Introduction to color science

CMTSAI

RGB color model

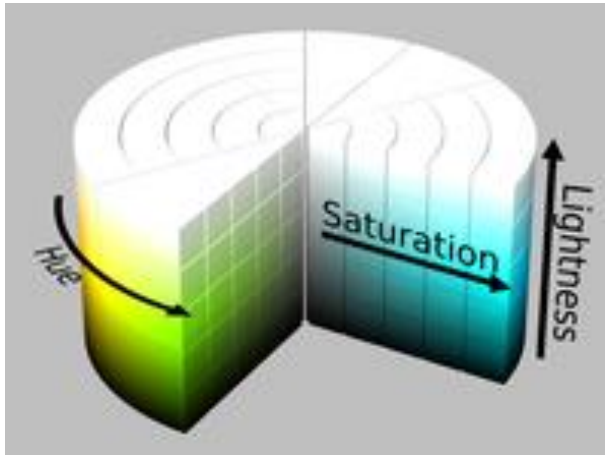
- The RGB color model is an **additive** color model in which red, green and blue light are added together in **various** ways to reproduce a broad array of colors.
- The name of the model comes from the initials of the three additive **primary** colors, red, green, and blue

Additive colors

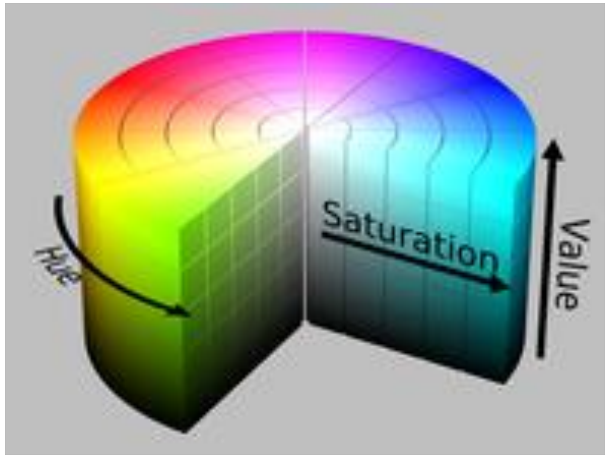
- Additive color mixing:
  - adding red to green yields yellow;
  - adding red to blue yields magenta;
  - adding green to blue yields cyan;
  - adding all three primary colors together yields white.

HSL and HSV color model

- HSL (hue, saturation, lightness) and HSV (hue, saturation, value) are alternative representations of the RGB color model, designed in the 1970s by **computer graphics** researchers to more *closely* align with the way **human vision perceives** color-making attributes.

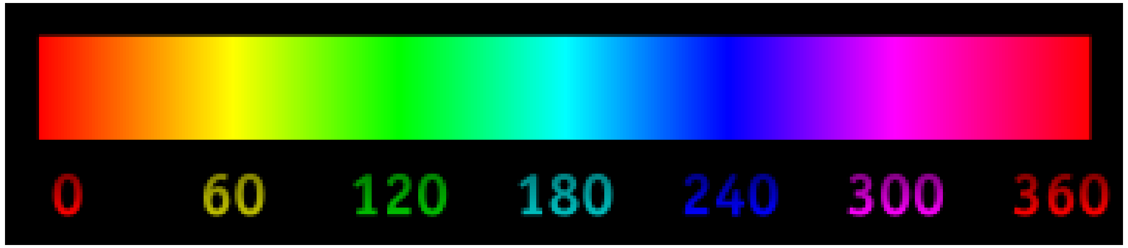


HSL cylinder.



HSV cylinder

- Hue
  - The "attribute of a visual sensation according to which an area appears to be similar to one of the perceived colors: red, yellow, green, and blue, or to a combination of two of them“



- Saturation
  - The "colorfulness of a stimulus relative to its own brightness".

Saturation scale (0% at left, corresponding to black and white).

- Lightness, value
  - The "brightness relative to the brightness of a similarly illuminated white".
- Brightness
  - The "attribute of a visual sensation according to which an area appears to emit more or less light".
  - Decreasing brightness with depth (underwater photo as example)

Color Transformation

- RGB $\leftrightarrow$ HSV in OpenCV
  - COLOR_RGB2HSV
  - COLOR_HSV2RGB

In case of 8-bit and 16-bit images, R, G, and B are converted to the floating-point format and scaled to fit the 0 to 1 range.

$$V \leftarrow max(R, G, B)$$

$$S \leftarrow \begin{cases} \frac{V - min(R,G,B)}{V} & \text{if } V \neq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$H \leftarrow \begin{cases} 60(G - B)/(V - min(R, G, B)) & \text{if } V = R \\ 120 + 60(B - R)/(V - min(R, G, B)) & \text{if } V = G \\ 240 + 60(R - G)/(V - min(R, G, B)) & \text{if } V = B \end{cases}$$

If $H < 0$ then $H \leftarrow H + 360$. On output $0 \leq V \leq 1, 0 \leq S \leq 1, 0 \leq H \leq 360$.

The values are then converted to the destination data type:

- 8-bit images: $V \leftarrow 255V, S \leftarrow 255S, H \leftarrow H/2 (\text{to fit to 0 to 255})$
- 16-bit images: (currently not supported) $V < -65535V, S < -65535S, H < -H$
- 32-bit images: H, S, and V are left as is

- RGB ↔ HSL in OpenCV
  - COLOR_RGB2HSL
  - COLOR_HSL2RGB

In case of 8-bit and 16-bit images, R, G, and B are converted to the floating-point format and scaled to fit the 0 to 1 range.

$$V_{max} \leftarrow max(R,G,B)$$

$$V_{min} \leftarrow min(R,G,B)$$

$$L \leftarrow \frac{V_{max}+V_{min}}{2}$$

$$S \leftarrow \begin{cases} \frac{V_{max}-V_{min}}{V_{max}+V_{min}} & \text{if } L < 0.5 \\ \frac{V_{max}-V_{min}}{2-(V_{max}+V_{min})} & \text{if } L \geq 0.5 \end{cases}$$

$$H \leftarrow \begin{cases} 60(G-B)/(V_{max}-V_{min}) & \text{if } V_{max}=R \\ 120+60(B-R)/(V_{max}-V_{min}) & \text{if } V_{max}=G \\ 240+60(R-G)/(V_{max}-V_{min}) & \text{if } V_{max}=B \end{cases}$$

If $H < 0$ then $H \leftarrow H + 360$. On output $0 \leq L \leq 1, 0 \leq S \leq 1, 0 \leq H \leq 360$.

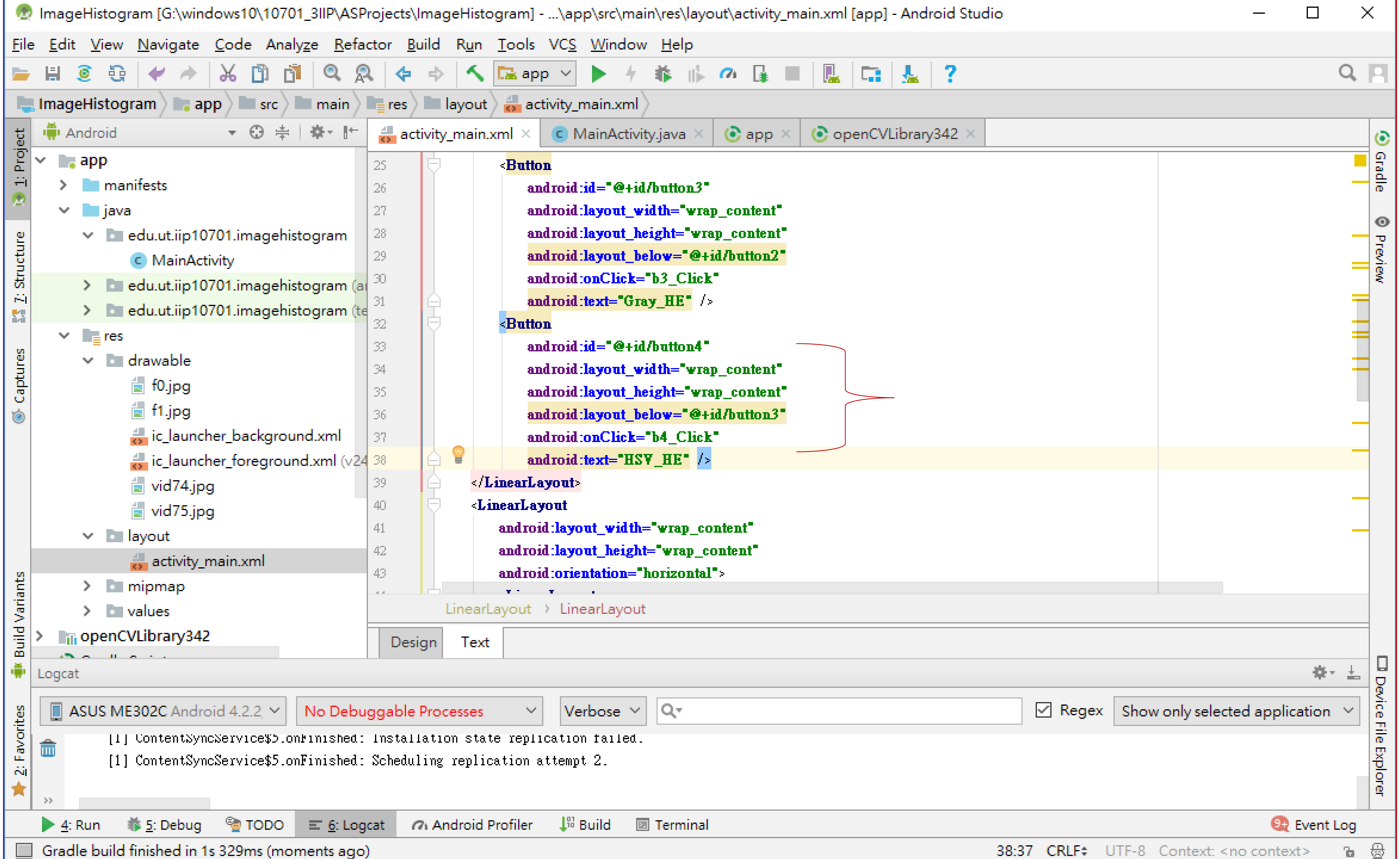
The values are then converted to the destination data type:

- 8-bit images: $V \leftarrow 255 \cdot V, S \leftarrow 255 \cdot S, H \leftarrow H/2 \text{ (to fit to 0 to 255)}$
- 16-bit images: (currently not supported) $V < -65535 \cdot V, S < -65535 \cdot S, H < -H$
- 32-bit images: H, S, V are left as is

HSV Histogram Equalization

UI: activity_main.xml

- Add one button


ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\res\layout\activity_main.xml [app] - Android Studio
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help
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android:layout_width="wrap_content"
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android:layout_below="@+id/button2"
android:onClick="b3_Click"
android:text="Gray_HE" />
<Button
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android:layout_height="wrap_content"
android:layout_below="@+id/button3"
android:onClick="b4_Click"
android:text="HSV_HE" />
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android:orientation="horizontal">
LinearLayout › LinearLayout
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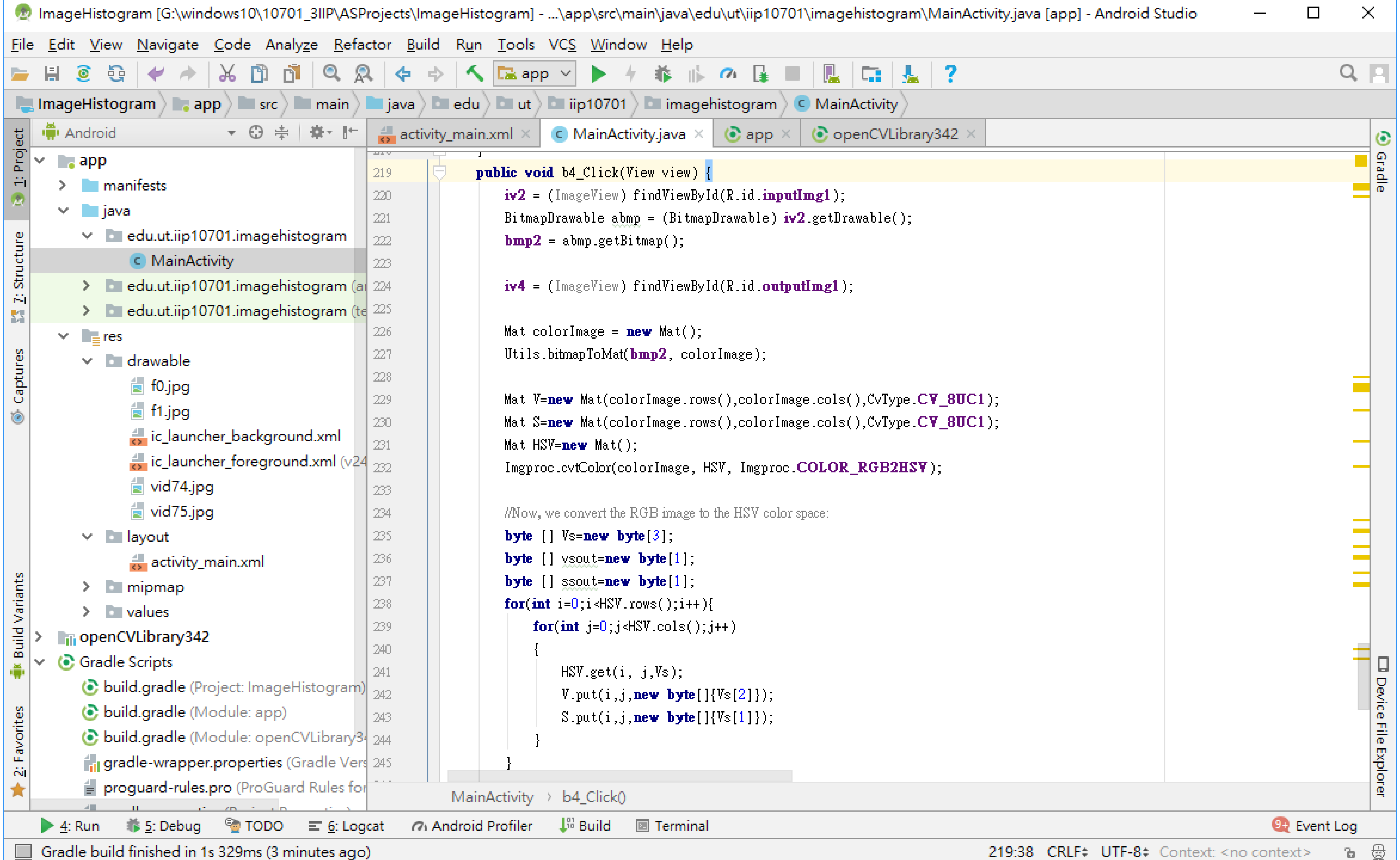
Text
Logcat
ASUS ME302C Android 4.2.2
No Debuggable Processes
Verbose
Regex
Show only selected application
[1] ContentSyncService$5.onFinished: Installation state replication failed.
[1] ContentSyncService$5.onFinished: Scheduling replication attempt 2.
4: Run
5: Debug
TODO
6: Logcat
Android Profiler
Build
Terminal
Event Log
Gradle build finished in 1s 329ms (moments ago)
38:37 CRLF: UTF-8 Context: <no context>
1: Project
7: Structure
Captures
Build Variants
2: Favorites
Gradle
Preview
Device File Explorer

Modify MainActivity.java

- public void b4_Click(View view)



ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\java\edu\ut\iip10701\imagehistogram\MainActivity.java [app] - Android Studio
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help
ImageHistogram app src main java edu ut iip10701 imagehistogram MainActivity
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edu.ut.iip10701.imagehistogram
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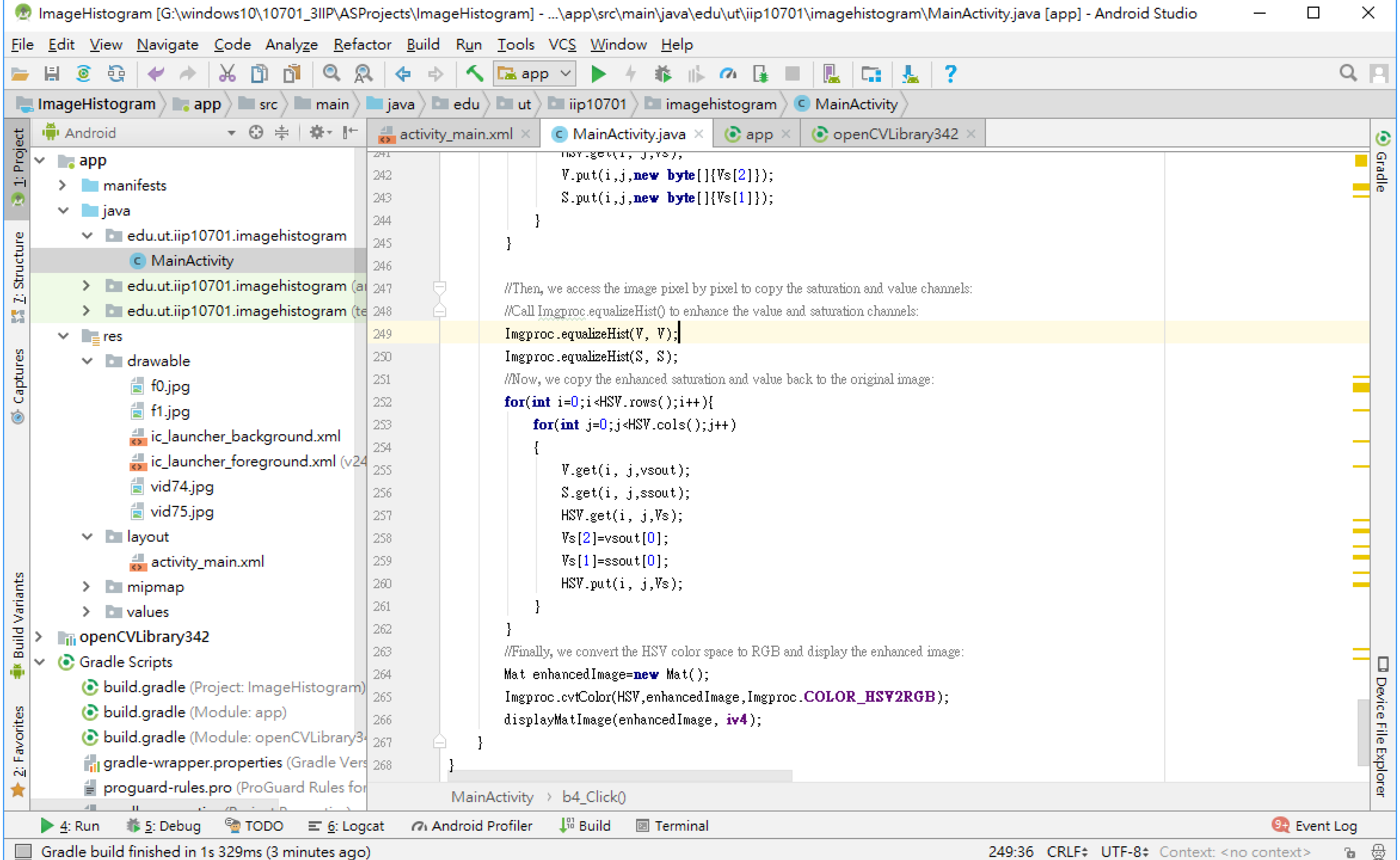
ic_launcher_background.xml
ic_launcher_foreground.xml
vid74.jpg
vid75.jpg
layout
activity_main.xml
mipmap
values
openCVLibrary342
Gradle Scripts
build.gradle (Project: ImageHistogram)
build.gradle (Module: app)
gradle-wrapper.properties
proguard-rules.pro
activity_main.xml
MainActivity.java
openCVLibrary342
public void b4_Click(View view) {
iv2 = (ImageView) findViewById(R.id.inputImg1);
BitmapDrawable abmp = (BitmapDrawable) iv2.getDrawable();
bmp2 = abmp.getBitmap();
iv4 = (ImageView) findViewById(R.id.outputImg1);
Mat colorImage = new Mat();
Utils.bitmapToMat(bmp2, colorImage);
Mat V=new Mat(colorImage.rows(),colorImage.cols(),CvType.CV_8UC1);
Mat S=new Mat(colorImage.rows(),colorImage.cols(),CvType.CV_8UC1);
Mat HSV=new Mat();
Imgproc.cvtColor(colorImage, HSV, Imgproc.COLOR_RGB2HSV);
//Now, we convert the RGB image to the HSV color space:
byte [] Vs=new byte[3];
byte [] vsout=new byte[1];
byte [] ssout=new byte[1];
for(int i=0;i<HSV.rows();i++){
for(int j=0;j<HSV.cols();j++)
{
HSV.get(i, j,Vs);
V.put(i,j,new byte[]{Vs[2]});
S.put(i,j,new byte[]{Vs[1]});
}
}
MainActivity b4_Click()
4: Run 5: Debug TODO 6: Logcat Android Profiler Build Terminal Event Log
Gradle build finished in 1s 329ms (3 minutes ago)
219:38 CRLF UTF-8 Context: <no context>



ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\java\edu\ut\iip10701\imagehistogram\MainActivity.java [app] - Android Studio
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help
ImageHistogram app src main java edu ut iip10701 imagehistogram MainActivity
Android
activity_main.xml
MainActivity.java
app
openCVLibrary342
app
manifests
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edu.ut.iip10701.imagehistogram
MainActivity
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edu.ut.iip10701.imagehistogram
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ic_launcher_foreground.xml
vid74.jpg
vid75.jpg
layout
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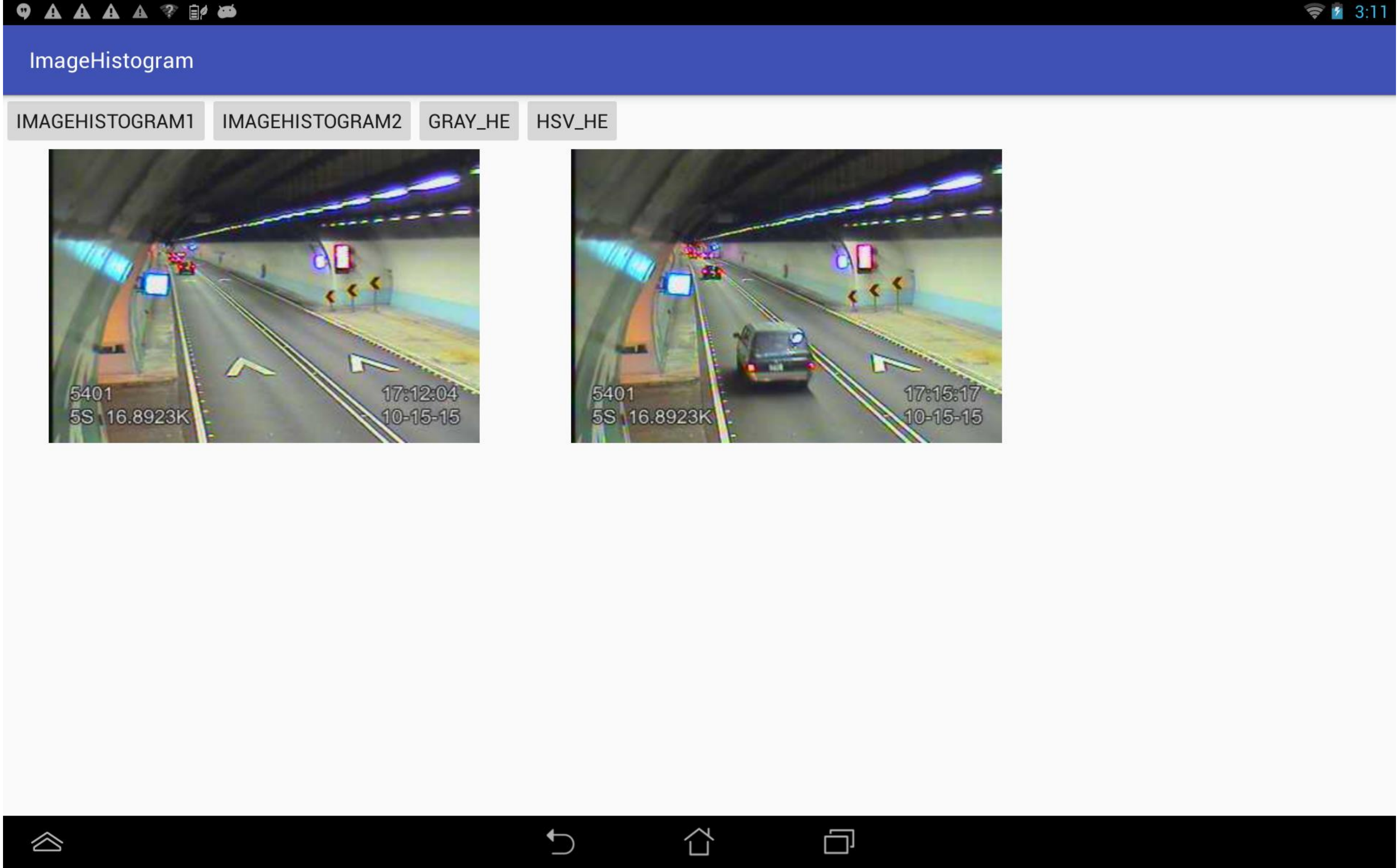
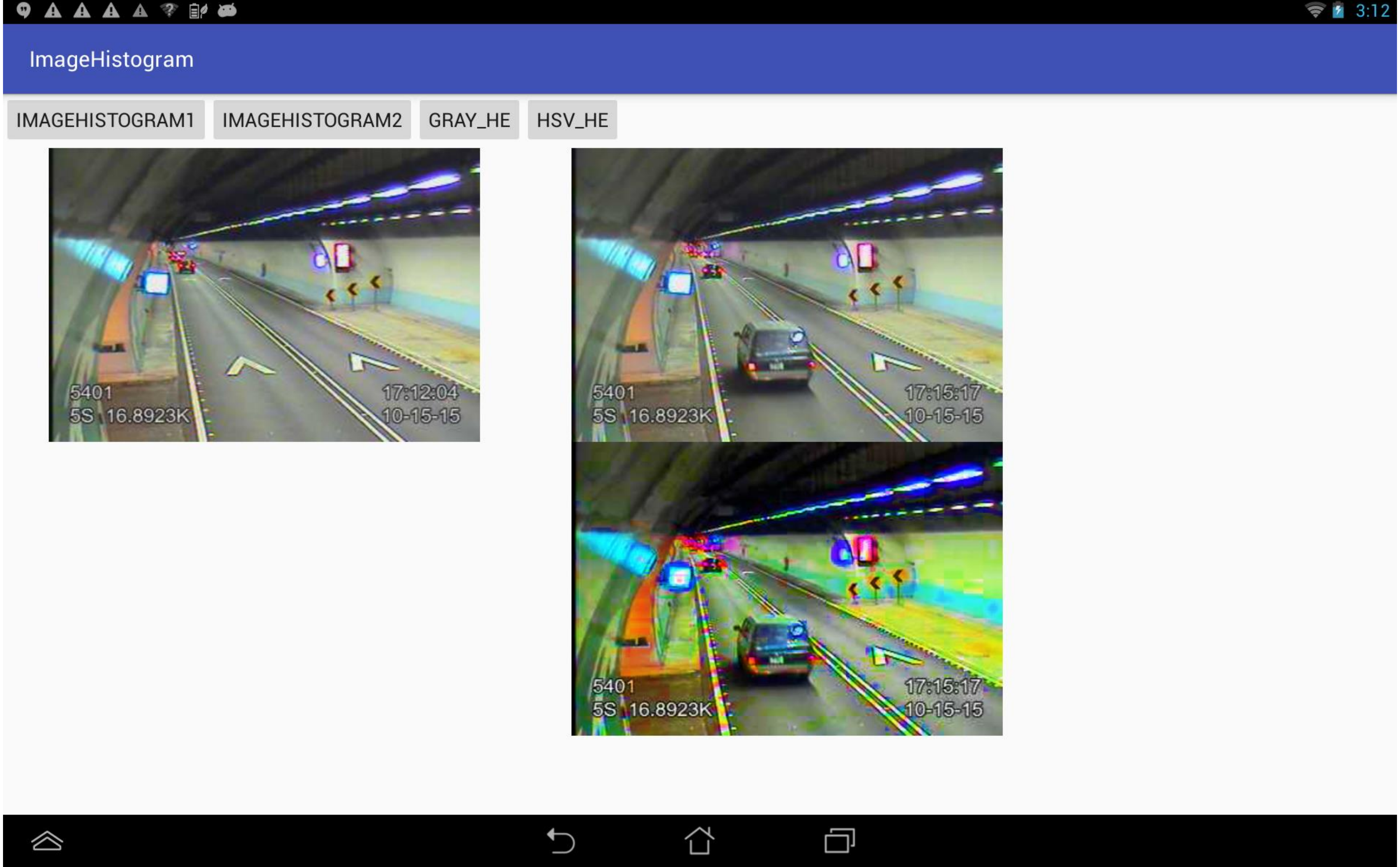
mipmap
values
openCVLibrary342
Gradle Scripts
build.gradle (Project: ImageHistogram)
build.gradle (Module: app)
build.gradle (Module: openCVLibrary3
gradle-wrapper.properties (Gradle Vers
proguard-rules.pro (ProGuard Rules for
                V.put(i,j,new byte[]{Vs[2]});
                S.put(i,j,new byte[]{Vs[1]});
            }
        }

        //Then, we access the image pixel by pixel to copy the saturation and value channels:
        //Call Imgproc.equalizeHist() to enhance the value and saturation channels:
        Imgproc.equalizeHist(V, V);
        Imgproc.equalizeHist(S, S);
        //Now, we copy the enhanced saturation and value back to the original image:
        for(int i=0;i<HSV.rows();i++){
            for(int j=0;j<HSV.cols();j++)
            {
                V.get(i, j,vsout);
                S.get(i, j,ssout);
                HSV.get(i, j,Vs);
                Vs[2]=vsout[0];
                Vs[1]=ssout[0];
                HSV.put(i, j,Vs);
            }
        }
        //Finally, we convert the HSV color space to RGB and display the enhanced image:
        Mat enhancedImage=new Mat();
        Imgproc.cvtColor(HSV,enhancedImage,Imgproc.COLOR_HSV2RGB);
        displayMatImage(enhancedImage, iv4);
    }
}
MainActivity › b4_Click()
4: Run
5: Debug
TODO
6: Logcat
Android Profiler
Build
Terminal
Event Log
Gradle build finished in 1s 329ms (3 minutes ago)
249:36 CRLF: UTF-8: Context: <no context>
1: Project
2: Structure
Captures
Build Variants
2: Favorites
Gradle
Device File Explorer

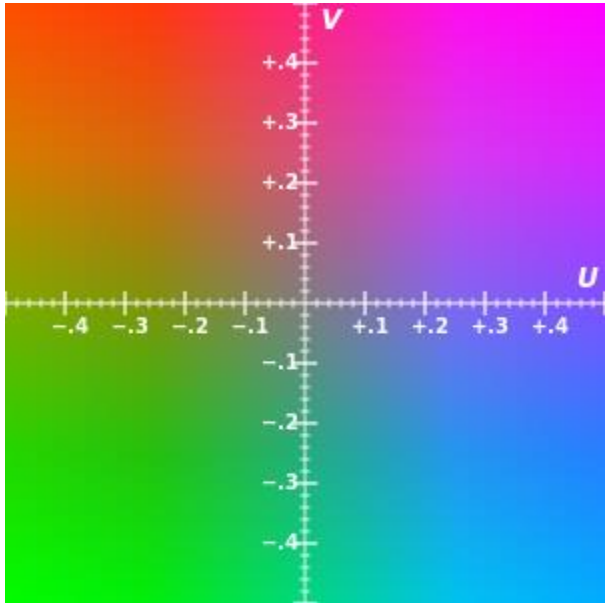
Try to run it


3:11
ImageHistogram
IMAGEHISTOGRAM1
IMAGEHISTOGRAM2
GRAY_HE
HSV_HE
5401
5S 16.8923K
17:12:04
10-15-15
5401
5S 16.8923K
17:15:17
10-15-15


3:12
ImageHistogram
IMAGEHISTOGRAM1
IMAGEHISTOGRAM2
GRAY_HE
HSV_HE
5401
5S 16.8923K
17:12:04
10-15-15
5401
5S 16.8923K
17:15:17
10-15-15
5401
5S 16.8923K
17:15:17
10-15-15

YUV color model

- YUV is a color **encoding** system typically used as part of a color image pipeline.
- It encodes a color image or video taking **human perception** into account,
  - allowing **reduced** bandwidth for chrominance components,
  - enabling transmission errors or compression artifacts
  - to be **more** efficiently masked by the human perception than using a "direct" RGB-representation.



Example of U-V color plane, Y’ value = 0.5, represented within RGB color gamut

RGB <-> YUV

$$Y = 0.299R + 0.587G + 0.114B$$

$$U' = (B - Y) * 0.565$$

$$V' = (R - Y) * 0.713$$

with reciprocal versions:

$$R = Y + 1.403V'$$

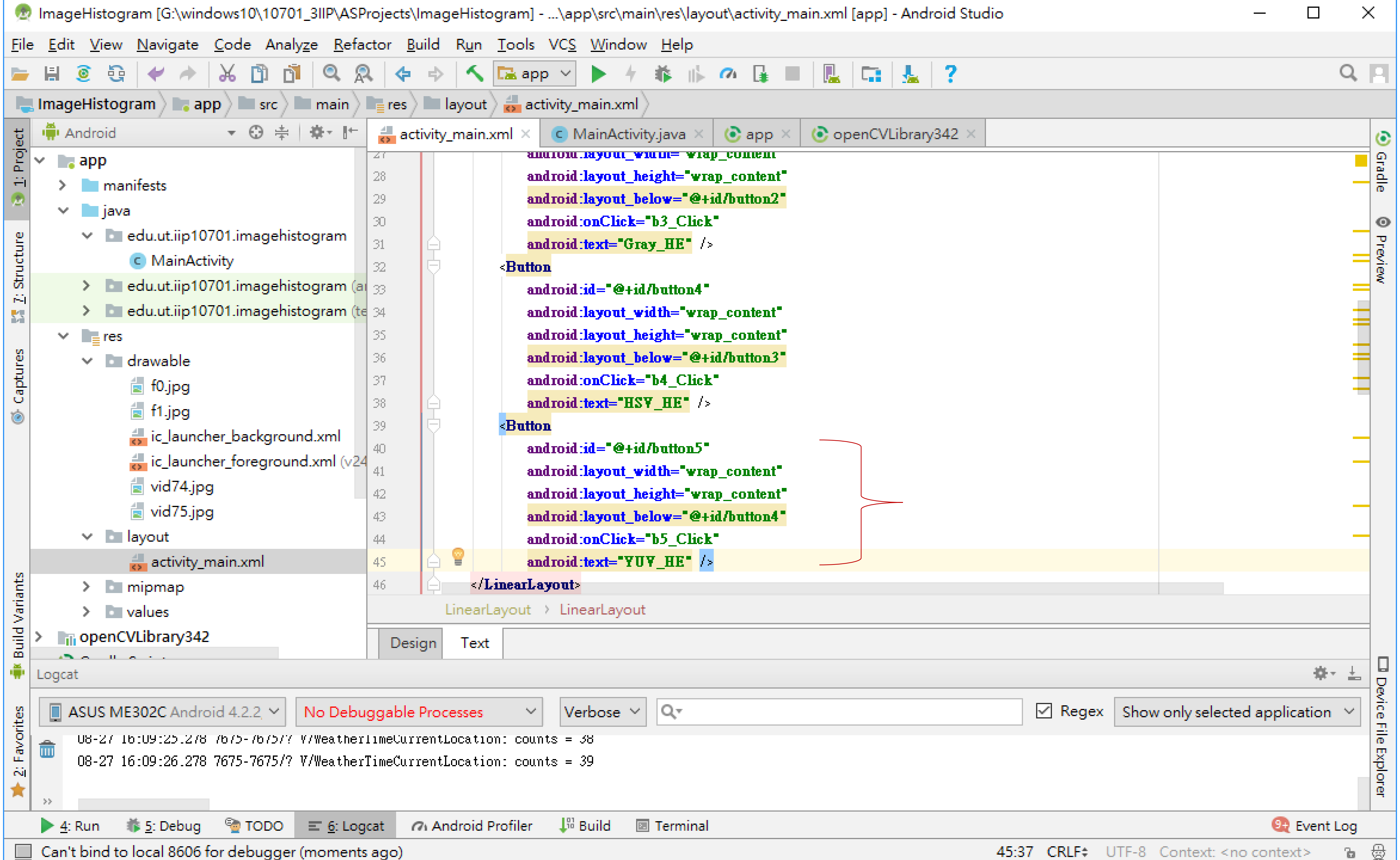
$$G = Y - 0.344U' - 0.714V'$$

$$B = Y + 1.770U'$$

YUV Histogram Equalization

UI: activity_main.xml

- Add one button


ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\res\layout\activity_main.xml [app] - Android Studio
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help
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android:onClick="b3_Click"
android:text="Gray_HE" />
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android:layout_width="wrap_content"
android:layout_height="wrap_content"
android:layout_below="@+id/button3"
android:onClick="b4_Click"
android:text="HSV_HE" />
<Button
android:id="@+id/button5"
android:layout_width="wrap_content"
android:layout_height="wrap_content"
android:layout_below="@+id/button4"
android:onClick="b5_Click"
android:text="YUV_HE" />
</LinearLayout>
LinearLayout LinearLayout
Design Text
Logcat
ASUS ME302C Android 4.2.2
No Debuggable Processes
Verbose
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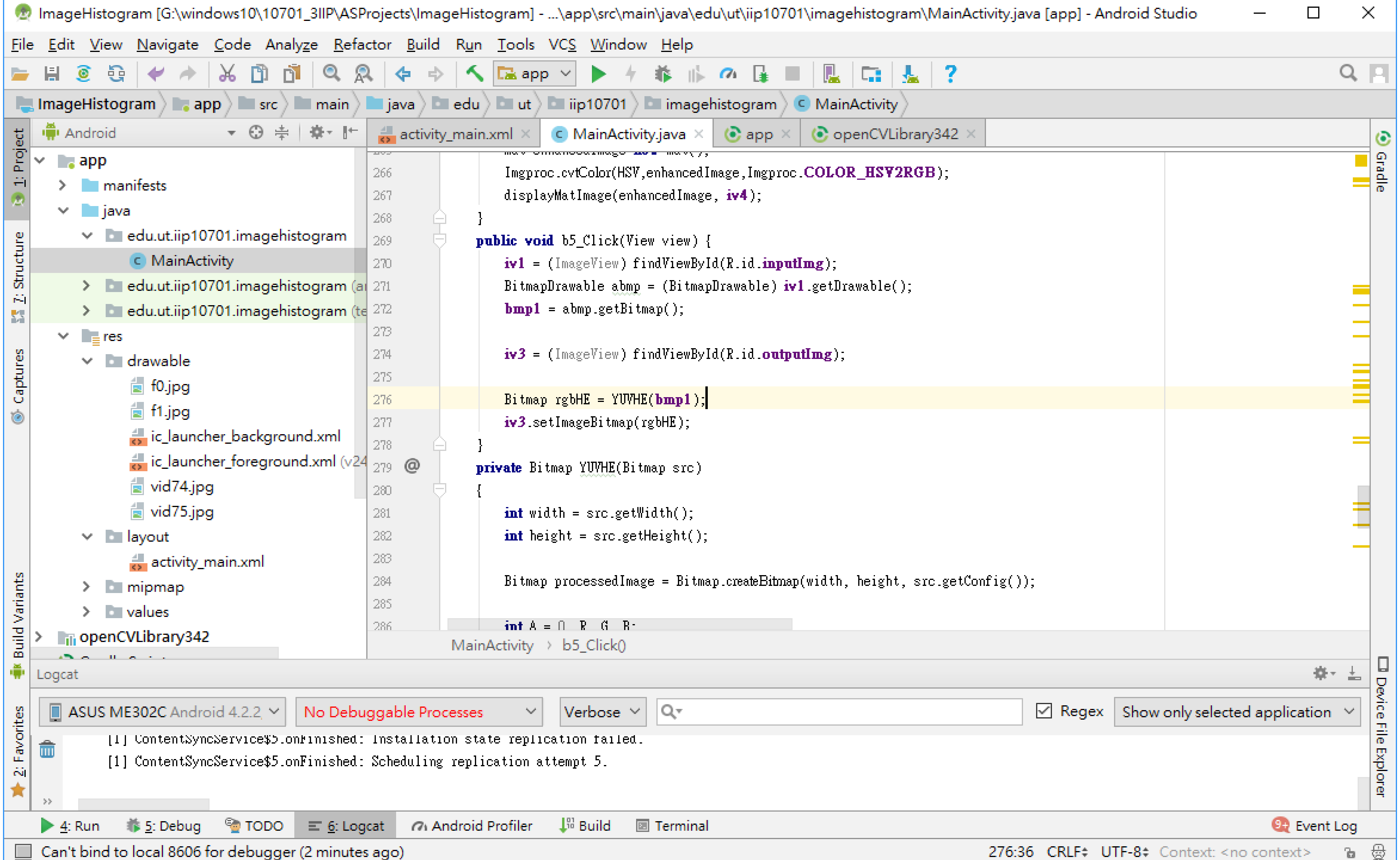
Show only selected application
08-27 16:09:26.278 7675-7675/? V/WeatherTimeCurrentLocation: counts = 39
4: Run 5: Debug TODO 6: Logcat Android Profiler Build Terminal Event Log
Can't bind to local 8606 for debugger (moments ago)
45:37 CRLF UTF-8 Context: <no context>

Modify MainActivity.java

- public void b5_Click(View view)



ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\java\edu\ut\iip10701\imagehistogram\MainActivity.java [app] - Android Studio
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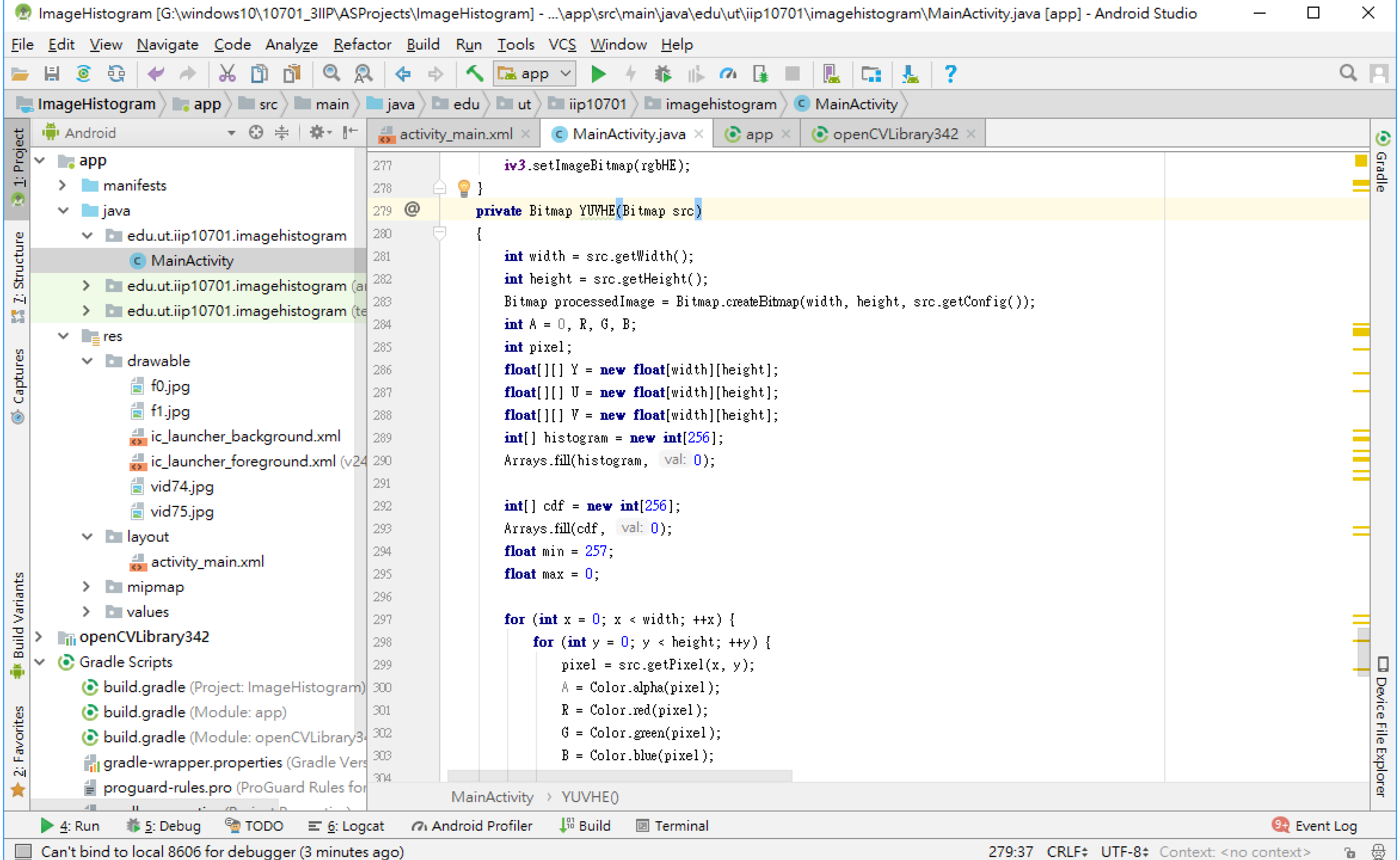
openCVLibrary342
activity_main.xml
MainActivity.java
app
openCVLibrary342
Imgproc.cvtColor(HSV,enhancedImage,Imgproc.COLOR_HSV2RGB);
displayMatImage(enhancedImage, iv4);
}
public void b5_Click(View view) {
iv1 = (ImageView) findViewById(R.id.inputImg);
BitmapDrawable abmp = (BitmapDrawable) iv1.getDrawable();
bmp1 = abmp.getBitmap();
iv3 = (ImageView) findViewById(R.id.outputImg);
Bitmap rgbHE = YUVHE(bmp1);
iv3.setImageBitmap(rgbHE);
}
private Bitmap YUVHE(Bitmap src)
{
int width = src.getWidth();
int height = src.getHeight();
Bitmap processedImage = Bitmap.createBitmap(width, height, src.getConfig());
MainActivity b5_Click()
Logcat
ASUS ME302C Android 4.2.2
No Debuggable Processes
Verbose
Regex
Show only selected application
[1] ContentSyncService$5.onFinished: Installation state replication failed.
[1] ContentSyncService$5.onFinished: Scheduling replication attempt 5.
4: Run
5: Debug
TODO
6: Logcat
Android Profiler
Build
Terminal
Event Log
Can't bind to local 8606 for debugger (2 minutes ago)
276:36 CRLF UTF-8 Context: <no context>
1: Project
7: Structure
Captures
Build Variants
2: Favorites
Gradle
Device File Explorer


ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\java\edu\ut\iip10701\imagehistogram\MainActivity.java [app] - Android Studio
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help
ImageHistogram app src main java edu ut iip10701 imagehistogram MainActivity
activity_main.xml MainActivity.java app openCVLibrary342
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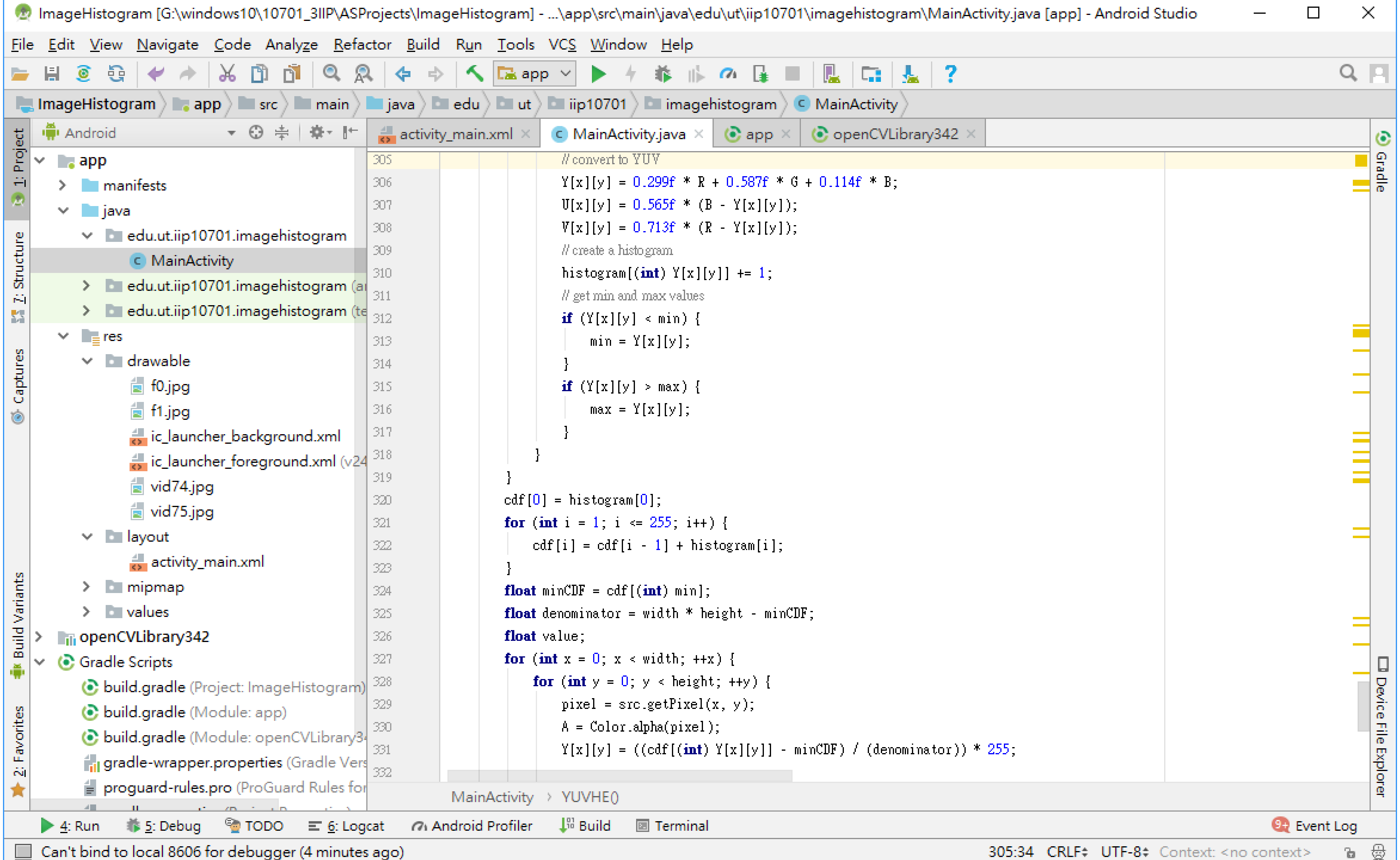
activity_main.xml
mipmap
values
openCVLibrary342
Gradle Scripts
build.gradle (Project: ImageHistogram)
build.gradle (Module: app)
gradle-wrapper.properties
proguard-rules.pro
iv3.setImageBitmap(rgbHE);
}
private Bitmap YUVHE(Bitmap src)
{
int width = src.getWidth();
int height = src.getHeight();
Bitmap processedImage = Bitmap.createBitmap(width, height, src.getConfig());
int A = 0, R, G, B;
int pixel;
float[][] Y = new float[width][height];
float[][] U = new float[width][height];
float[][] V = new float[width][height];
int[] histogram = new int[256];
Arrays.fill(histogram, val: 0);
int[] cdf = new int[256];
Arrays.fill(cdf, val: 0);
float min = 257;
float max = 0;
for (int x = 0; x < width; ++x) {
for (int y = 0; y < height; ++y) {
pixel = src.getPixel(x, y);
A = Color.alpha(pixel);
R = Color.red(pixel);
G = Color.green(pixel);
B = Color.blue(pixel);
MainActivity › YUVHE()
4: Run 5: Debug TODO 6: Logcat Android Profiler Build Terminal Event Log
Can't bind to local 8606 for debugger (3 minutes ago)
279:37 CRLF UTF-8 Context: <no context>



ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\java\edu\ut\iip10701\imagehistogram\MainActivity.java [app] - Android Studio
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help
ImageHistogram app src main java edu ut iip10701 imagehistogram MainActivity
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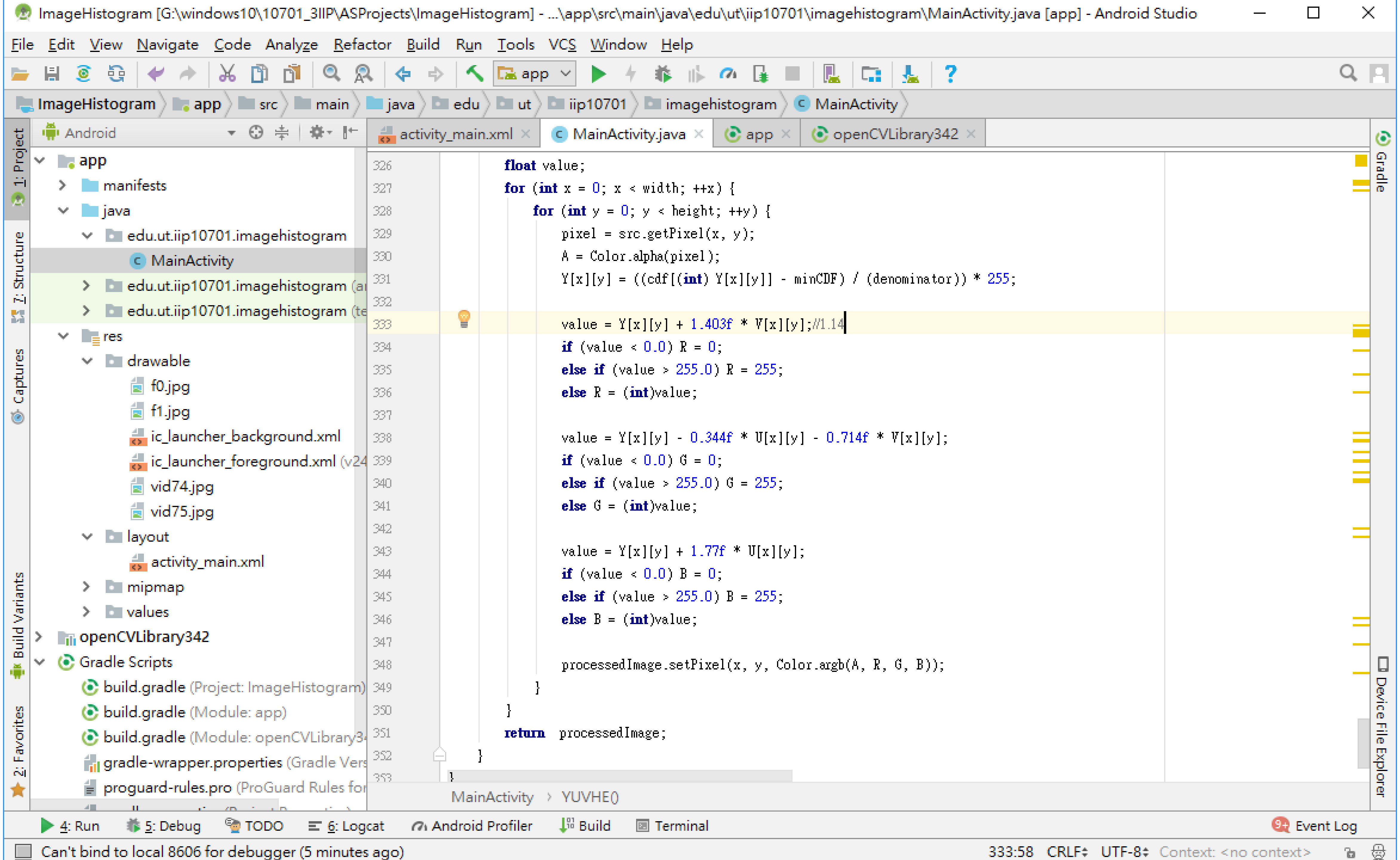
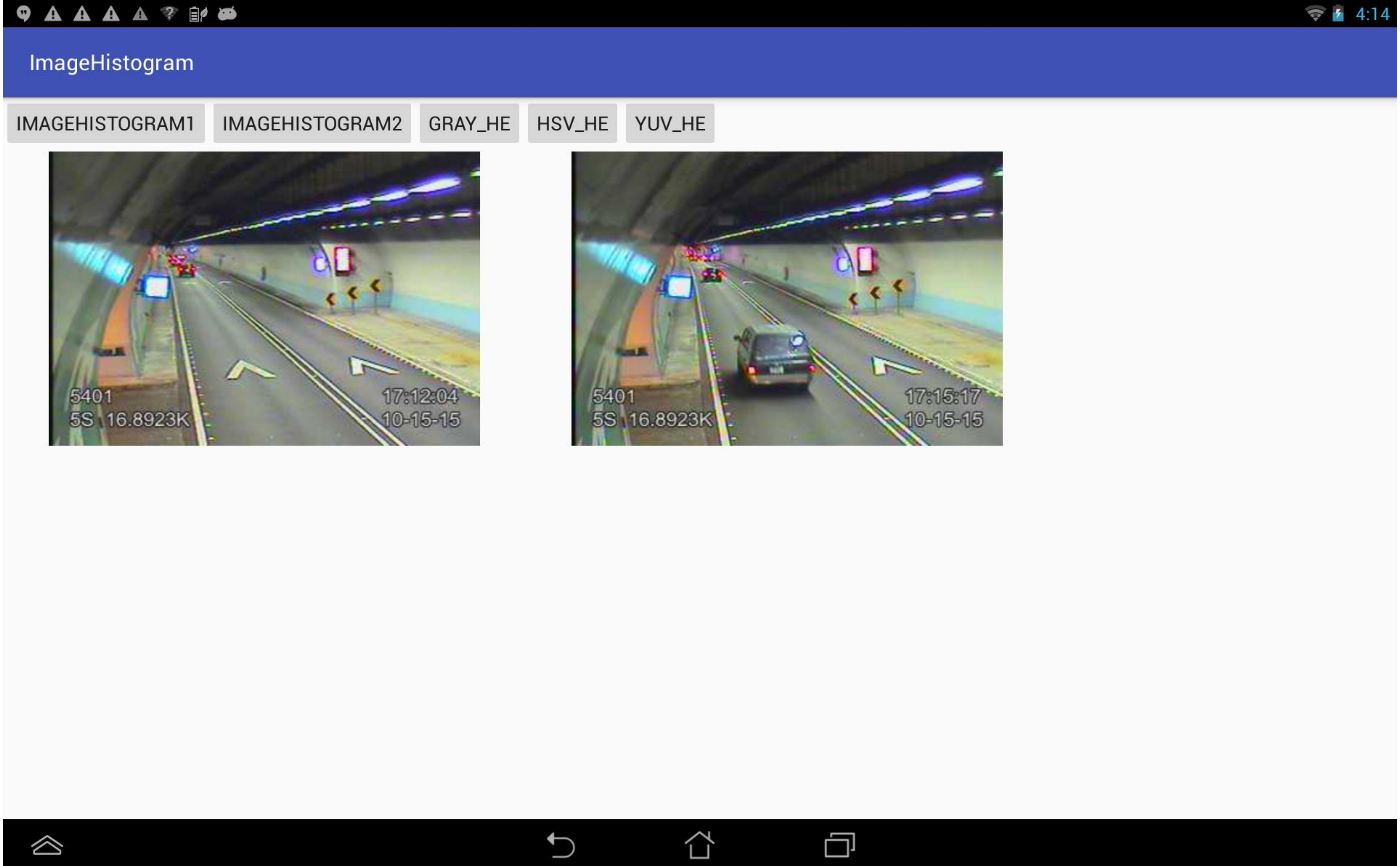
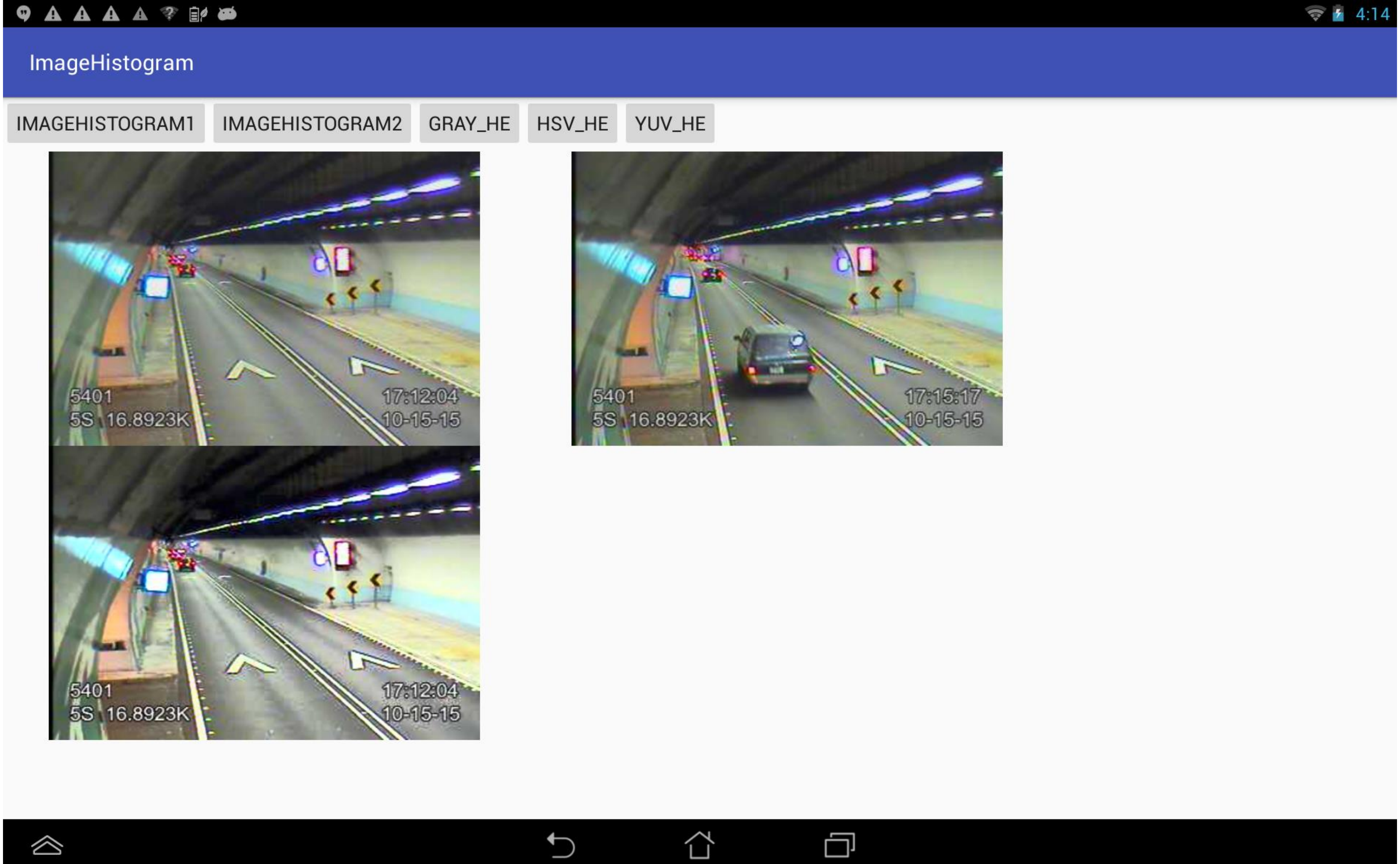
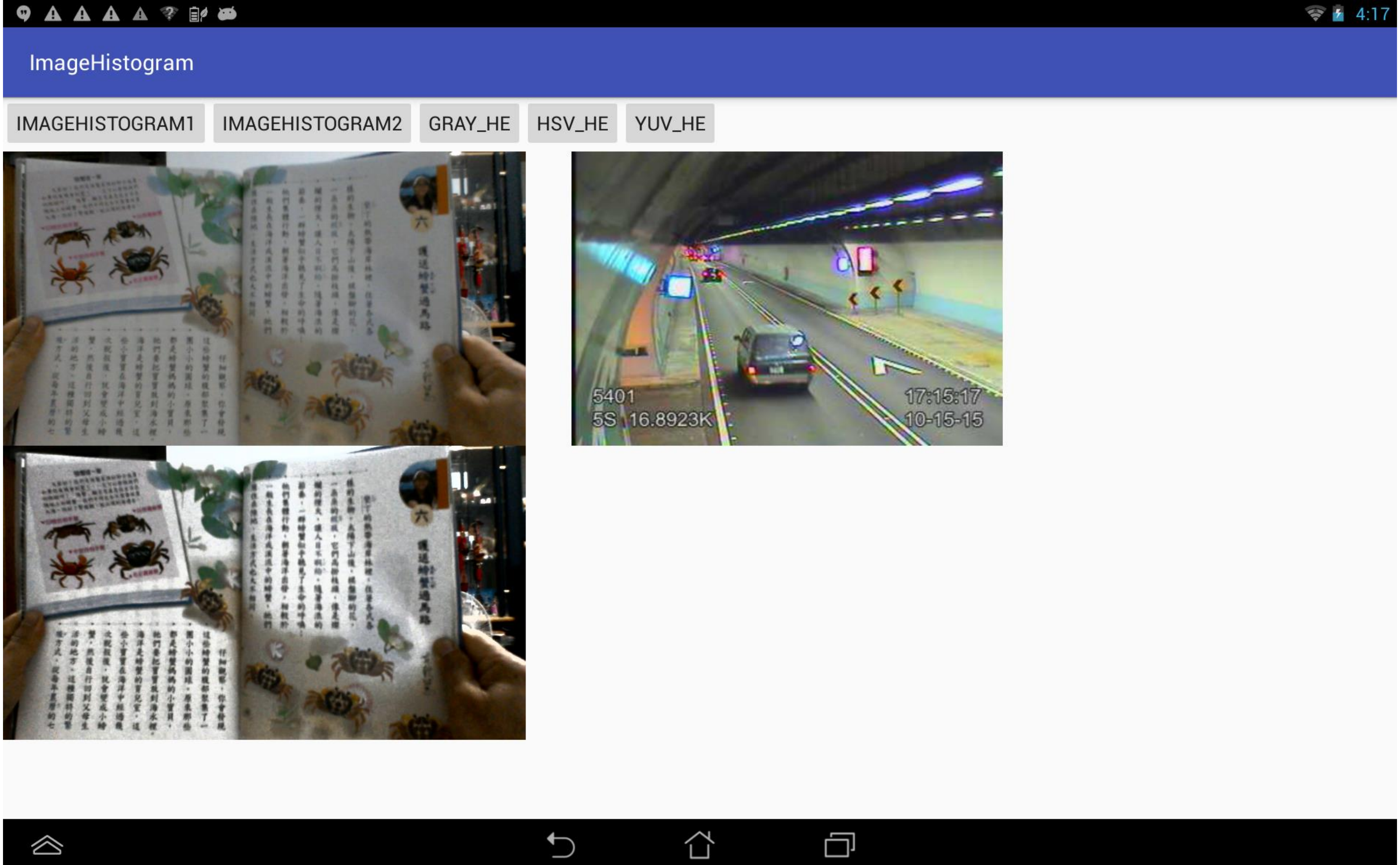
openCVLibrary342
Gradle Scripts
build.gradle (Project: ImageHistogram)
build.gradle (Module: app)
build.gradle (Module: openCVLibrary3
gradle-wrapper.properties (Gradle Vers
proguard-rules.pro (ProGuard Rules for
activity_main.xml MainActivity.java app openCVLibrary342
// convert to YUV
Y[x][y] = 0.299f * R + 0.587f * G + 0.114f * B;
U[x][y] = 0.565f * (B - Y[x][y]);
V[x][y] = 0.713f * (R - Y[x][y]);
// create a histogram
histogram[(int) Y[x][y]] += 1;
// get min and max values
if (Y[x][y] < min) {
min = Y[x][y];
}
if (Y[x][y] > max) {
max = Y[x][y];
}
}
}
cdf[0] = histogram[0];
for (int i = 1; i <= 255; i++) {
cdf[i] = cdf[i - 1] + histogram[i];
}
float minCDF = cdf[(int) min];
float denominator = width * height - minCDF;
float value;
for (int x = 0; x < width; ++x) {
for (int y = 0; y < height; ++y) {
pixel = src.getPixel(x, y);
A = Color.alpha(pixel);
Y[x][y] = ((cdf[(int) Y[x][y]] - minCDF) / (denominator)) * 255;
MainActivity › YUVHE()
4: Run 5: Debug TODO 6: Logcat Android Profiler Build Terminal Event Log
Can't bind to local 8606 for debugger (4 minutes ago)
305:34 CRLF UTF-8 Context: <no context>
1: Project 2: Structure Captures Build Variants 2: Favorites Gradle Device File Explorer


ImageHistogram [G:\windows10\10701_3IIP\ASProjects\ImageHistogram] - ...\app\src\main\java\edu\ut\iip10701\imagehistogram\MainActivity.java [app] - Android Studio
activity_main.xml
MainActivity.java
openCVLibrary342
float value;
for (int x = 0; x < width; ++x) {
for (int y = 0; y < height; ++y) {
pixel = src.getPixel(x, y);
A = Color.alpha(pixel);
Y[x][y] = ((cdf[(int) Y[x][y]] - minCDF) / (denominator)) * 255;
value = Y[x][y] + 1.403f * V[x][y];//1.14
if (value < 0.0) R = 0;
else if (value > 255.0) R = 255;
else R = (int)value;
value = Y[x][y] - 0.344f * U[x][y] - 0.714f * V[x][y];
if (value < 0.0) G = 0;
else if (value > 255.0) G = 255;
else G = (int)value;
value = Y[x][y] + 1.77f * U[x][y];
if (value < 0.0) B = 0;
else if (value > 255.0) B = 255;
else B = (int)value;
processedImage.setPixel(x, y, Color.argb(A, R, G, B));
}
}
return processedImage;
}
}
MainActivity › YUVHE()
Can't bind to local 8606 for debugger (5 minutes ago)
333:58 CRLF UTF-8 Context: <no context>

Try to run it


4:14
ImageHistogram
IMAGEHISTOGRAM1
IMAGEHISTOGRAM2
GRAY_HE
HSV_HE
YUV_HE
5401
5S 16.8923K
17:12:04
10-15-15
5401
5S 16.8923K
17:15:17
10-15-15


4:14
ImageHistogram
IMAGEHISTOGRAM1
IMAGEHISTOGRAM2
GRAY_HE
HSV_HE
YUV_HE
5401
5S 16.8923K
17:12:04
10-15-15
5401
5S 16.8923K
17:15:17
10-15-15
5401
5S 16.8923K
17:12:04
10-15-15


4:17
ImageHistogram
IMAGEHISTOGRAM1
IMAGEHISTOGRAM2
GRAY_HE
HSV_HE
YUV_HE
5401
5S 16.8923K
17:15:17
10-15-15

References

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- https://en.wikipedia.org/wiki/RGB_color_model
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