Sensing Mobile Devices

and what it means for app developers

Why the “Sensory Smartphone”?

- Smartphones are becoming more and more powerful
- And near ubiquitous
- They are adding all the capabilities that we have as sensing human
  - And augmenting them in ways that humans don’t have

Developments in Sensory Smartphones

- Accelerometer/Gyroscope
- Magnetometer
- *Locationing*
- *Ambient light*
- *Ambient temperature*
- *Air pressure*
- *Proximity*
- *Humidity*
- *Force Sensitivity*

Accelerometer/Gyroscope

- Accelerometer
  - acceleration as three values (x,y,z axes) in m/s^2
  - almost every smartphone has one now
- Gyroscope
  - acceleration as three values (x,y,z axes) in $radians/s^2$
  - can be done with accelerometer and magnetometer but not as smooth
  - iPhones and most highend Android devices have gyroscopes

Accelerometer/Magnetometer for Real World Coordinates

```
if(SensorManager.getRotationMatrix(R, null, AccelerometerValues_last,
    MagneticFieldValues_last))
{
  SensorManager.remapCoordinateSystem(R, SensorManager.AXIS_Y,
    SensorManager.AXIS_MINUS_X, remapR);
  SensorManager.getOrientation(remapR, orientationValues);

  Matrix.multiplyMV(orientationVector, 0, remapR, 0, sZVector, 0);
  pitch = (float) (-Math.atan2(orientationVector[1], orientationVector[2]) *
    RADIANS_TO_DEGREES);

  orientation = (float) (-Math.atan2(orientationVector[0], orientationVector[1]) *
    RADIANS_TO_DEGREES);

  Matrix.invertM(remapR_inv, 0, remapR, 0);
  Matrix.multiplyMV(azimuthVector, 0, remapR_inv, 0, sZVector, 0);
  azimuth = (float) (180 + Math.atan2(azimuthVector[0], azimuthVector[1]) *
    RADIANS_TO_DEGREES);
}
```

Hierarchy of Location Capabilities

- GPS
  - Precision of 20-50m
  - 3 satellites for 2D fix, 4 satellites for 3D fix
  - Doesn’t work indoors, drains battery
- Cell tower triangulation
- Wifi network triangulation
- *Indoor locationing*
- *RFID*
- *Extended Large Tag NFC*

Indoor Locationing Techniques

- Wifi/WLAN
  - WLAN “fingerprinting” makes it more accurate (database of Wifi signature data)
  - Often in combination with indoor maps
- Bluetooth
  - Range: 10-30m, precision 5-10m (many access points required)
  - Bluetooth 4 on most devices (must be set to visible)
- RFID
  - Up to 200m range
- UWB
  - High precision (<0.3m), high data rates, low energy
  - Not in smartphones yet , high cost
- Zigbee
  - Same underlying technology as UWB, not available directly on smartphones today
- Ultrasound
  - High precision (~1cm), lots of sensors, vulnerable to interference
- IR
  - Requires line of sight, very high precision (~1mm), superceded by other technologies

System/ Solution	Wireless technologies	Positioning algorithm	Accuracy	Precision	Complexity	Scalability/ Space dimension	Robust-ness	Cost
Microsoft RADAR [35, 36]	WLAN, Received Signal Strength (RSS)	*k* NN, Viterbi-like algorithm	3~5m	50%within around 2.3 m and 90% within around 5.9 m	Moderate	Good /2D,3D	Good	Low
Horus [37,38]	WLAN RSS	Probabilistic method	2m	90% within 2.1m	Moderate	Good/2D	Good	Low
DIT [41, 19]	WLAN RSS	MLP, SVM, etc.	3m	90% within 5.12m for SVM; 90% within 5.40m for MLP	Moderate	Good/2D,3D	Good	Low
Ekahau[11]	WALN RSSI	Probabilistic method (Tracking-assistant)	1m	50% within 2m	Moderate	Good/2D	Good	Low
SnapTrack[3]	Assisted GPS, TDOA		5m-50m	50% within 25m	High	Good/2D,3D	Poor	Medium
WhereNet[4]	UHF TDOA	Least Square/ RWGH	2-3m	50% within 3m	Moderate	Very good / 2D,3D	Good	Low
Ubisense[6]	unidirectional UWB TDOA+ AOA	Least Square	15cm	99% within 0.3m	Real time response (1Hz – 10 Hz)	2-4 sensors per cell (100-1000m); 1 UbiTag per object /2D,3D	Poor	Medium to High
Sappire Dart[9]	unidirectional UWB TDOA	Least Square	<0.3m	50% within 0.3m	response frequency (0.1Hz – 1Hz)	Good/2D, 3D	Poor	Medium to High
SmartLOCUS [58]	WLAN(RSS) + Ultrasound(RTOF)	N/A	2-15cm	50% within 15cm	Medium	Good/2D	Good	Medium to High
EIRIS[58]	IR + UHF (RSS) + LF	Based on PD	<1m	50% within 1m	Medium to High	Good/2D	Poor	Medium to High
SpotON [28]	Active RFID RSS	Ad-Hoc lateration	Depends on cluster size	N/A	Medium	Cluster at least 2 Tags/2D	Good	Low
LANDMARC [29]	Active RFID RSS	KNN	<2m	50% within 1m	Medium	Nodes placed densely	Poor	Low
TOPAZ [12]	Bluetooth (RSS) + IR	Based on PD	2m	95% within 2m	positioning delay 15-30s	Nodes placed every 2-15 m	Poor	Medium
MPS[13]	QDMA	Ad-Hoc lateration	10m	50% within 10m	1s	Excellent/2D,3D	Good	Medium
GPPS[61]	DECT cellular system	Gaussian process (GP), *k*NN	7.5 m for GP; 7 m for *k*NN	50% within 7.3m	Medium	Good/2D	Good	Medium
Robot-based[44, 46, 49]	WLAN (RSS)	Bayesian approach	1.5 m	Over 50% within 1.5m	Medium	Good/2D	Good	Medium
MultiLoc [74]	WLAN (RSS)	SMP	2.7 m	50% within 2.7m	Low	Good/2D	Good	Medium
TIX [75]	WLAN (RSS)	TIX	5.4 m	50% within 5.4m	Low	Good/2D	Good	Medium
PinPoint 3D-ID [57]	UHF (40MHz) (RTOF)	Bayesian approach	1 m	50% within 1m	5s	Good/2D,3D	Good	Low
GSM fingerprinting[31]	GSM cellular network (RSS)	Weighted *k*NN	5 m	80% within 10m	Medium	Excellent / 2D,3D	Good	Medium

Ambient Light Sensors

- Implemented as multiple photodiodes
- Saves smartphone power by optimizing brightness
- Reduces eyestrain
- Not really used in apps today
- Except indirectly

Ambient Light Sensor Code

```
public class AndroidLightSensorActivity extends Activity {
 public void onCreate(Bundle savedInstanceState) {
       SensorManager sensorManager = (SensorManager)getSystemService(Context.SENSOR_SERVICE);
        Sensor lightSensor = sensorManager.getDefaultSensor(Sensor.TYPE_LIGHT);
        if (lightSensor == null){
         Toast.makeText(AndroidLightSensorActivity.this,
           "No Light Sensor! quit-",
           Toast.LENGTH_LONG).show();
        }else{
         float max =  lightSensor.getMaximumRange();
         lightMeter.setMax((int)max);
         textMax.setText("Max Reading: " + String.valueOf(max));
         sensorManager.registerListener(lightSensorEventListener,
           lightSensor,
           SensorManager.SENSOR_DELAY_NORMAL);
         }
    }
    SensorEventListener lightSensorEventListener
    = new SensorEventListener(){
    public void onSensorChanged(SensorEvent event) {
       if(event.sensor.getType()==Sensor.TYPE_LIGHT){
         float currentReading = event.values[0];
       lightMeter.setProgress((int)currentReading);
       textReading.setText("Current Reading: " + String.valueOf(currentReading));
     }
   }
};
```

Ambient Temperature

- Temperature measures battery temperature and is available on most devices
  - But its deprecated as of Android 4.0
- Ambient Temperature measures ambient air temperature
  - new in Android 4.0 (Ice Cream Sandwich)
- Few devices today
  - Arrows Z ISW13F
- But Sensirion has ambient temperature/humidity chip

Relative Humidity

- Combined with ambient temperature get dew point:

$$td(t,RH) = Tn \cdot \frac{\ln(RH/100\%) + m \cdot t/(Tn+t)}{m - [\ln(RH/100\%) + m \cdot t/(Tn+t)]}$$

- Absolute humidity

$$dv(t,RH) = 216.7 \cdot \frac{(RH/100\%) \cdot A \cdot \exp(m \cdot t/(Tn+t)}{273.15 + t}$$

Ambient Air Pressure

- Barometer showing up on more and more devices
  - Xperia Active. Xperia Go. Galaxy S3. Galaxy Nexus. Galaxy Note. Galaxy Note2. Motorola Xoom
- Provides altitude information WITHOUT GPS
- Accelerates GPS calculations as it provides first cut guess at altitude before satellite fix
- Predicting impending storms when out in the field
- See Barometer and Altimeter apps on Google Play

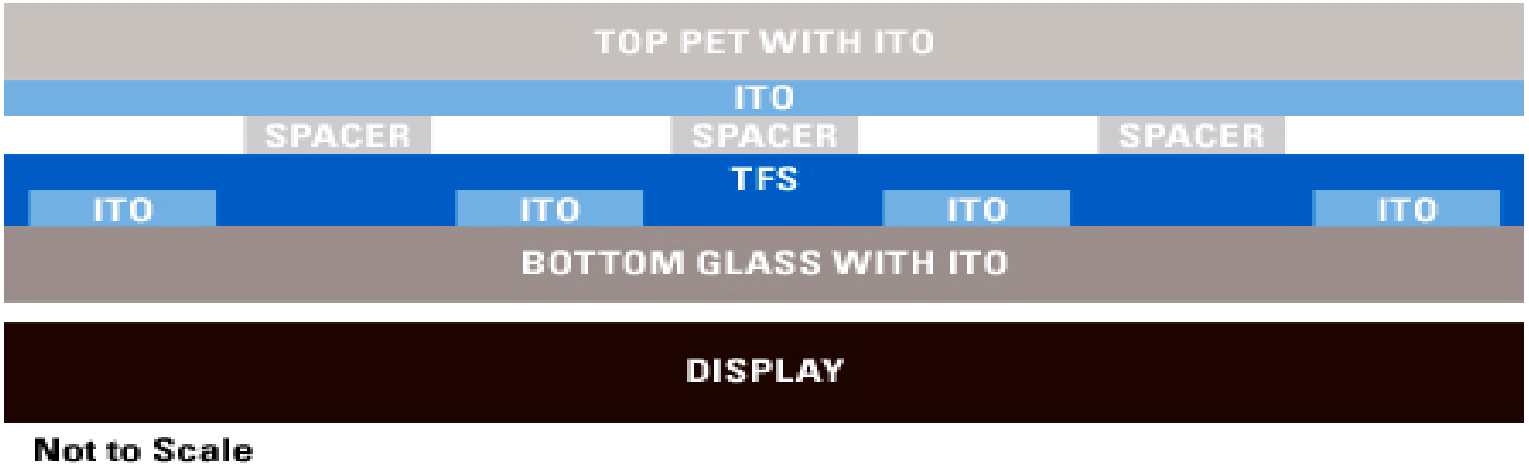
Proximity

- On Android, returns number of centimeters distant
  - Not exposed on iPhone formally (but some apps use it anyway)
- Most often implemented on Android as light sensor
  - Specifically ISL29003/23 or GP2A chip
- Note that most sensors return only “near” or “far” (high or low) values

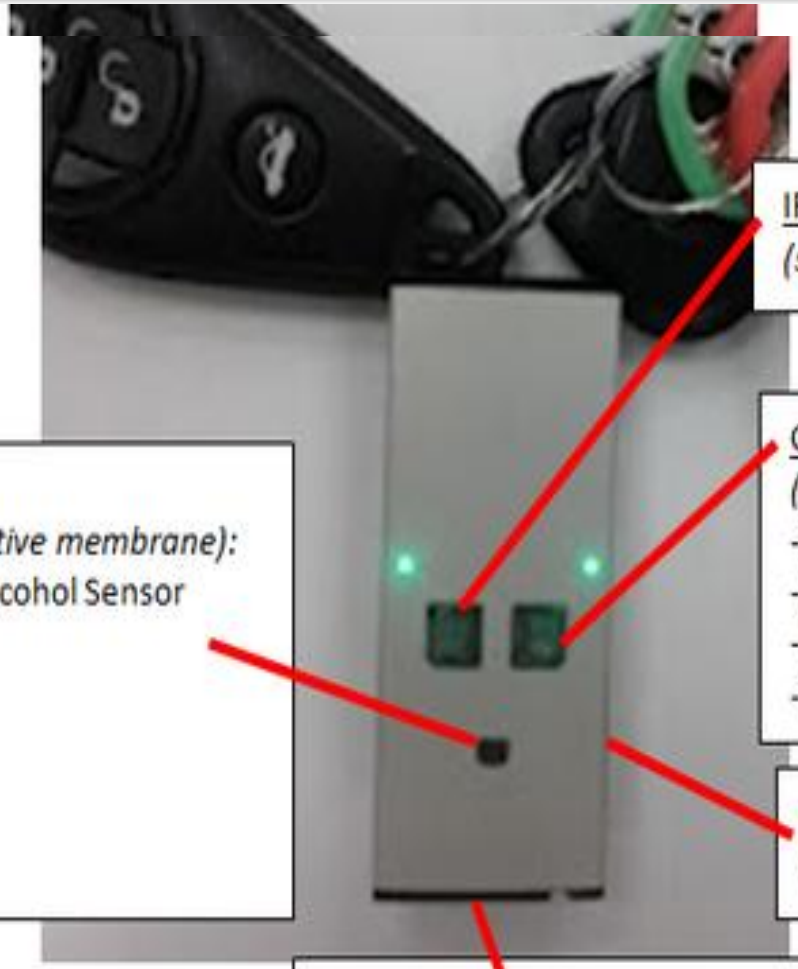
```
public void onSensorChanged(SensorEvent event) {
   if (event.sensor.getType() == Sensor.TYPE_PROXIMITY) {
    if (event.values[0] <
 proximitySensor.getMaximumRange()){
  startSpeechRecognition();
    }
  }
}
```

Force Sensors

- Three approaches
  - Accelerometer-based
  - Touch-width based – on some Android devices such as Nexus One
  - External direct force-sending
- Example Direct Force-Sending
  - Motorola Force Sensing Technology: http://www.motorola.com/Business/US-EN/Technology_Licensing/Proprietary+Technology+Licensing/Force-Sensing+Touch+Technology
  - Works with resistive or capacitive screens



SensorDrone



IR temperature sensor
(sensor 7 located behind clear plastic)

Color/Light sensor
(sensors 9-12 located behind clear plastic):
- Red intensity sensor
- Green intensity sensor
- Blue intensity sensor
- Clear intensity sensor (visible light)

Air Sensor Port
(sensors 1-6 behind a protective membrane):
- Carbon Monoxide/Toxic/Alcohol Sensor
- Reducing gas sensor
- Oxidizing gas sensor
- Temperature
- Humidity
- Barometric Pressure

Capacitance
(sensor 8 located behind back wall)

External Hardware
(connector for external sensor/HW)

SensorDrone Sensors

- Precision Electrochemical Gas Sensor – Calibrated for Carbon Monoxide (Also can be used for precision measurements of Alcohol, Hydrogen, and others)
- Gas Sensor for Oxidizing Gases – MOS type for Chlorine, Ozone, Nitrogen Dioxide, etc.
- Gas Sensor for Reducing Gases – (MOS type for methane, Propane, alcohols, other hydrocarbons, etc.)
- Temperature – Simple resistance temperature sensor type
- Humidity
- Pressure – can be used for Barometer, Altimeter, Blood Pressure, etc.
- Non-Contact Thermometer – Infrared sensor for scanning object temperature
- Proximity Capacitance – fluid level, intrusion detection, stud finder & more applications
- Red Color Intensity
- Green Color Intensity
- Blue Color Intensity
- Illumination – combine RGB & illumination for color matching
- Digital & Analog Interface - Expansion connector for connecting anything you want to your mobile device through the Sensordrone

Others?

- Radiation (dosimeter)
- Air quality
- Alcohol
- Glucose
- Breath analysis
- Fingerprint
  - Motorola Atrix
  - iPhone 5s: http://www.3g.co.uk/PR/March2013/Apple%20iPhone%205S%20-%20To%20sport%20a%20fingerprint%20sensor.html

Healthcare

- One-lead ECG
- Body temperature
- Blood glucose
- Heart rate
- Blood oxygen saturation
- Body fat percentage
- Stress levels

Why Should App Developers Care?

Modern smartphone apps are different from web apps

- They use geolocation, camera, PIM contacts in interesting ways

Broad array of new smartphones senses opens up new classes of apps:

- Augmented reality – information about the world around you
  - Pollution
  - Altitude
  - Barometric pressure
- More responsive intuitive games and user interfaces
  - Pressure sensitivity: another intuitive input dimension
- Location-based apps – indoor and outdoor
  - Promotions based on location
  - Context-awareness in all apps
- Enhanced navigation/logistics/delivery
  - Based on altitude, acceleration, directio
- Better self-driven healthcare

Why Do I Care?

- RhoMobile mission was always easy framework for enterprise apps
  - My mission at Motorola is all developer facing APIs (Rho, Android Java, C# for Windows Embedded Handheld)

- The sensor event handling model can be awkward with Android Java
- Its not crossplatform there
- There is overlap between those APIs and external devices

Sensor Handling in Android

```
public class SensorActivity extends Activity implements SensorEventListener {
  private SensorManager mSensorManager;
  private Sensor mPressure;
  @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);
    mPressure = mSensorManager.getDefaultSensor(Sensor.TYPE_PRESSURE);
  }
  @Override public final void onAccuracyChanged(Sensor sensor, int accuracy) {
    // Do something here if sensor accuracy changes.
  }
  @Override public final void onSensorChanged(SensorEvent event) {
    float millibars_of_pressure = event.values[0];
    // Do something with this sensor data.
  }
  @Override protected void onResume() {
    // Register a listener for the sensor.
    super.onResume();
    mSensorManager.registerListener(this, mPressure, SensorManager.SENSOR_DELAY_NORMAL);
  }
  @Override  protected void onPause() {
    // Be sure to unregister the sensor when the activity pauses.
    super.onPause();
    mSensorManager.unregisterListener(this);
  }
}
```

Observer Patterns Make Event Handling Simple

```
require “observer”
class Notifier
end

class PressureNotifier < Notifier
  def update(pressureValues)
    if pressureValues.altitude.meters>3000
       p “Watch out for hypoxia”
    end
  end
end
```

JavaScript for Sensor Data in RhoElements (http://docs.rhomobile.com/rhoelements/RawSensors)

```
<META HTTP-EQUIV="RawSensors" CONTENT="sensorEvent:url('Javascript:onSensor(%json);');all:enabled; ">
<SCRIPT>
   function onSensor(jsonObject)
   {
      var theOutput = "<BR><BR><B>Accelerometer  </B>";
      theOutput = theOutput + "X: " + jsonObject.accelerometerX + ", Y: " + jsonObject.accelerometerY + ", Z: " + jsonObject.accelerometerZ + "<BR>";
      theOutput = theOutput + "<B>Orientation  </B>";
      theOutput = theOutput + "X: " + jsonObject.deviceOrientation  + "<BR>";
      theOutput = theOutput + "<B>Tilt  </B>";
      theOutput = theOutput + "X: " + jsonObject.tiltangleX  + ", Y: " + jsonObject.tiltangleY  + ", Z: " + jsonObject.tiltangleZ  + "<BR>";
      theOutput = theOutput + "<B>Motion  </B>";
      theOutput = theOutput + "X: " + jsonObject.motion  + "<BR>";
      theOutput = theOutput + "<B>Ecompass  </B>";
      theOutput = theOutput + "X: " + jsonObject.ecompass  + "<BR>";
      theOutput = theOutput + "<B>Magnetometer  </B>";
      theOutput = theOutput + "X: " + jsonObject.magnetometerX  + ", Y: " + jsonObject.magnetometerY  + ", Z: " + jsonObject.magnetometerZ  + "<BR>";
      theOutput = theOutput + "<B>Gyroscope  </B>";
      theOutput = theOutput + "X: " + jsonObject.gyroscopeX  + ", Y: " + jsonObject.gyroscopeY  + ", Z: " + jsonObject.gyroscopeZ  + "<BR>";
      theOutput = theOutput + "<B>AmbientLight  </B>";
      theOutput = theOutput + "X: " + jsonObject.ambientLight  + "<BR>";
      theOutput = theOutput + "<B>Proximity  </B>";
      theOutput = theOutput + "X: " + jsonObject.proximity  + "<BR>";
      theOutput = theOutput + "<B>Proximitylongrange  </B>";
      theOutput = theOutput + "X: " + jsonObject.proximitylongrange  + "<BR>";
      theOutput = theOutput + "<B>Pressure  </B>";
      theOutput = theOutput + "X: " + jsonObject.pressure  + "<BR>";
      theOutput = theOutput + "<B>Temperature  </B>";
      theOutput = theOutput + "X: " + jsonObject.temperature  + "<BR>";
      theOutput = theOutput + "<B>Humidity  </B>";
      theOutput = theOutput + "X: " + jsonObject.humidity  + "<BR>";
      theOutput = theOutput + "<B>Gravity  </B>";
      theOutput = theOutput + "X: " + jsonObject.gravityX  + ", Y: " + jsonObject.gravityY  + ", Z: " + jsonObject.gravityZ  + "<BR>";
      theOutput = theOutput + "<B>Linear Acceleration  </B>";
      theOutput = theOutput + "X: " + jsonObject.linearAccelerationX  + ", Y: " + jsonObject.linearAccelerationY  + ", Z: " + jsonObject.linearAccelerationZ  + "<BR>";
      theOutput = theOutput + "<B>Rotation  </B>";
      theOutput = theOutput + "X: " + jsonObject.rotationX  + ", Y: " + jsonObject.rotationY  + ", Z: " + jsonObject.rotationZ  + "<BR>";
      theOutput = theOutput + "<B>Orientation  </B>";
      theOutput = theOutput + "X: " + jsonObject.orientationX  + ", Y: " + jsonObject.orientationY  + ", Z: " + jsonObject.orientationZ  + "<BR>";
      outputDiv.innerHTML = theOutput;
   }
</SCRIPT>
<div id="outputDiv">Sensor Output Goes Here</div>
<P>
  <INPUT align="center" type="button" value="Retrieve Sensor Data" onclick="RawSensors.getSensorData();"><br>
```

The Sensory Smartphone

- Definition of modern smartphone app continues to change
  - •Continues to be about richer device capabilities and computing at the edge
  - • Accelerates the different between “native apps” and web standards
- New categories of apps are possible
- Frameworks and tools can add accelerate these trends