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This article introduces augmented reality technology, some current applications, and augmented reality technology for wearable devices. Then it introduces how to use NyARToolKit as a software library to build AR applications.

The article also introduces how to design an AR application in Google Glass. The application can recognize two different images through NyARToolKit build-in function. After find match pattern files, the application will draw different 3D graphics according to different input images.

Headings:

Augmented Reality

Google Glass Application - Design

Google Glass Application - Development

RESEARCH ON AUGMENT REALITY TECHNOLOGY AND BUILD AR  
APPLICATION ON GOOGLE GLASS

by  
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# Table of Contents

Table of Contents .....	1
1. Introduction.....	2
2. LITERATURE REVIEW .....	4
2.1 Technologies for AR .....	4
2.2 Applications Using AR .....	6
2.3 Augmented Reality for Wearable Glasses.....	7
2.4 Google Glass Development .....	11
2.5 AR Software Development .....	13
2.6 Issues with AR and Glass Development .....	15
3 PROTOTYPE DESIGN AND DEVELOPMENT.....	17
3.1 Application Description .....	17
3.2 Workflow Chart.....	18
3.3 Development Steps .....	19
3.4 Testing.....	26
4 TECHNOLOGY CHALLENGES .....	29
5 DISCUSSION .....	30
5.1 Advantages .....	30
5.2 Potential Use .....	30
5.3 Limitations .....	31
5.4 Next Step.....	32
6 TAKEWAYS FROM THE PROJECT .....	33
REFERENCES .....	34
Appendix A: Pattern Images .....	39

# 1. Introduction

Augmented Reality (AR) is a live direct or indirect view of a physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data [1].

In this article, I introduces Augment Reality's current technology and current applications. Through analyzing previous research on Augment Reality technology, we can see Augmented Reality is getting popular and is easier for use. The current Augment Reality applications tells us Augmented Reality is changing our life and make the information around more interactive.

NyARToolKit is an open source library for building Augmented Reality applications. I use NyARToolKit for Android design a simple application for Google Glass. This application can recognize two different images and give users two different 3D graphics output. This is application is based on the sample in NyARToolKit (SimpleLite).

SimpleLite is an Android application which can recognize single image and gives user a 3D box. I add some functions, and some new classes to make it more complex. I also change some configuration file to make it run on Google Glass. Users can also launch the application by saying "Recognize This". Because of the hardware limitation in Google

Glass, the application may cause some issues such as overheat, I will keep exploring  
Augmented Reality world and find some solutions in the future.

## **2. LITERATURE REVIEW**

### **2.1 Technologies for AR**

The requirements for AR technology are very high and related to a lot of fields. Knowing the past and current technology can help us develop AR application and predict the future AR technology. The development of new technology also helps to improve AR development.

#### **Hardware**

The development of hardware is one of the most important of AR's development. Augmented Reality needs a fast response time between the information and people. And a good processor is the key point of the response time. The main hardware for augmented reality are processor, display, sensors and input devices.[1]

#### **Displays**

Displays is the way how users "see" the information Advanced displays can make information more interactive and real. That's also why people need Augmented Reality Technology. Optical projection system, monitors, mobile devices, and display systems worn on one's person can be used in Augmented Reality display [1].

There are two categories of Augmented Reality visual displays. The first is "See-through" AR displays, which means users can see image directly around them. The second one is Monitor based AR displays, which means images are either analogically or digitally overlaid onto live or stored video images.[2]

### **Spatial**

The most realistic display is no display. That's why spatial technology came to AR world. Spatial Augmented Reality (SAR) technology can show 3D image without help of screen or monitors. The technology is helpful in large scale of presentations and exhibitions. Stoakley et al present users a map of environment to assist in navigation. [8]

### **Modeling environments**

The AR system need to know environment and user's location to annotate image. The annotation always relies on environmental model. To treat huge dataset, Ray-tracing algorithms because they create an image in time sub-linear in the number of objects. [4,9]

### **User interface**

Users always want better user experience. A better user interface can help communicate with computer more convenient. The traditional WIMP(windows, icons, menus and pointing) UI, doesn't fit the AR requirement well. Users need a more freedom way to communicate with computer rather than just mouse or keyboard. Users want to select, rotate, and zoom AR image easily and fast. The current main UI paradigm for AR are tangible UI, Haptic UI, Aural UI, Hybrid, Visual UI and etc. [4]

## **2.2 Applications Using AR**

### **Medical**

Doctors can use AR technology to get information about surgery such as heartbeat rate, the blood pressure, and the state of patients' organ. AR technology can transfer 3D dataset of a patient into 3D image. With the help of 3D image, doctors can perform better in minimally invasive surgery. [1, 3] In UNC Chapel Hill, a research group successfully generate a 3D representation of a fetus inside a mother's womb [5].

### **Industrial applications**

Now Augmented Reality is widely used in Industry to help to improve efficiency and products' quality. Volkswagen intends to use AR for comparing calculated and actual crash test imagery.[3, 6] Also, Honda, Ford, and Volvo ordered Nomad Expert Vision Technician systems to help their technicians with the vehicle history and repair information[4, 7].

### **Daily Life**

Professor Mann developed HDR(high dynamic range) photography

Several decades ago, and has been used in Eyetab wearable computer. The glass can provide daily aid about vision.

At the same time, some tour guide using AR technology shows up.



Through these current applications, we can see AR technology is getting popular and changing human's life. Augmented Reality can make our life convenient and fun. Not just a single, the whole society are benefit from AR technology.

### **2.3 Augmented Reality for Wearable Glasses**

With the development of new technology, a lot of wearable devices come into human's life, such as Google Glass. Apple IWatch an etc. Wearable devices provides a hand-free way to use AR technology. Wearable devices also allow a much closer association with users. Body-worn computer can help users more intelligently, consistently and continuously than desktop devices.

Thomas et al has developed a wearable computer system with a see-through display, digital compass and differential GPS then provide visual information about orienteering in 1998. The wearable computer with augmented reality performed well in navigation while users travelled in outdoor environment. [14] Wayne and Bruce extended a desktop game, Quake, and made it into the ARQuake system. The ARQuake project led to the development of the Tinmith software system[15, 16].

As we can from above advance in wearable devices and AR technology. People has been tried to use AR in devices for almost 20 years. And now, there are many excellent applications using AR for wearable devices.

### **2.3.1 Wearable Devices**

A wearable devices can be a belt, a backpack PC, head-mounted display, wireless communications hardware and etc. [17] There are three main goals for wearable devices: mobile, augmented reality and context sensitivity. [17]

### **2.3.2 Technology**

#### **Head-Worn Displays (HWD)**

With HWD, users can mount displays on heads and get information anytime through the device. There are two types of HWD, they are optical see-through and video see-through.[18] HWD is not always convenient for people. Some old Head-Worn Displays are too heavy to ware. But the current electronic glasses is lighter and easier to take.

#### **Remembrance Agent**

Remembrance Agent is a program which augments human memory by displaying a list of documents related with the current environment [11]. The remembrance agent can provide timely information to users and handle large scale dataset well. These feature of

remembrance agent make it fit for the development of augmented reality. Remembrance agent became support wearable device feature since 1994[13].

### **Camera-base Realities**

When a wearable system has access to a digitizer and the CPU power to process the images, the camera becomes a sensor then integrated into user interface itself [12]. Visual Tag System and Global Positioning System inside wearable camera can be used to recognize and track objects. [12]

### **itWarns AR System**

"itWarns", Intelligent Tetherless Wearable Augmented Reality Navigation System

AR in Glass, is an AR system which can optionally be connected to a computer then send and receive data. The current system displays artificial horizon, cardinal directions, pitch, roll angel, and etc.[24]

### **WIMMS AR System**

WIMMS(Wearable Immersive Multimedia Information System), is an integrated system which combined computer network with generated display content. The system allows device receive video and stereo audio through analog RF transmissions channels and HRTF(head-related transfer functions). The system can be expended to a true AR system by transferring the rendering mode of WIMMS of wire-frame rendering with black background.[24]

### **Lenses**

Lenses is an important way for users to communicate with outside world using wearable devices. One of the most excellent lenses is MagicLenses. Julian et al[25] implement a 3D lenses which is called MagicLenses. MagicLenses are semi-transformations to whatever content lies beneath them[26]. Julian three technology to make their lens fit for AR devices and accomplish some interaction tasks: "Magnification; Object Selection and Manipulation; and Information Filtering[25].

### **2.3.3 Technology in Glasses**

In 2012, Google went public its plan to offer augmented-reality glasses-"Project Glass." The glass wearer can control music, get directions, take pictures.[19] Google Glass open a new door for wearable devices and augmented reality. This is the first time an AR project garnered widespread.[20]

A technology company, TTP(The Technology Partnership), also developed a glass with augment-reality technology. The difference between this glass and Google Glass is that the glass's system is invisible to anyone watching and doesn't require a change of gaze by the wearer. The users can also control the device by just moving eyes to left or right. The develop team made this by passive electrodes mounted on the glasses that monitor signals that are indicative of eye movement. [21]

EyeTap Glass, also known as Generation-2 Glass[22], is made by University of Washington. The glass allows rays of light are collinear with the rays of light presented by the Glass with its camera, display and diverter.[23]

## **2.4 Google Glass Development**

### **2.4.1 Development Overview**

Google Glass is one of the most popular and well-known technology with an optical head-mounted display (OHMD). [30] Google Glass has touchpad, camera, Liquid Srystal on Silicon(LCoS) and LED illuminated display[31].

There are three main best ways to develop Google Glass applications:

#### **The Glass Development Kit**

The Glass Development Kit(GDK) is an add-on to the Android SDK which can make the application directly runs on Glass. By using GDK, developer can directly use thousands of Android APIs and Google Glass APIs.[27]

#### **Mirror API**

Google also provided cloud based TESTful services which allows web developers develop glass wares. It can help the developers with limited Java knowledge or Android knowledge.

#### **Hybrid Glassware**

Hybrid Glassware is the combination of Mirror API with GDK glassware through a menu item.

### **2.4.2 Design Patterns [29]**

#### **Ongoing task**

Ongoing tasks are long-running live cards which users may leave and come back frequently. For example, a stopwatch glasswares need to invoke ongoing task.

#### **Immersion**

Immersion describes displaying immersions in the form of Android activities. Users can swipe down the glass to return back.

#### **Periodic notifications**

By using periodic notifications, users can insert static cards in the timeline. The card may pop out according to its trigger.

### **2.4.3 Development Tools**

There are two main develop IDE- Eclipse and Android Studio.

#### **Eclipse**

Eclipse is a famous IDE for Java, C++, PHP and etc. developer. They have many add-on tools for software developers.[31] Glassware developers using Eclipse need to install Android Development Tools(ADT), which is a plugin for Eclipse IDE. With the ADT,

developers can quickly set up Android projects, create application UI add package and debug. The current version of ADT is 23.0.6(March 2015). [32]

### **Android Studio**

Android Studio is the official IDE for Android application development, based on IntelliJ IDEA.[33, 34]. Android Studio is easier for new Android developer and learner. It has a lot of code templates and rich layout editor.

In my project, I use Eclipse SDK as my development IDE.

### **2.4.4 Emulator**

There is no Official Google Glass emulator. Developers must have a Google Glass while developing glassware. Developers can use Eclipse or Android Studio's Android Phone Monitor to run same simple tasks. But there are a lot of limitations such as the missing camera and voice control.

But there are some unofficial Google Glass emulator such as Scarygami mirror-api.[36]

## **2.5 AR Software Development**

There are some software developments kits which allows users to develop AR applications, such as Metaio, Vuforia and Total Immersion.[40]

ARToolkit is a software library for building Augmented Reality applications. It uses computer vision algorithm to solve the relation between the user's viewpoint with the real

world.[36] The ARToolKit now support both video and optical see-through augmented reality[37]. ARToolkit has implementations about Camera Calibration, Image Processing, Pose Estimation, Background Video Stream Display. Developers can use these implementations through calling some functions.[38]

There are ARToolKit for Mobile for developers to develop AR applications using ARToolKit.[39] It includes ARToolKit for IOS and ARToolkit for Android. There are some different specific version for different port[42]. FLARToolKit is for ActionScript port.[43]. JSARToolkit is a JavaScript port of FLARToolkit.[44]. SLARToolkit is a Silverlight port of NyARToolkit.[45]

In my project, I use NyARToolkit library. NyARToolkit is AR class library derived from ARToolkit.[41] It contains APIS for Augment Reality development. NyARToolkit support a lot of image format and faster than ARToolkit.[46]

Now HITLabNZ(Human Interface Technology Laboratory New Zealand) is working on how to make NyARToolkit run on Google Glass. And now they have released the APK file of the glassware. But they don't release the code. And developer need to type command in computer's terminal to run the glassware.[47]



## 2.6 Issues with AR and Glass Development

Google Glass is an innovation which is changing human's life. As a result of innovation, there are always some issues coming with that.

One of the serious issue is the privacy. Google Glass's camera is hard to tell whether is on or off. Users can take photos without notifying others. Google Glass can get the users' location and account information. When developing application for Google Glass, we should notice that and tried to avoid the issues about that. Jason introduce a lesson from Ubiquitous Computing Project [48]. He said the project group didn't build any privacy protection strategy. They put whether the application work in the first place. Finally, the popular press gave very low evaluation to their project.

The augment reality technology and the wearable devices may also cause some issues which we need to consider. And the developers don't need to possess a Google Glass devices.[28]

In 2000, Wendy[49] conducted some projects focus on the augment reality's influence on human's behavior on computer technology. He had investigated some situation where augment reality technology started to replacement for paper artifact. He found AR seemed to a tricky problem- remaining all the advantages as human beings to deal with physical objects, but benefiting from the computer. The augment artifact may confuse human's existing understanding of physical objects. People are relying on the augment

reality too much and that may make them ignore the physical objects. And he also pointed that we should consider the link between on-line and off-line documents. There are some potential dangerous if users relies on augmented reality's documents too much [49].

## **3 PROTOTYPE DESIGN AND DEVELOPMENT**

### **3.1 Application Description**

The application can recognize two different images and give user two different output.

Depending on what it found, it will draw either a 3D box or a 3D triangle. The

application use NyARToolKit as external library and based on the demo in the

NyARToolKit. . In the future developing steps, I will expand the pattern data files and

draw more complex pictures.

In my application, users can launch it by clicking its icon or by saying "Recognize This"

to glass. Then the application will open Google Glass's camera. If the camera capture

Augment Reality images, it will auto convert it into 3D image. There is a demo called

SimpleLiteActivity in NyARToolKit library. The demo activity can shows a 3D box if

glass's camera detect a given pattern files. Based on the demo, I will add more pattern

files and let the application make a choice when it detects different patterns. Currently

my application can detect 2 pattern files and can give users a 3D box or a 3D triangle

using java OpenGL library depends on the input pattern

### 3.2 Workflow Chart

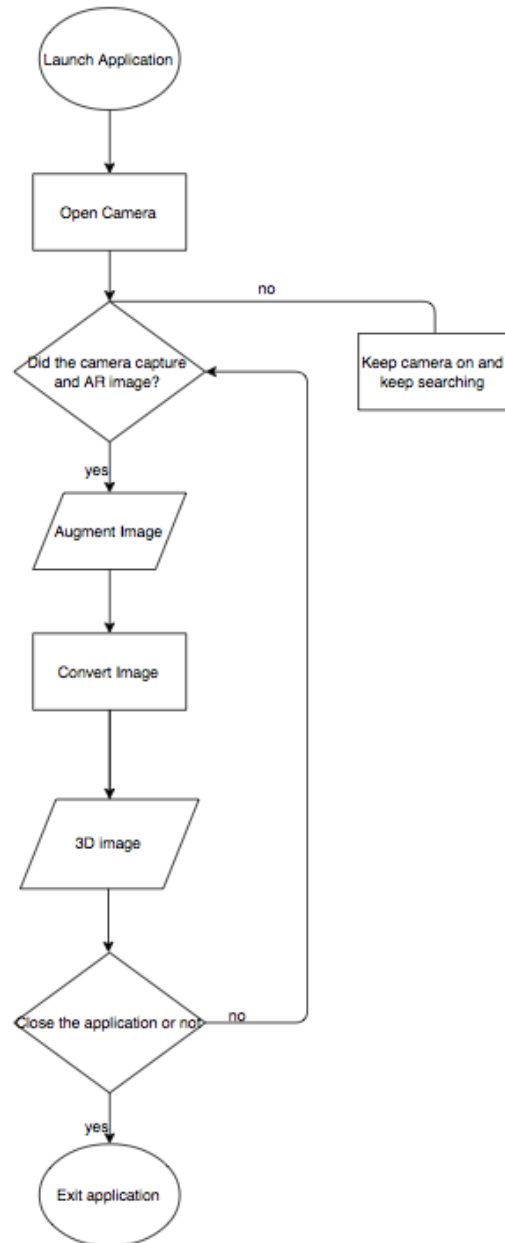


Figure 1

## 3.3 Development Steps

### 3.3.1 Set up development environment

Download Eclipse and install ADT plugin in Eclipse. The latest version of Glass

Development Kit(GDK) is in Android 4.4.2. So after ADT plugin installed, go to the

Android SDK manager and download Android 4.4.2(API 19).

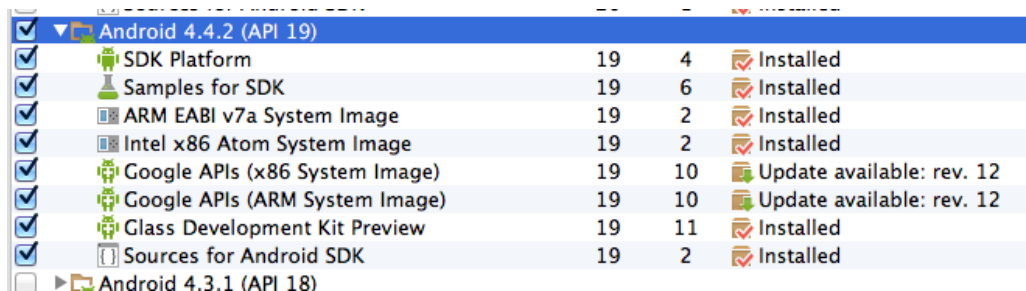


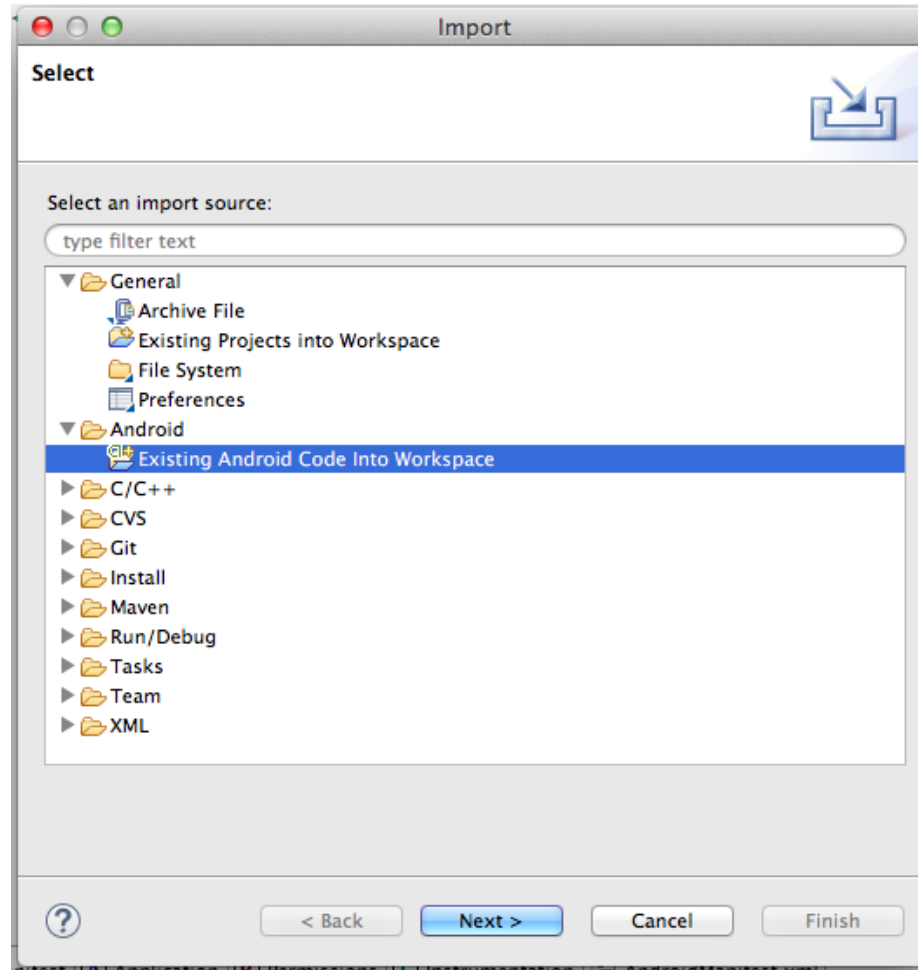
Figure 2

### 3.3.2 Import NYARToolKit library into Eclipse

Download NyARToolKit From <http://en.sourceforge.jp/projects/nyartoolkit->

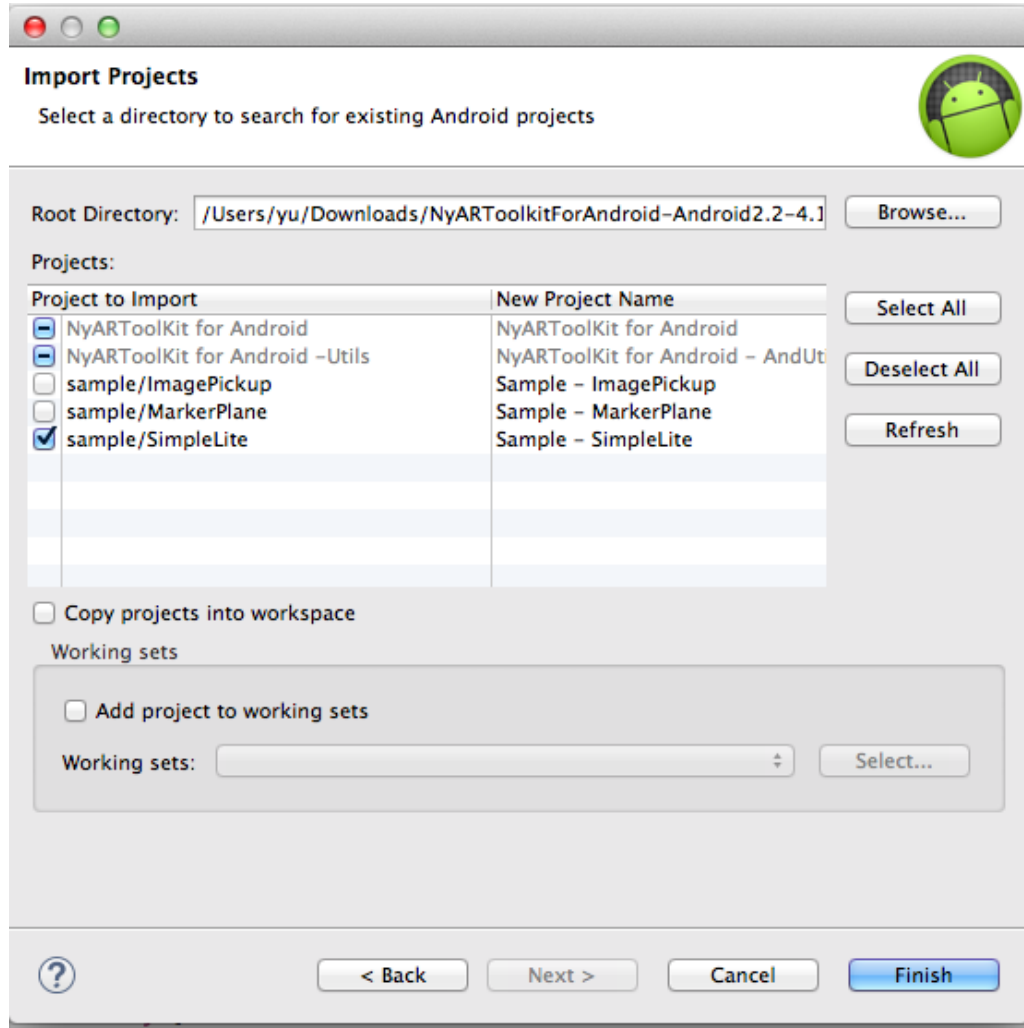
[and/downloads/57619/NyARToolkitForAndroid-Android2.2-4.1.1.zip/](http://en.sourceforge.jp/projects/nyartoolkit-and/downloads/57619/NyARToolkitForAndroid-Android2.2-4.1.1.zip/)

In eclipse, select file-import-Existing Android project into workspace. Show as Figure 3.



**Figure 3**

Then we have 5 projects in the file we download. NyARToolKit for Android and NyarToolKit for Android – Utils are basic library I will use in my Project. Also, the demo of SimpleLite gives me a good start and my project is based on the SimpleLite projects, so select as Figure 4.



**Figure 4**

Move all package in NyARToolKit for Android and NyARToolKit -Utils into sample/SimpleLite.

The main activity is SimpleLite.java and locates in jp.Nyatlta.nyartoolkit.and package.

We also need to remove the reference project information in project.properties since we have moved all packages in NyARToolKit for Android and NyARToolKit -Utils into one project

### 3.3.3 Process Pattern Files

#### ARToolKit Maker:

ARToolkit can recognize and track some images in a video stream. This kind of images are called ARToolKit Markers. Makers are created by developers and serves as input to ARToolkits. In my projects, I use ARToolKit Maker Generator online (<http://flash.tarotaro.org/blog/2008/12/14/artoolkit-marker-generator-online-released/>) to generate makers.

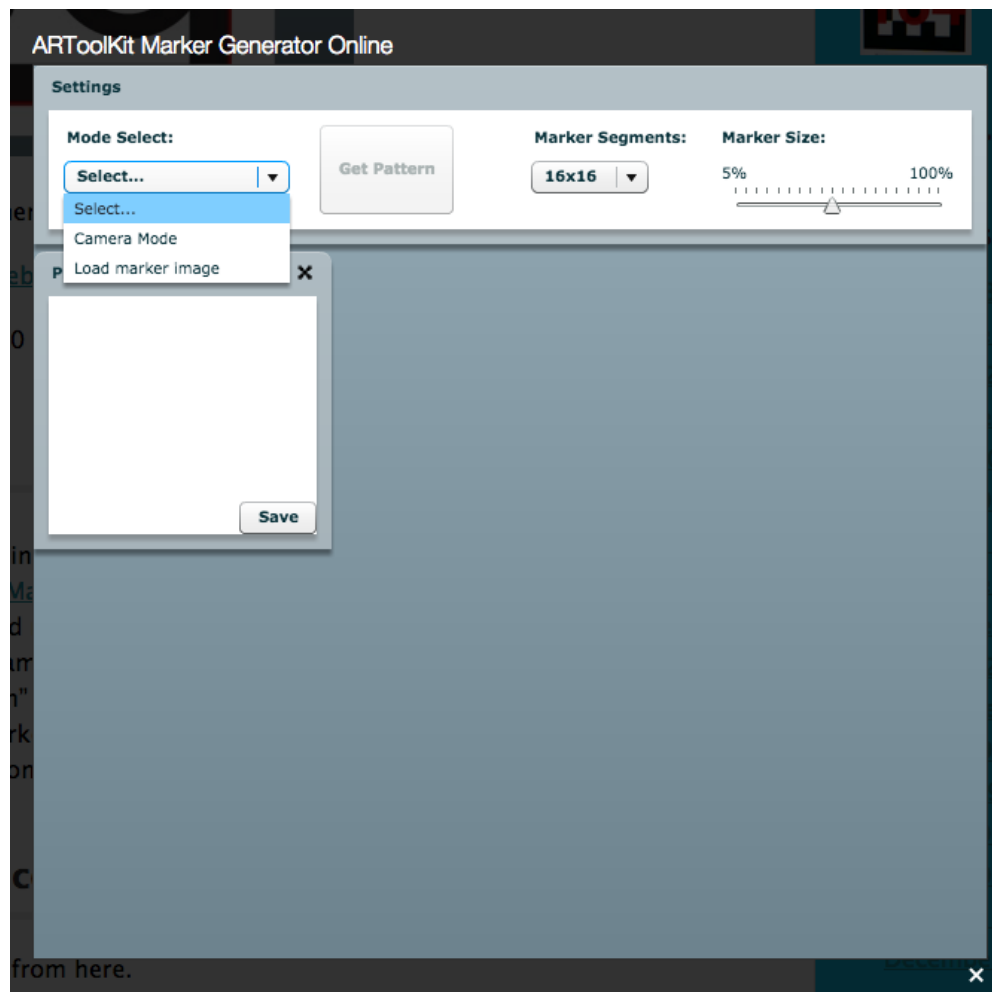


Figure 5



Figure 5 is screenshot of ARToolKit Maker Generator online. Users can open computer's camera or select local drive's images, then the online generator can generate pattern files.

### **Pattern files**

Pattern files are data files which can represent image. Pattern files can be open by Photoshop or GIMP.

### **NyARToolKit Marker System**

In NyARToolKit, there is a Marker System package called `jp.androidgroup.nyartoolkit`. This package can process input information including read pattern files, convert pattern files and store pattern files. NyARToolKit gives developer a easy way to use the maker system. I create a `NyARAndSensor` class and a `NyARAndMarkerSystem` class to manage input information.

`NyARAndMarkerSystem.addARMaker` can add pattern files as marker. Using `NyARAndMakerSystem` and `NyARAnSensor` classes, developers can directly use some encapsulation method to do some basic AR tasks.

Then call `NyARAndSensor.start()` function, the processing will begin.

```
this._mid[0]=this._ms.addARMarker(assetMng.open("AR/data/hiro.pat"),16,25,80);
this._mid[1]=this._ms.addARMarker(assetMng.open("AR/data/3.pat"),16,25,80);
this._ss.start();
```

**Figure 6**

### **3.3.4 Recognize Match Pattern Files**

When the application is launched, the camera will keep searching matched pattern images.

The camera will send the current image it captures into the application. The application will call `NyARAndMarkerSystem.isExistMarker()` method. If the images sent into application is a previous stored pattern files, it will return true. Then the application will call `draw 3D image` method to give users output results.

```

if(this._ms.isExistMarker(_mid[0])){
    this.text.draw("found"+this._ms.getConfidence(_mid[0]),0,16);
    gl.glMatrixMode(GL10.GL_MODELVIEW);
    gl.glLoadMatrixf(this._ms.getGlMarkerMatrix(_mid[0]),0);

    this.box.draw(0,0,20);

    gl.glTranslatef(0,0,20);
}
else if(this._ms.isExistMarker(_mid[1])){
    this.text.draw("found"+this._ms.getConfidence(_mid[1]),0,16);
    gl.glMatrixMode(GL10.GL_MODELVIEW);
    gl.glLoadMatrixf(this._ms.getGlMarkerMatrix(_mid[1]),0);

```

**Figure 7**

### 3.3.5 Draw Output Image for each Pattern Files

After add ARToolkit markers, I need to give each marker different match output information. Then when users use the application, if camera finds marker image, it will give users the matched output 3D image.

In my project, I use java OpenGL library to draw images. In NyARToolKit, it give users an `AndGLBox` class which can draw a 3D box. I also create a similar `AndGLTri` class which can draw a 3D triangle.

### 3.3.5 Make it running in Google Glass

NyARToolKit is an Android Project, I need to change some part to make it can running fine in Google Glass.

Add voice trigger:

Void trigger gives user a hand-free way to lunch activity. When user declares a voice command, the command will also show up in a touch menu interface.

Google have a list of voice command which developer can use.

<https://developers.google.com/glass/develop/gdk/reference/com/google/android/glass/app/VoiceTriggers.Command>

In my project, I will use "Recognize This" as my application's voice trigger.

Create "xml" folder in the res folder. Then create my voice trigger .xml file in the xml folder.

The AndroidManifest is figure 8

```

<?xml version="1.0" encoding="utf-8" ?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="jp.nyatla.nyartoolkit.and"
    android:versionCode="1"
    android:versionName="1.0" >

    <uses-sdk android:minSdkVersion="8" />
    <uses-permission android:name="com.google.android.glass.permission.DEVELOPMENT" />
    <uses-feature android:name="android.hardware.camera"/>
    <uses-feature android:name="android.hardware.camera.autofocus"/>
    <uses-permission android:name="android.permission.CAMERA"/>

    <application
        android:icon="@drawable/ic_launcher"
        android:label="@string/app_name" android:debuggable="true">
        <activity
            android:name=".SimpleLiteActivity"
            android:label="@string/app_name" >
            <intent-filter>
                <action android:name="com.google.android.glass.action.VOICE_TRIGGER" />
            </intent-filter>
            <meta-data
                android:name="com.google.android.glass.VoiceTrigger"
                android:resource="@xml/start_ar"
            />
        </activity>
    </application>
</manifest>

```

**Figure 8**

### 3.4 Testing

The code can be found in GitHub: [https://github.com/yonghaoy/SILS\\_NyARToolKit](https://github.com/yonghaoy/SILS_NyARToolKit)

The video about how the applications can be found at:

[https://www.dropbox.com/s/qc51r8mayzixo6u/IMG\\_2683.MOV?dl=0](https://www.dropbox.com/s/qc51r8mayzixo6u/IMG_2683.MOV?dl=0)

1. Run Application: My application can be launched in Google Glass touch menu. Users can also launch the application by saying "Recognize this".
2. Recognize the right image. When camera capture the right Pattern, a text "Found" will shows up.



Figure 9

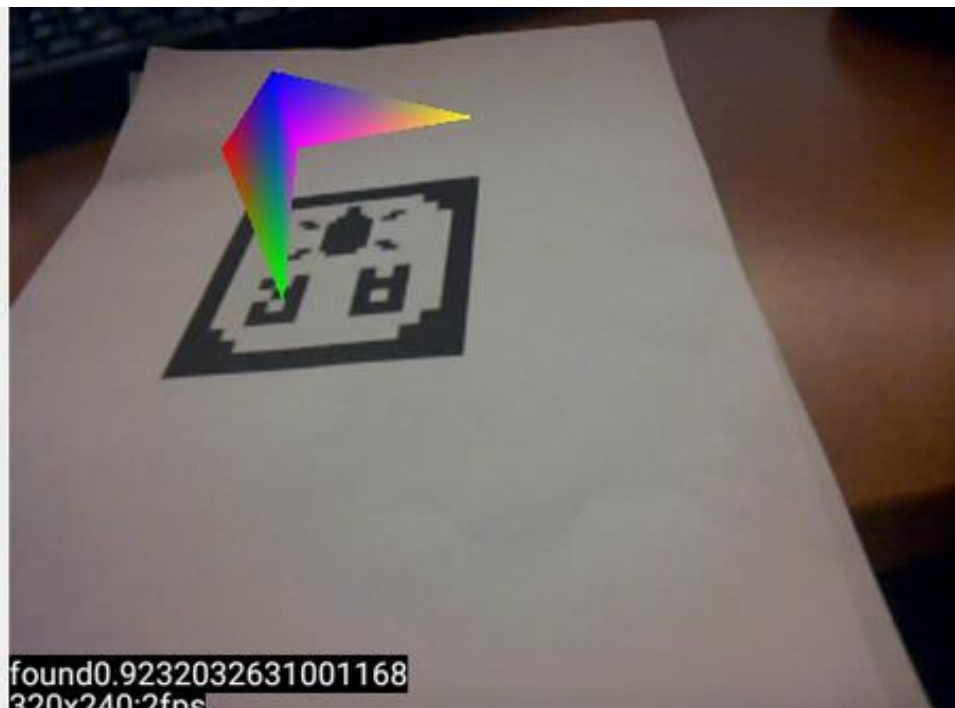


Figure 10

In Figure 9 Google Glass doesn't find any matched images, so no information shows up.

In Figure 10, Google Glass found matched pattern - "hiro.pat", so a text shows to tell users find a image.

3. Recognize different markers and generate different output. Figure 10 and Figure 11 are different pattern files and then generate a box and a triangle.



**Figure 11**

## 4 TECHNOLOGY CHALLENGES

NyArToolKit needs different markers for different output information. The markers need to be stored in the projects. If the application wants to generate a 3D movie stream, it will need thousands of pattern files. But Google Glass has limited storage space and users also don't want the application getting too large. To solve the problem, I need to find a way to store pattern files in Google Cloud or Dropbox. But if I use Internet remote storage space, the application can't run without accessing to Internet. And the speed of Internet becomes an important factor to the program's response time.

Also, the application needs thousands of different drawing method to draw different images. Even these drawing methods are similar, I still need to write codes for each drawing method using OpenGL. That also needs a large storage space.

## **5 DISCUSSION**

### **5.1 Advantages**

Google Glass gives a hand-free way to use Augmented Reality technology. Compared using the application in Google Glass with mobile devices, Google Glass is more convenient for users to use the application. Users don't need to hold a mobile device and keep searching pattern files using mobile devices' camera. With the help of Google Glass, users just need to "look at" the pattern files - a 3D image will show up.

The application can draw 3D images according to different pattern files. The generated 3D images give people a better way to learn the world than learn from 2D images. In some cases, 2D images are too abstract for people to understand. 3D images can solve the problem by providing a new sight for users.

### **5.2 Potential Use**

The current application is just a simple demo. But the operations in the applications are basic operations for most Augmented Reality applications. If there are a lot of images shows rapidly, users can seen a 3D movie from the Google Glass. Then we can use augmented reality technology to build some museums or art center. Visitors can learn



knowledge by wearing Google Glass. 3D movie can help visitors get a better experience about the museums' content. To make the application can produce a 3D movie, the application needs faster response time and faster processing time.

The application can also be used in some game development. Through connecting Google Glass with computer, computer can send games' pictures into Google Glass. Then users can see the game scene through Google Glass and play some realistic 3D games.

The application also shows potential use in education field. It's hard for students to know some animals, plants, or ancient buildings. With the help of Google Glass and Augment Reality technology, students can see "real" and "live" model rather than just learning them from paper text books.

### **5.3 Limitations**

Through testing, I also found some limitations of the application.

#### **Overheat**

If I use the application more than 20 minutes, the Glass will be very hot and warning shows up and tell me to shut down the glass. That's because the application use too much resource and the glass's processor is not advanced enough. When the application is running, the processing will keep running fast. Also, the camera also can produce a lot of heat.

## **Battery Life**

When the application is running, the power consumption becomes higher. That's also because running camera needs a lot of power. The current power of Google Glass's battery can't support the application for more than 30 minutes. But a normal 3D movie's length is more than one hour.

## **5.4 Next Step**

The current application can recognize 2 different pattern files and can generate two different 3D images. One is a 3D box; another one is a 3D triangle. In the future, I will keep exploring the augmented reality world. I will add more pattern files and draw more complex 3D graphics. I will try to build a general OpenGL class, which can give the application a general way to draw general graphics. Now, because the limited time and my limited knowledge on OpenGL, the application doesn't have an abstract OpenGL image class.

Also, I will also try to solve the battery and the overheat problem. If the application didn't find a matched pattern file for a long time, a textbox will pop up and ask whether to close the camera.

To make the application have a faster response time, I also need to change some build-in method such as the searching matched pattern files. I can use HashTable rather than the current ArrayList data structure

## 6 TAKEAWAYS FROM THE PROJECT

NyARToolKit is a very interesting project as well as a large scale project. There are thousands of classes and the project structure is complex. It took me a lot of time to figure out the relations between different classes and different packages. Through the projects I took some online Android course and learn some Android Development textbooks. That makes be more familiar with Android Development. I feel I am not a Android beginner now.

The projects also need knowledge about OpenGL. I learned OpenGL for a week to know how to draw different images. That make me more familiar how computer graphs are generated and how it works.

In the developing course I met a lot of troubles and difficulties. I use Google, Stack Overflow, GitHub, some forum to solve these problems myself. That make me know how to learn by myself and how to solve problems by myself rather than just keeping asking professor. It's very important for my future career. When I meet problems in my work, and there is no professor to get help, I know how to solve these problems.

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## Appendix A: Pattern Images



3.pat



**Hiro.pat**