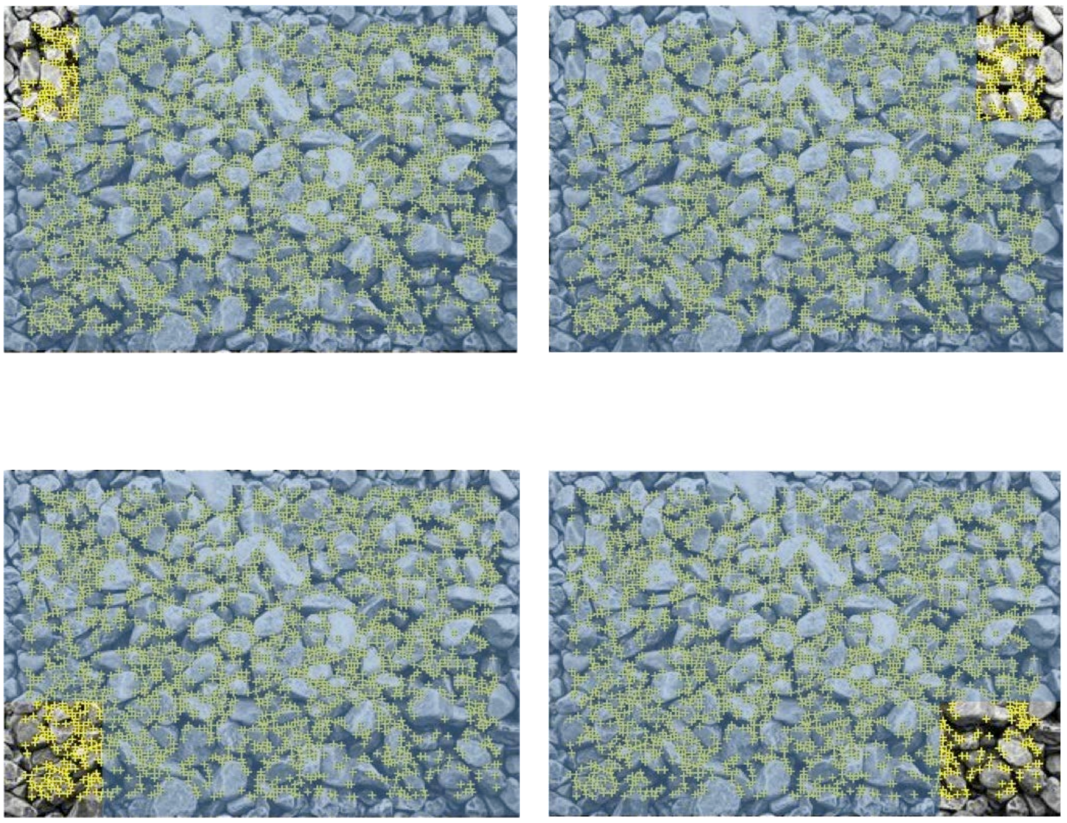


Figure 6.37 occlusion tracking test

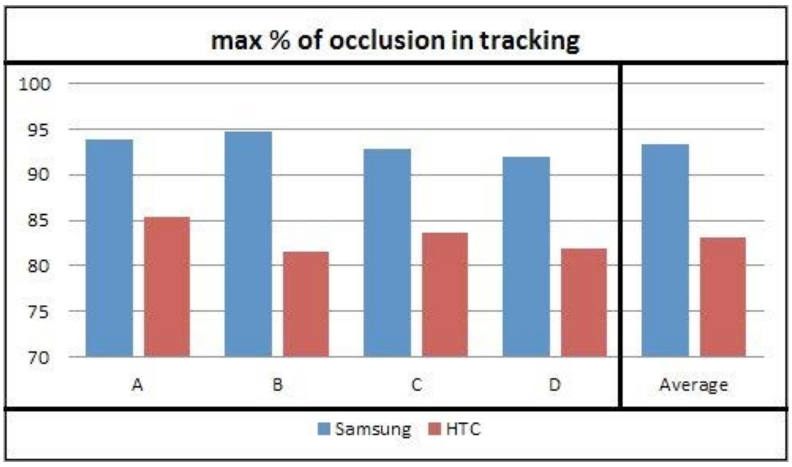


Figure 6.38 occlusion tracking test

As can be understood image tracking not only depend on the visible image's percentage. Theoretically recognition algorithm selects a set of points called as said before features and compares it is distribution with the stored one at dataset. Taking into account the considerations concluded in 6.3.1.3 about the features density in visible areas and comparing the obtained results with current ones it is assumed that image targets requires less features constellation once detected.

6.3.2.4 Minimum angle

The aim of latest tracking test is find the minimum angle of incidence able to track the image. This angle determines, like before, the minimum area needed to the smartphone camera to do not lose the AR object.

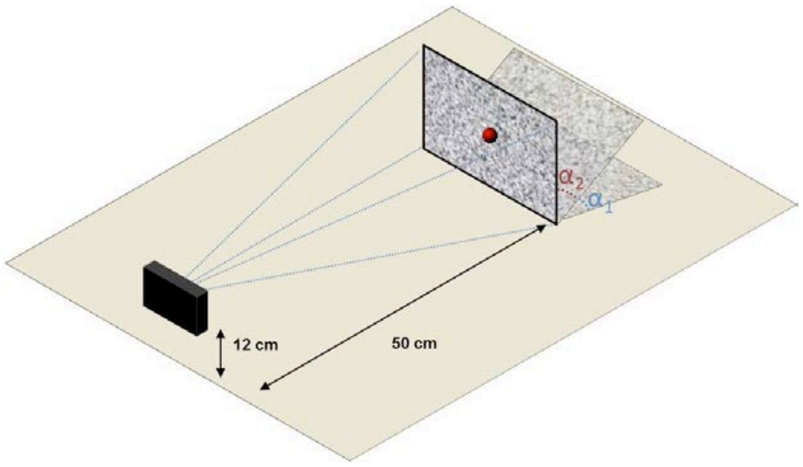


Figure 6.39 minimum angle test

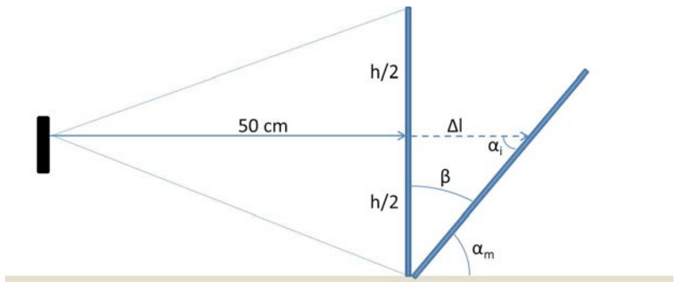


Figure 6.40 incidence angle

Device	α_i
Samsung	2º
HTC	8º

Table 6.22 minimum angle of tracking

CHAPTER 7 CONCLUSIONS AND OBSERVATIONS

Finally this last chapter presents our observations and test conclusions during the development of this Master thesis including our personal approach.

Personal approach

Upon completion of the thesis, and looking back we can see the progression in knowledge that has been acquired, considering our starting position was the most absolute ignorance regarding this matter is concerned. Moreover is important emphasize that personal motivations were achieved.

During the stay in this college have not had the opportunity to learn anything about smart phones and augmented reality. Thus, we have found a learning gap during the first months of the thesis due to the lack of knowledge about Unity environment, but finally we have acquired the necessary skills understand the elements and develop using the SDK.

At the beginning of the year 2013 Qualcomm announced the launching of a new release, Vuforia 2.0. Due to there has been tremendous interest from developers all over the world, Qualcomm Vuforia’s documentation page has been improved including extended useful information which was not present at 1.5. Qualcomm's Vuforia developer guide at the beginning of this research was almost nonexistent and scattered. Actually, and with the new version, both documentation and the website itself are much better, but unfortunately for us had been late. A basis of testing and test, we understood how they worked the functionalities before the new documentation had been published, but at the cost of spending too much time.

In conclusion, we believe that the trend towards by the usability of smartphones is the interaction with all elements at its disposal, considering that they have the camera and the screen only. With this in mind, either Vuforia or any other augmented reality technology can be the solution for better interaction between smartphones and persons. Moreover, we have seen there has been during the last two months a lot of interest from developers towards Vuforia, indicating that the trend seems to be this.

Used tools observations

The Vuforia platform provides maximum creative control and technical flexibility by supporting a range of development tools: Xcode, Eclipse and Unity.

Unity 3D alternative supports pretty good our expectations using SDK's extension which is easily configured. Create AR applications based on image recognition using this technology no needs high programming level. On the other hand, major knowledge is required to furnish extended features to AR objects based on Unity scripts.

The use of the elements that form Vuforia's architecture is pretty simple and intuitive. Unity software is a fully integrated game engine that reduces development time which probably would be higher using Eclipse.

At first the idea was to design our own 3D objects using Blender and export them to Unity, but we run into problems using textures. Therefore, we decided to use the included in Unity.

Test conclusions

The number of items processed, recognized and rendered in Vuforia is directly proportional to mobile capabilities device being the GPU and optical quality decisive features.

Vuforia SDK only allows image pattern recognition not object recognition. Object recognition is basically based on its texture patterns. Due to this, controlled environments previously processed are required to guarantee the correct work of application. Minimum alteration on image target patterns probably leads to application malfunction, requiring its upload at TMS.

Vuforia’s recognition algorithm is not optimized for simple images usage which are low rated at TMS, for example image logos, due to its reduced number of features. By altering its composition, shading or shaping, Image Targets improvement could be achieved at TMS increasing its star rating.

Vuforia’s TMS processes images in grey-scale. Optimal tonality changes are from white to black tones or vice versa. Similar tone colours had a minimum perception of these tonality changes, being the dark tones more accurate than clear white ones. In addition, if an Image Target is altered darkening its tonality, had better performance in terms of detection and trackability than if its get brighten. Image Targets in white tones provides lower features than dark shades.

Apparently the minimum number of required features to provide tracking is between 20-30 features per 5-10% of Image Target area.

Features density increasing not reduces the minimum percentage of non-occluded Image Target area. High density areas are grouped.

Minimum pitch changes in groups of two pixels are required to mark image features which are randomly set .If the algorithm processes Image Targets composed by a groups in same color and size 15x15 pixels, then features markers positioning are more predictable and clearly identified at group corners.

Image Targets are easily identified and is not necessary a great percentage of its area to get detected (about 50%). Once detected the percentage of image tends to approach 100% to image occlusion without losing the trackable. It is important to remember that these results were fit to a five stars rated Image Target at TMS (high featured image with distributed density). On the other hand no occlusion is allowed using Frame markers.

ANNEX

A I Classes and functions

An application programming interface (API) is a specification intended to be used as an interface by software components to communicate with each other. An API may include specifications for routines, data structures, object classes, and variables. The API Reference contains information on the class hierarchy and member functions of the Vuforia SDK.

Vuforia SDK provides a set of actions:

- ***Events callback.***
- ***Access to hardware units***
- ***Trackables (tracking types):***
  - *Image Targets*
  - *Multi Targets*
  - *Frame Markers*
- ***Real-world interactions***
  - *Virtual Buttons*

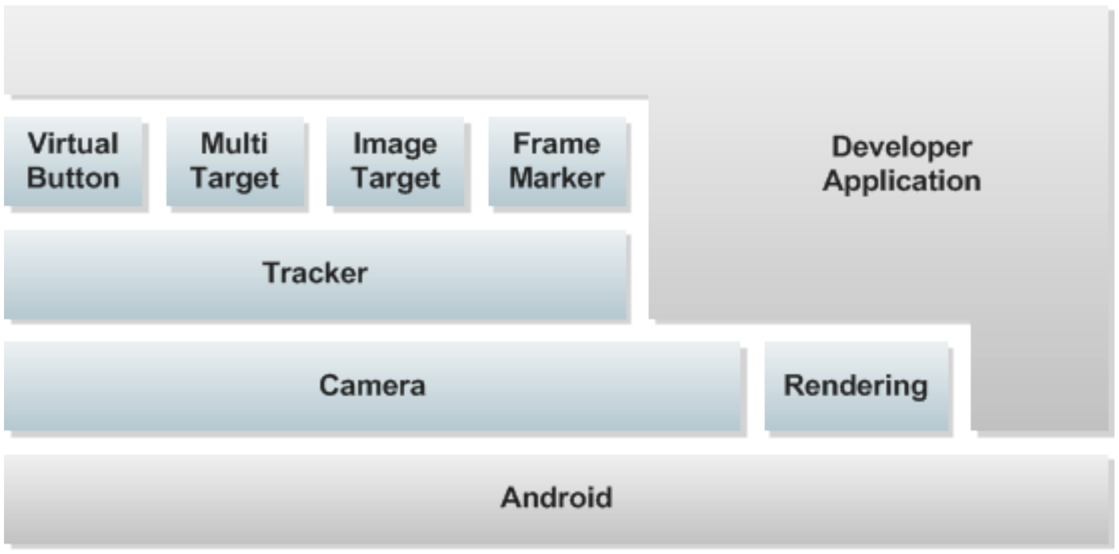


Fig. I.1 High-level system overview of Vuforia SDK

AI.I QCAR::Area

Area is the base class used in QCAR [16]to define 2D shapes. This class inherits from QCAR::Rectangle. In fact, rectangle is the only 2D shape provided at the moment.

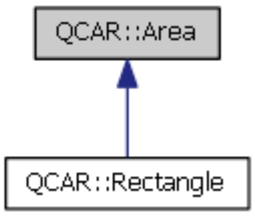


Fig. I.I.1 QCAR::Area inheritance diagram.

getType():

Returns the type of area. Area types are invalid or rectangle.

AI.II QCAR::CameraCalibration

This class holds the camera parameters.

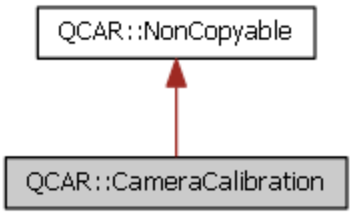


Fig. I.II.1 QCAR::CameraCalibration inheritance diagram.

getSize()

Returns the resolution of the camera as 2D vector[17].

getFocalLength()

Returns the focal length in x- and y-direction as 2D vector.

[16] QCAR: QualComm Augmented Reality Vuforia SDK

[17] Henceforth known as Vec2F

getPrincipalPoint()

Returns the principal point as 2D vector.

getDistortionParameters()

Returns the radial distortion as 4D vector[18].

AI.III QCAR::CameraDevice

Access to the phone's camera.

getInstance()

Returns the CameraDevice singleton instance.

init():

Initializes the camera

deinit()

Deinitializes the camera.

start()

Starts the camera and frames delivering.

stop()

Stops the camera and frames delivering.

getNumVideoModes()

Returns the number of available video modes.

MODE_DEFAULT=-1	Default camera mode.
MODE_OPTIMIZE_SPEED=-2	Fast camera mode.
MODE_OPTIMIZE_QUALITY =-3	High-quality camera mode.

Table 0.1 Camera's video Modes

[18] Henceforth known as Vec4F

getVideoMode(int nIdex)

Returns the video mode selected.

selectVideoMode(int index)

Chooses a video mode

getCameraCalibration()

Provides read-only access to camera calibration data.

Returns CameraCalibration object.

setFlashTorchMode(bool on)

Enable the torch mode on the device if the device supports this API.

setFocusMode(int focusMode)

Set the active focus mode. This method returns false if the requested focus mode is not supported on this device.

FOCUS_MODE_NORMAL	**Default focus mode.**
FOCUS_MODE_TRIGGERAUTO	Triggers a single autofocus operation.
FOCUS_MODE_CONTINUOUSAUTO	Continuous autofocus mode.
FOCUS_MODE_INFINITY	Focus set to infinity.
FOCUS_MODE_MACRO	Macro mode for close-up focus.

Table 0.2 Camera's focus modes

AI.IV QCAR::DataSet

A container of one or more trackables.

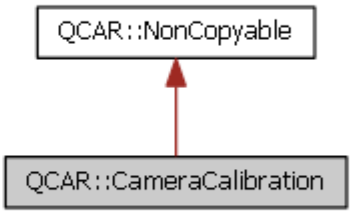


Fig. I.IV.1 QCAR::DataSet inheritance diagram

A dataset may contain multiple ImageTargets and MultiTargets. An empty DataSet instance is created using the DataSet factory function provided by the ImageTracker class. The dataset is then loaded given a dataset XML and corresponding dataset DAT file. The dataset may be loaded from the storage locations defined belowOnce loaded the dataset can be activated using ImageTracker::activateDataSet(). Methods to modify a DataSet must not be called while it is active. The DataSet must be deactivated first before reconfiguring it.

load(const char *path, STORAGE_TYPE storageType)

Loads the dataset at the specified path and storage location.

Returns true if the dataset was loaded successfully. The relative path to the dataset XML must be passed to this function for all storage locations other than STORAGE_ABSOLUTE

STORAGE_APP	**Storage private to the application.**
STORAGE_APPRESOURCE	Storage for assets bundled with the application
STORAGE_ABSOLUTE	Helper type for specifying an absolute path

Table 0.3 Storage locations

getNumTrackables()

Returns the overall number of 3D trackable objects in this data set.

Trackables that are part of other trackables are not counted here.

getTrackable(int index)

Returns a pointer to a trackable object.

createMultiTarget(const char * name)

Creates a new MultiTarget object and registers it with the dataset.

destroy(Multitarget * multitarget)

Destroys a MultiTarget.

exists(const char *path, STORAGE_TYPE storageType)

Checks if the dataset exists at the specified path and storage location.

Returns true if both the dataset XML and DAT file exist at the given storage location. The relative path to the dataset XML must be passed to this function for all storage locations other than STORAGE_ABSOLUTE.

AI.V QCAR::Frame

Frame is a collection of different representations of a single camerasnapshot A Frame object can include an arbitrary number of image representations in different formats or resolutions together with a time stamp and frame index. Frame implements the RAII pattern: A newly created frame holds new image data whereas copies of the share this data. The image data held by Frame exists as long as one or more Frame objects referencing this image data exist.

frame()

Creates a new frame.

frame(const Frame & other)

Creates a reference to an existing frame.

~Frame ()

Destructor.

getTimeStamp()

A time stamp that defines when the original camera image was shot.

Value in seconds representing the offset to application startup time. Independent from image creation the time stamp always refers to the time the camera image was shot.

getIndex ()

Returns the index of the frame.

getNumImages ()

Returns the number of images in the image-array.

getImage(int indx)

Read-only access to an image.

AI.VI QCAR::Image

An image is. returned by the CameraDevice object.

The image's pixel buffer can have a different size than the getWidth() and getHeight() methods report. This is e.g. the case when an image is used for rendering as a texture without non-power-of-two support. The real size of the image's pixel buffer can be queried using getBufferWidth() and getBufferHeight().

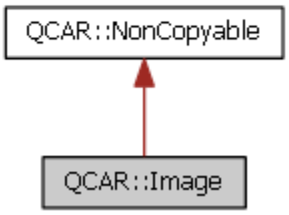


Figure I.VI.5 QCAR::Image inheritance diagram

getWidth()

Returns the width of the image in pixels.

getHeight()

Returns the height of the image in pixels.

getStride()

Returns the number bytes from one row of pixels to the next row.

getBufferWidth()

Returns the number of pixel columns that fit into the pixel buffer.

getBufferHeight()

Returns the number of pixel rows that fit into the pixel buffer.

getFormat()

Returns the pixel format of the image.

Actual pixel encoding types are shown in the following table:

UNKNOWN_FORMAT	**Unknown format - default pixel type for undefined images**
RGB565	A color pixel stored in 2 bytes using 5 bits for red, 6 bits for green and 5 bits for blue
RGB888	A color pixel stored in 3 bytes using 8 bits each

GRAYSCALE	A grayscale pixel stored in one byte.
YUV	A color pixel stored in 12 or more bits using Y, U and V planes

Table 0.4 Pixel encoding types

getPixels()

Provides read-only access to pixel data.

AI.VII QCAR::ImageTarget

A flat natural feature target.

Methods to modify an ImageTarget must not be called while the corresponding DataSet is active. The dataset must be deactivated first before reconfiguring an ImageTarget.

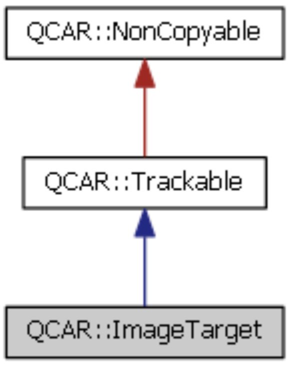


Figure I.VII.6 QCAR::ImageTarget inheritance diagram

getSize()

Returns the size (width and height) of the target (in 3D scene units).

setSize(const Vec2F &size)

Set the size (width and height) of the target (in 3D scene units).

The dataset this ImageTarget belongs to must not be active when calling this function or it will fail. Returns true if the size was set successfully, false otherwise.

getNumVirtualButtons()

Returns the number of virtual buttons defined for this ImageTarget.

getVirtualButton(int index)

Provides read-only or access to a specific virtual button.

getVirtualButton(const char *name)

Returns a virtual button by its name.

Returns NULL if no virtual button with that name exists in this ImageTarget

createVirtualButton(const char *name,const Area &area)

Creates a new virtual button and adds it to the ImageTarget.

Returns NULL if the corresponding DataSet is currently active.

removesVirtualButton(VirtualButton *button)

Removes and destroys one of the ImageTarget's virtual buttons.

Returns false if the corresponding DataSet is currently active.

AI.VIII QCAR::ImageTracker

The ImageTracker tracks ImageTargets and MultiTargets contained in a DataSet. The ImageTracker class provides methods for creating, activating and deactivating datasets. Note that methods for swapping the active dataset should not be called while the ImageTracker is working at the same time. Doing so will make these methods block and wait until the tracker has finished. The suggested way of swapping datasets is during the execution of UpdateCallback, which guarantees that the ImageTracker is not working concurrently. Alternatively the ImageTracker can be stopped explicitly. However, this is a very expensive operation.

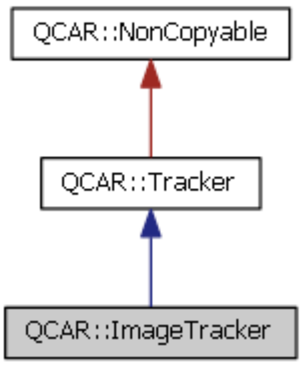


Figure I.VIII.7 QCAR::ImageTracker inheritance diagram

createDataset()

Factory function for creating an empty dataset. Returns the new instance on success, NULL otherwise.

destroyDataSet(DataSet * dataset)

Destroys the given dataset and releases allocated resources. Returns false if the given dataset is currently active.

activateDataSet(DataSet * dataset)

Activates the given dataset.

Only a single DataSet can be active at any one time. This function will return true if the DataSet was successfully activated and false otherwise. The recommended way to swap datasets is during the execution of the UpdateCallback, which guarantees that the ImageTracker is not working concurrently.

deactivateDataSet(DataSet * dataset)

Dectivates the given dataset.

This function will return true if the DataSet was successfully deactivated and false otherwise (E.g. because this dataset is not currently active). The recommended way to swap datasets is during the execution of the UpdateCallback, which guarantees that the ImageTracker is not working concurrently.

getActiveDataSet()

Returns the currently active dataset. Returns NULL if no DataSet has been activated.

AI.IX QCAR::Marker

A rectangular marker.

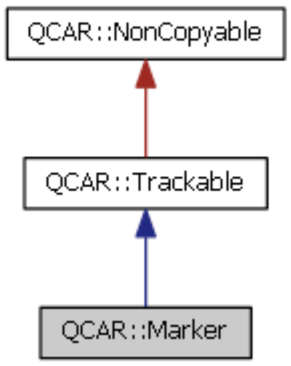


Figure I.IX.8 QCAR::Marker inheritance diagram

getSize()

Returns the size of the marker in 3D scene units.

setSize(const Vec2F &size)

Sets a new size (in 3D scene units) for the marker.

getMarkerId()

Returns the marker ID (as opposed to the trackable's id, which can be queried using getId())

getMarkerType()

Returns the marker type (as opposed to the trackable's type, which can be queried using getType())

INVALID	**Invalid marker type.**
ID_FRAME	An id-encoded marker that stores the id in the frame

Table 0.5 Marker types

AI.X QCAR::MarkerTracker

The MarkerTracker tracks rectangular markers and provides methods for creating and destroying these dynamically. Note that the methods for creating and destroying markers should not be called while the MarkerTracker is working at the same time. Doing so will make these methods block and wait until the MarkerTracker has finished. The suggested way of doing this is during the execution of UpdateCallback, which guarantees that the MarkerTracker is not working concurrently. Alternatively the MarkerTracker can be stopped explicitly.

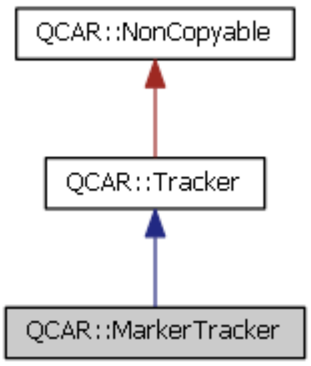


Figure I.X.9 QCAR::MarkerTracker inheritance diagram

createFrameMarker(int markerId, const * char name, const QCAR:Vect2F & size)

Creates a new Marker.

Creates a new marker of the given name, size and id. Returns the new instance on success, NULL otherwise.

destroyMarker(Marker * marker)

Destroys a Marker.

getNumMarkers()

Returns the total number of Markers that have been created.

getMarker(int indx)

Returns a pointer to a Marker object.

AI.XI QCAR::Matrix34F

Matrix with 3 rows and 4 columns of float items.

AI.XII QCAR::Matrix44F

Matrix with 4 rows and 4 columns of float items.

AI.XIII QCAR::Multitarget

A set of multiple targets with a fixed spatial relation.

Methods to modify a MultiTarget must not be called while the corresponding DataSet is active. The dataset must be deactivated first before reconfiguring a MultiTarget.

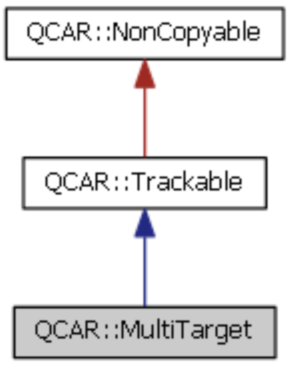


Figure I.XIII.10 QCAR::Multitarget inheritance diagram

getNumParts()

Returns the number of Trackables that form the MultiTarget.

getPart(int indx)

Provides write or read-only access to a specific Trackable.

Returns NULL if the index is invalid.

addPart(Trackable * trackable)

Adds a Trackable to the MultiTarget.

Returns the index of the new part on success. Returns -1 in case of error. Use the returned index to set the Part's pose via setPartPose().

remove(int idx)

Removes a Trackable from the MultiTarget.

Returns true on success. Returns false if the index is invalid or if the corresponding DataSet is currently active.

setPartsOffset(int indx, const Matrix34F &offset)

Defines a Part's spatial offset to the MultiTarget center.

getPartsOffset(int indx, Matrix34F &offset)

Retrieves the spatial offset of a Part to the MultiTarget center.

AI.XIV QCAR::NonCopyable

Base class for objects that can not be copied.

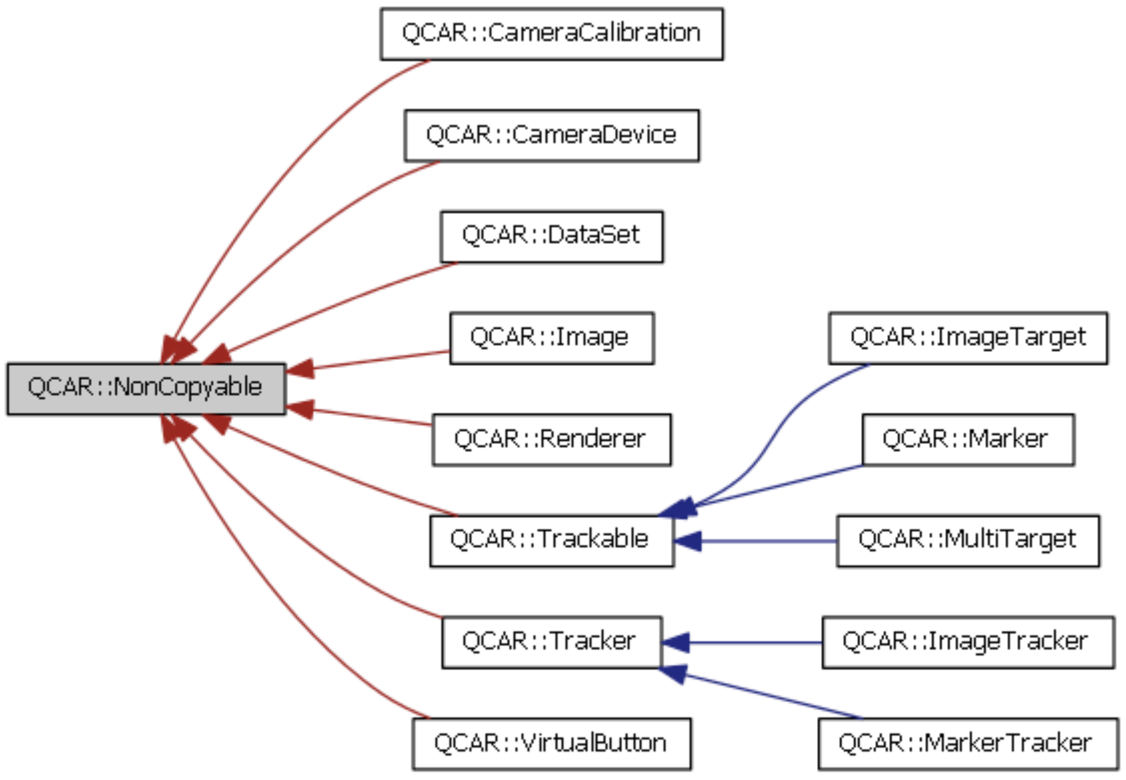


Figure I.XIV.11 QCAR::NonCopyable inheritance diagram

NonCopyable()

Constructor.

~NonCopyable

Destructor

AI.XV QCAR::Rectangle

Defines a 2D rectangular area.

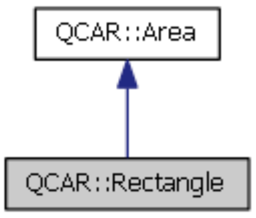


Figure I.XV.11 QCAR::Rectangle inheritance diagram

rectangle()

Constructor.

rectangle(const Rectangle & other)

Constructor.

rectangle(float leftTopX, float leftTopY,float rigthBottomX,float rigthBottomY)

Constructor.

~rectangle()

Destructor

getLeftTopX()

Returns rectangle’s x top left position float.

getLeftTopY()

Returns rectangle’s y top left position float.

getRigthBottomX()

Returns rectangle’s x bottom right position float.

getRightBottomY()

Returns rectangle’s y bottom right position float

getWidth()

Returns rectangle’s width float.

getHeight()

Returns rectangle’s height float.

getAreaSize()

Returns rectangle’s area size float

getType()

Returns the type of area. Area types are invalid or rectangle as seen at AI.I.

AI.XVI QCAR::Renderer

The Renderer class provides methods to fulfill typical AR related tasks such as rendering [19]the video background and 3D objects with up to date pose data. Methods of the Renderer class must only be called from the render thread.

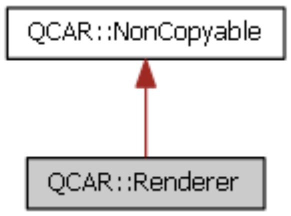


Figure I.XVI.11 QCAR::Renderer inheritance diagram

getInstance()

Returns the Renderer singleton instance.

begin()

Marks the beginning of rendering for the current frame and returns the State object.

drawVideoBackground()

Draws the video background This should only be called between a begin() and end() calls

end()

Marks the end of rendering for the current frame.

bindVideoBackground(int unit)

Binds the video background texture to a given texture unit This should only be called between a begin() and end() calls

setVideoBackgroundConfig(const videoBackgroundConfig & cfg)

Configures the layout of the video background (location on the screen and size).

getVideoBackgroundConfig()

Retrieves the current layout configuration of the video background.

[19] Rendering is the process of generating an image from a model

getVideoBackgroundTextureInfo()

Returns the texture info associated with the current video background.

setVideoBackgroundTextureID(int textureID)

Tells QCAR where the texture id to use for updating video background data

setARProjection(float nearPlane, float farPlane)

Tool method to calculate a perspective projection matrix for AR rendering and apply it to OpenGL

AI.XVII QCAR::State

A consistent view on the augmented reality state including a camera frame and all trackables. Similar to Frame, State is a light weight object that shares its data among multiple instances. Copies are therefore cheap and suggested over usage of references.

State()

Default constructor.

State(const State &other)

Copy constructor.

~State()

Destructor.

getFrame()

Returns the Frame object that is stored in the State.

getNumTrackables()

Returns the number of Trackable objects currently known to the SDK.

getTrackable(int indx)

Provides access to a specific Trackable.

getNumActiveTrackables()

Returns the number of Trackable objects currently being tracked.

getActiveTrackable(int indx)

Provides access to a specific Trackable object currently being tracked.

The returned object is only valid as long as the State object is valid

AI.XVIII QCAR::Trackable

Base class for all objects that can be tracked in 6DOF.

A Trackable is an object who's pose can be estimated in six degrees of freedom (3D, 6DOF). Every Trackable has a name, an id, a type, a pose and a status (e.g. tracked). See the TYPE enum for a list of all classes that derive from Trackable.

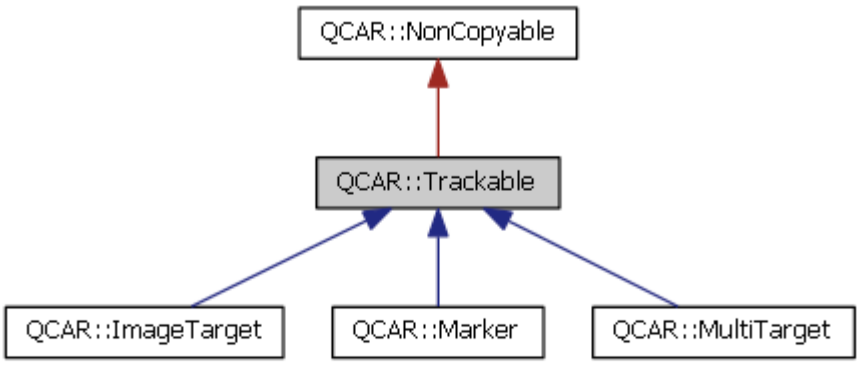


Figure I.XVIII.12 QCAR::Trackable inheritance diagram

getType()

Returns the type of 3D object.

UNKNOWN_TYPE	**A trackable of unknown type.**
IMAGE_TARGET	A trackable of ImageTarget type.
MULTI_TARGET	A trackable of MultiTarget type.
MARKER	A trackable of Marker type.

Table 0.6 Trackable types

isOfType(Type type)

Returns true if the object is of or derived of the given type.

getStatus()

Returns the tracking status.

UNKNOWN	**The state of the trackable is unknown.**
UNDEFINED	The state of the trackable is not defined (this trackable does not have a state)
NOT_FOUND	The trackable was not found.
DETECTED	The trackable was detected.
TRACKED	The trackable was tracked.

Table 0.7 Status of the trackables

getId()

Returns a unique id for all 3D trackable objects.

getName()

Returns the Trackable's name

getPose()

Returns the current pose matrix in row-major order. (Matrix34F)

~Trackable()

Destructor.

AI.XIX QCAR::Tracker

Base class for all tracker types.

The class exposes generic functionality for starting and stopping a given Tracker as well as querying the tracker type. See the TYPE enum for a list of all classes that derive from Tracker.

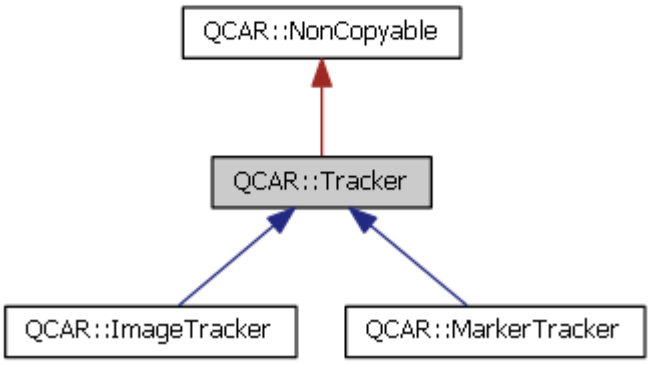


Figure I.XIX.13 QCAR::Tracker inheritance diagram

getType()

Returns the tracker type.

IMAGE_TRACKER	**Tracks ImageTargets and MultiTargets.**
MARKER_TRACKER	Tracks Markers.

Table 0.8 Tracker types

start()

Starts the Tracker.

stop()

Stops the Tracker.

~Tracker()

Destructor.

AI.XX QCAR::TrackerManager

The TrackerManager singleton provides methods for accessing the trackers available in QCAR as well as initializing specific trackers required by the application. See the Tracker base class for a list of available tracker types.

getInstance()

Returns the TrackerManager singleton instance.

initTracker(Tracker::Type tracker)

Initializes the tracker of the given type.

Initializing a tracker must not be done when the CameraDevice is initialized or started. This function will return NULL if the tracker of the given type has already been initialized or if the CameraDevice is currently initialized.

getTracker(Tracker::Type tracker)

Returns the instance of the given tracker type.

See the Tracker base class for a list of available tracker classes. This function will return NULL if the tracker of the given type has not been initialized.

deinitTracker(Tracker::Type tracker)

Deinitializes the tracker of the given type.

Deinitializes the tracker of the given type and frees any resources used by the tracker. Deinitializing a tracker must not be done when the CameraDevice is initialized or started. This function will return false if the tracker of the given type has not been initialized or if the CameraDevice is currently initialized.

AI.XXI QCAR::UpdateCallback

UpdateCallback interface.

QCAR_onUpdate(State &state)

Called by the SDK right after tracking finishes.

AI.XXII QCAR::Vec2F

2D vector of float items

AI.XXIII QCAR::Vec2I

2D vector of int items

AI.XXIV QCAR::Vec3F

3D vector of float items

AI.XXV QCAR::Vec3I

3D vector of int items

AI.XXVI QCAR::Vec4F

4D vector of float items

AI.XXVII QCAR::Vec4I

4D vector of int items

AI.XXVIII QCAR::VideoBackgroundConfig

Video background configuration.

mEnable()

Enables/disables rendering of the video background.

mSynchronous()

Enables/disables synchronization of video background and tracking data.

Depending on the video background rendering mode this may not always be possible. If deactivated the video background always shows the latest camera image.

mPosition()

Relative position of the video background in the render target in pixels. Describes the offset of the center of video background to the center of the screen (viewport) in pixels. A value of (0,0) centers the video background, whereas a value of (-10,15) moves the video background 10 pixels to the left and 15 pixels upwards.

mSize()

Width and height of the video background in pixels.

Using the device's screen size for this parameter scales the image to fullscreen. Notice that if the camera's aspect ratio is different than the screen's aspect ratio this will create a non-uniform stretched image.

AI.XXIX QCAR::VideoBackgroundTextureInfo

Video background configuration.

mTextureSize()

Width and height of the video background texture in pixels.

Describes the size of the texture in the graphics unit depending on the particular hardware it will be a power of two value immediately after the image size

mImageSize()

Width and height of the video background image in pixels.

Describe the size of the image inside the texture. This corresponds to the size of the image delivered by the camera

mPixelFormat()

Format of the video background image.

Describe the pixel format of the camera image as seen at Table 0.4 Pixel encoding types

AI.XXX QCAR::VideoMode

Implements access to the phone's built-in camera.

mWidth()

Video frame width.

mHeight()

Video frame height.

mFramerate()

Video frame rate.

AI.XXXI QCAR::VirtualButton

A virtual button on a trackable.

Methods to modify a VirtualButton must not be called while the corresponding DataSet is active. The dataset must be deactivated first before reconfiguring a VirtualButton.

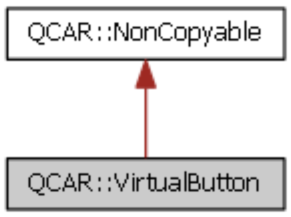


Figure I.XXXI.14 QCAR::VirtualButton inheritance diagram

setArea(const Area & area)

Defines a new area for the button area in 3D scene units (the coordinate system is local to the ImageTarget). This method must not be called while the corresponding DataSet is active or it will return false.

getArea()

Returns the currently set Area.

setSensitivity(Sensitivity sensitivity)

Sets the sensitivity of the virtual button.

Sensitivity allows deciding between fast and robust button press measurements. This method must not be called while the corresponding DataSet is active or it will return false.

HIGH	**Fast detection.**
MEDIUM	Balananced between fast and robust.
LOW	Robust detection.

Table 0.9 Virtual button sensitivity

setEnable(bool enable)

Enables or disables a virtual button.

This method must not be called while the corresponding DataSet is active or it will return false.

isEnable()

Returns true if the virtual button is active (updates while tracking).

getName()

Returns the name of the button as ASCII string.

isPressed()

Returns true if the virtual button is pressed.

getId()

Returns a unique id for this virtual button.

A II Test result tables

AII.I Detection

AII.I.I Image Targets

AII.I.I.I Minimum distance of detection

Minimum Distance of Detection 24x16		
Device	**Distance in cm**	**Average**
Samsung	85	87,73
	90	
	84	
	91	
	88	
	88	
	84	
	90	
	88	
	91	
	86	
Device	**Distance in cm**	**Average**
HTC	70	72,4
	75	
	74	
	73	
	75	
	72	
	71	
	70	
	73	

	71	
Device	**Distance in cm**	**Average**
SGNII	**130**	**130,5**
	140	
	130	
	135	
	130	
	140	
	130	
	120	
	125	
	130	

Minimum Distance of Detection using alterated shade Image Target		
Device	**Darkened Image**	**Average**
Samsung	60	60,40
	58	
	62	
	60	
	62	
	Cleared Image	**Average**
	55	57,90
	57	
	53	
	58	
	54	
Device	**Darkened Image**	**Average**
HTC	45	48,6

	50	
	48	
	51	
	49	
	Cleared Image	**Average**
	----	----

Minimum Distance of Detection 37x26cm		
Device	**Distance in cm**	**Average**
Samsung	129	131,73
	133	
	128	
	135	
	130	
	130	
	133	
	134	
	132	
	134	
	131	
Device	**Distance in cm**	**Average**
HTC	105	106,8
	110	

	109	
	107	
	110	
	104	
	106	
	102	
	109	
	106	

AII.I.I.II Minimum time of detection

Minimum time of detection					
Device	**Time in s at 50cm**	**Average**	**Time in s at 70cm**	**Average**	**Time in s at max dist.**
Samsung	1	1,15	1	1,15	x
	1,2		1,2		x
	1		1		x
	1,1		1,1		x
	1,3		1,3		x
	1,4		1,4		x
	1,2		1,2		x
	1		1		x
	1,1		1,1		x
	1		1		x
	1,3		1,3		x
Device	**Time in s at 50cm**	**Average**	**Time in s at 70cm**	**Average**	**Time in s at max dist.**
HTC	1,5	1,4	1,5	1,4	x
	1,3		1,3		x
	1,4		1,4		x
	1,3		1,3		x
	1,7		1,7		x
	1,4		1,4		x
	1,2		1,2		x
	1,3		1,3		x
	1,5		1,5		x
	1,4		1,4		x

Minimum time of detection (2 Simultaneous Image Targets)

Distance 50 cm					Distance 70 cm			
Device	**Time in s to spot image target 1 (stones)**	**Average**	**Time in s to spot image target 2 (chips)**	**Averag e**	**Time in s to spot image target 1 (stones)**	**Averag e**	**Time in s to spot image target 2 (chips)**	**Average**
	1,3		2,8		1,3		3,1	
	1,4		3,5		1,4		3,5	
	1,2		2,4		1,1		3,7	
	1,4		3,6		1,5		2,9	
	1,3		3,1		1,4		2,8	
Samsung	1,5	1,32	2,4	2,95	1,3	1,40	3,5	3,25
	1,1		2,8		1,2		3,3	
	1,4		2,4		1,5		3,1	
	1,2		3,1		1,6		2,9	
	1,3		2,8		1,4		3,4	
	1,4		3,5		1,7		3,5	
Device	**Time in s to spot image target 1 (stones)**	**Average**	**Time in s to spot image target 2 (chips)**	**Averag e**	**Time in s to spot image target 1 (stones)**	**Averag e**	**Time in s to spot image target 1 (stones)**	**Average**
	1		2,9		1,3		3,5	
	1,3		3,4		1,5		3,4	
	1,5		2,5		1,4		3,1	
	1,1		2,9		1,5		3,4	
	1,8		2,7		1,7		3,5	
HTC	1,1	1,28	3,4	2,97	1,5	1,46	3,6	3,28
	1,2		2,4		1,1		3,8	
	1,3		2,8		1,5		3,2	
	1,4		3,3		1,3		2,9	
	1,1		3,4		1,8		2,4	

AII.I.I.III Minimum angle of detection

Minimum Angle of Detection at 50 cm of distance		
Device	**Angle**	**Average**
Samsung	45	43,6
	43	
	47	
	42	
	41	
Device	**Angle**	**Average**
HTC	53	52
	49	
	54	
	50	
	54	

AII.I.I.IV Maximum % of occlusion

%Occlusion			
Device	**Distance**	**Size (in mm)**	**%**
Samsung	50cm	55 x 55	70,10%
			32,72%
			49,09%
			54,54%
Device	**Distance**	**Size**	**%**
HTC	50cm	55 x 55	72,72%
			36,36%
			33,05%
			36,36%

AII.I.II Frame Markers

AII.I.II.I Minimum distance of detection

Test minimum distance in cm		
Device	**Distance**	**Average**
Samsung	171 165 172 168 169	169
Device	**Distance**	**Average**
HTC	120 123 119 125 121	121,6

AII.I.II.II Minimum time of detection

	Simultaneous frame markers				
	1	**2**	**3**	**4**	
Samsung	0,2	0,3	0,3	0,3	**Time (s)**
HTC	0,2	0,3	0,3	0,3	**Time (s)**

AII.II Tracking

AII.II.I Image Targets

AII.II.I.I Maximum distance

Maximum Distance of Tracking with strange elements		
Device	**Distance in cm**	**Average**
Samsung	270	267,2
	260	
	266	
	270	
	270	
Device	**Distance in cm**	**Average**
HTC	251	246
	250	
	244	
	245	
	240	
Maximum Distance of Tracking with clear view		
Device	**Distance in cm**	**Average**
Samsung	280	278
	275	
	280	
	275	
	280	
Device	**Distance in cm**	**Average**
HTC	250	251,2
	255	
	248	
	251	
	252	

Device	Distance in cm	Average
SGN II	280	276
	270	
	270	
	280	
	280	

AII.II.I.II Minimum re-detection time

Minimum time of re-detection					
Device	**Time in s**	**Time in s at 1 m**	**Average**	**Time in s at max dist.**	**Average**
Samsung	less than 0,5	1	1,15	1	1,15
	less than 0,5	1,2		1,2	
	less than 0,5	1		1	
	less than 0,5	1,1		1,1	
	less than 0,5	1,3		1,3	
	less than 0,5	1,4		1,4	
	less than 0,5	1,2		1,2	
	less than 0,5	1		1	
	less than 0,5	1,1		1,1	
	less than 0,5	1		1	
	less than 0,5	1,3		1,3	
Device	**Time in s**	**Time in s at 1 m**	**Average**	**Time in s at max dist.**	**Average**
HTC	less than 0,5	1,5	1,4	1,5	1,4
	less than 0,5	1,3		1,3	
	less than 0,5	1,4		1,4	
	less than 0,5	1,3		1,3	
	less than 0,5	1,7		1,7	
	less than 0,5	1,4		1,4	
	less than 0,5	1,2		1,2	
	less than 0,5	1,3		1,3	
	less than 0,5	1,5		1,5	
	less than 0,5	1,4		1,4	

Minimum time of re-detection using simultaneous Image Targets				
	Distance 50 cm		Distance 70 cm	
Device	Time in s to re-detect (stones)	Time in s to re-detect(chips)	Time in s to re-detect (stones)	Time in s to re-detect(chips)
Samsung	less than 0,5	less than 0,5	less than 0,5	1
	less than 0,5	less than 0,5	less than 0,5	1,2
	less than 0,5	less than 0,5	less than 0,5	1,1
	0,9	1	0,9	1
	0,7	0,8	0,7	1,3
	less than 0,5	less than 0,5	less than 0,5	1,5
	less than 0,5	less than 0,5	less than 0,5	1,4
	less than 0,5	less than 0,5	less than 0,5	1,3
	0,8	1	0,8	1,5
	less than 0,5	less than 0,5	less than 0,5	1,4
	0,8	1	0,8	1,4
Device	Time in s (stones)	Time in s (chips)	Time in s (stones)	Time in s (chips)
HTC	less than 0,5	less than 0,5	1	1,5
	less than 0,5	less than 0,5	1,2	1,4
	less than 0,5	less than 0,5	1	1,3
	less than 0,5	0,8	1,1	1,4
	less than 0,5	less than 0,5	1	1,1
	less than 0,5	less than 0,5	1	1,5
	less than 0,5	1	1,2	1,6
	less than 0,5	less than 0,5	0,8	1,8
	less than 0,5	0,8	0,9	1,4
	less than 0,5	less than 0,5	1	1,6

AII.II.I.III Maximum % of occlusion

%Occlusion in uniformly distributed features										
Device	**Distance**	**Stars**	**Size**							
Samsung	50cm	5	213,422	A1	A2	A3	A4	Ao	At	%
				58,41	142	0	0	200,41	213,422	93,90%
				61,408	140,798	0	0	202,206	213,422	94,74%
				141,332	56,88	0	0	198,212	213,422	92,87%
				142,4979	53,6805	0	0	196,1784	213,422	91,92%
				71,734	47,64	38,04	46,052	203,466	213,422	95,34%
Device	**Distance**	**Stars**	**Size**							
HTC	50cm	5	213,422	A1	A2	A3	A4	Ao	At	%
				48,085	134	0	0	182,085	213,422	85,32%
				50,768	123,176	0	0	173,944	213,422	81,50%
				130,652	47,677	0	0	178,329	213,422	83,56%
				131,8239	42,88	0	0	174,7039	213,422	81,86%
				57,494	45,24	38,04	46,052	186,826	213,422	87,54%

AII.II.II Frame markers

AII.II.II.I Maximum distance

Maximum distance in cm		
Device	**Distance**	**Average**
Samsung	205 202 204 207 206	204,8
Device	**Distance**	**Average**
HTC	190 186 192 195 188	190,2

GLOSSARY

An **Application Programming Interface** (API) is a protocol intended to be used as an interface by software components to communicate with each other. An API is a library that may include specification for routines, data structures, object classes, and variables. An API specification can take many forms, including an International Standard such as POSIX, vendor documentation such as the Microsoft Windows API, the libraries of a programming language, e.g. Standard Template Library in C++ or Java API.

The **ARM** architecture describes a family of RISC-based computer processors designed and licensed by British company ARM Holdings. It was first developed in the 1980s and globally as of 2013 is the most widely used 32-bit instruction set architecture in terms of quantity produced. In 2011 alone, producers of chips based on ARM architectures reported shipments of 7.9 billion ARM-based processors, representing 95% of smartphones, 90% of hard disk drives, 40% of digital televisions and set-top boxes, 15% of microcontrollers and 20% of mobile computers.

Augmented Reality (AR) is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer generated sensory input such as sound, video, graphics or GPS data. As a result, the technology functions by enhancing one's current perception of reality.

A **Floating-Point Unit** (FPU) is a part of a computer system specially designed to carry out operations on floating point numbers. Typical operations are addition, subtraction, multiplication, division, and square root. Some systems (particularly older, microcode-based architectures) can also perform various transcendental functions such as exponential or trigonometric calculations, though in most modern processors these are done with software library routines.

A **Software Development Kit** (SDK) is typically a set of software development tools that allows for the creation of applications for a certain software package, software framework, hardware platform, computer system, video game console, operating system, or similar development platform.

The **General Public License** (GPL) is the most widely used free software license, which guarantees end users (individuals, organizations, companies) the freedoms to use, study, share (copy), and modify the software. Software that ensures that these rights are retained is called free software. The license was originally written by Richard Stallman of the Free Software Foundation (FSF) for the GNU project.

The **GNU** is the most widely used free software license, which guarantees end users (individuals, organizations, companies) the freedoms to use, study, share (copy), and modify the software. Software that ensures that these rights are retained is called free software. The license was originally written by Richard Stallman of the Free Software Foundation (FSF) for the GNU project.

Graphical User Interface (GUI) is a type of user interface that allows users to interact with electronic devices using images rather than text commands. *GUI*s can be used in computers, hand-held devices such as MP3 players, portable media players or gaming devices, household appliances, office, and industry equipment. A *GUI* represents the information and actions available to a user through graphical icons and visual indicators such as secondary notation, as opposed to text-based interfaces, typed command labels or text navigation. The actions are usually performed through direct manipulation of the graphical elements.

An **Integrated Development Environment** (IDE) is a software application that provides comprehensive facilities to computer programmers for software development. An IDE normally consists of a source code editor, build automation tools and a debugger.

OpenGL for Embedded Systems (OpenGL ES) is a subset of the OpenGL 3D graphics application programming interface (API) designed for embedded systems such as mobile phones, PDAs, and video game consoles.

Secure Digital or (**SD**) is a non-volatile memory card format for use in portable devices, such as mobile phones, digital cameras, GPS navigation devices, and tablet computers.

Target Management System (TMS) is an online application created by Qualcomm to create a different datasets for image targets.

eXtensible Markup Language (XML) is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. It is defined in the XML 1.0 Specification produced by the W3C, and several other related specifications, all gratis open standards.

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