Android Sensor Programming

- Arindam Ghosh

Sensing and Sensors

- *a capability that can capture measurements about the device and its external environment*

- Can detects and responds to some type of input from the physical environment.

- The specific input could be light, heat, motion, moisture, pressure, etc.

- Convert the measurement into a signal that can be read.

Example Sensor Data

1|MPU6500 **Acceleration Sensor**|[-1.6741456,9.370906,2.6886885]|**1441670212915**

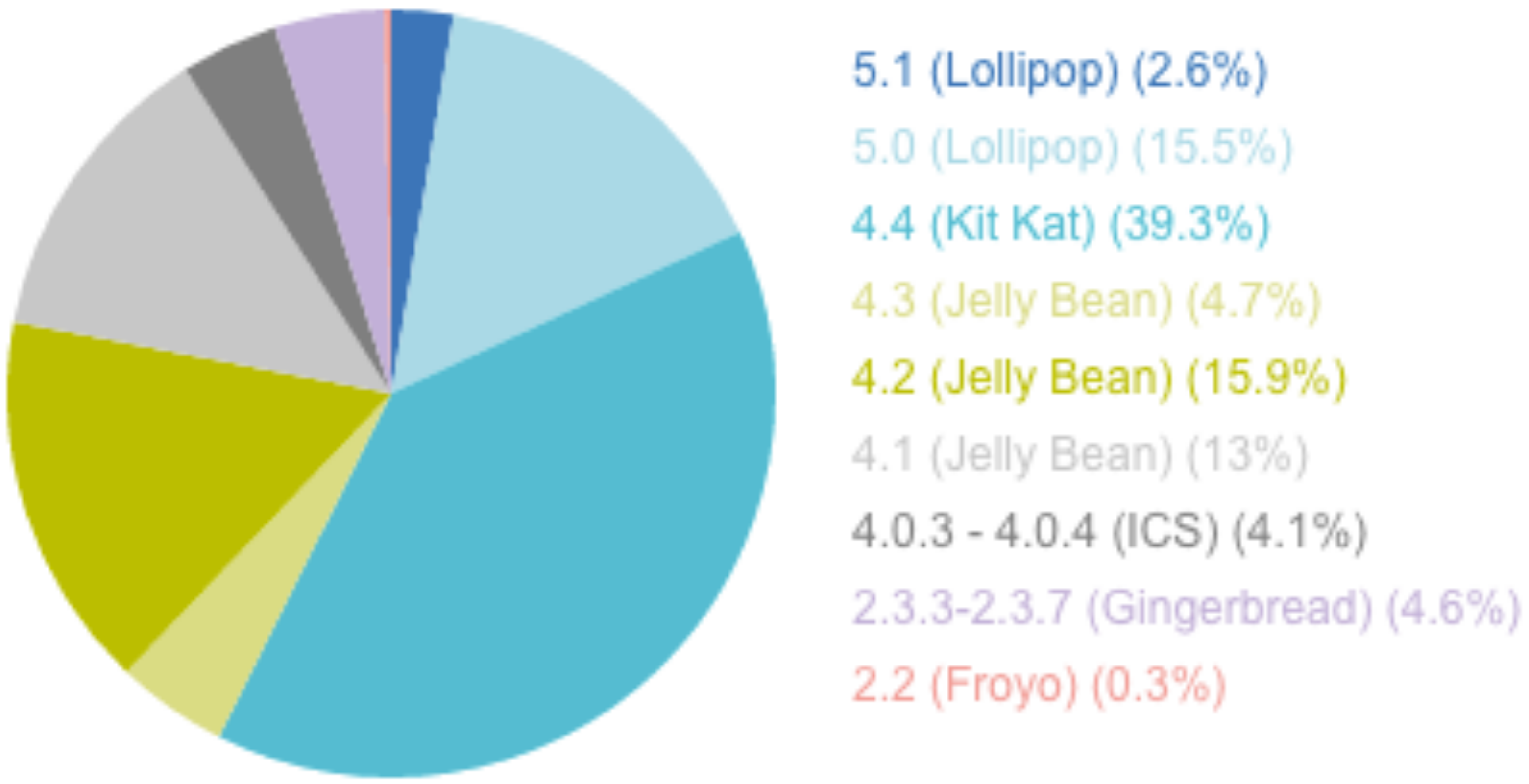
1|MPU6500 **Gyroscope Sensor**|[-0.02263687,-0.016777916,-0.008788432]|**1441670213508**

1|AK09911C **Magnetic field Sensor**|[16.86,-64.26,-62.7]|**1441670213400**

1|**GPS**|{"mProvider":"fused","mResults":[0.0,0.0],"mAccuracy":29.0,"mAltitude":83.0," ,"mLatitude":40.748431", mLongitude":73.985741 … }|**1441573552851**

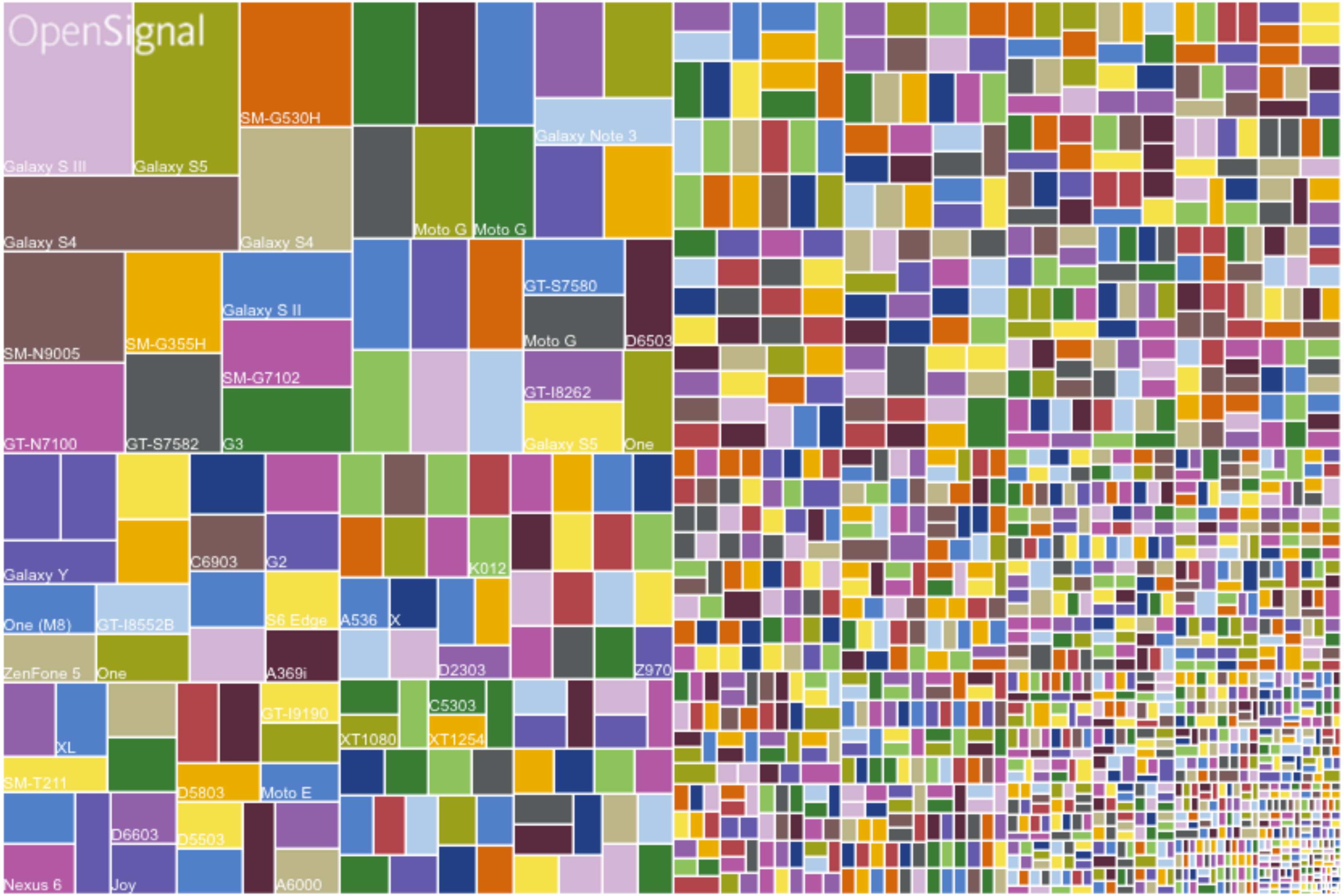
1|**WiFi**|{"BSSID":"00:21:6c:87:02:d1","SSID":"eduroam","capabilities":"[WPA2-EAP-CCMP]","frequency": 2462,"level":-82}|**1392465248466**

Android OS Fragmentation



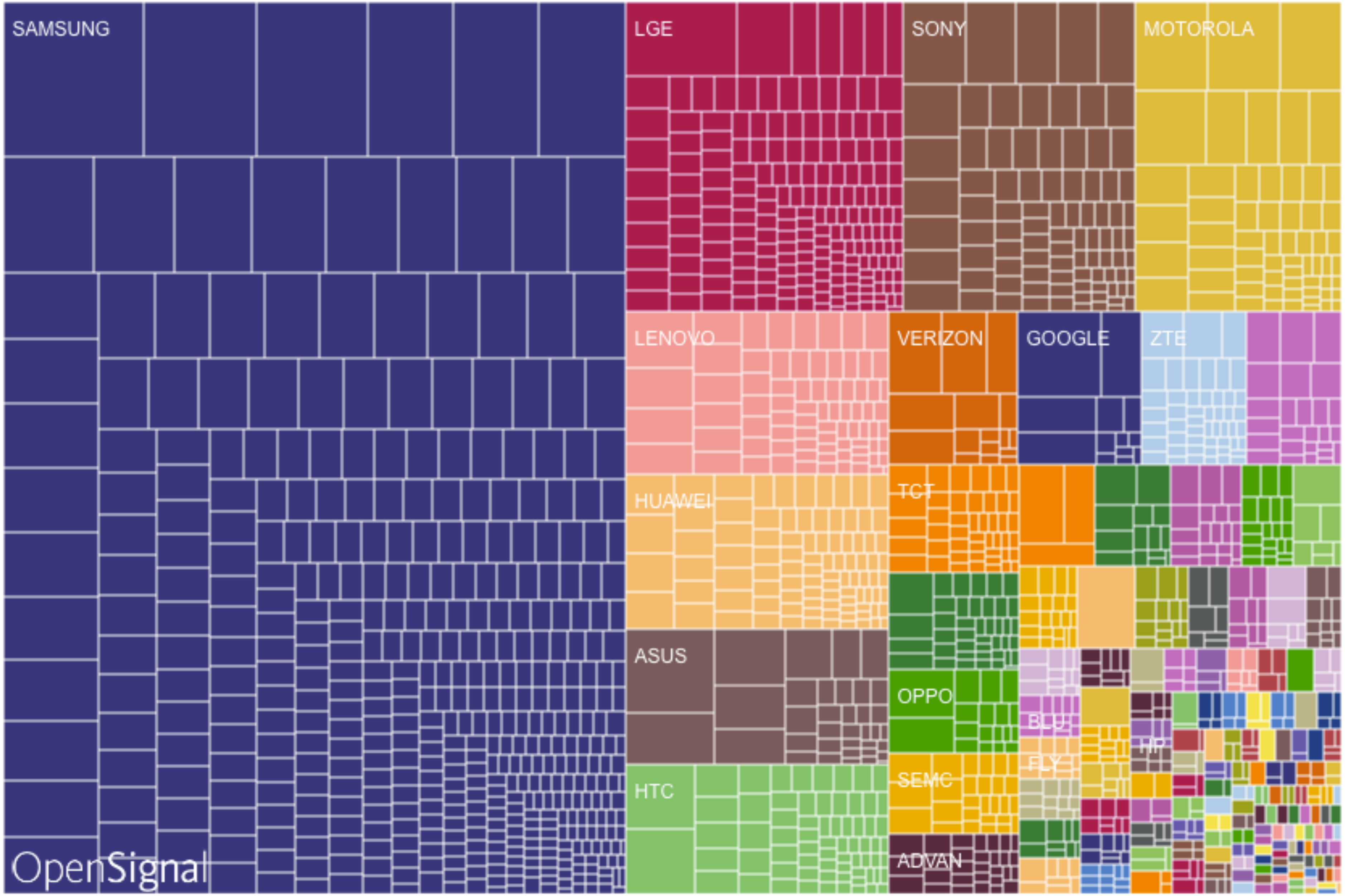
http://opensignal.com/reports/2015/08/android-fragmentation/

DEVICE FRAGMENTATION



http://opensignal.com/reports/2015/08/android-fragmentation/

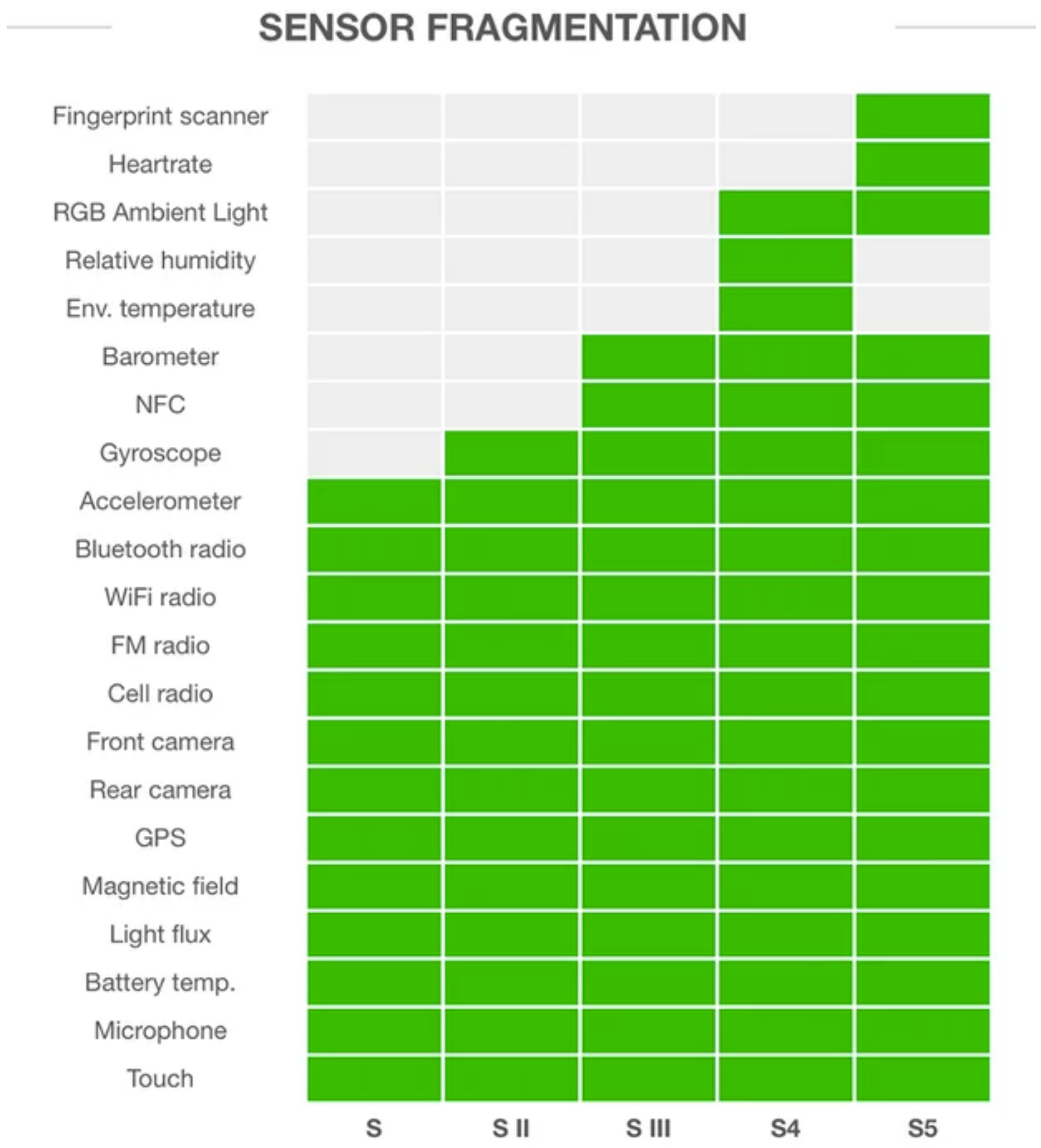
BRAND FRAGMENTATION



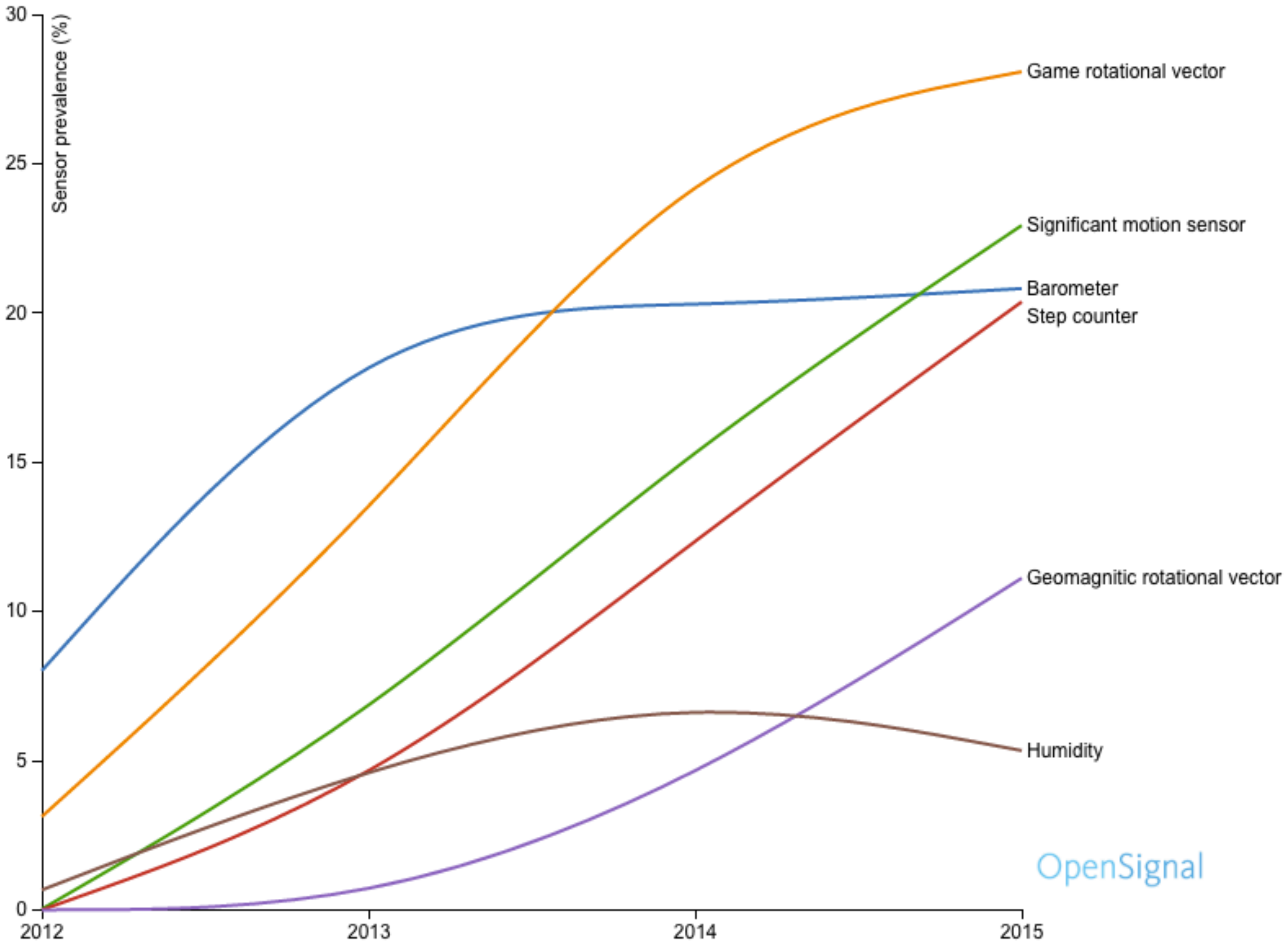
http://opensignal.com/reports/2015/08/android-fragmentation/

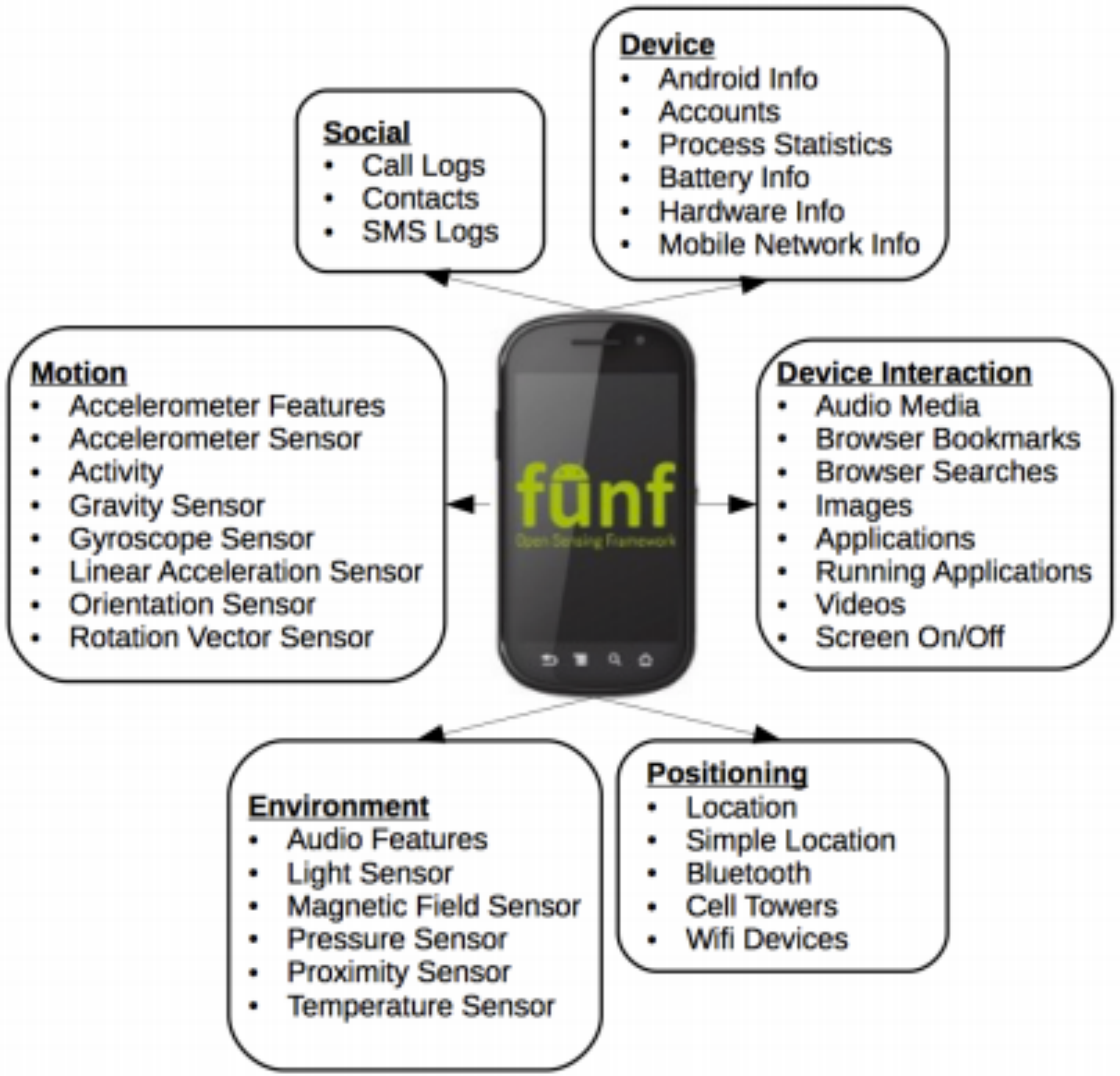
Sensor Availability

- Varies from device to device
- May vary between Android versions



Newer Sensors Over Time





Social
Call Logs
Contacts
SMS Logs
Device
Android Info
Accounts
Process Statistics
Battery Info
Hardware Info
Mobile Network Info
Motion
Accelerometer Features
Accelerometer Sensor
Activity
Gravity Sensor
Gyroscope Sensor
Linear Acceleration Sensor
Orientation Sensor
Rotation Vector Sensor
funf
Device Interaction
Audio Media
Browser Bookmarks
Browser Searches
Images
Applications
Running Applications
Videos
Screen On/Off
Environment
Audio Features
Light Sensor
Magnetic Field Sensor
Pressure Sensor
Proximity Sensor
Temperature Sensor
Positioning
Location
Simple Location
Bluetooth
Cell Towers
Wifi Devices

Sensors

- **Position sensors**

  GPS, orientation sensors and magnetometers.

- **Motion sensors**

  accelerometers, gravity sensors, gyroscopes, etc.

- **Environmental sensors**

  barometers, photometers, and thermometers.

Sensor Framework

Access sensors and and acquire raw sensor data.

- Determine which sensors are available on a device.
- Determine an individual sensor's capabilities, such as its maximum range, manufacturer, power requirements, and resolution.
- Acquire raw sensor data and define the minimum rate at which you acquire sensor data.
- Register and unregister sensor event listeners that monitor sensor changes.

Sensors

- Hardware-based or Software-based
- Hardware-based sensors - physical components built into a handset or tablet device
  - directly measuring specific environmental properties.
    - acceleration, geomagnetic field strength, or angular change.
- Software-based sensors - mimic hardware-based sensors
  - derive their data from one or more of the hardware-based sensors and are sometimes called virtual sensors or synthetic sensors.
    - The linear acceleration sensor and the gravity sensor.

Sensor Framework

Access sensors and and acquire raw sensor data.

Android Sensor Framework includes three classes and one interface.

- SensorManager
- Sensor
- SensorEvent
- SensorEventListener

- Identifying sensors and sensor capabilities
- Monitor sensor events

http://developer.android.com/guide/topics/sensors/sensors_overview.html

```
public class SensorActivity extends Activity, implements SensorEventListener {
    private final SensorManager mSensorManager;
    private final Sensor mAccelerometer;

    public SensorActivity() {
        mSensorManager = (SensorManager)getSystemService(SENSOR_SERVICE);          1
        mAccelerometer = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
    }

    protected void onResume() {          2
        super.onResume();
        mSensorManager.registerListener(this, mAccelerometer, SensorManager.SENSOR_DELAY_NORMAL);
    }

    protected void onPause() {          5
        super.onPause();
        mSensorManager.unregisterListener(this);
    }

    public void onAccuracyChanged(Sensor sensor, int accuracy) {          3
    }

    public void onSensorChanged(SensorEvent event) {          4
    }
}
```

SensorManager

- System Service that manages sensors

```
public SensorActivity() {
    mSensorManager = (SensorManager)getSystemService(SENSOR_SERVICE);
    mAccelerometer = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
}
```

1

- First the application needs to get a reference to the SensorManager
  - *getSystemService(SENSOR_SERVICE);*

- Access a specific sensor with
  - SensorManager.getDefaultSensor(int type)

Sensor

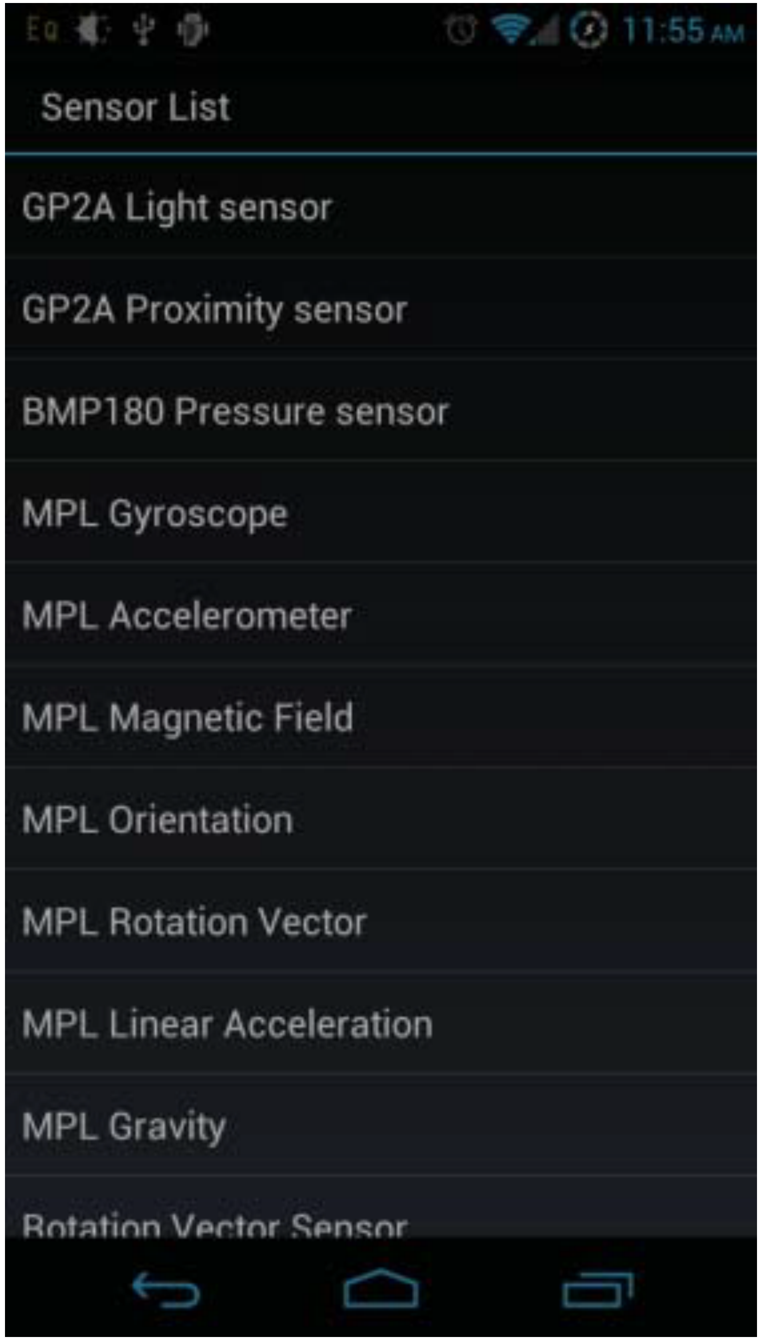
```
public SensorActivity() {
    mSensorManager = (SensorManager)getSystemService(SENSOR_SERVICE);
    mAccelerometer = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
}
```

1

- Accelerometer
  - Sensor.TYPE_ACCELEROMETER
- Magnetic Field
  - Sensor.TYPE_MAGNETIC_FIELD
- Pressure
  - Sensor.TYPE_PRESSURE

Get a List of All Sensors

```
SensorManager sensorManager =
        (SensorManager) getActivity().getSystemService(
                Activity.SENSOR_SERVICE);
List<Sensor> sensors = sensorManager.getSensorList(Sensor.TYPE_ALL);
```



SensorEventListener

- For an application to receive information from a Sensor
  - It needs to implement a SensorEventListener
  - Before starting to receive sensorEvents

```
protected void onResume() {        2
    super.onResume();
    mSensorManager.registerListener(this, mAccelerometer, SensorManager.SENSOR_DELAY_NORMAL);
}
```

  - Type of Sensor
  - Delay

SensorEventListener

registerListener

```
boolean registerListener (SensorEventListener listener,
                Sensor sensor,
                int samplingPeriodUs)
```

listener	SensorEventListener: A SensorEventListener object.
sensor	Sensor: The Sensor to register to.
samplingPeriodUs	int: The rate sensor events are delivered at. This is only a hint to the system. Events may be received faster or slower than the specified rate. Usually events are received faster. The value must be one of SENSOR_DELAY_NORMAL, SENSOR_DELAY_UI, SENSOR_DELAY_GAME, or SENSOR_DELAY_FASTEST or, the desired delay between events in microseconds. Specifying the delay in microseconds only works from Android 2.3 (API level 9) onwards. For earlier releases, you must use one of the SENSOR_DELAY_* constants.

SensorDelay

SENSOR_DELAY_FASTEST

`int SENSOR_DELAY_FASTEST`

get sensor data as fast as possible

Constant Value: 0 (0x00000000)

SENSOR_DELAY_UI

`int SENSOR_DELAY_UI`

rate suitable for the user interface

Constant Value: 2 (0x00000002)

SENSOR_DELAY_GAME

`int SENSOR_DELAY_GAME`

rate suitable for games

Constant Value: 1 (0x00000001)

SENSOR_DELAY_NORMAL

`int SENSOR_DELAY_NORMAL`

rate (default) suitable for screen orientation changes

Constant Value: 3 (0x00000003)

SensorEventListener

registerListener

```
boolean registerListener (SensorEventListener listener,
                Sensor sensor,
                int samplingPeriodUs,
                Handler handler)
```

`handler`	`Handler`: The `Handler` the `sensor events` will be delivered to.

SensorEventListener

registerListener

```
boolean registerListener (SensorEventListener listener,
                Sensor sensor,
                int samplingPeriodUs,
                int maxReportLatencyUs,
                Handler handler)
```

`maxReportLatencyUs`	`int`: Maximum time in microseconds that events can be delayed before being reported to the application. A large value allows reducing the power consumption associated with the sensor. If maxReportLatencyUs is set to zero, events are delivered as soon as they are available, which is equivalent to calling `registerListener(SensorEventListener, Sensor, int)`.

SensorEventListener

- For an application to receive information from a Sensor
  - It needs to implement a SensorEventListener
    - Invoked when accuracy of a sensor changes
    - When the sensor acquires a new reading

abstract void	onAccuracyChanged (Sensor sensor, int accuracy) Called when the accuracy of the registered sensor has changed.
abstract void	onSensorChanged (SensorEvent event) Called when sensor values have changed.

onAccuracyChanged

```
public void onAccuracyChanged(Sensor sensor, int accuracy) {    3
}
```

- Accuracy is represented by one of four status constants:
  - SENSOR_STATUS_UNRELIABLE
    - Constant Value: 0 (0x00000000)
  - SENSOR_STATUS_ACCURACY_LOW,
    - Constant Value: 1 (0x00000001)
  - SENSOR_STATUS_ACCURACY_MEDIUM,
    - Constant Value: 2 (0x00000002)
  - SENSOR_STATUS_ACCURACY_HIGH,
    - Constant Value: 3 (0x00000003)

https://developer.android.com/reference/android/hardware/SensorManager.html

onAccuracyChanged

```
public void onAccuracyChanged(Sensor sensor, int accuracy) {
        // Do something here if sensor accuracy changes.
        // You must implement this callback in your code.
        if (sensor == mValuen) {
            switch (accuracy) {
                case 0:
                    System.out.println("Unreliable");
                    con=0;
                    break;
                case 1:
                    System.out.println("Low Accuracy");
                    con=0;
                    break;
                case 2:
                    System.out.println("Medium Accuracy");
                    con=0;

                    break;
                case 3:
                    System.out.println("High Accuracy");
                    con=1;
                    break;
            }
        }
    }
```

onSensorChanged

```
public void onSensorChanged(SensorEvent se) {
  float x = se.values[0];
  float y = se.values[1];
  float z = se.values[2];
  mAccelLast = mAccelCurrent;
  mAccelCurrent = (float) Math.sqrt((double) (x*x + y*y + z*z));
  float delta = mAccelCurrent - mAccelLast;
  mAccel = mAccel * 0.9f + delta; // perform low-cut filter
}
```

onSensorChanged

```
public void onSensorChanged(SensorEvent event) {
    if (event.sensor.getType() == Sensor.TYPE_MAGNETIC_FIELD)
        magnetic = event.values;
    if (event.sensor.getType() == Sensor.TYPE_ACCELEROMETER)
        gravity = event.values;
    if ((gravity == null) || (magnetic == null))
        return;
```

SensorEventListener

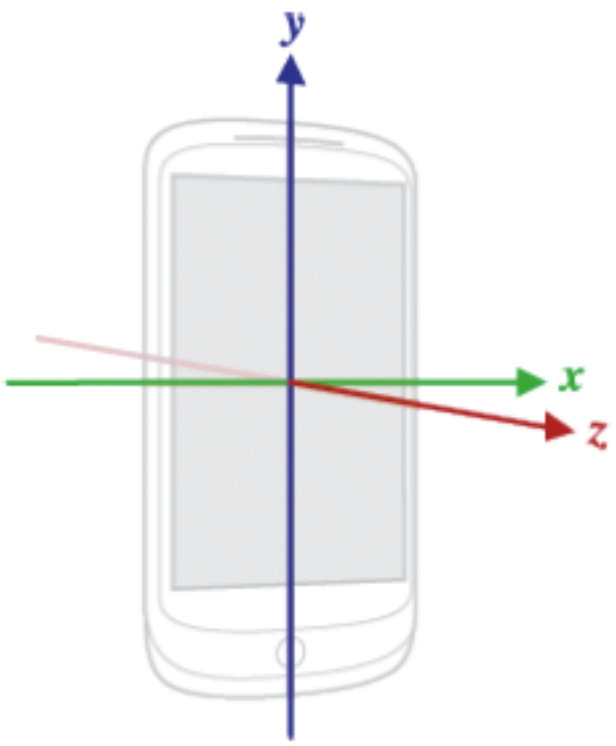
- Once you are done Using the Sensor

```
protected void onPause() {
    super.onPause();
    mSensorManager.unregisterListener(this);
}
```

```
public class SensorActivity extends Activity, implements SensorEventListener {
    private final SensorManager mSensorManager;
    private final Sensor mAccelerometer;

    public SensorActivity() {
        mSensorManager = (SensorManager)getSystemService(SENSOR_SERVICE);        1
        mAccelerometer = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
    }

    protected void onResume() {             2
        super.onResume();
        mSensorManager.registerListener(this, mAccelerometer, SensorManager.SENSOR_DELAY_NORMAL);
    }

    protected void onPause() {
        super.onPause();                    5
        mSensorManager.unregisterListener(this);
    }

    public void onAccuracyChanged(Sensor sensor, int accuracy) {    3
    }

    public void onSensorChanged(SensorEvent event) {            4
    }
}
```

Sensor Coordinate System

- The sensor framework uses a standard 3-axis coordinate system to express data values.
  - **X axis** is horizontal and points to the right
  - **Y axis** is vertical and points up
  - **Z axis** points toward the outside of the screen face
    - coordinates behind the screen have negative values



Sensor Coordinate System

Such a coordinate system is used by:

- Acceleration sensor
- Gravity sensor
- Gyroscope
- Linear acceleration sensor
- Geomagnetic field sensor

Points to Remember

- Your application must not assume that a device's natural (default) orientation is portrait.
  - The sensor coordinate system is always based on the natural orientation of a device.
  - The natural orientation for many tablet devices is landscape.

- Verify sensors before you use them
  - Verify that a sensor exists on a device before you attempt to acquire data from it
    The sensor's coordinate system never changes as the device moves

- You must test your sensor code on a physical device.
  - You currently can't test sensor code on the emulator because the emulator cannot emulate sensors.
  - There are, however, sensor simulators that you can use to simulate sensor output.

Verify sensors before you use them

```
private SensorManager mSensorManager;
...
mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
if (mSensorManager.getDefaultSensor(Sensor.TYPE_PRESSURE) != null){
// Success! There's a pressure sensor.
}
else {
// Failure! No pressure sensor.
}
```

If you are publishing your application on Google Play you can
use the <uses-feature> element in your manifest file
to filter your application from devices that
do not have the appropriate sensor configuration for your application.

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

Points to Remember

- Unregister sensor listeners
  - when you are done using the sensor or when the sensor activity pauses.
  - If a sensor listener is registered and its activity is paused, the sensor will continue to acquire data and use battery resources unless you unregister the sensor.

- Don't block the onSensorChanged() method
  - Sensor data can change at a high rate - system may call the onSensorChanged(SensorEvent) method quite often
  - Do as little as possible within the onSensorChanged(SensorEvent) method so you don't block it

- Choose sensor delays wisely
  - Sensors can provide data at very high rates.
  - Sending extra data that you don't need wastes system resources and uses battery power.

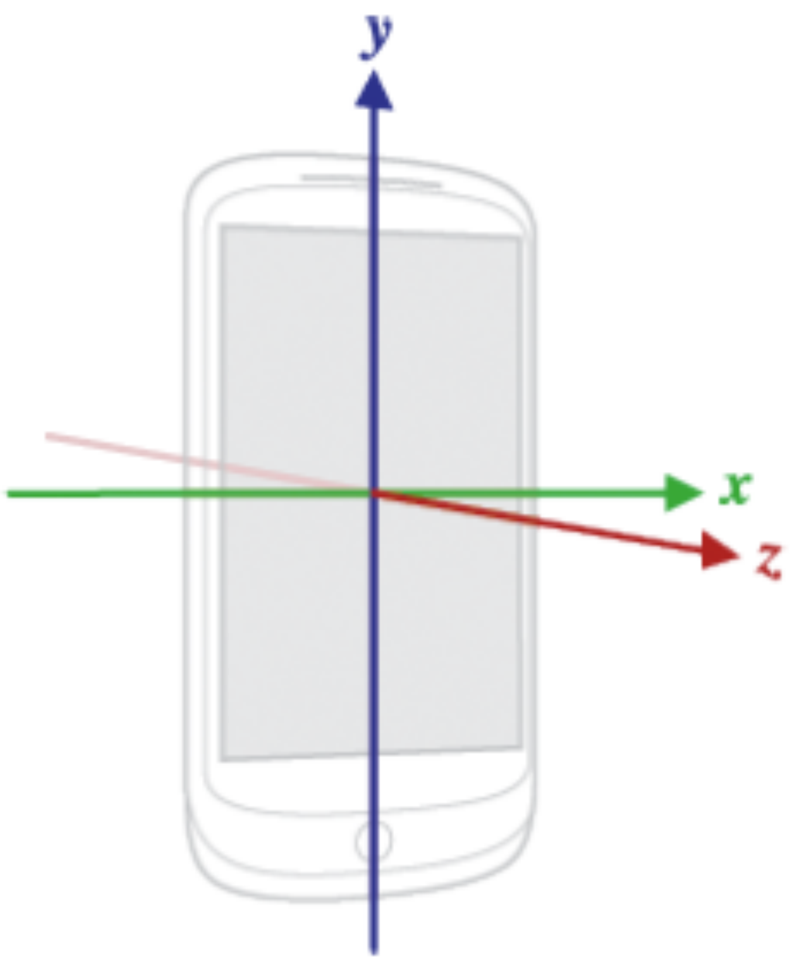
Orientation Sensors

- **TYPE_ACCELEROMETER** uses the accelerometer and only the accelerometer. It returns raw accelerometer events, with minimal or no processing at all.

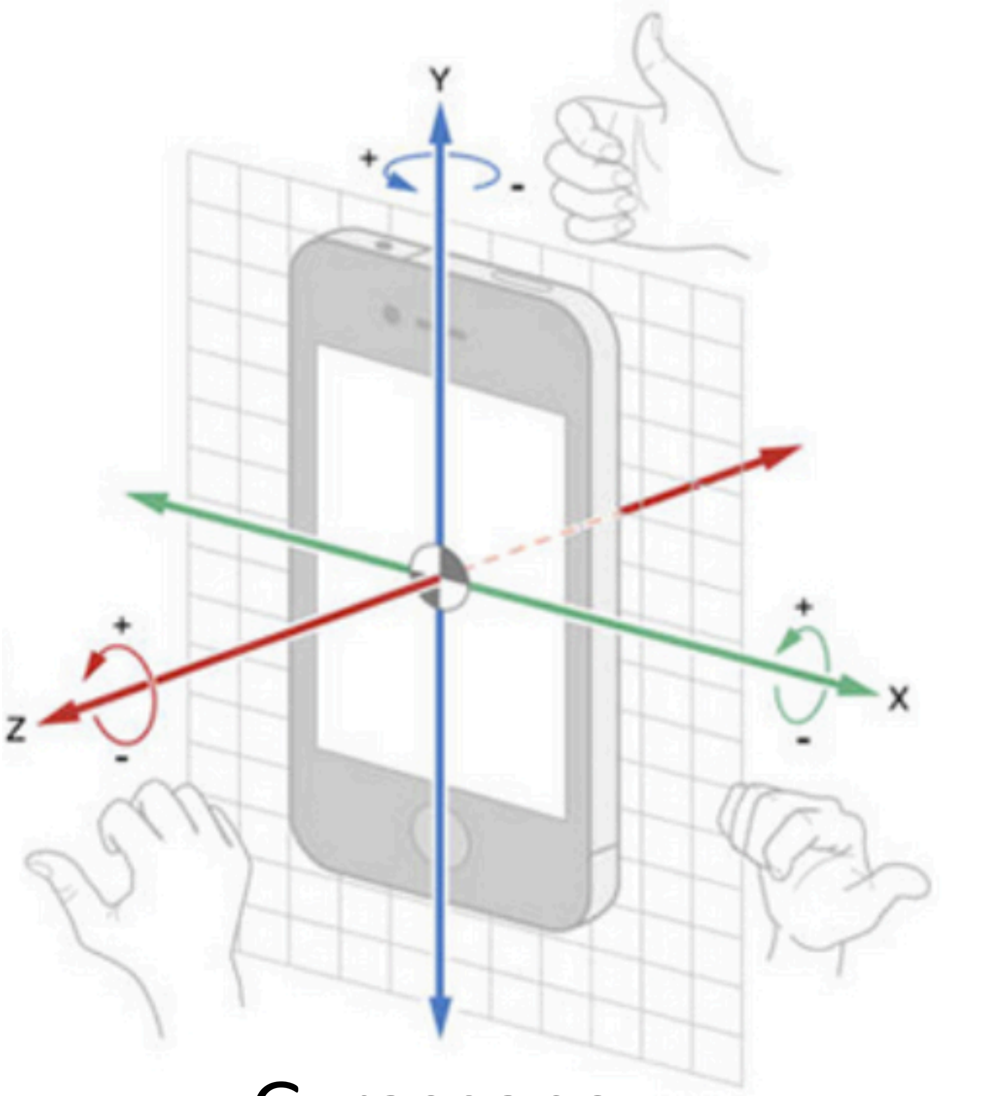
- **TYPE_LINEAR_ACCELERATION** (if present) uses the gyroscope and only the gyroscope. Like above, it returns raw events (angular speed un rad/s) with no processing at all (no offset / scale compensation).

- **TYPE_ORIENTATION** is deprecated. It returns the orientation as yaw/ pitch/roll in degrees.
  - This sensor uses a combination of the accelerometer and the magnetometer.
  - Marginally better results can be obtained using SensorManager's helpers.
  - This sensor is heavily "processed".

Orientations



Accelerometer



Gyroscope

Orientation Sensors

TYPE_ACCELEROMETER	SensorEvent.values[0]	Acceleration force along the x axis (including gravity).	m/s^2
	SensorEvent.values[1]	Acceleration force along the y axis (including gravity).	
	SensorEvent.values[2]	Acceleration force along the z axis (including gravity).	
TYPE_GRAVITY	SensorEvent.values[0]	Force of gravity along the x axis.	m/s^2
	SensorEvent.values[1]	Force of gravity along the y axis.	
	SensorEvent.values[2]	Force of gravity along the z axis.	
TYPE_GYROSCOPE	SensorEvent.values[0]	Rate of rotation around the x axis.	rad/s
	SensorEvent.values[1]	Rate of rotation around the y axis.	
	SensorEvent.values[2]	Rate of rotation around the z axis.	

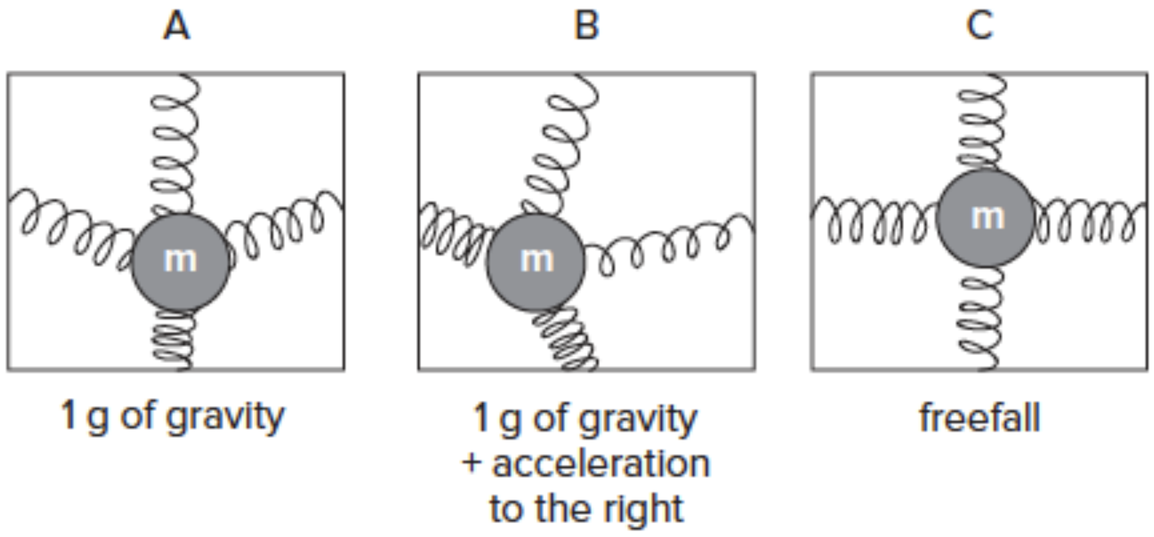
Orientation Sensors.

- **TYPE_LINEAR_ACCELERATION, TYPE_GRAVITY, TYPE_ROTATION_VECTOR** are "fused" sensors which return respectively
  - the linear acceleration,
  - gravity and
  - rotation vector (a quaternion).
  - On some devices they are implemented in h/w,
  - On some devices they use the accelerometer + the magnetometer
  - On some other devices they use the gyro.

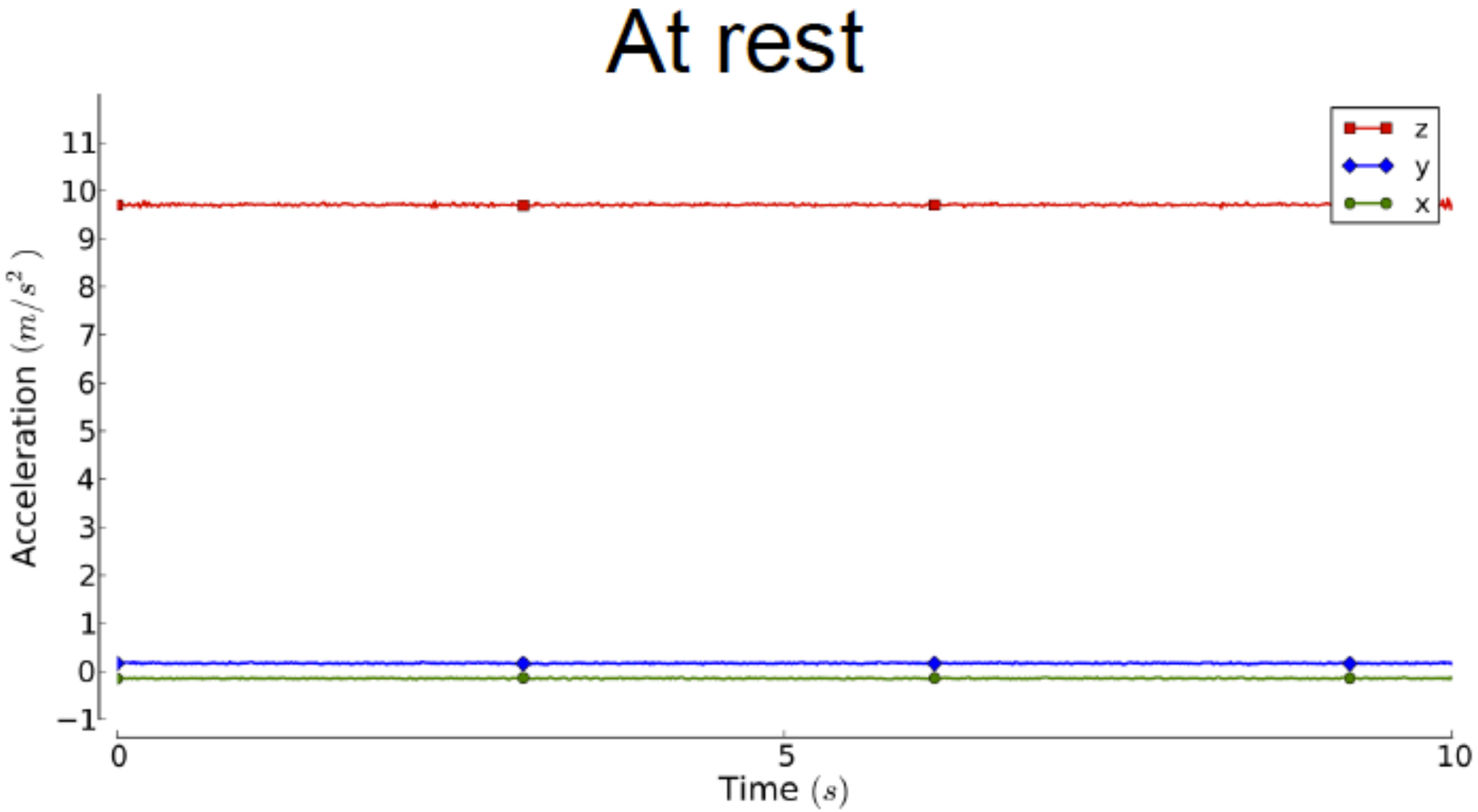
TYPE_LINEAR_ACCELERATION	`SensorEvent.values[0]`	Acceleration force along the x axis (excluding gravity).	m/s^2
	`SensorEvent.values[1]`	Acceleration force along the y axis (excluding gravity).	
	`SensorEvent.values[2]`	Acceleration force along the z axis (excluding gravity).	

TYPE_ACCELEROMETER

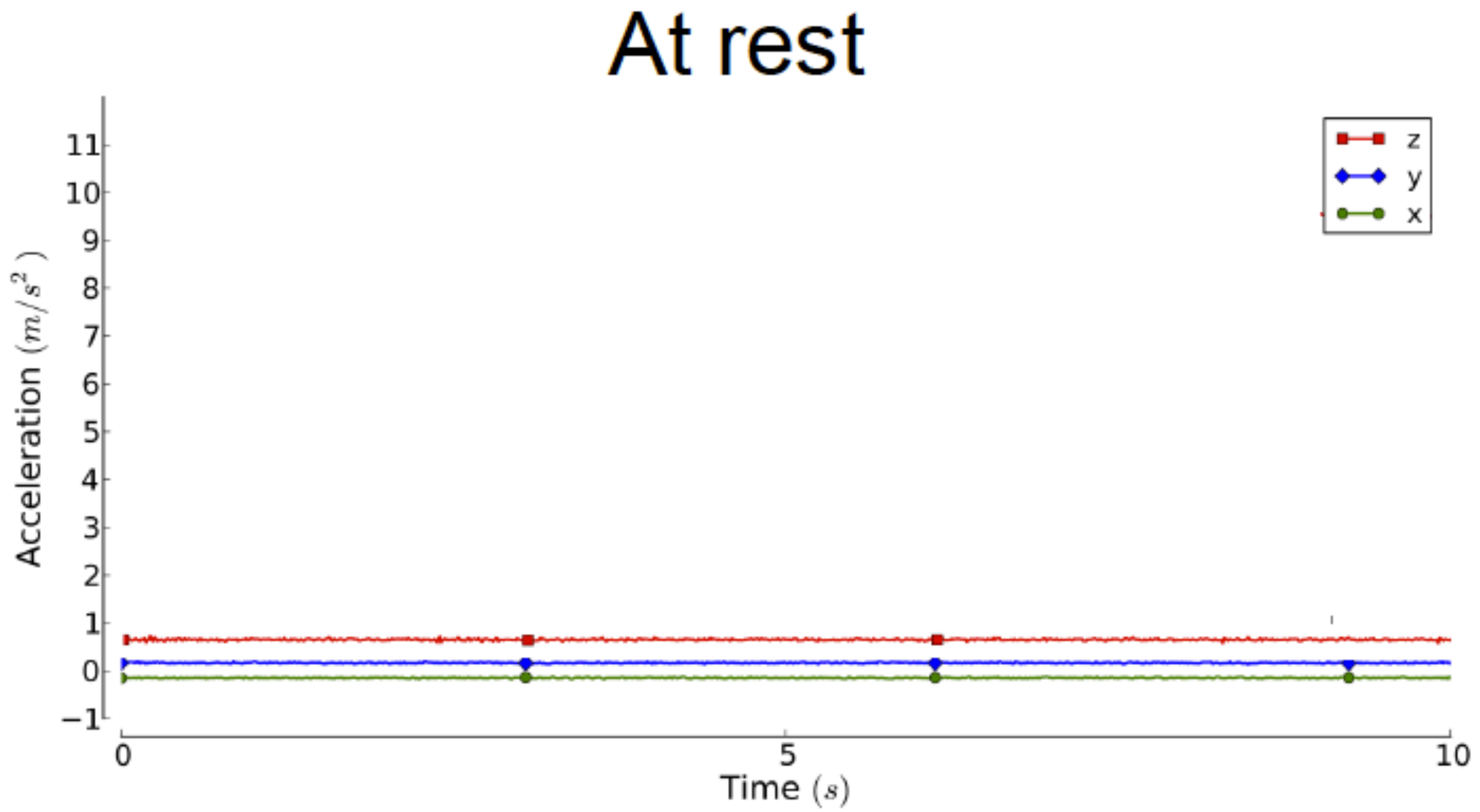
- MEMS accelerometers are tiny masses on tiny springs.
- They can sense
  - Speeding up or slowing down in a straight line
  - Shaking the device
  - Earth's gravity, which is 1 g downward



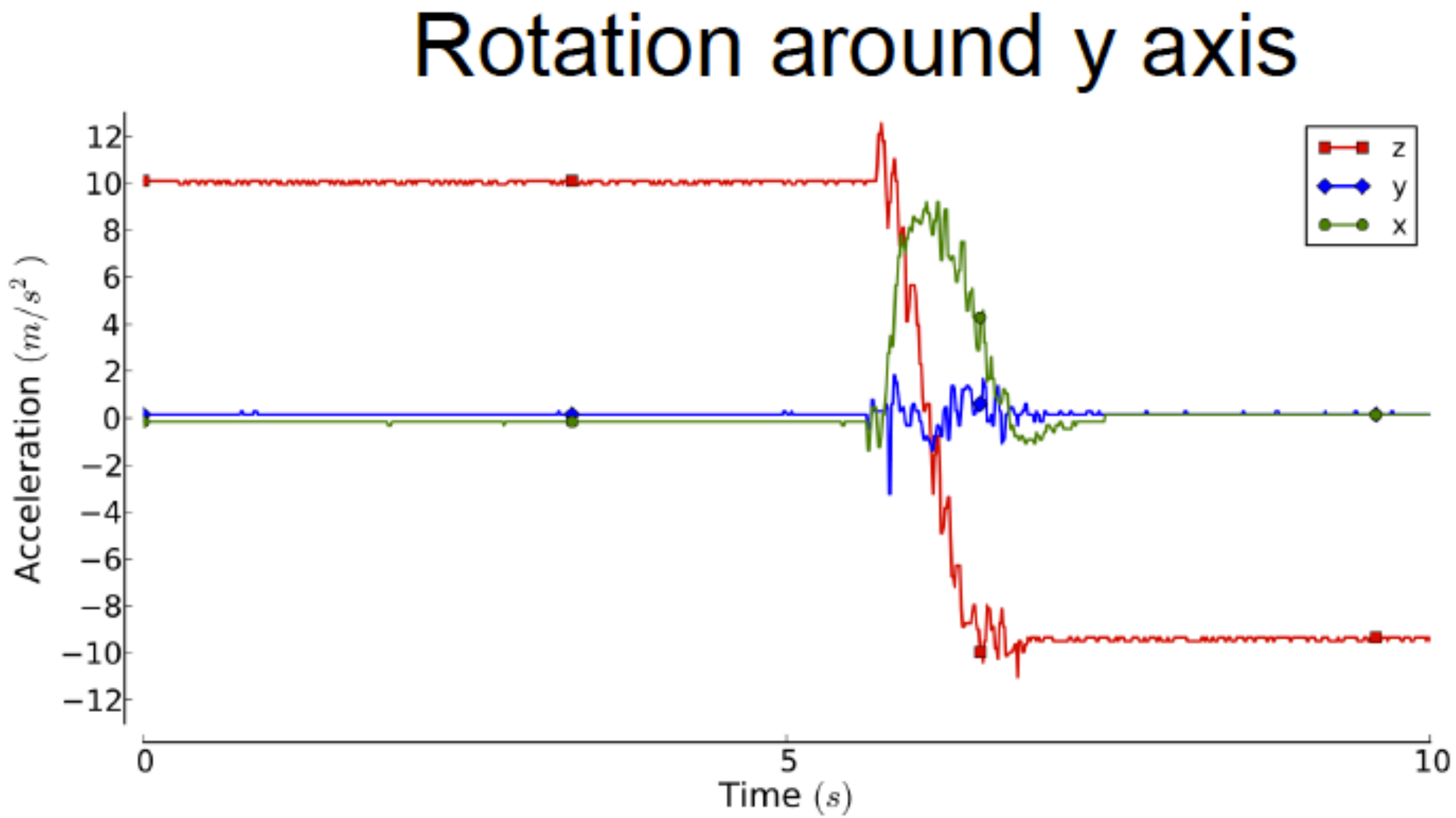
TYPE_ACCELEROMETER



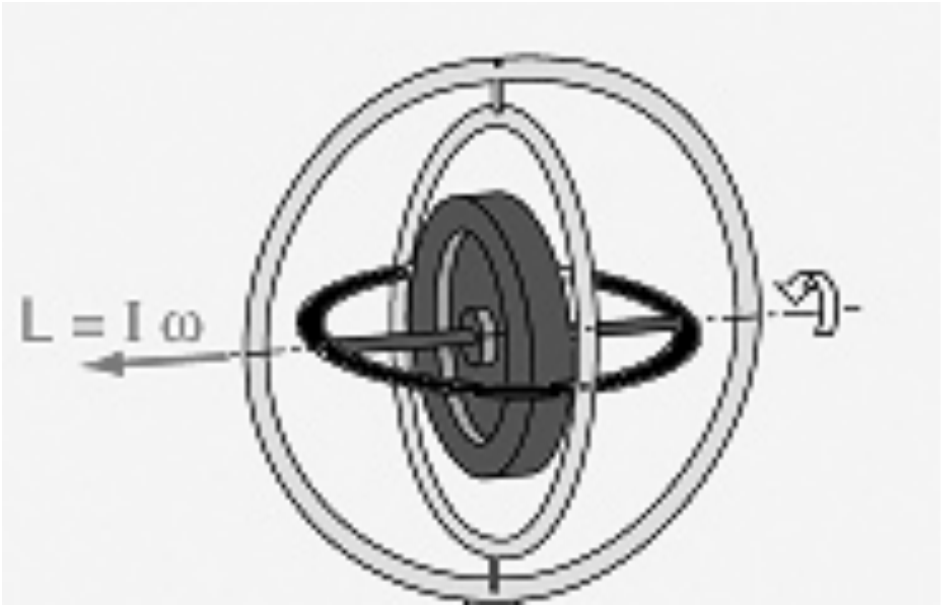
TYPE_LINEAR_ACCELERATION

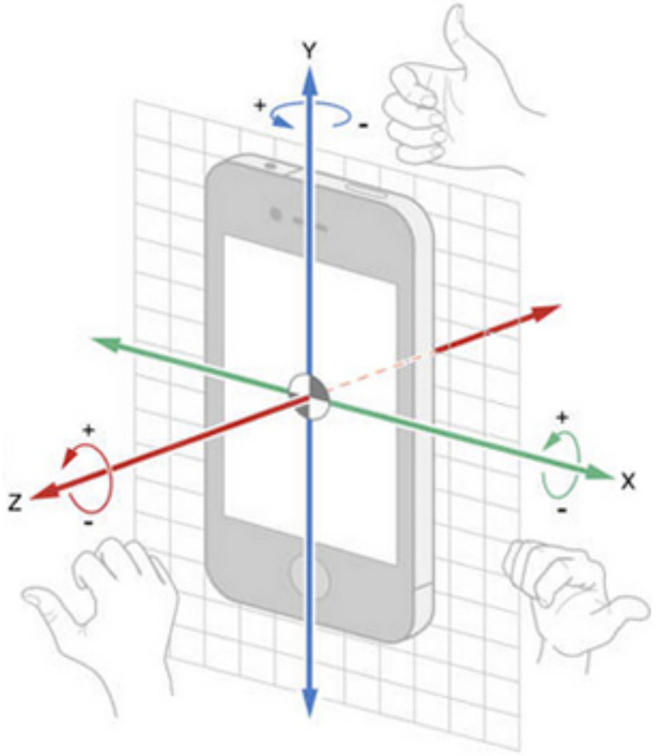


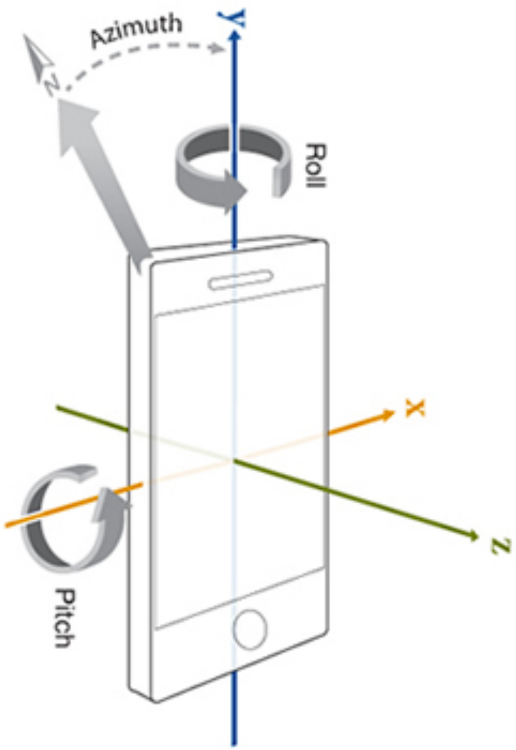
TYPE_ACCELEROMETER



TYPE_GYROSCOPE







Measures rate of rotation.

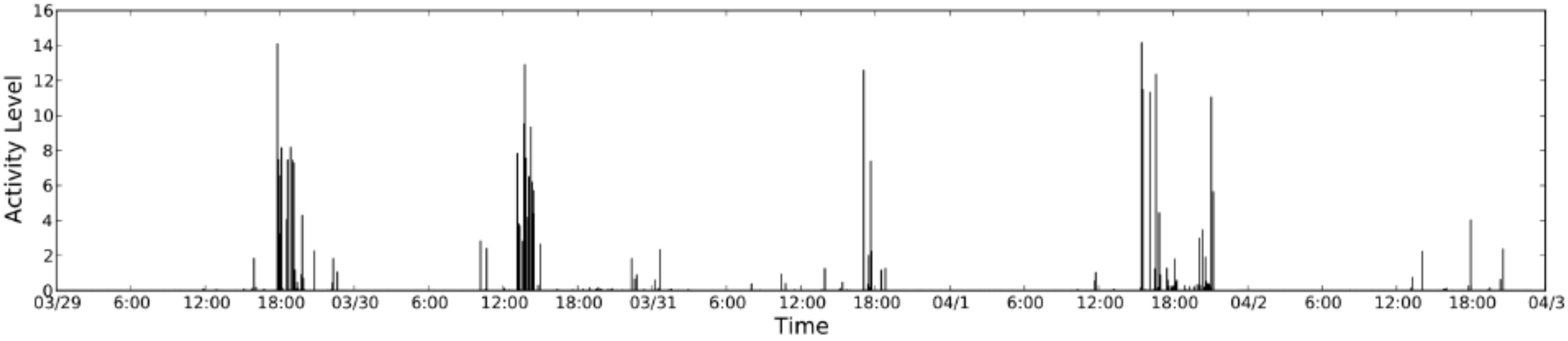
You cannot directly measure angle using a gyroscope.

You can integrate the rate of rotation over time to get angle

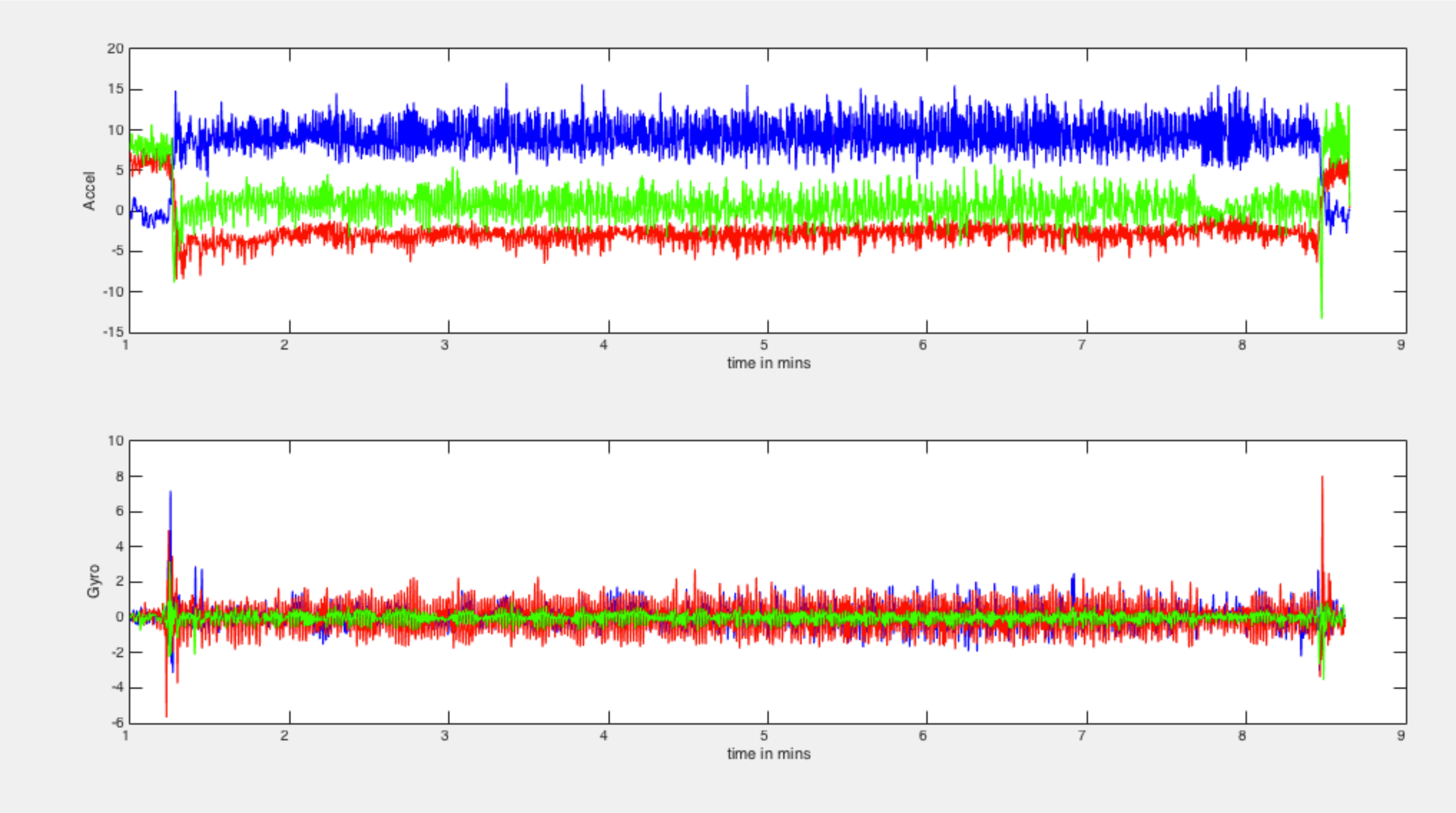
Activity Recognition

Physical Activity Level Inference

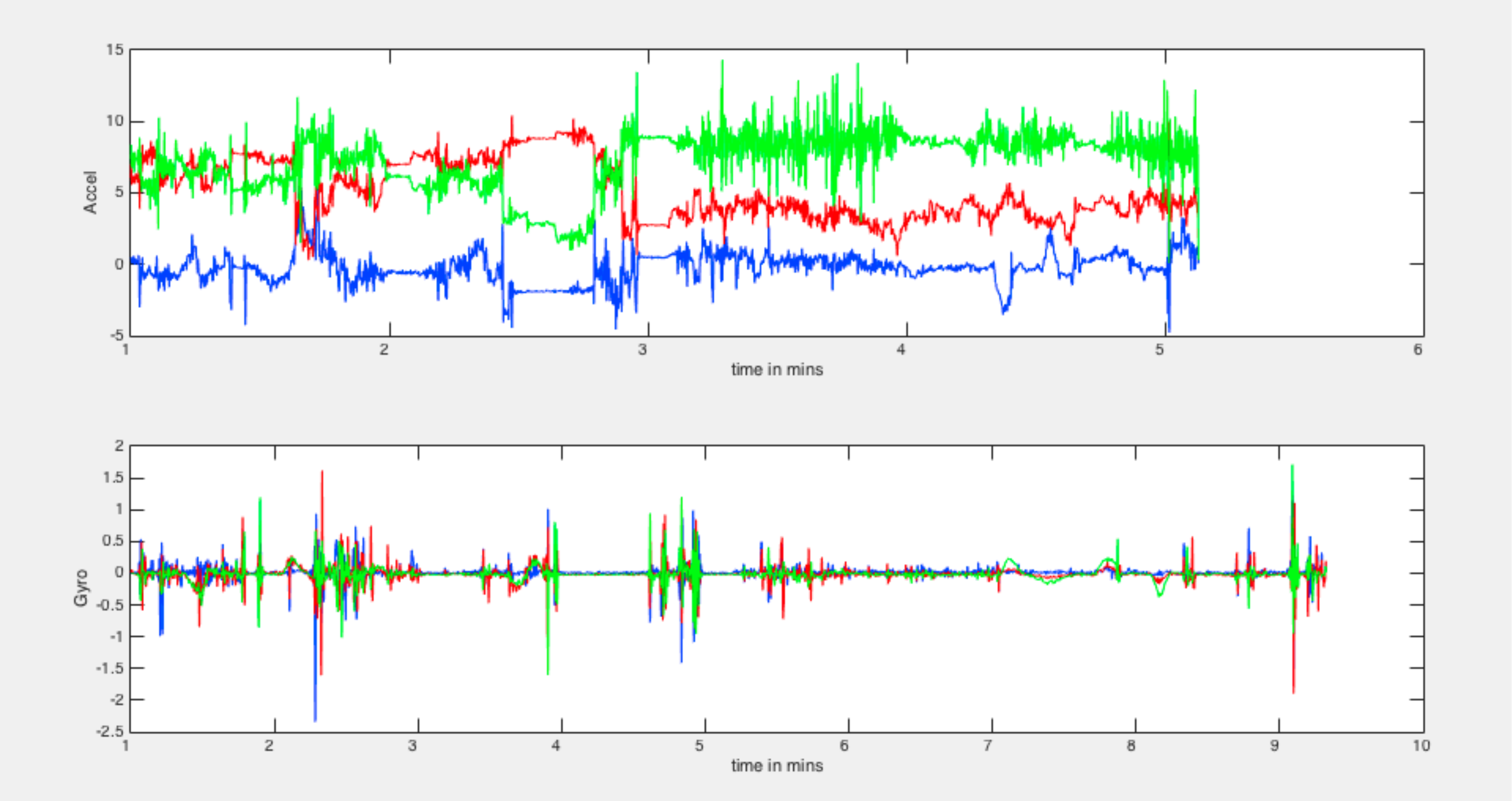
$$m = \sqrt{a_x^2 + a_y^2 + a_z^2}$$



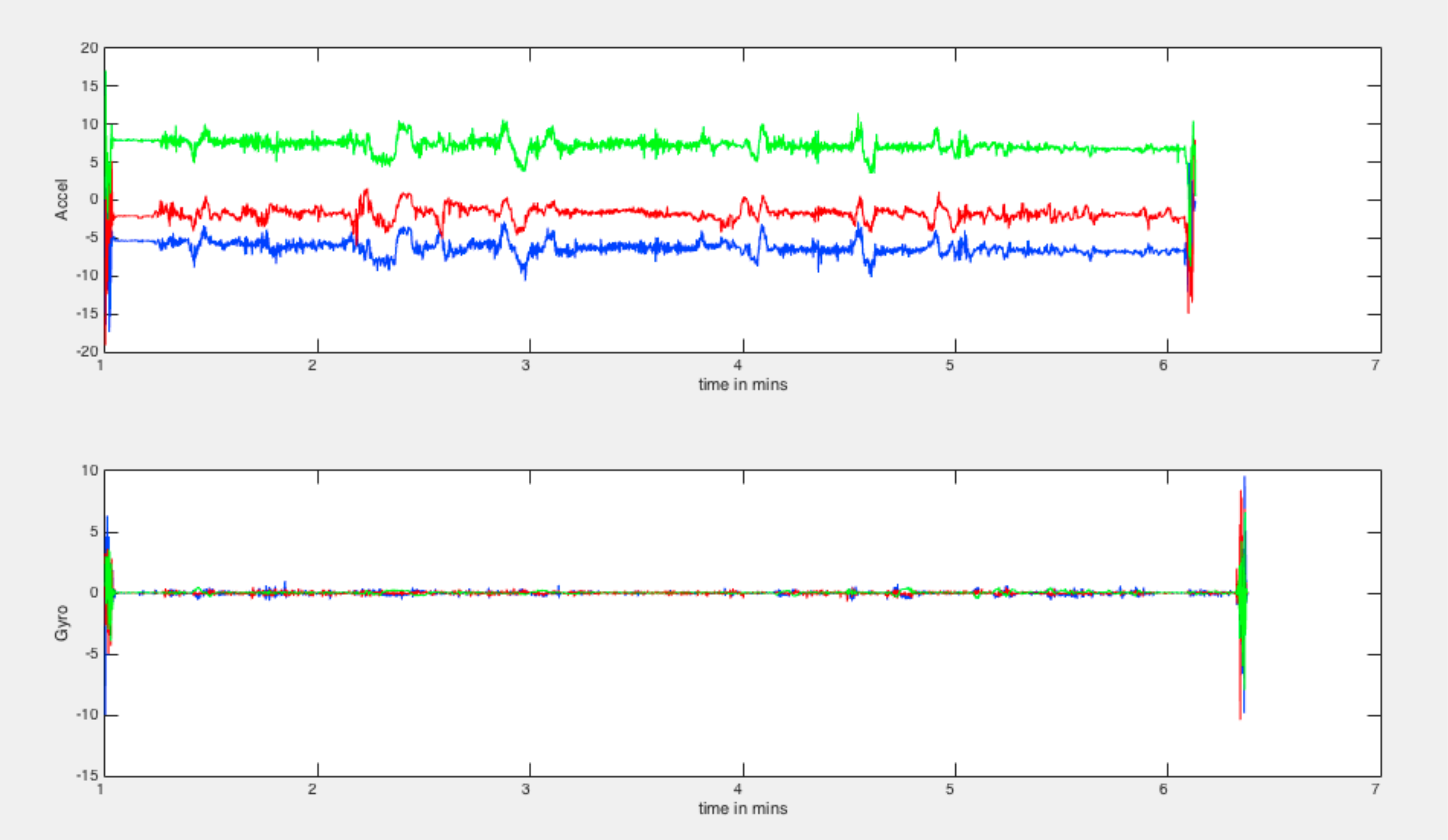
Walking



Bus

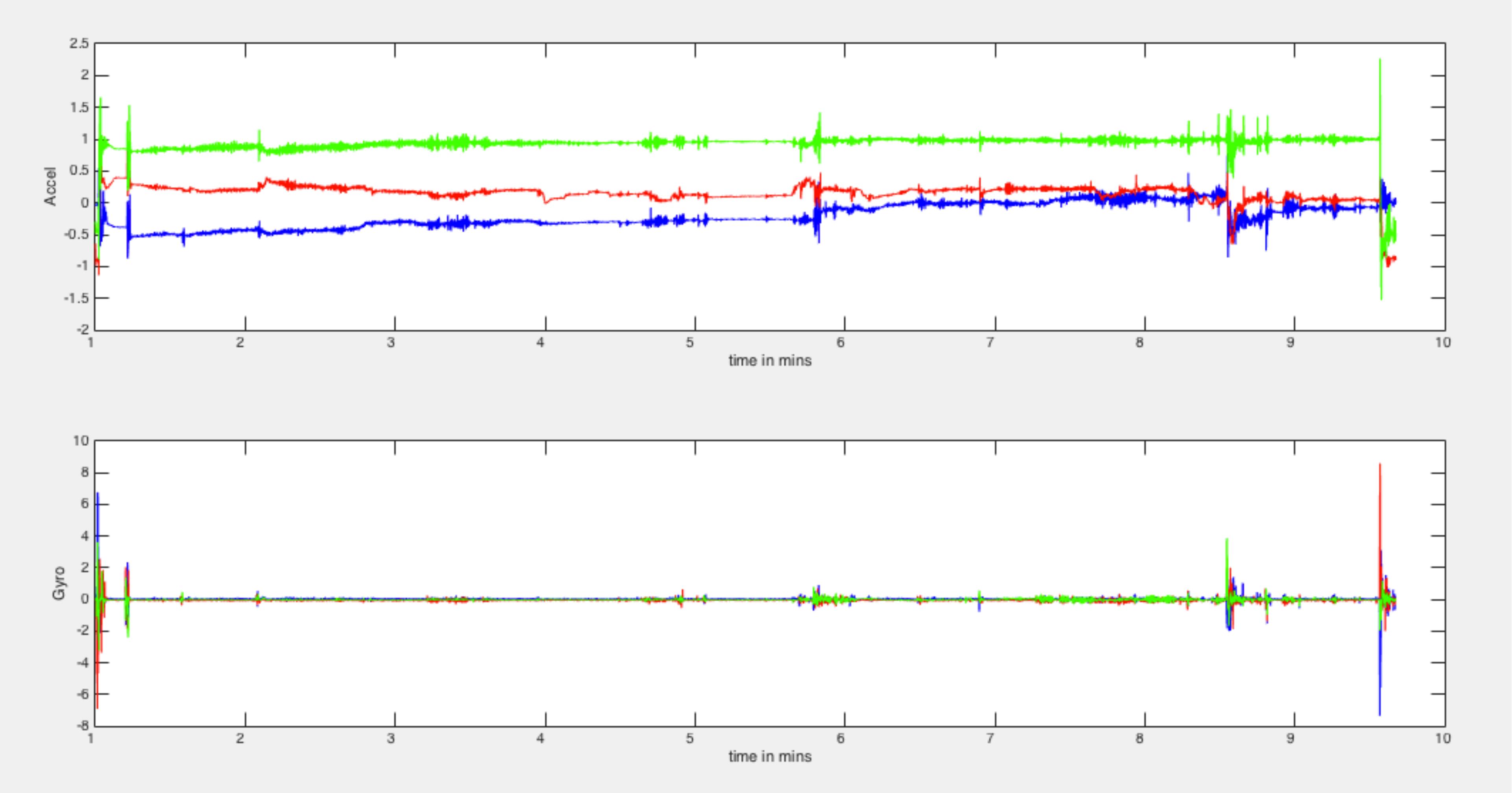

15
10
5
0
-5
Accel
1
2
3
4
5
6
time in mins
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Gyro
1
2
3
4
5
6
7
8
9
10
time in mins

Driving



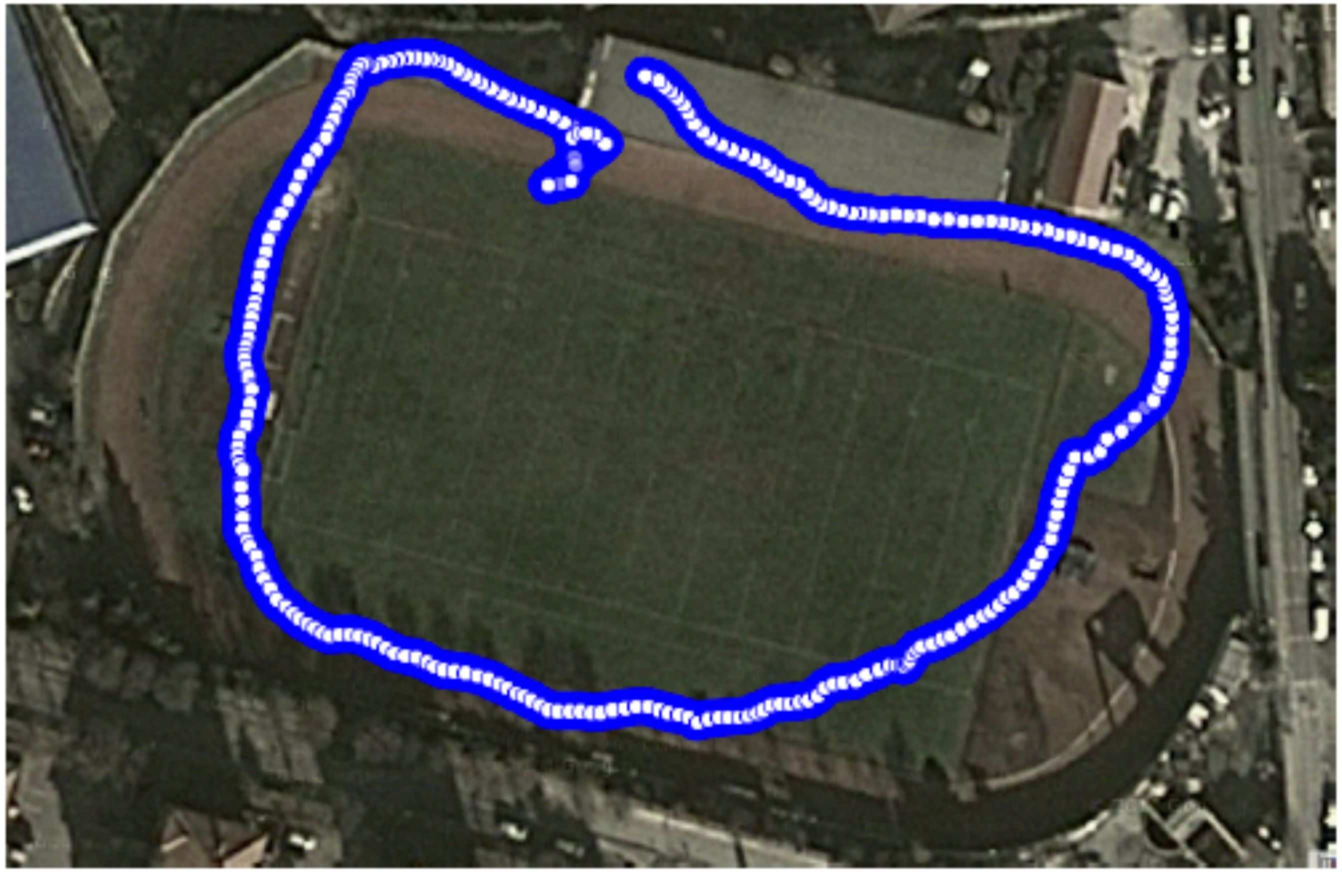
20
15
10
5
0
-5
-10
-15
-20
Accel
1
2
3
4
5
6
7
time in mins
10
5
0
-5
-10
-15
Gyro
1
2
3
4
5
6
7
time in mins

Train



Activity Recognition Study

Running



Android “DetectedActivity” API

int	IN_VEHICLE	The device is in a vehicle, such as a car.
int	ON_BICYCLE	The device is on a bicycle.
int	ON_FOOT	The device is on a user who is walking or running.
int	RUNNING	The device is on a user who is running.
int	STILL	The device is still (not moving).
int	TILTING	The device angle relative to gravity changed significantly.
int	UNKNOWN	Unable to detect the current activity.
int	WALKING	The device is on a user who is walking.

https://developers.google.com/android/reference/com/google/android/gms/location/DetectedActivity

TYPE_MAGNETIC_FIELD

- Hardware Sensor
- Mostly Hall effect Sensors
- Android reports magnetic fields in microtesla.
- Earth’s magnetic fi eld can vary from 30 microtesla to 60 microtesla
- Uses
  - Compass
  - The magnetic field sensor can be influenced by nearby metal, some people have used the sensor to make an Android device into a crude metal detector
    - Due to an effect called hysteresis

TYPE_PROXIMITY

- Hardware Sensor
- Lets you determine how far away an object is from a device
    - Some proximity sensors provide a boolean value (near/far).
        - Typically, the far value is a value > 5 cm, but this can vary from sensor to sensor.
- Usually used to determine how far away a person's head is from the face of a handset device
    - To lock the screen when a user is on a call

TYPE_PROXIMITY

```
public class SensorActivity extends Activity implements SensorEventListener {
  private SensorManager mSensorManager;
  private Sensor mProximity;

  @Override
  public final void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    setContentView(R.layout.main);

    // Get an instance of the sensor service, and use that to get an instance of
    // a particular sensor.
    mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
    mProximity = mSensorManager.getDefaultSensor(Sensor.TYPE_PROXIMITY);
  }
```

TYPE_PROXIMITY

```
@Override
public final void onSensorChanged(SensorEvent event) {
  float distance = event.values[0];
  // Do something with this sensor data.
}

@Override
protected void onResume() {
  // Register a listener for the sensor.
  super.onResume();
  mSensorManager.registerListener(this, mProximity, SensorManager.SENSOR_DELAY_NORMAL);
}

@Override
protected void onPause() {
  // Be sure to unregister the sensor when the activity pauses.
  super.onPause();
  mSensorManager.unregisterListener(this);
}
```

TYPE_STEP_COUNTER

- Returns the number of steps taken by the user since the last reboot while activated.
- Reset to zero only on a system reboot.
- The timestamp of the event is set to the time when the last step for that event was taken.
- This sensor is implemented in hardware and is expected to be low power.
- Application needs to stay registered for this sensor because step counter does not count steps if it is not activated.

TYPE_STEP_DETECTOR

- Triggers an event each time a step is taken by the user.
- The only allowed value to return is 1.0 and an event is generated for each step.
- The timestamp indicates when the event (here the step) occurred
  - When the foot hits the ground - generating a high variation in acceleration.

ENVIRONMENT SENSORS

- The Android platform provides four sensors that let you monitor various environmental properties.
  - Ambient Pressure
    - Measures the ambient air pressure in hPa or mbar.
  - Ambient Humidity
    - Ambient humidity near the phone (expressed as % atmospheric humidity)
  - Illuminance
    - Used to control screen brightness (measured in lux)
  - Ambient temperature
    - Ambient humidity near the phone (measured in degree centigrade)
- They are all hardware sensors.

TYPE_HEART_RATE

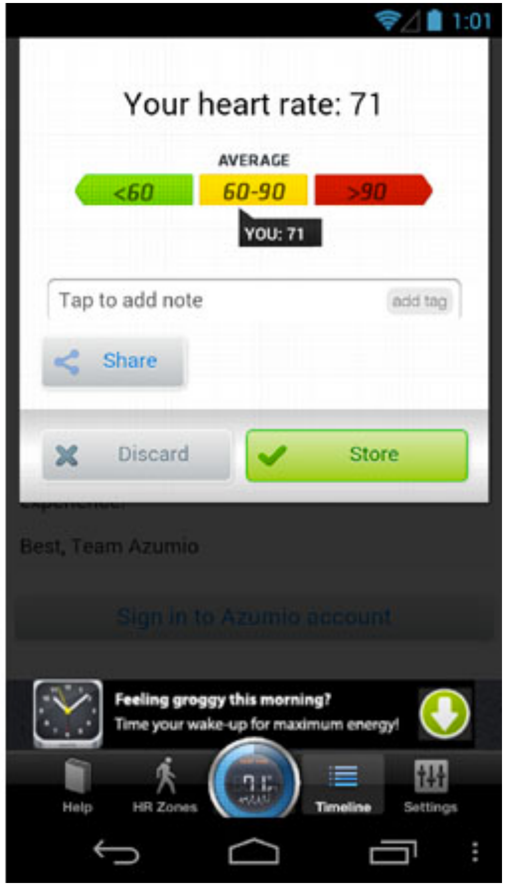
- Found in Android Wearables.
- The reported value is the heart rate in beats per minute.
- This sensor requires permission android.permission.BODY_SENSORS
- It will not be returned by SensorManager.getSensorsList or SensorManager.getDefaultSensor if the permission is missing.

HEART RATE SENSOR

- Measured using a Photoplethysmography (PPG sensor).
- Measures the differential reflection of light by oxygenated and deoxygenated blood

HEART RATE SENSOR

- Similar to the principle of android apps to measure heart rate using the camera.



ARTIFACTS IN HEART RATE

- **Sensor Movement Artifact**
- **Nervous Fidgeting Artifact**

Removal of Local Fidgeting

Changes in Wristband Acc + Physiological signal = YES
Changes in Smartphone Acc/Gyro = NO

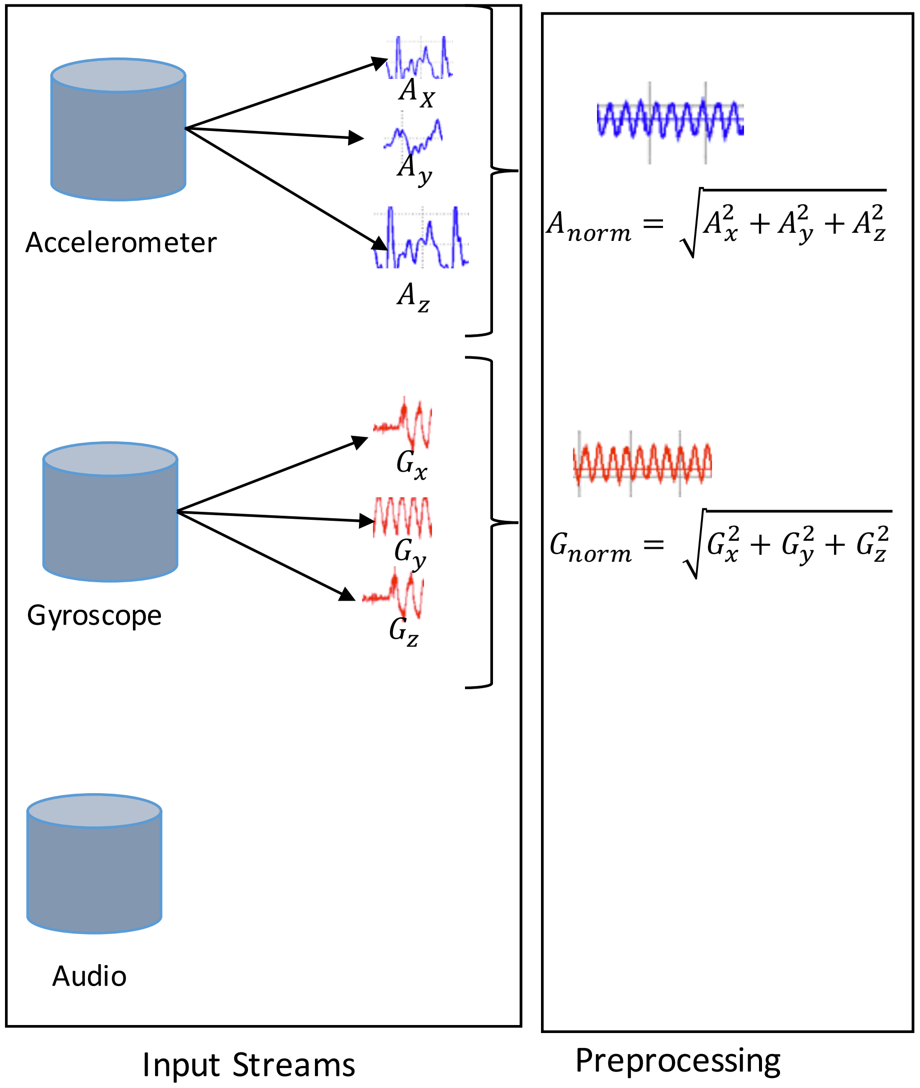
Remove next 30 seconds

Artifact Removal – Activity Recognition Use Case.

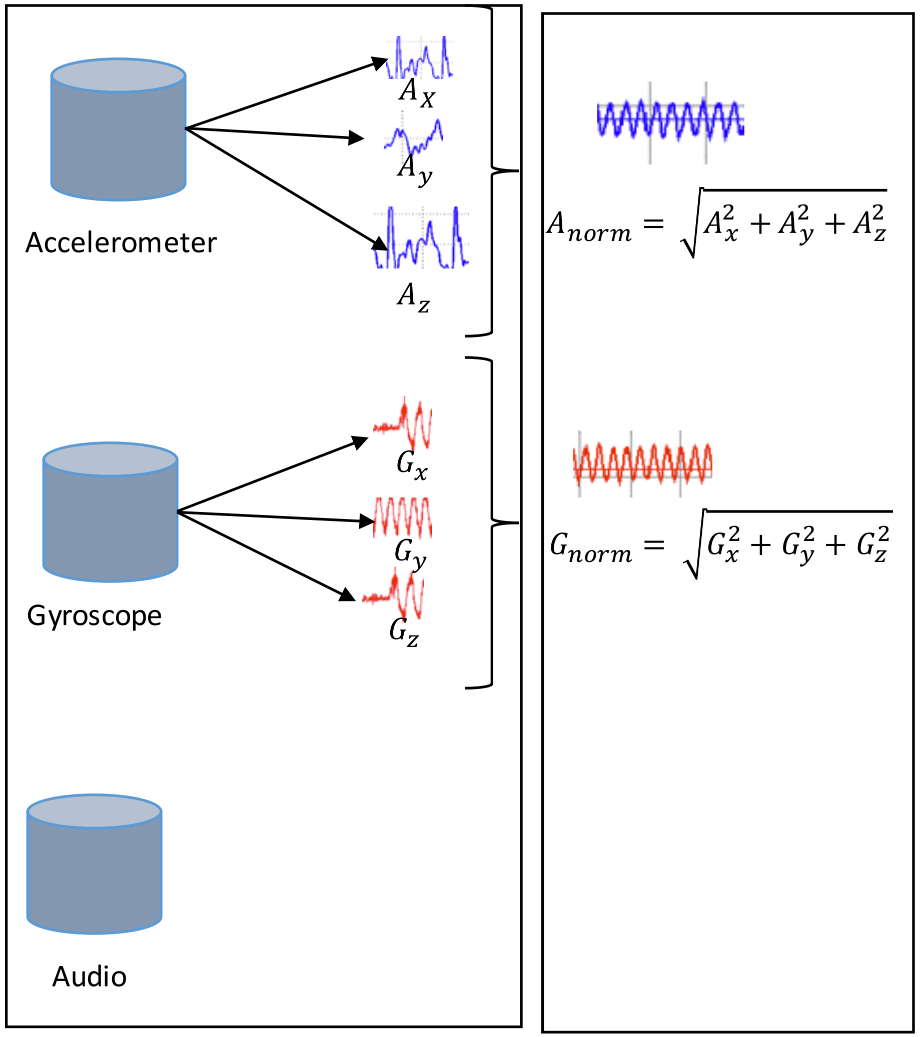
Removal Artifacts using Filtering

- Two common filtering techniques
  - Low-pass filters
    - Pass frequencies lower than cut off frequency
    - Deemphasize transient force change (vibrations)
    - Emphasize constant force components
    - e.g., for a bubble level
  - High-pass filters
    - Pass frequencies higher than cut off frequency
    - Emphasize transient force changes
    - Deemphasize constant force components (gravity)
    - e.g., for a game controller

Signal Preprocessing



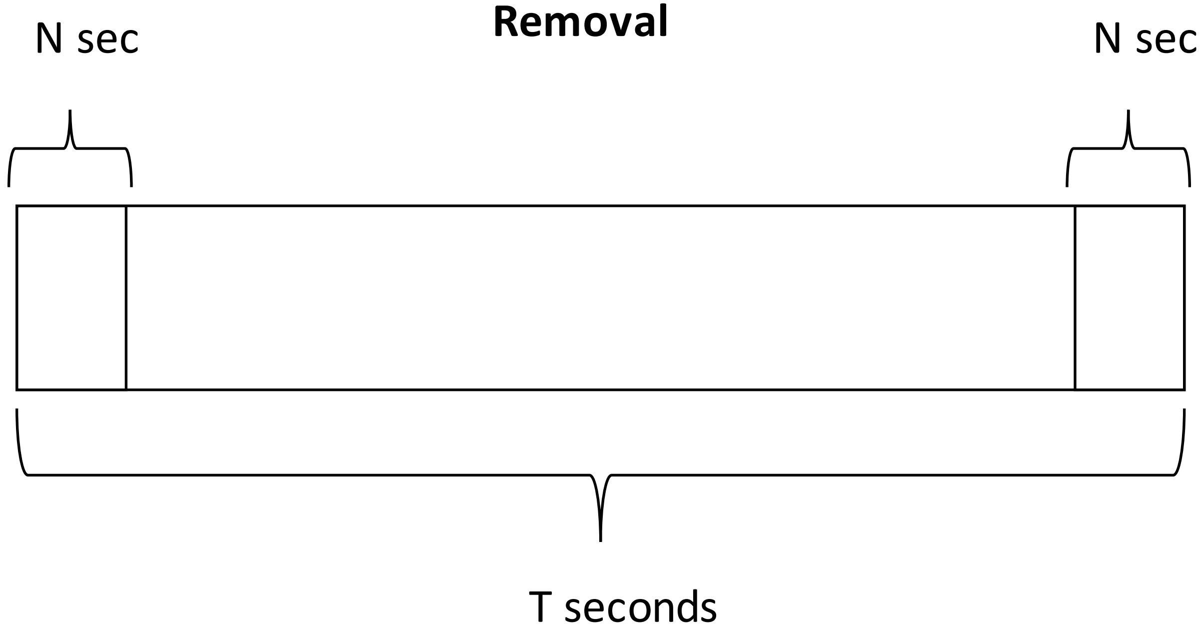
Signal Preprocessing



Input Streams

Preprocessing

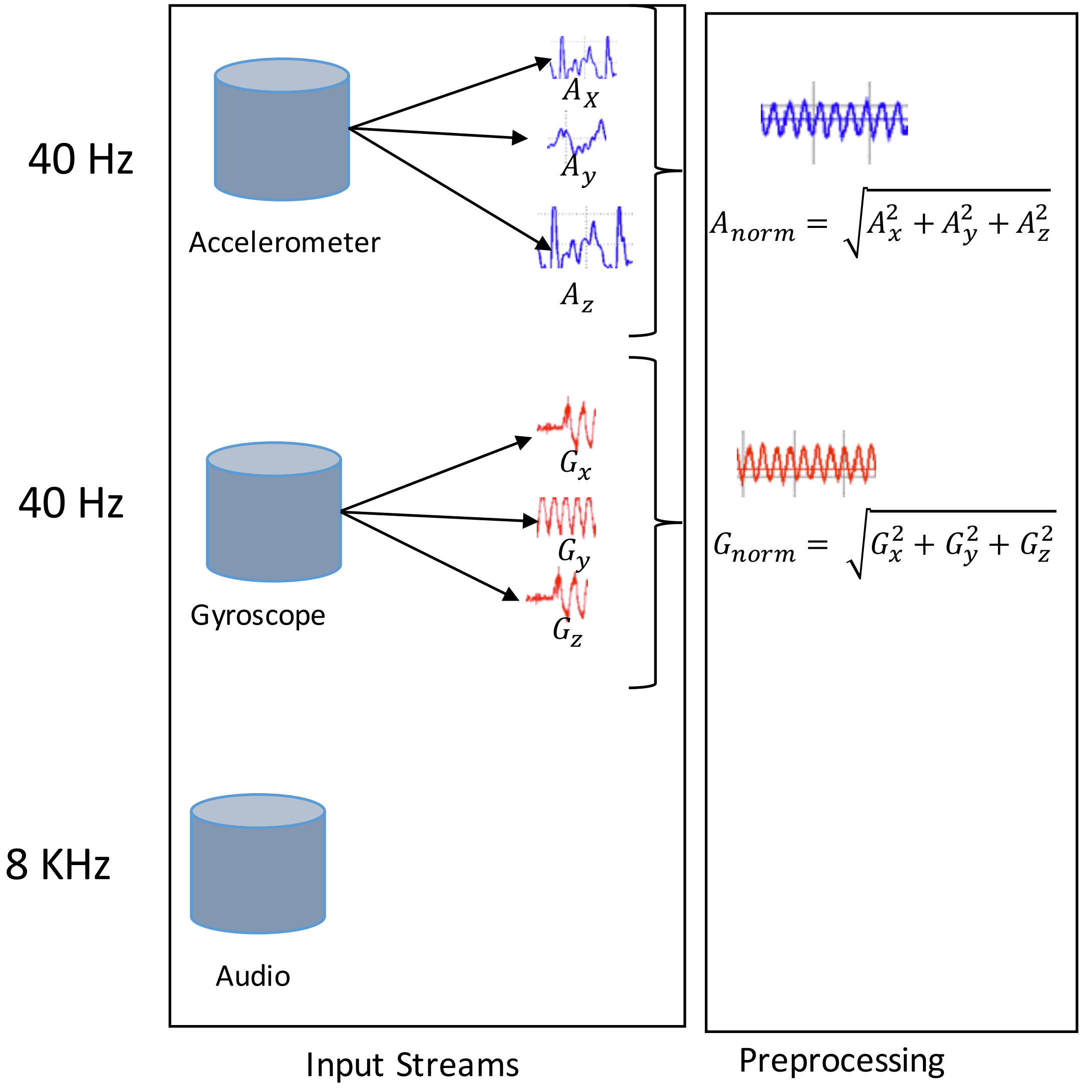
Boundary Removal



N = T/ 10 if N < 300

N = 30 secs Otherwise

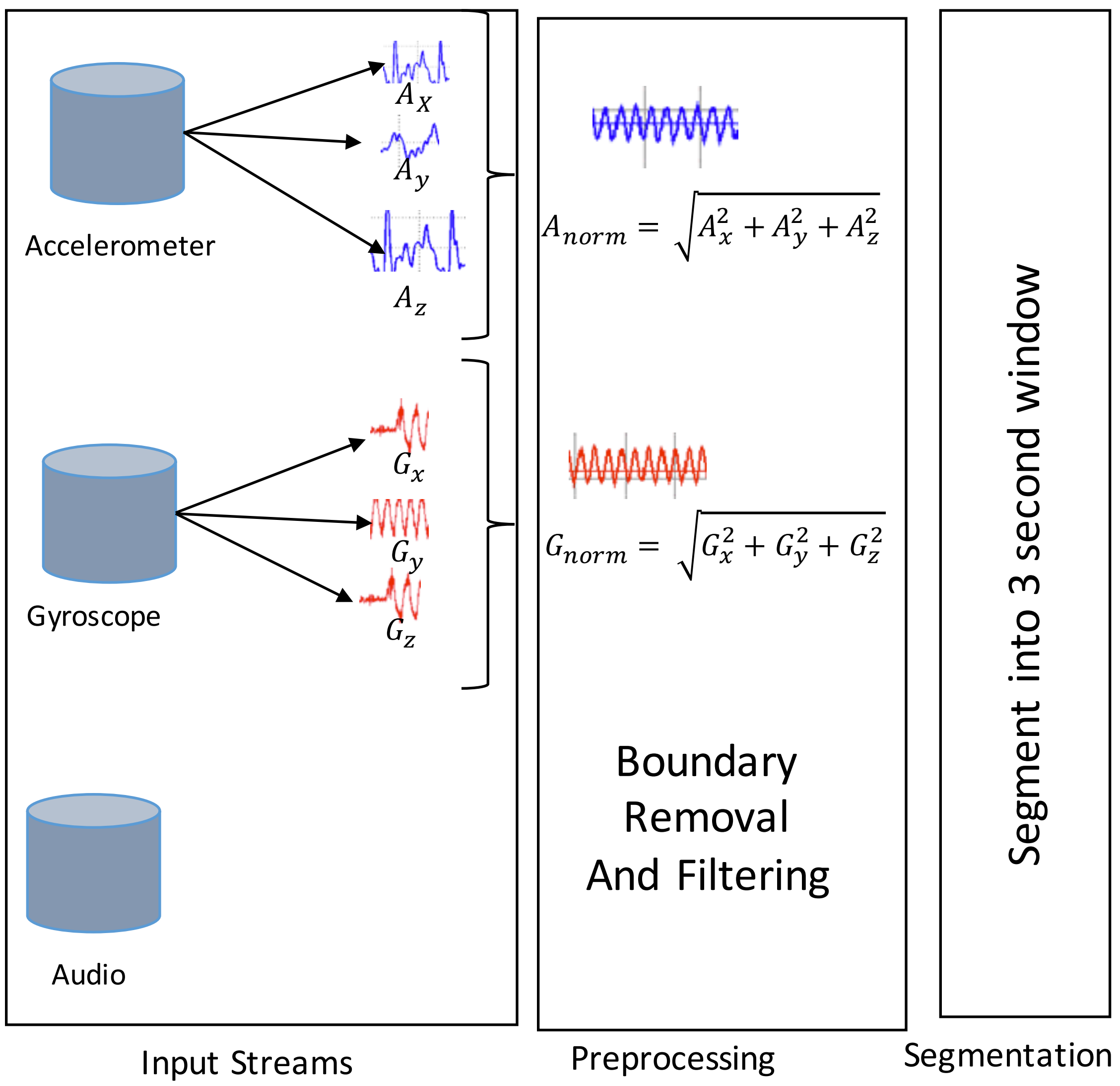
Signal Preprocessing



Screen-on checking and removal

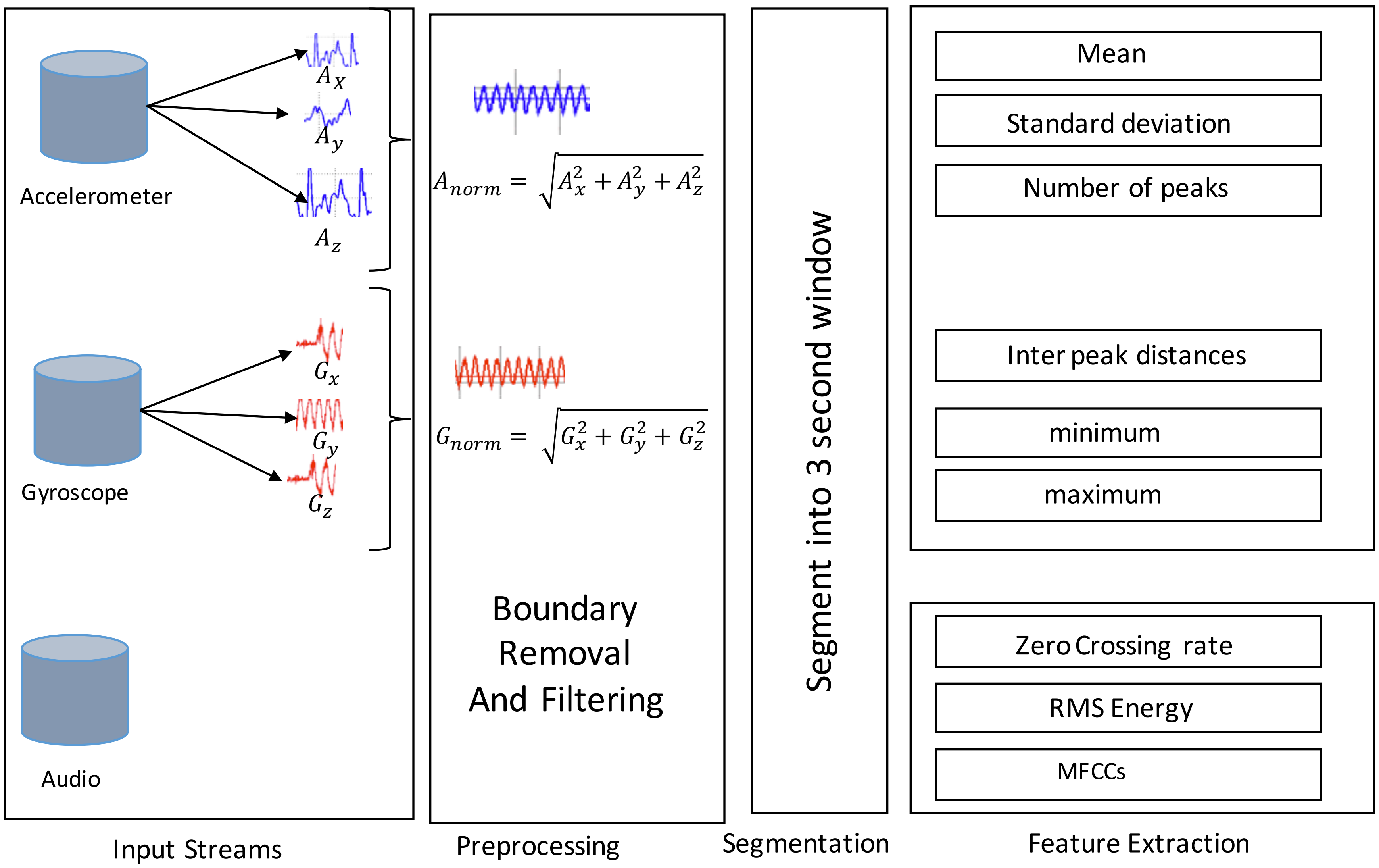
For controlled scenario: If screen-unlocked > 10 seconds

Signal Preprocessing

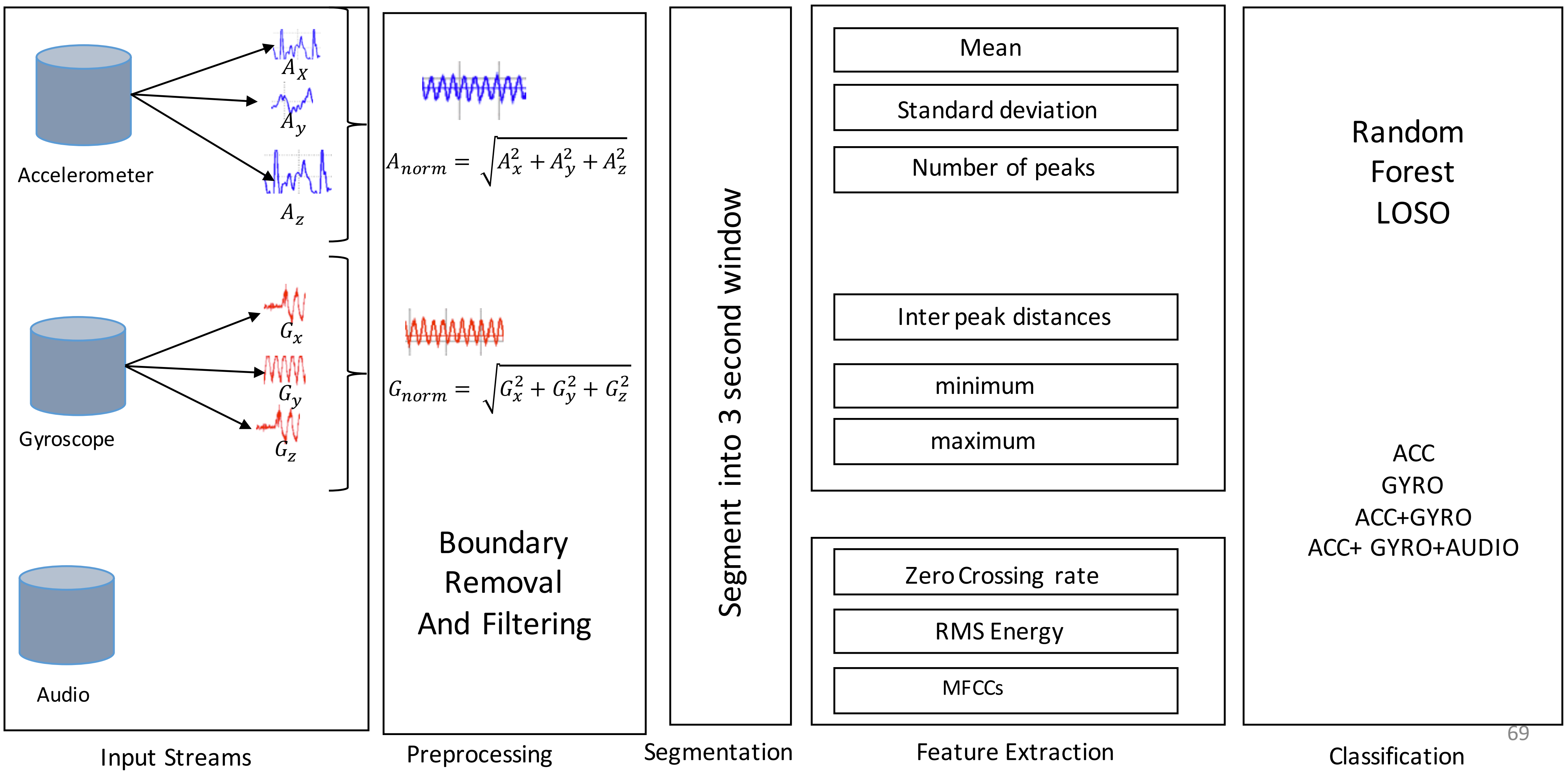


Human Average Stride rate is between 80-120 steps a minute

Signal Preprocessing



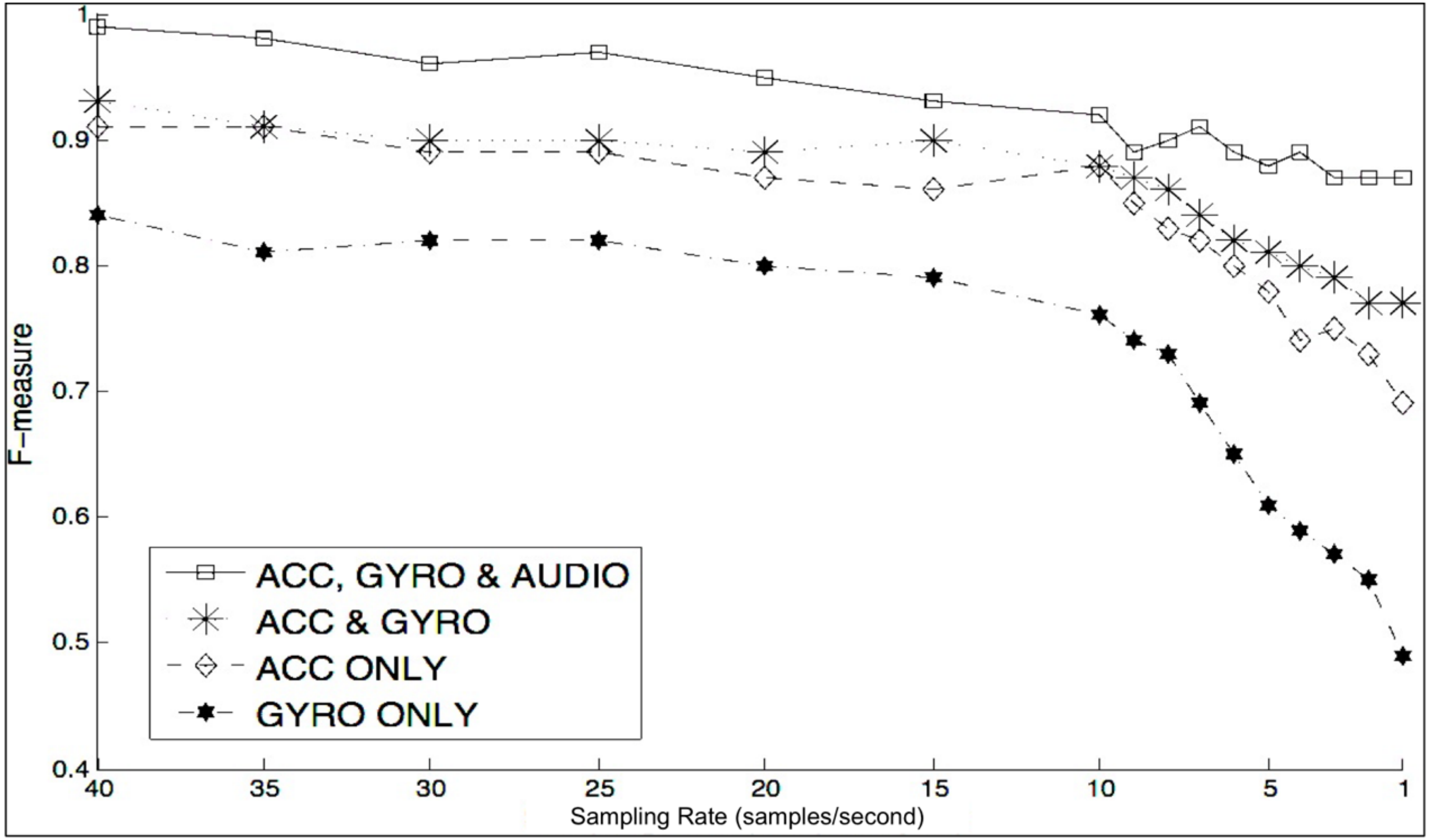
Signal Preprocessing



Challenge

High sampling rate drains battery

Effects of lowering sampling rates



Publication Related to this section

Recognizing Human Activities from Smartphone Sensor Signals.
ACM Multimedia 2014,
Ghosh, Arindam , and Riccardi, Giuseppe