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Making Android 3D Graphics Applications Respond to Motion

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1. Revision History

Revision Date	Revision	Description
06/26/2012	1.0	Document created

2. Purpose

This document is a quick start guide on how to provide one-to-one motion on a 3D graphics object using OpenGL and Android's Sensor Manager. Knowledge of Android's SDK and application development is needed before reading this document. Some knowledge of OpenGL is also useful when creating this application. Please refer to the documentation provided in the reference section for more information on Android's OpenGL development and working with Android's Sensor Manager.

3. Requirements

- Eclipse
- Android SDK
- Java Programming Knowledge
- Knowledge of quaternion and rotations
- Completion of Android's OpenGL ES tutorial

4. Making Your App Respond to Device Motion

Most Android-powered devices have built-in sensors that measure motion. These sensors are capable of providing raw data with high precision and accuracy, and are useful if you want to monitor three-dimensional device movement or positioning. For example, a game might track readings from a device's gravity sensor to infer complex user gestures and motions, such as tilt, shake, rotation, or swing. Likewise, a travel application might use the geomagnetic field sensor and accelerometer to report a compass bearing.

The Android platform provides six types of sensors that let you monitor the motion of a device. Three of these sensors are always hardware-based (the accelerometer, magnetometer, and gyroscope), and three of these sensors can be either hardware-based or software-based (the gravity, linear acceleration, and rotation vector sensors). For example, on some devices the software-based sensors derive their data from the accelerometer and magnetometer, but on other devices they may also use the gyroscope to derive their data. Most Android-powered devices have an accelerometer, and many now include a gyroscope. The availability of the software-based sensors is more variable because they often rely on one or more hardware sensors to derive their data.

This tutorial document shows you how to use the sensed motion information to animate the graphics object in your app. There are four sections in this tutorial:

1. **Detecting the Presence of Motion Sensors**: This section teaches how to make the app visible only to the devices that have built in motion sensors.
2. **Adding Motion Sensor Event Listener to an OpenGL ES 2.0 Graphics App**: This section teaches how to make the graphic app receive motion sensor data stream.
3. **Defining and Drawing 3D Shapes**: This section shows how to create a simple 3D cube in OpenGL ES 2.0 environment.
4. **Move the Graphics Objects with Device Motion**: This section teaches how to add the quaternion, which is derived from motion sensor input, to the viewing transformation matrix of the graphics object, so that the object responds to device motion.

Note that the example code in this class is built upon the sample code from the prerequisite class "Displaying Graphics with OpenGL ES" in the Android Training site. Readers are encouraged to go through the link first before continuing this class.

4.1 Detecting the Presence of Motion Sensors

Before we make our Android app respond to motion, we first need to check whether the device is equipped with motion sensors or not. To do so we add the following <user-feature> elements to the manifest file of our app:

```
<uses-feature android:name="android.hardware.sensor.accelerometer" android:required="true" />
<uses-feature android:name="android.hardware.sensor.gyroscope" android:required="true" />
<uses-feature android:name="android.hardware.sensor.compass" android:required="true" />
```

Google Play uses <user-feature> elements to filter the applications that are visible to users, so that users can see and download only those applications which are compatible with their devices. Therefore, by adding the above three lines to the .xml manifest file of your app, Google Play will guarantee that your app will only be installed to the devices that have motion sensors.

For more detailed information about <user-feature> element and manifest file, please go to the "Google Play and Feature-Based Filtering" section in Android Developer site.

Note that although not all the Android-powered devices have built-in gyroscope, it is highly recommended that the motion-based apps run only on those devices which have gyroscopes. The gyroscope captures the rotation movement in high precision, and therefore it is an essential component to derive the rotation vector. The rotation vector derived from only the accelerometer and magnetometer tends to have delayed response and jitte problems.

4.2 Adding Motion Sensor Event Listener to an OpenGL ES 2.0 Graphics App

To register and activate sensors in the Android SensorManager to the OpenGL ES 2.0 app, we modify the code in the following steps:

1. Implement the SensorEventListener interface to the OpenGL ES SurfaceView class,
2. Declare a public variable in GLRenderer class to store sensor data for graphics use,
3. Modify the callback function OnSensorChanged() so that it stores the sensor data to the designated public variable whenever the data is available,
4. Register the sensor that we want to receive data from (in this example we listen to the rotation vector),
5. Activate the registered sensor.

We start by implementing the SensorEventListener interface to the MyGLSurfaceView class, the dedicated surface in our sample code for displaying OpenGL rendering:

```
class MyGLSurfaceView extends GLSurfaceView implements SensorEventListener{

    private final MyGLRenderer mRenderer;
    private SensorManager mSensorManager;
```

The SensorEventListener holds a callback function OnSensorChanged() that will go off whenever sensor data is available. To pass the sensor data to the graphics instance, we declare a public variable `quat` in the MyGLRenderer class

```
    public volatile float[] quat = {1,0,0,0};
```

And modify OnSensorChanged() to store the acquired motion data (in this example we use quaternion to represent the device orientation) in `quat`. After the quaternion has been stored, request the renderer to redraw the frame since the quaternion has been updated. The code will look like this:

```
  @Override
    public void onSensorChanged(SensorEvent event) {
        if(event.sensor.getType() == Sensor.TYPE_ROTATION_VECTOR){
            SensorManager.getQuaternionFromVector(mRenderer.quat, event.values);
            requestRender();
        }
  }
```

For more information about how the rotation vector and quaternion represent the orientation of the device, please check Reference [5] and [6].

Now that SensorEventListener has been implemented, the SensorManager can now be configured to activate Sensors. In the GLSurfaceView constructor get an instance of the SensorManager like this:

```
mSensorManager = (SensorManager) context.getSystemService(Context.SENSOR_SERVICE);
```

The overall constructor will be:

```
    public MyGLSurfaceView(Context context) {
        super(context);
```

```
        // Create an OpenGL ES 2.0 context.
        setEGLContextClientVersion(2);

        // Set the Renderer for drawing on the GLSurfaceView
        mRenderer = new MyGLRenderer();
        setRenderer(mRenderer);

        // Get instance of SensorManager so that sensors can be registered/unregistered
        mSensorManager = (SensorManager)
context.getSystemService(Context.SENSOR_SERVICE);

        // Render the view only when there is a change in the drawing data
        setRenderMode(GLSurfaceView.RENDERMODE_WHEN_DIRTY);
    }
```

The StartSensors() and StopSensors() functions are created in order for the main activity to have control over whether or not the sensors should be activated. The Main Activity should deactivate the sensors whenever it is not running so that power can be saved.

```
    // Only start the sensors when the program is running to save power
    public void startSensors(){
        //get the sensor list
        List<Sensor> listSensors = mSensorManager.getSensorList(Sensor.TYPE_ALL);

        //iterate through sensor list and activate desired sensor
        if (listSensors.size() > 0) {
            for(int i = 0; i<listSensors.size(); i++){
                Sensor itemSensor = listSensors.get(i);

                switch (itemSensor.getType()){

                case Sensor.TYPE_ROTATION_VECTOR:
                    //Activate only the Invensense's sensor
                    if(itemSensor.getVendor().equals("Invensense")){
                        mSensorManager.registerListener(this, itemSensor,
                                SensorManager.SENSOR_DELAY_GAME);
                    }
                    break;
                default:
                    break;
                }
            }
        }

    }

    // Stop the sensors if they are not needed to save power.
    public void stopSensors(){
        mSensorManager.unregisterListener(this);
```

```
    }
```

Grabbing the sensor list with the mSensorManager.getSensorList(Sensor.*TYPE_ALL*); function call will return a list of the available sensors that can be used. Each type of phone may have varying sensors so it is a good practice to look through this list and view at what sensors are available.

When the mSensorManager.registerListener function call is called one parameter to highlight is the data rate that the sensor will be set to. The available data rates that the sensors can be set to are:

int	SENSOR_DELAY_FASTEST	get sensor data as fast as possible (100 HZ)
int	SENSOR_DELAY_GAME	rate suitable for games (50HZ)
int	SENSOR_DELAY_NORMAL	rate (default) suitable for screen orientation changes (5HZ)
int	SENSOR_DELAY_UI	rate suitable for the user interface (15HZ)

When activating the TYPE_ROTATION_VECTOR sensor it is possible that there can be more than one implementation of this type. To guarantee the performance it is recommended to check the vendor info by function getVendor() to ensure that the sensor data comes from the desired vendor. In this example we use the Rotation Vector from InvenSense.

The Main Activity can now be modified to start and stop the sensors in this class whenever it needs to.

```
    @Override
    protected void onPause() {
        super.onPause();
        mGLView.stopSensors();

        // The following call pauses the rendering thread.
        // If your OpenGL application is memory intensive,
        // you should consider de-allocating objects that
        // consume significant memory here.
        mGLView.onPause();
    }

    @Override
    protected void onResume() {
        super.onResume();
        // The following call resumes a paused rendering thread.
        // If you de-allocated graphic objects for onPause()
        // this is a good place to re-allocate them.
        mGLView.onResume();
        mGLView.startSensors();

}
```

4.3 Defining and Drawing 3D Shapes

Now that we have linked the motion sensor to the graphics Surface View, the next step is to extend the 2D square object in the OpenGL ES example code to 3D cube, and make it respond to the 3D motion. Defining a 3D cube will be exactly like defining a square except that it will require more coordinates and the drawOrder will increase. Like the square, only the 8 corners of the square will need to be defined since the points can be reused to define all of the triangles. Here's the code for the cube:

```
class Cube {

    private final FloatBuffer vertexBuffer;
    private final ShortBuffer drawListBuffer;

    // number of coordinates per vertex in this array
    static final int COORDS_PER_VERTEX = 3;
    static float cubeCoords[] = {   //FRONT FACE
                                   -0.25f,  0.25f, 0.25f,   // top left
                                   -0.25f, -0.25f, 0.25f,   // bottom left
                                    0.25f, -0.25f, 0.25f,   // bottom right
                                    0.25f,  0.25f, 0.25f,     // top right
                                    //BACK FACE
                                    -0.25f,  0.25f, -0.25f,   // top left
                                    -0.25f, -0.25f, -0.25f,   // bottom left
                                     0.25f, -0.25f, -0.25f,   // bottom right
                                     0.25f,  0.25f, -0.25f }; // top right

    private final short drawOrder[] = { 0, 1, 2, 0, 2, 3,  //front
                                        4, 7, 6 , 6, 5, 4,//back
                                        0, 4, 5, 5, 1, 0, //Left
                                        3, 2, 6, 6, 7, 3, //Right
                                        1, 5, 6, 6, 2, 1, //Bottom
                                        0, 3, 7, 7, 4, 0}; // order to draw vertices

    public Cube() {
        // initialize vertex byte buffer for shape coordinates
        ByteBuffer bb = ByteBuffer.allocateDirect(
        // (# of coordinate values * 4 bytes per float)
                cubeCoords.length * 4);
        bb.order(ByteOrder.nativeOrder());
        vertexBuffer = bb.asFloatBuffer();
        vertexBuffer.put(cubeCoords);
        vertexBuffer.position(0);

        // initialize byte buffer for the draw list
        ByteBuffer dlb = ByteBuffer.allocateDirect(
        // (# of coordinate values * 2 bytes per short)
                drawOrder.length * 2);
        dlb.order(ByteOrder.nativeOrder());
        drawListBuffer = dlb.asShortBuffer();
        drawListBuffer.put(drawOrder);
```

```
        drawListBuffer.position(0);
    }
```

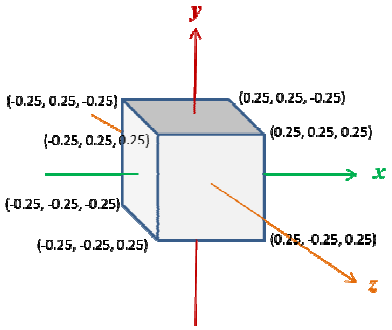


Figure 1. The cube object defined in this example

If we are to follow the square's draw method the cube will end up having one color and becoming flat. To avoid this 6 different face colors can be declared and whenever the draw function is called each of those faces can have a different color set.

```
    // Declare different face colors for each of the faces
    float color1[] = { 0.8f, 0.0f, 0.0f, 1.0f };
    float color2[] = { 0.0f, 0.8f, 0.0f, 1.0f };
    float color3[] = { 0.0f, 0.0f, 0.8f, 1.0f };
    float color4[] = { 0.8f, 0.8f, 0.0f, 1.0f };
    float color5[] = { 0.8f, 0.0f, 0.8f, 1.0f };
    float color6[] = { 0.0f, 0.8f, 0.8f, 1.0f };
```

CULL_FACE is enabled so that OpenGL is able to differentiate whether a drawn face is facing forward or backward. Without setting CULL_FACE the faces will be drawn in order and some of the faces will look like they are in front of one face when in reality they are the opposite.

```
GLES20.glEnable(GLES20.GL_CULL_FACE);  // for determining whether shape is front facing
```

In the cube's draw function ensure that each color is set every time and that each face is treated as a separate draw case. The example code can be seen here:

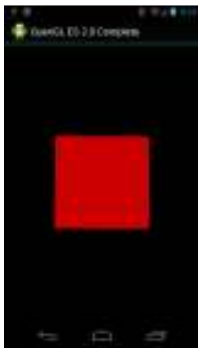
```
        //draw the cube
        //each face will be drawn separately with different colors
        drawListBuffer.position(0);
        GLES20.glUniform4fv(mColorHandle, 1, color1, 0);
        GLES20.glDrawElements(GLES20.GL_TRIANGLES, drawOrder.length/6,
                              GLES20.GL_UNSIGNED_SHORT, drawListBuffer);

        GLES20.glUniform4fv(mColorHandle, 1, color2, 0);
        drawListBuffer.position(6);
        GLES20.glDrawElements(GLES20.GL_TRIANGLES, drawOrder.length/6,
                              GLES20.GL_UNSIGNED_SHORT, drawListBuffer);
```

```
        GLES20.glUniform4fv(mColorHandle, 1, color3, 0);
        drawListBuffer.position(12);
        GLES20.glDrawElements(GLES20.GL_TRIANGLES, drawOrder.length/6,
                              GLES20.GL_UNSIGNED_SHORT, drawListBuffer);

        GLES20.glUniform4fv(mColorHandle, 1, color4, 0);
        drawListBuffer.position(18);
        GLES20.glDrawElements(GLES20.GL_TRIANGLES, drawOrder.length/6,
                              GLES20.GL_UNSIGNED_SHORT, drawListBuffer);

        GLES20.glUniform4fv(mColorHandle, 1, color5, 0);
        drawListBuffer.position(24);
        GLES20.glDrawElements(GLES20.GL_TRIANGLES, drawOrder.length/6,
                              GLES20.GL_UNSIGNED_SHORT, drawListBuffer);

        GLES20.glUniform4fv(mColorHandle, 1, color6, 0);
        drawListBuffer.position(30);
        GLES20.glDrawElements(GLES20.GL_TRIANGLES, drawOrder.length/6,
                              GLES20.GL_UNSIGNED_SHORT, drawListBuffer);
```

In order to draw this cube onto the buffer the onDrawFrame can be modified to call the Cube's draw function. After the Cube object has been initialized that onDrawFrame will look like this:

```
@Override
    public void onDrawFrame(GL10 unused) {

        // Draw background color
        GLES20.glClear(GLES20.GL_COLOR_BUFFER_BIT);

        // Set the camera position (View matrix)
        Matrix.setLookAtM(mVMatrix, 0, 0, 0, 3, 0f, 0f, 0f, 0f, 1.0f, 0.0f);

        // Calculate the projection and view transformation
        Matrix.multiplyMM(mMVPMatrix, 0, mProjMatrix, 0, mVMatrix, 0);

        mCube.draw(mMVPMatrix);
    }
```

The result of this will be a cube with no movement:



4.4 Move the Graphics Objects with Device Motion

We have connected the sensor data stream into our app, and we have created a 3D object in the Surface View. The last step is to make the 3D cube rotate based on the received motion sensor data. We do so by modifying the OnDrawFrame() function. The main operation in the callback function OnDrawFrame() is to calculate the transformation matrix that projects the 3D coordinates of the drawn objects onto the display surface. To make the drawn object respond to the device orientation, we simply add one more transformation matrix to rotate the viewport based on the device's actual orientation, which is indicated by the quaternion data that we derived from the rotation vector that SensorManager gives us:

```
@Override
    public void onDrawFrame(GL10 unused) {

        // Draw background color
        GLES20.glClear(GLES20.GL_COLOR_BUFFER_BIT);

        // Set the camera position (View matrix)
        Matrix.setLookAtM(mVMatrix, 0, 0, 0, 3, 0f, 0f, 0f, 0f, 1.0f, 0.0f);

        // Calculate the projection and view transformation
        Matrix.multiplyMM(mMVPMatrix, 0, mProjMatrix, 0, mVMatrix, 0);

        Matrix.setRotateM(mRotationMatrix, 0,
                (float) (2.0f * Math.acos(quat[0]) * 180.0f / Math.PI),
               quat[1], quat[2], quat[3]);

        Matrix.multiplyMM(mMVPMatrix, 0, mRotationMatrix, 0, mMVPMatrix, 0);
         mCube.draw(mMVPMatrix);
      }

    @Override
    public void onSurfaceChanged(GL10 unused, int width, int height) {
        // Adjust the viewport based on geometry changes,
        // such as screen rotation
        GLES20.glViewport(0, 0, width, height);

        float ratio = (float) width / height;

        // this projection matrix is applied to object coordinates
        // in the onDrawFrame() method
```

```
        Matrix.frustumM(mProjMatrix, 0, -ratio, ratio, -1, 1, 3, 20);

    }
```

For more information about how to convert quaternion to rotation matrix, please check Reference [5].

The cube can now move smoothly with the device's movement and the 3D cube can be viewed with different face colors.

5. Reference

[1] http://developer.android.com/training/graphics/opengl/index.html
[2] http://developer.android.com/guide/topics/graphics/opengl.html
[3] http://developer.android.com/guide/topics/sensors/index.html
[4] http://developer.android.com/index.html
[5] http://en.wikipedia.org/wiki/Quaternions_and_spatial_rotation
[6] http://developer.android.com/guide/topics/sensors/sensors_motion.html#sensors-motion-rotate
[7] http://developer.android.com/training/graphics/opengl/projection.html