Improving Accuracy and Extending Battery Life in Wearable GPS Products
Wearable Fitness Challenges

MOST IMPORTANT WEARABLE FEATURES:

#1 ACCURACY  #2 COMFORT  #3 BATTERY LIFE

Why do Wearables End Up in the Sock Drawer?

37% have discontinued use of their wearable. Why?

- 40% Too much of a hassle to continually recharge
- 29% Not accurate enough/didn’t trust readings
- 26% Uncomfortable to wear
- 24% Did not provide continually interesting insights

The State of Wearables Today
June 2016
GPS is a Wearable Battery Killer

Problem 1: GPS usage kills battery life

Fitbit Surge:
- 7 day Battery life on standby
- 5hr GPS Battery life

Apple Watch 2:
- 10 hour battery life in workout mode without GPS
- 5 hour battery life in workout mode with GPS

Android Fitness Apps
- 4-6hr Battery Life w/ GPS

Many early smartwatches didn’t include GPS due to power drain. Users not happy with this easy solution due to accuracy sacrifice.

Better Solution: Use less GPS

- Duty cycle GPS and bridge outages with sensors
  - Distance, speed and trajectory using less GPS
  - Minimize time using GPS, thus minimize battery drain
Problem 2: poor accuracy on wearables
   • Sensors drift over time
   • GPS not accurate enough on wearables
     – Small antenna
     – Attenuation from body
     – Arm swinging
     – Lack of assistance data to watch GPS

Solution: Combine GPS + sensors
   – Improves accuracy of multipath GPS by filtering
   – GPS can correct PDR sensor drift or offset errors (e.g. position drifts, stride length bias)
Coursa Sports
Sensor-Assisted GPS Fitness Tracking

- Speed
- Distance
- Route
- GPS Duty-Cycle
- Improve Accuracy
- Reduce Power
Data Flow of Coursa Sports

- Provides distance & speed in real-time at low power
- Provides accurate post mission route from cloud

Real-Time Outputs
1. Speed
2. Distance

Post-Mission Outputs
1. Route
2. Speed
3. Distance

Mobile App (using Coursa Sports SDK)

GNSS, Sensors Speed/Distance

Coursa Sports Speed/Dist/Route Service

Customer Cloud

GNSS, Motion Speed/Distance

Route + More Accurate Speed/Distance
GPS Duty Cycling Concept

Coursa Sports Low Power Mode
• GNSS on for 15 sec then off for 45 sec
• Seamless route solution using only 25% GPS
• Distance and route are similar performance as GPS on all the time

Duty Cycling Challenges
• GPS needs to be left on for around 15 seconds to assure a few ‘good’ GPS measurements are received
• Reacquisition errors have to be filtered out by Coursa Sports
Coursa Sports Duty Cycling Modes

- How to optimally balance power consumption vs accuracy?
  - *The right answer depends on the application and device being used*
- Coursa Sports designed with 3 modes to control power vs accuracy

<table>
<thead>
<tr>
<th></th>
<th>Low Power Mode</th>
<th>Balanced Mode</th>
<th>Performance Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Usage of GPS</strong>&lt;br&gt;(duty cycle)</td>
<td>Aggressive duty cycle (approx. 25% GPS)</td>
<td>Light duty cycle (approx. 50% GPS)</td>
<td>No duty cycle&lt;br&gt;GPS + sensors</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>30-60% less power than GPS on all the time</td>
<td>15-30% less power than GPS on all the time</td>
<td>1-10% more power than GPS on all the time</td>
</tr>
<tr>
<td><strong>Distance/Speed</strong></td>
<td>Similar to GPS on all the time</td>
<td>25-50% better than GPS on all the time</td>
<td>50-75% better than GPS on all the time</td>
</tr>
<tr>
<td><strong>Route</strong></td>
<td>Similar to GPS on all the time</td>
<td>Better in multipath environments such as downtown.</td>
<td>Better than GPS on all the time in all environments</td>
</tr>
</tbody>
</table>
Android & Android Wear Test Results
Coursa Sports on Android Wearables

- Only a few Android Wear devices have included GPS over the past year. Examples:
  - Sony Watch 3, Samsung Gear S2, Moto 360
- There are other good GPS implementations on wearables but they are not Android Wear
  - e.g. Fitbit Surge
- Moto 360 is one of the better GPS implementations on Android Wear and contains 6 axis (accel + gyro)
Example 1: Coursa Sports Performance Mode vs Strava in Open Sky

- Below example shows ‘Performance Mode’ of operation on a Moto 360 watch
  - GNSS on all the time for Strava in blue and Coursa Sports in red
  - Coursa Sports route is more accurate than GNSS on all the time, even in open sky when GNSS is performing at its best
  - Strava distance travelled error = 7.9%
  - Coursa Sports distance travelled error = 2.2%

Strava with GNSS on all the time

Coursa Sports
Example 2: Coursa Sports Low Power vs Strava in Downtown GPS Multipath

- Below example shows ‘Low Power Mode’ of operation on a Moto 360 watch
  - Coursa Sports using 25% GPS duty cycle on the Moto 360
  - GPS on all the time for Strava on the Moto 360
  - Coursa Sports route similar to GPS on all the time, but with power savings on the Moto 360
  - Strava distance travelled error = 13.3%
  - Coursa Sports distance travelled error = 6.2%
Example 2: Speed in Downtown

Person walked at an approximately steady speed at 1.4 m/s, with some stops. Coursa Sports is more accurate and does not suffer from GPS multipath errors.
Example 3: Wearables Performance Comparison in Downtown Multipath

- Reference path = 2.65 km
- All paths have some error due to GPS multipath.
- Below example shows ‘Performance Mode’ of operation for Coursa Sports on a Moto 360 watch compared to:
  1. Fitbit Surge watch
     - 2.92 km (10.1% error)
  2. Apple Workout APP on the Apple Watch 2
     - 2.60 km (1.9% error)
  3. Samsung S Health running on Gear S2 watch
     - 1.84 km (31% error)
  4. Coursa Sports Performance Mode
     - 2.70 km (1.9% error)
How much energy can Coursa Sports save in comparison to GPS on all the time?

**uBlox MAX-M8C operating in continuous mode @ 1 Hz**

<table>
<thead>
<tr>
<th>Time to Fix (s)</th>
<th>Current Consumption (mA)</th>
<th>Voltage (V)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial acquisition</td>
<td>28</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Hot start reacquire</td>
<td>1</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>GNSS tracking @ 1Hz</td>
<td>17</td>
<td>3</td>
<td>51</td>
</tr>
<tr>
<td>6 axes Sensors + Coursa SW</td>
<td>3</td>
<td>1.8</td>
<td>5.4</td>
</tr>
</tbody>
</table>

**Energy savings for Coursa Sports Low Power Mode**

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Coursa Sports Low Power, Energy Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>24%</td>
</tr>
<tr>
<td>5</td>
<td>46%</td>
</tr>
<tr>
<td>10</td>
<td>54%</td>
</tr>
<tr>
<td>20</td>
<td>58%</td>
</tr>
<tr>
<td>30</td>
<td>60%</td>
</tr>
</tbody>
</table>
Coursa Sports on Android Phones

- Android phones typically have good GPS implementations
  - Benchmark devices: Samsung S6 or Nexus 6
  - Since phones have cloud connectivity the GPS implementations are noticeably better than watches
  - Coursa Sports absolute distance/route performance dependent on baseline GPS performance
Example 4: Coursa Sports Low Power Mode on Track

- Below example shows ‘Low Power Mode’ of operation on an S6 phone

  - Coursa Sports (Low Power Mode)
  - GPS used in duty cycle

© 2015 Google
Example 4: Coursa Sports Height on the Flat Track

Track is flat with nearly no height gain/loss
Coursa Sports is much more accurate than GPS on all the time
Example 5: Coursa Sports Performance Mode on S6 Phone in Downtown

- Below results all collected using Samsung Galaxy S6 phone
  - Baseline GPS of the S6 better than wearable GPS
  - Coursa Sports Performance Mode is most accurate

- Strava
- MyTracks
- MapMyRun
- Coursa Sports (Performance Mode)
Example 5: Coursa Sports Speed in Downtown

Person walked an approximately constant speed at 1.4 m/s. Coursa Sports is most accurate and does not suffer from GPS multipath errors.
**Distance/Speed Benchmarking on Android Devices**

- Coursa Sports designed as an SDK to work on a variety of devices
  - Accuracy benchmarking performed using several Android devices
- Hundreds of exercise sessions used to calculate the following statistics
- Statistics used from all environments (open sky + track + foliage + downtown)

<table>
<thead>
<tr>
<th></th>
<th>Distance/Speed Errors w.r.t. Distance Travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coursa Sports Low Power</strong> (25% duty cycle)</td>
<td>7%</td>
</tr>
<tr>
<td><strong>Coursa Sports Balanced</strong> (50% duty cycle)</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Coursa Sports Performance</strong> (no duty cycle)</td>
<td>4%</td>
</tr>
<tr>
<td>GPS on all the time at 1 Hz</td>
<td>8%</td>
</tr>
</tbody>
</table>
Comparing Coursa Sports to the Apple Watch Series 2
Apple Watch 2 Benchmark

• Apple released their Series 2 of the Apple Watch in September 2016
  – Focus is on fitness tracking
  – Walk, run, bike, swim…

• Apple Watch 2 validates approach taken by Coursa Sports
  – Speed/pace & distance provided in real-time
  – Route provided after finishing an exercise session and only displayed on the iPhone

• Apple Watch 2 lays down benchmark performance for Android vendors
  – Quality GPS implementation on a watch
  – Good distance & route accuracy
Apple Watch GPS Implementation

• Apple has done a good job integrating GPS hardware on their Watch 2
  – Accuracy of GPS position & velocity similar to Android phone performance
    • Positions within 5 meter accuracy (correct side of road)
    • Initial acquisition time within a few seconds
  – Better positioning accuracy and acquisition timing than Android Wear implementations to date, such as Sony Watch 3, Gear S2 and Moto 360
    • Sony Watch 3 and Gear S2 had positioning accuracy good to 10’s of meters
    • Moto 360 had better positioning accuracy but it’s acquisition time was longer than 15 seconds

• Apple benefits from good GPS to calibrate distance
  – Early testing shows Apple Watch 2 distance estimation accuracy around 3-4% on average through different GPS environments
Distance Benchmark Set by Apple

- Accuracy benchmarking of Coursa Sports performed using several Android devices

<table>
<thead>
<tr>
<th>Device/Setting</th>
<th>Average Distance Errors w.r.t. Distance Travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Watch 2, GPS on all the time</td>
<td>3-4%</td>
</tr>
<tr>
<td>Android Phone GPS-only</td>
<td>8%</td>
</tr>
<tr>
<td>Coursa Sports Performance on Android (GPS on all the time)</td>
<td>4%</td>
</tr>
<tr>
<td>Coursa Sports Balanced on Android (50% duty cycle)</td>
<td>5%</td>
</tr>
<tr>
<td>Coursa Sports Low Power on Android (25% duty cycle)</td>
<td>7%</td>
</tr>
</tbody>
</table>
Route Comparisons

1) Apple Watch 2 smooths out GPS errors (GOOD)
2) Apple Watch 2 smooths some turns when smoothing GPS multipath (BAD)
3) Apple Watch 2 does not provide a position when GPS signals are lost (BAD)

Reference

Coursa Sports

1) Apple Watch smooths GPS errors

2) Apple Watch smooths some real turns, even in open sky.

Coursa Sports provides smoothing without sacrificing turns.

3) Apple Watch 2 does not provide a position indoors or when GPS signals are lost.

Coursa Sports solution is seamless.
Apple Watch Power Consumption

- Apple Watch 2 can be used in workout mode for 5 hours with GPS ON and 10 hours with GPS OFF
  - 273 mAh battery
  - 27 mA/hour extra burn with GPS on

- Coursa Sports Low Power Mode uses about 25-30% GPS through duty cycling
  - Should extend battery life of Apple Watch 2 with GPS ON to about 8 hours

- Coursa Sports Balanced Mode uses about 50% GPS through duty cycling
  - Should extend battery life of Apple Watch 2 with GPS ON to about 7 hours
## Apple Watch vs Android GPS vs Coursa Sports

**Conclusion:** Android devices can benefit from Coursa Sports to compete with the Apple Watch 2 performance benchmarks

<table>
<thead>
<tr>
<th></th>
<th>Distance Performance</th>
<th>Route Performance</th>
<th>Power Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apple Watch 2</strong></td>
<td>The benchmark, good distance estimation</td>
<td>Smooth in open sky and in mild multipath. Does not bridge GPS outages. Problems with turns.</td>
<td>5 hours with GPS ON</td>
</tr>
<tr>
<td><strong>Android Phone</strong></td>
<td>2x worse than Apple Watch</td>
<td>Subject to GPS multipath errors and does not bridge GPS outages.</td>
<td>4-6 hours with GPS ON, depending on device</td>
</tr>
<tr>
<td><strong>GPS-only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coursa Sports</strong></td>
<td>Can get Android devices to similar performance as Apple Watch in Coursa Sports Performance Mode</td>
<td>Smooth in all conditions &amp; bridges GPS signal outages. Can get better path than Apple Watch 2 in signal loss scenarios and during turns.</td>
<td>3 hours more than Apple Watch 2 and Android mobile devices in Coursa Sports Low Power Mode</td>
</tr>
</tbody>
</table>
Coursa Sports Software & Integration
Cross-Platform SW Availability

<table>
<thead>
<tr>
<th>Real-Time Software Requirements</th>
<th>MIPS</th>
<th>Code (KB)</th>
<th>Data (KB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;6</td>
<td>115</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Application Processor or Microcontroller

Embedded Library for OEMs or SDK for App Developers
• Real time distance and speed computation is done on the device
• GNSS is duty cycled on the device
• Route is calculated on Coursa Sports servers
• Session data processed by the Coursa Sports server is available via REST APIs
## SDK Integration Lifecycle

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Request access to SDK &amp; wait for approval</td>
</tr>
<tr>
<td>2.</td>
<td>Login to download Android &amp; iOS SDK</td>
</tr>
<tr>
<td>3.</td>
<td>Integrate iOS &amp; Android SDK using the <strong>SDK key</strong> granted to the account. Verify distance &amp; speed</td>
</tr>
<tr>
<td>4.</td>
<td>Use unique user id’s and upload data to the Coursa Sports servers</td>
</tr>
<tr>
<td>5.</td>
<td>Use the <strong>API key</strong> to download <strong>processed route</strong> data from Coursa Sports servers</td>
</tr>
<tr>
<td>6.</td>
<td>Test and verify implementation</td>
</tr>
</tbody>
</table>
Coursa Sports Eval App

Distance
Speed
Time

Use Case: Handheld

GPS On Percent

Start

Eval app available for demo on Android, Android Wear and iOS devices
Thank You