RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

MINING SMARTPHONE MOBILITY DATA

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
- Accounts ("identity")
- Mobile app basics

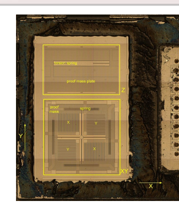
Smartphone sensors
(Android)

Sensor	Type	Avail. since
Accelerometer	HW	1.5
Light	HW	1.5
Magnetic field	HW	1.5
Proximity	HW	1.5
Temperature	HW	1.5 (4.0)
Orientation	SW	1.5
Gyroscope	HW	2.3
Pressure	HW	2.3
Gravity	SW/HW	2.3
Linear acceleration	SW/HW	2.3
Rotation vector	SW/HW	2.3
Relative humidity	HW	4.0

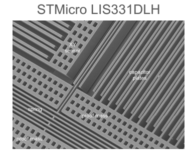
- Hardware or software ("virtual")
- iPhone: more standardized
- Android: greater variety, no minimum required, varied APIs across versions

Accelerometer
Introduction

- Measures acceleration
  - Static (gravity) → 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)
  - ±2g / ±4g / ±8g selectable range
  - 16-bit dynamic range
  - 0.5Hz – 1KHz sample rate
  - Simple interrupt generators (free fall, motion)

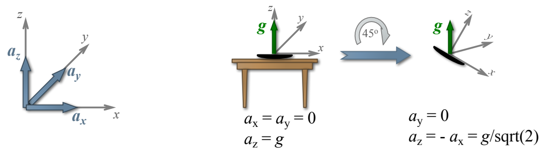


STMicro LIS331DLH



http://www.memsjournal.com/2010/12/motion-sensing-in-the-iphone-4-mems-accelerometer.html

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 45º rotation:
  - Same magnitude, but rotated

Accelerometer
Example code (1/3)

Android (1/2)

```
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);
  }
```

[continued]

Accelerometer
Example code (2/3)

Android (2/2)

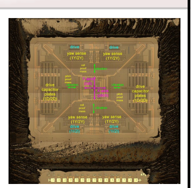
```
[continued]

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

  @Override
  public final void onAccuracyChanged(Sensor sensor, int accuracy)
  { ... }

  ...
}  // SensorActivity
```


Accelerometer
Shortcomings

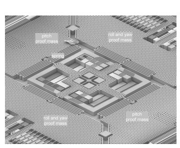
- Cannot distinguish between gravity and acceleration
  - Impossible: "equivalence principle"
  - Solution: use low-pass filter to estimate gravity
- What if device simultaneously rotates & linearly accelerates?
  - Confused; need more data → gyroscope

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
  - ±250dps / ±500dps / ±2000dps range
  - 16-bit dynamic range
  - 100 / 200 / 400 / 800Hz sample rate
  - Temperature sensor (8-bit range)
  - Simple interrupt generator & FIFO

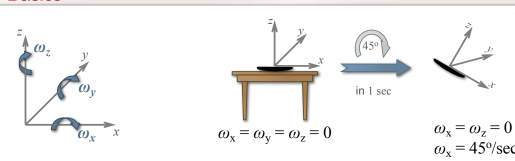


STMicro L3G4200D



http://www.memsjournal.com/2011/01/motion-sensing-in-the-iphone-4-mems-gyroscope.html

Gyroscope
Basics

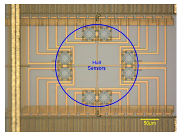


- Measures angular speed of rotation
  - Represented by numbers for each axis (but: rotation axis is different)
  - Right-hand rule
- Integrate to obtain orientation
  - …with care, since non-collinear rotations are not commutative

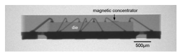
Magnetometer (compass)

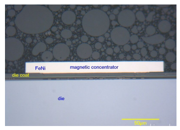
Introduction

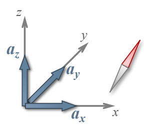
- Measures direction and magnitude of (Earth's) magnetic field
- Example*: AK8973/5 (iPhone)
  - <$1 (Wikipedia), ~$2 (AliExpess; non-bulk)
  - 20mW sensor on / 3mW @10Hz: 11 days / 76 days



AKM AK8975







http://www.memsjournal.com/2011/02/motion-sensing-in-the-iphone-4-electronic-compass.html

Inertial measurement & navigation

- Summarizing: 9 DoF (degrees of freedom) available
  - 3-axis accelerometer — Linear acceleration (translation)
  - 3-axis gyro — Angular velocity (rotation)
  - 3-axis magnetometer — Global reference (Earth)

  } Dead reckoning
- 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:

$$g_t = \lambda_0(a_t + a_{t-2}) + \lambda_1 a_{t-1} - \kappa_1 g_{t-1} - \kappa_2 g_{t-2}$$

Basic operation, also used for:

- Linear acceleration estimate $a_t - g_t$
- 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 ($\sim t^3$)
- 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 output temperature as well
- Light intensity
- Pressure (barometric) → altitude

Future trend:

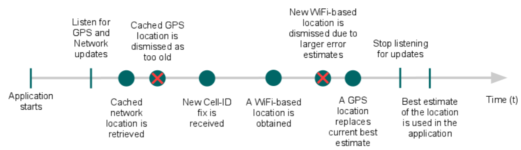
- Independent motion / sensor processors
  - Already on iPhones for a couple of years

Location APIs

- Low-level location providers:
  - GPS
  - WiFi
  - Cell tower
  - …
- Mid-level:
  - Fused location providers
- Higher-level:
  - Geo-fencing
  - Activity recognition

Location APIs
Location providers (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
Fused location services

- Combine different 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
Geo-fences and activities

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
  - Also: iBeacon (BLE-based, proximity)
- Other applications have used other signals (like audio)
- Custom solutions also exist (e.g., ultrasound-based)
- More on this later …

Overview

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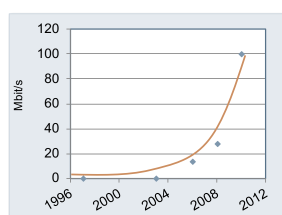
Cellular

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



Cellular

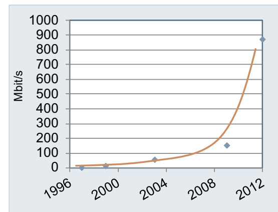
- Historical technologies:
  - 2G: GPRS (GSM)
  - 2.5G: EDGE
- Current technologies:
  - "3G": UMTS (HSDPA, HSUPA, HS[DP]A+)
  - "4G": LTE
- Other technologies (failed adoption):
  - WiBro, WiMax, …

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	14-42mb/s	1(?)-6mb/s
HSPA+	2008	28-168mb/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).

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

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
2.0 + EDR	3
3.0 + HS	24

Bluetooth Low Energy (BLE)

Spec	Bluetooth "Classic"	BLE
Range (max)	100m	50m
Data rate	1-3Mbit/s	1Mbit/s
App. throughput	0.7-2.1Mbit/s	0.27Mbit/s
Latency	100ms (typ.)	6ms
Time to send data	100ms	~3ms
Peak current	<30 mA	<15 mA
Power consumption	100% (reference)	10-50% (use case dep.)

- Entirely separate stack (Zigbee derivative)
- Goals: low power, low latency, low(er) cost
- Initially developed by Nokia, became standard in 2010
- Standard on both iPhone and Android

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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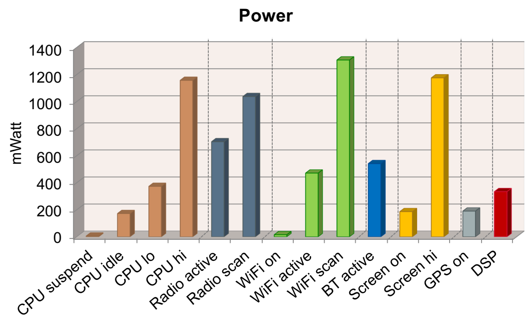
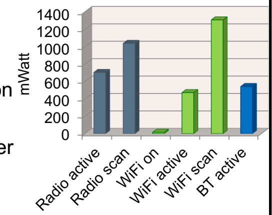
Power overview



//device/samsung/crespo/+/android-4.1.2_r2.1/overlay/frameworks/base/core/res/res/xml/power_profile.xml

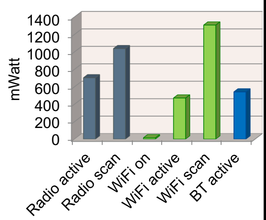
Cellular and WiFi power

- 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



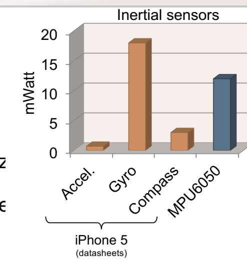
Bluetooth power

- 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



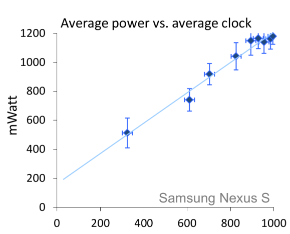
Sensor power

- 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

CPU power

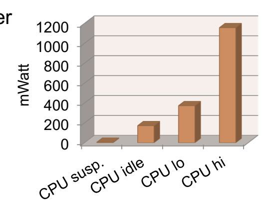


- All modern processors can adjust speed based on workload
- DVFS (dynamic voltage frequency scaling)
- Several policies; defaults are usually fine
- Power consumption is proportional to clock speed (plus a fixed penalty – this is important)

Advanced sleep modes

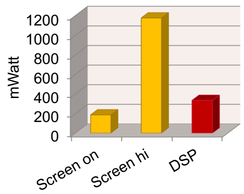
CPU power

- 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.

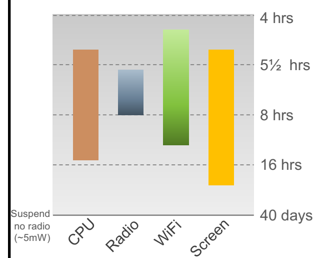


Display power

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



Power consumption summary

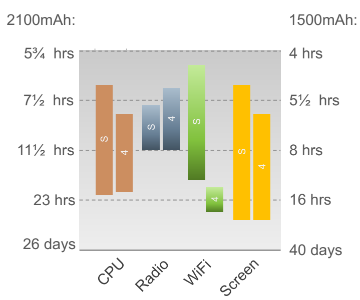


- Primary power consumers:
  - CPU
  - Radios
  - Display

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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Device / installation identifiers

- Often, a unique identifier for a specific app installation is what's really required
  - Simple; e.g., generate new random UUID on first run
  - Safer, less intrusive
- Hardware identifier
  - On phones: IMEI or ESN/MEID (may be illegal to modify) usually works; also ICCID (SIM card)
  - Non-phones: ANDROID_ID (UUID on first boot; versions > 2.2)
  - Caveat: persists when device changes owner
  - Requires READ_PHONE_STATE permission

Account authentication

- Web: OAuth has become dominant standard
- Mobile: APIs serving similar purpose, OS-specific
- E.g., Android account manager APIs:
  - Based on pluggable authenticator modules
  - Can generate service auth tokens for apps that request them
  - May allow reuse of token by different apps (e.g., auto-login)
  - Good support for background processes (e.g., sync adapters)
  - Multiple token types (e.g., read-only vs. full-access), similar to Oauth
  - Use of token is service-dependent (protocol, data format, etc)

Sync adapters & content providers

- Sync adapter (Android):
  - Centralized facility for background syncing of on-device and remote data (e.g., contacts, posts, etc)
  - Allows optimizations (e.g., to conserve power)
- Content provider (Android):
  - APIs to expose (synced) data to other applications
  - Well-defined query endpoints and schemas
  - Cursor-like API

Overview

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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
- …

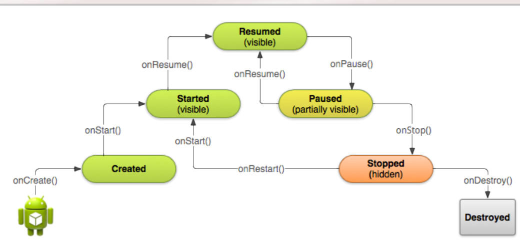
Application must use resources efficiently; e.g.
- May be pre-empted and/or killed at any time
- May choose to respond to status information (e.g, battery level)
- …

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 it's *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)



A note on "deep linking"

- Android: an app can declare which activities handle a particular URL pattern
  - E.g., YouTube app could declare that URLs with http:// protocol and youtube.com domain can be handled by it's video player activity
  - If multiple apps can handle the same URL type, the user will be prompted to choose
- iOS: similar, but not as general/broad (?)

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

Tutorial plan

11:55 – 13:00 Katharina
- Resource-constrained graphical models
- App usage mining and traffic prediction

Lunch break (13:30-14:30)

14:30 – 15:15 Tina
- Local-based social networks
- Mobile advertising and search

15:15 – 16:10 Dimitrios
- Learning from trajectory data
- Crowdsourcing and applications

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