MINING DATA FROM MOBILE DEVICES

Mobile technology overview

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Mobile OSes

• iOS
• Android
• Windows Phone
• Blackberry
• Symbian
• (Ubuntu, Mozilla, OpenMoko, …)

Why do you care?

• What is possible?
• What might be possible?
• What is not possible?

A basic understanding of the realities helps make realistic assumptions about

• Collection
• Transmission
• Processing

Overview

• Sensors & location API
• Network connectivity
• Power
• Mobile app basics

Smartphone sensors

(“virtual”)
• iPhone: more standardized
• Android: greater variety, no minimum required, varied APIs across versions

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Type</th>
<th>Avail. since</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Light</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Proximity</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Temperature</td>
<td>HW</td>
<td>1.5 (4.0)</td>
</tr>
<tr>
<td>Orientation</td>
<td>SW</td>
<td>1.5</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Pressure</td>
<td>HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Gravity</td>
<td>SW/HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Linear acceleration</td>
<td>SW/HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Rotation vector</td>
<td>SW/HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>HW</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Accelerometer

Introduction

• Measures acceleration
  • Static (gravity) \( \rightarrow \) orientation
  • Dynamic (linear motion)

• Example*: LIS33DLH (iPhone)
  • ~$1.5 (DigiKey, bulk)
  • 0.7mW on / 0.03mW low power:
    • 325 days / 20 years (1440mAh @ 3.8V)
    • \( \pm 2g \) / \( \pm 4g \) / \( \pm 8g \) selectable range
    • 16-bit dynamic range
    • 0.5Hz – 1kHz sample rate
    • Simple interrupt generators (free fall, motion)
**Accelerometer Basics**

- Measures force exerted on device (vector)
- Stationary device, lying flat:
  - Force preventing it from falling (opposite to gravity)
  - Zero force → Free fall
- Stationary device, after 45° rotation:
  - Same magnitude, but rotated

**Example code (1/3)**

```java
public class SensorActivity extends Activity
    implements SensorEventListener {

    private SensorManager mSensorManager;
    private Sensor mAccelerometer;

    @Override
    public final onCreate(Bundle savedInstanceState) {
        mSensorManager = (SensorManager)getSystemService(Context.SENSOR_SERVICE);
        mAccelerometer = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
        mSensorManager.registerListener( 
            this, mAccelerometer, 
            SensorManager.SENSOR_DELAY_NORMAL);
    }

    ...  // SensorActivity
```

**Example code (2/3)**

```java
@Override
public final void onSensorChanged(SensorEvent event) {
    float ax = event.values[0],
    ay = event.values[1],
    az = event.values[2];
    ...
}
```

**Example code (3/3)**

```java
@Override
public final void onAccuracyChanged(Sensor sensor, int accuracy) {
    ...
    ...  // SensorActivity
```

**Shortcomings**

- Cannot distinguish between gravity and acceleration
  - Impossible: “equivalence principle”
  - Solution: use low-pass filter to estimate gravity
- What if device simultaneously rotates & linearly accelerates?
  - Confused; need more data → gyroscope

**Gyroscope Introduction**

- Measures angular speed
  - Degrees per second (dps)
- Example: L3G4200D (iPhone)
  - ~$6.5 (DigiKey, bulk)
  - 18mW on / 4.5mW sleep (0.02mW off):
    - 12.5 days / 50 days
  - ±250 dps / ±500 dps / ±2000 dps range
  - 16-bit dynamic range
  - 100 / 200 / 400 / 800Hz sample rate
  - Temperature sensor (8-bit range)
  - Simple interrupt generator & FIFO
**Gyroscope Basics**

- Measures angular speed of rotation
  - Represented by numbers for each axis (but: rotation axis is different)
  - Right-hand rule
- Integrate to obtain orientation
  - …with care, since non-collinear rotations are not commutative

**Magnetometer (compass)**

- Measures direction and magnitude of (Earth’s) magnetic field
- Example: AK8973/5 (iPhone)
  - <$1 (Wikipedia), ~$2 (AliExpress; non-bulk)
- 20mW sensor on / 3mW @10Hz:
  - 11 days / 76 days

**Inertial measurement & navigation**

- 9 DoF (degrees of freedom) available
  - 3-axis accelerometer
  - 3-axis gyro
  - 3-axis magnetometer
- Combine in software for accurate:
  - Position, velocity, and acceleration (linear and angular)
  - Dead reckoning

**Inertial measurement**

**Gravity estimation**

Low-pass filter on acceleration data;
  - e.g., on Android Gingerbread:
    \[
    \tilde{g}_t = \tilde{a}_0 \cdot (\tilde{a}_t + \tilde{a}_{t-2}) + \tilde{a}_1 \cdot \tilde{a}_{t-1} - \kappa_1 \cdot \tilde{g}_{t-1} - \kappa_2 \cdot \tilde{g}_{t-2}
    \]
  - where \( \kappa_1, \kappa_2 \) depend on sampling rate and user-defined decay parameters

Basic operation, also used for:
  - Linear acceleration estimate \( \tilde{a}_t - \tilde{g}_t \)
  - Rotation vector (orientation wrt. magnetic north)

**Inertial navigation**

**Dead reckoning**

1. Integrate gyro to obtain orientation
2. Use accelerometer and gyro (orientation) data to estimate linear acceleration
3. Doubly integrate acceleration to obtain position change

- Errors accumulate over time (~\( t^2 \))
- Error depends on sampling rate
- How accurate is it?
  - "Pro" (air navigation) answer:
    - GPS: better than 9m
    - Inertial: ~650m after one hour

**Other sensors**

- Proximity
- Less common:
  - Thermometer
    - But: gyroscope & compass often has temperature output as well
  - Light
  - Pressure (barometric) \( \rightarrow \) altitude
Location APIs

- Low-level location providers:
  - GPS
  - WiFi
  - Cell tower
  - ...

- Mid-level:
  - Fused location providers

- Higher-level:
  - Geo-fencing
  - Activity recognition

Location APIs (low-level)

- GPS, WiFi, cell tower, ...
- Differ in:
  - Accuracy
  - Availability / freshness
  - Power consumption
- Listen for location updates
- Choose how to update location estimate

Location APIs (mid-level)

- Fused location providers
- User specifies:
  - Min and max update period
  - Accuracy preferences
- Location service takes care of managing different low-level providers, to obtain best accuracy at low(est) power

Location APIs (higher-level)

- Geo-fencing:
  - User specifies a POI or map area
  - Requests to receive alerts when user is near / inside fence
- Activity recognition (Android APIs):
  - Use sensor and location data to detect what user is doing
  - Walking vs cycling vs driving
  - Provides probability for each activity

Indoor localization

- No O/S level APIs (?)
- Google Maps offers indoors navigation
  - Mix of WiFi-based localization and (very rough) dead reckoning
- May be possible to obtain WiFi RSS data
  - Android offers APIs, iOS is restricted
- Other applications have used other signals (like audio)
- Custom solutions also exist (e.g., ultrasound-based)
- More on this later ...

Overview

- Sensors
- Network connectivity
- Power
- Mobile app basics
**Cellular**

- Various standards have evolved over the years
- Hard to track (too much marketing hype…)
- But: rapidly increasing bandwidth and decreasing cost

**Standard** | **Year** | **D/L (max)** | **U/L (max)**
--- | --- | --- | ---
GPRS | 1997 | 60-80kb/s | 20-40kb/s
EDGE | 2003 | 177-237kb/s | 60-118kb/s
HSPA | 2006 | 14.4-2mb/s | 1(?)-6mb/s
HSPA+ | 2008 | 28-16mb/s | 11-22mb/s
LTE | 2010 | 12-300mb/s | 5-75mb/s

*numbers based on marketing claims, please take with grain(s) of salt
**approx. year (first major deployment)

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**802.11b/g/n (WiFi)**

- Introduced around the same time as GPRS
- Evolved over time: bandwidth and ubiquity

**Protocol** | **Year** | **B/W (Mbit/s max)**
--- | --- | ---
—— | 1997 | 2
b | 1999 | 11
g | 2003 | 54
n | 2009 | 72.2 (2.4GHz)
150 (5GHz)
ac (draft) | 2012 | 88-867

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**Bluetooth**

- Developed by Ericsson in 1994
- Standardized in 1998
- Developed over years

- Designed almost concurrently with WiFi; designed for short-range communications with peripherals (not Ethernet/IP packets only)
  - Fairly complex
  - Fairly ubiquitous

**Class** | **mW (max)** | **Range (m)**
--- | --- | ---
1 | 100 | 100
2 | 2.5 | 10
3 | 1 | 1

**Version** | **Data rate (Mbit/s)**
--- | ---
1.2 | 1.2
2.0 + EDR | 3
3.0 + HS | 24

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**Bluetooth Low Energy (BLE)**

<table>
<thead>
<tr>
<th>Spec</th>
<th>Bluetooth “Classic”</th>
<th>BLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (max)</td>
<td>100m</td>
<td>50m</td>
</tr>
<tr>
<td>Data rate</td>
<td>1-3Mb/s</td>
<td>1Mb/s</td>
</tr>
<tr>
<td>App. throughput</td>
<td>0.7-2.1Mb/s</td>
<td>0.27Mb/s</td>
</tr>
<tr>
<td>Latency</td>
<td>100ms (typ.)</td>
<td>6ms</td>
</tr>
<tr>
<td>Time to send data</td>
<td>100ms</td>
<td>3ms</td>
</tr>
<tr>
<td>Peak current</td>
<td>&lt;30 mA</td>
<td>&lt;15 mA</td>
</tr>
<tr>
<td>Power consumption</td>
<td>100% (reference)</td>
<td>10-50% (use case dep.)</td>
</tr>
</tbody>
</table>

- Entirely separate stack (Zigbee derivative)
- Goals: low power, low latency, low(er) cost
- Initially developed by Nokia, became standard in 2010
- Standard on iPhone, not yet on Android

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**Other**

- Zigbee / XBee
- Cheap transceivers (e.g., Nordic chipsets)
- Non-standard (on phones), require ugly dongles, etc.
- But, might be worth it for prototyping
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Power overview

Cellular and WiFi power

- Overall comparable power draw
- WiFi can consume substantially less (esp. if kept connected)
- But cellular is always available/on
- One larger transfer is much better than many small ones

Bluetooth power

- Comparable to WiFi
- Bluetooth 4.0 (BLE):
  - Up to 10x lower power draw
  - Lower latency & cost
  - Designed for peripherals / sensors
  - iPhone: standard
  - Android: not yet

Sensor power

- Not substantial, per se
  - 3-20 mW → several days of power from iPhone 5 battery
  - What’s the big deal?
- CPU power consumption!
  - For reasonable accuracy; 200Hz sample rate prevents CPU from entering sleep mode (more soon…)
- Solution: dedicated processor; either
  - Separate app.-specific processor chip
  - All-in-one IMU chip (e.g., MPU6050)

Frequency scaling

- All modern processors can adjust speed based on workload
- DVFS (dynamic voltage frequency scaling)
- Several policies; defaults are usually fine
- Power consumption is proportional to clock speed (plus a fixed penalty – this is important)
Advanced sleep modes

CPU power

- If doing no work, it’s much better to turn off CPU completely
- Even for a few milliseconds (better than nothing)
- Around 30x less power draw
- All modern phones will do this automatically
- Additionally, facilities to reduce number of wakeups; e.g., batching timer events, background messaging (aka. push notifications), etc.

Display power

- Substantial power draw, esp. at high brightness
- Not really relevant for sensing applications (unless user interaction is required?)

Power consumption summary

- Primary power consumers:
  - CPU
  - Radios
  - Display

Power overview

Nexus S (Dec 2010) vs Nexus 4 (Nov 2012)

Phones released two years apart: mostly similar
- (Except WiFi, not sure what's going on there…)
- Battery capacity up… a bit

Don’t assume power draw will magically go down; need to actively manage it in your design and code!

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Programming paradigm

Heavily event-oriented!

Application must respond to its environment; e.g.
- Network connectivity changes
- Incoming calls / messages / events
- Sensor / location data
  - …

Application must use resources efficiently; e.g.
- May be pre-empted and/or killed at any time
- May choose to respond to status information (e.g., battery level)
  - …

Cannot:
- Assume a single main() thread with sequential flow
- Control lifetime of thread(s)
Programming paradigm

Android: activity paradigm
- You can think of an activity as a screen
- Can be in different states during its lifecycle
- Need to respond to state-change events
- System determines state based on:
  - User interactions (e.g., start a different activity)
  - External events (e.g., screen rotation, incoming call, …)
  - Available resources (memory, CPU, etc)
- Execute in the main app thread
- Responsible for persisting any app-specific state, as necessary

Activity lifecycle (Android)

Background tasks

Short lived (e.g., fetch a URL):
- Can be started in separate threads
- But: need to be prepared for activity termination/restart

Long lived:
- Need to use system APIs to register themselves and allow system to manage them
- Timers, background services, RPC interfaces

Avoid whenever possible!!
- Use system services instead, e.g., geo-fences, push notifications, etc

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