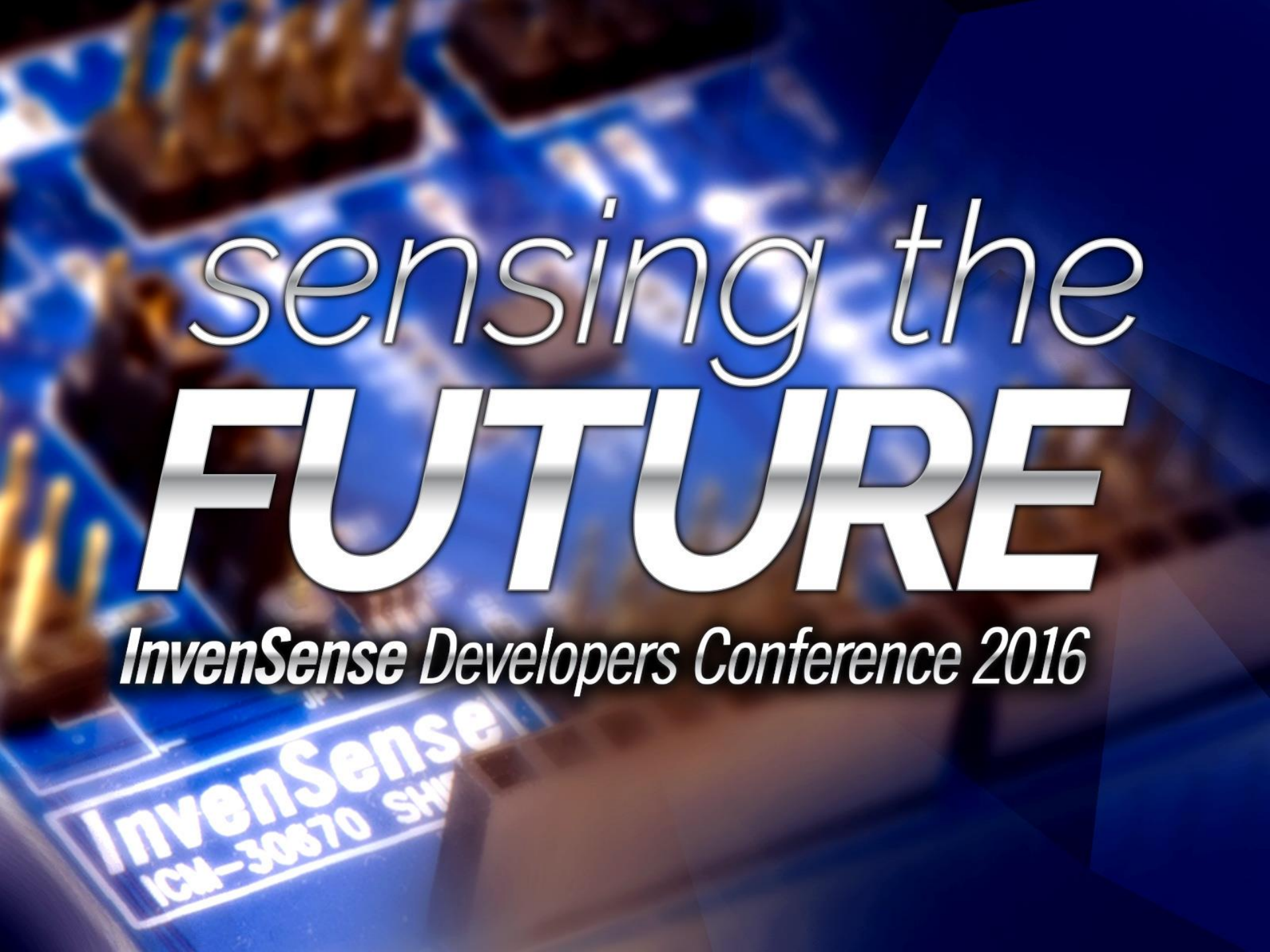
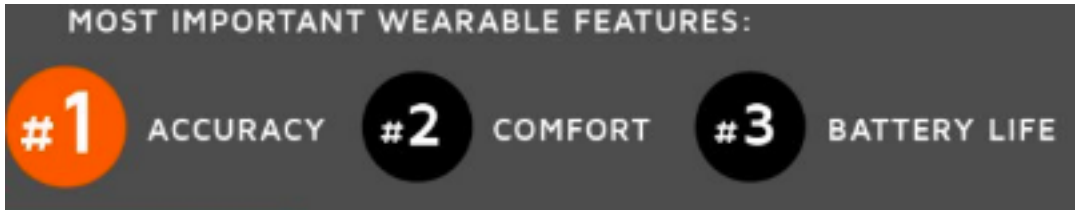

sensing the
FUTURE
InvenSense Developers Conference 2016
InvenSense
ICM-30670

Improving Accuracy and Extending Battery Life in Wearable GPS Products

Wearable Fitness Challenges

sensing the FUTURE



VALENCELL

MEMS & Sensors Industry Group®

The State of Wearables Today
June 2016

GPS is a Wearable Battery Killer

sensing the FUTURE

Problem 1: GPS usage kills battery life

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

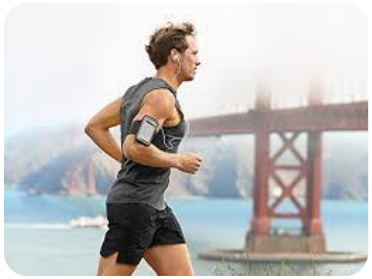
Apple Watch 2:
- 10 hour battery life in workout mode without GPS
- 5 hour battery life in workout mode with GPS

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

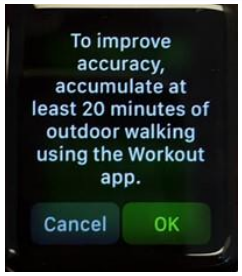


Accuracy: GPS or Sensors?

sensing the FUTURE

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



Reference

GPS from Gear S2

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

sensing the FUTURE

Speed 

Distance

Route 

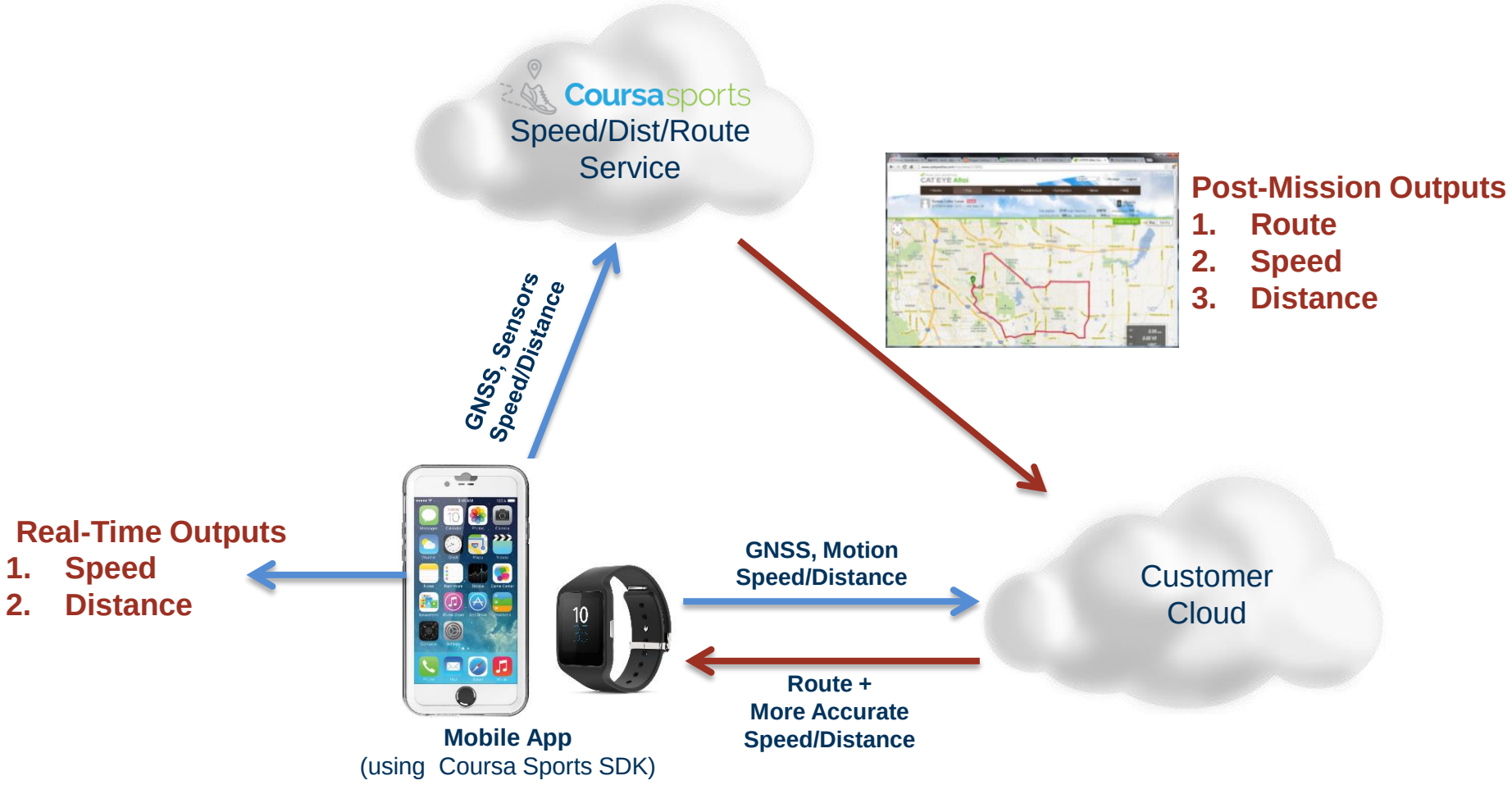
GPS Duty-Cycle

Improve Accuracy  Reduce Power

Data Flow of Coursa Sports

sensing the FUTURE

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

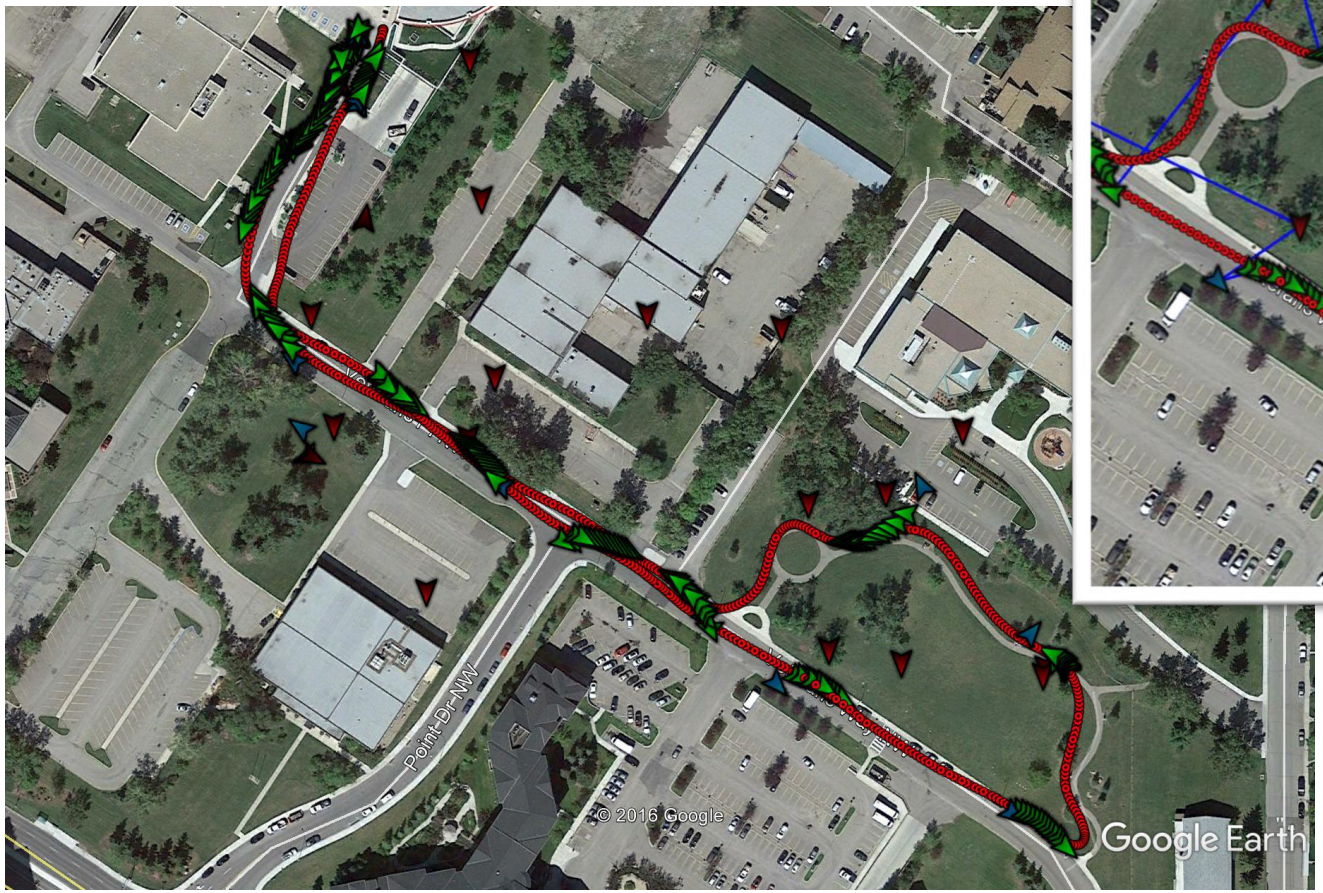


GPS Duty Cycling Concept

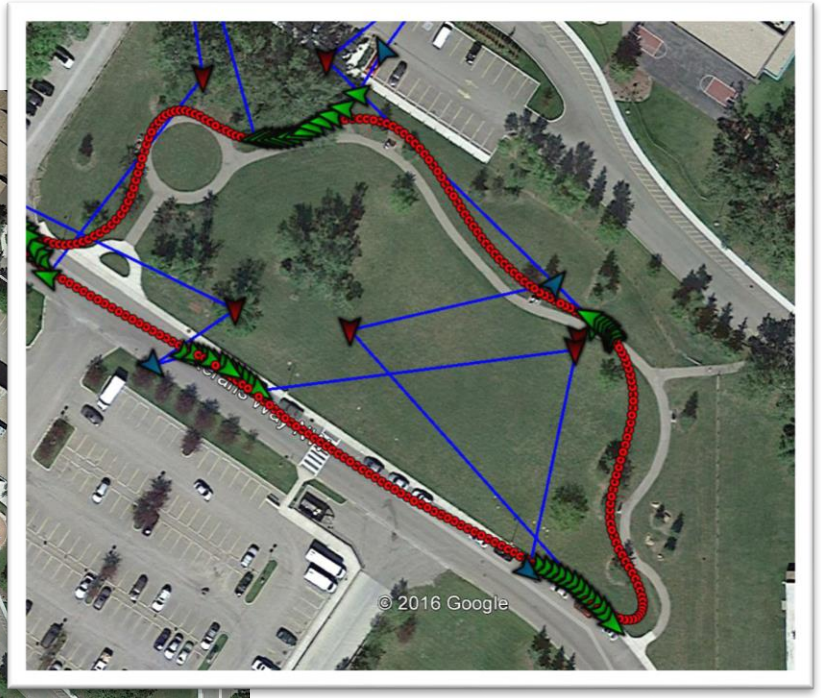
sensing the FUTURE

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



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



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

sensing the FUTURE

- 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

	Low Power Mode	Balanced Mode	Performance Mode
Usage of GPS (duty cycle)	Aggressive duty cycle (approx. 25% GPS)	Light duty cycle (approx. 50% GPS)	No duty cycle GPS + sensors
Power Consumption	**30-60% less power than GPS on all the time**	**15-30% less power than GPS on all the time**	1-10% more power than GPS on all the time
Distance/Speed	Similar to GPS on all the time	**25-50% better than GPS on all the time**	**50-75% better than GPS on all the time**
Route	Similar to GPS on all the time	**Better in multipath environments such as downtown.**	**Better than GPS on all the time in all environments**

Android & Android Wear Test Results

Coursa Sports on Android Wearables

sensing the FUTURE

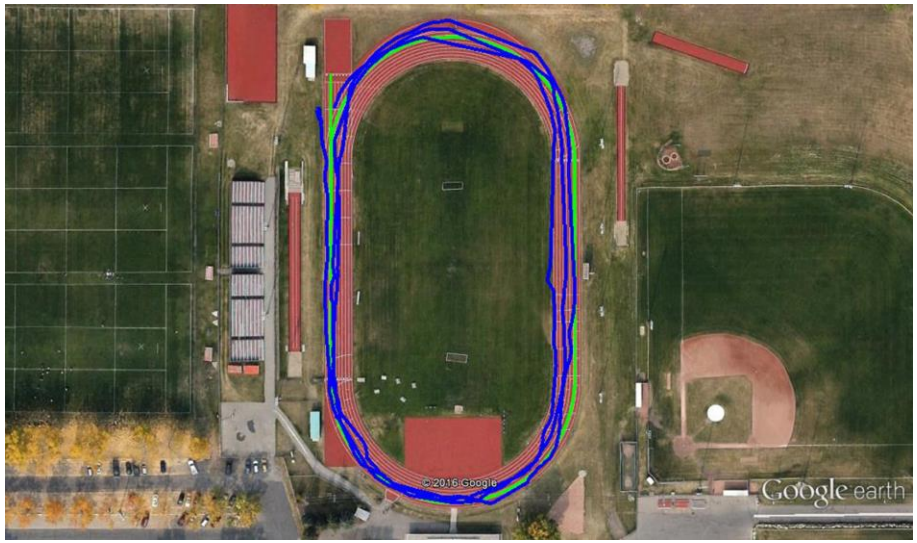
- Only a few Android Wear devices have included GPS over the past year. Examples:
  - Sony Watch 3, Samsung Gear S2, Moto 360
- There are other good GPS implementations on wearables but they are not Android Wear
  - e.g. Fitbit Surge
- Moto 360 is one of the better GPS implementations on Android Wear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

Example 1: Coursa Sports Performance Mode vs Strava in Open Sky

sensing the FUTURE

- 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

sensing the FUTURE

- 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%

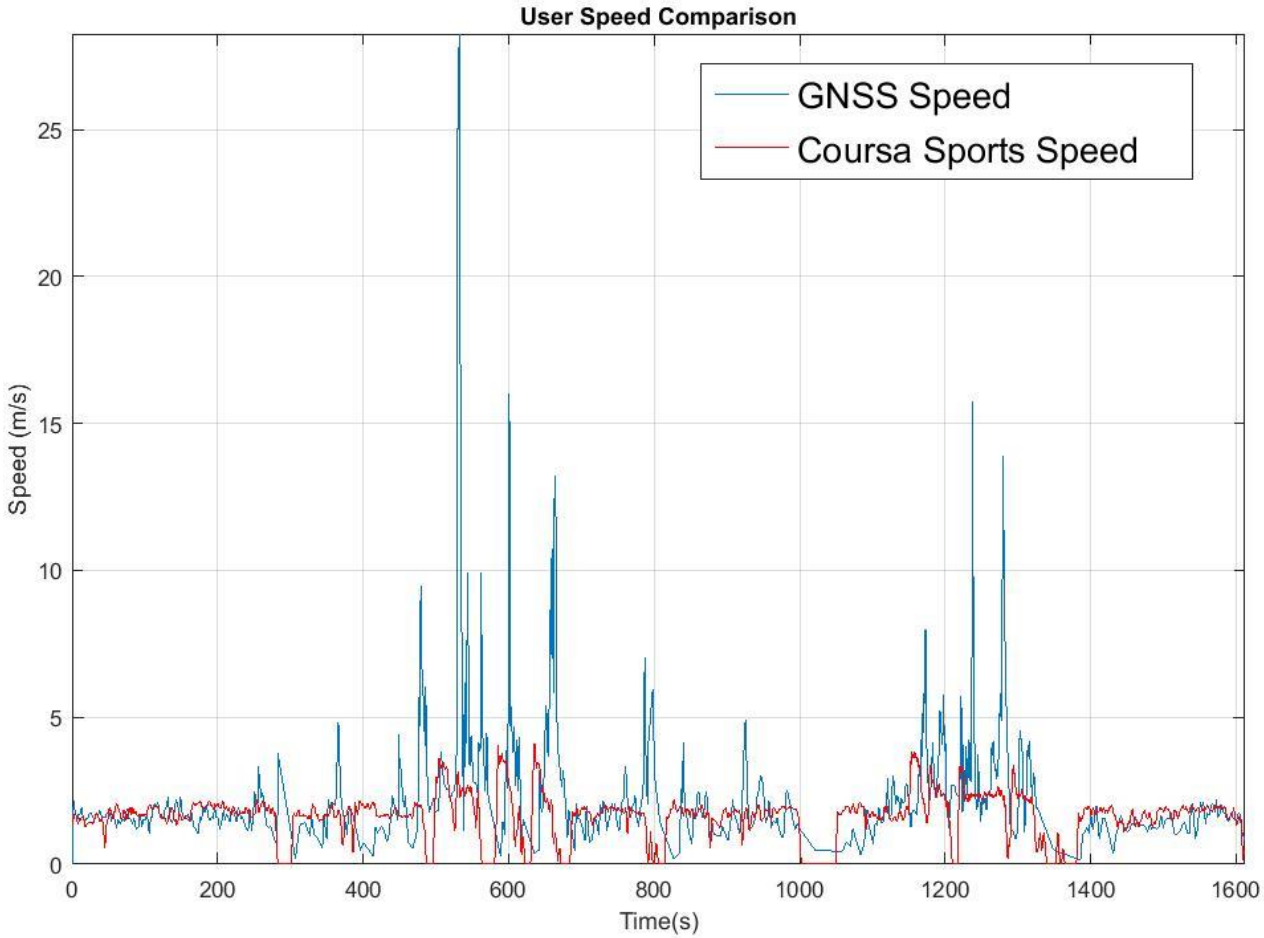
Strava

Coursa Sports

Example 2: Speed in Downtown

sensing the FUTURE

Person walked 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

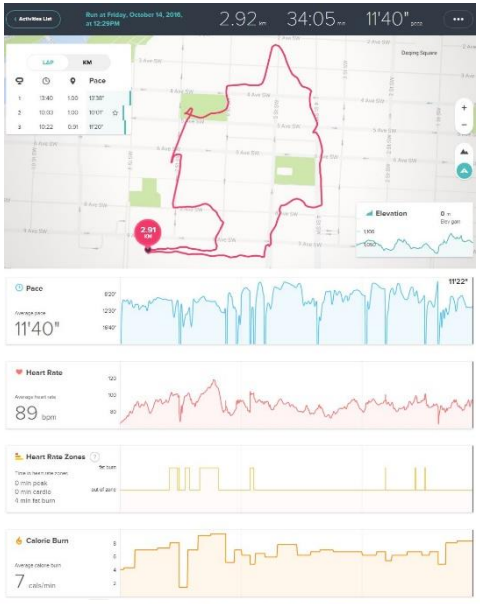


Example 3: Wearables Performance Comparison in Downtown Multipath

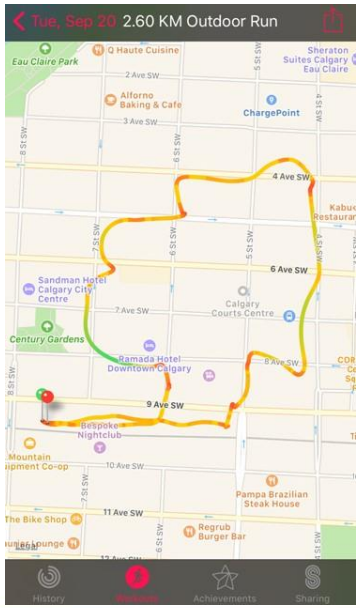
sensing the FUTURE

- 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)

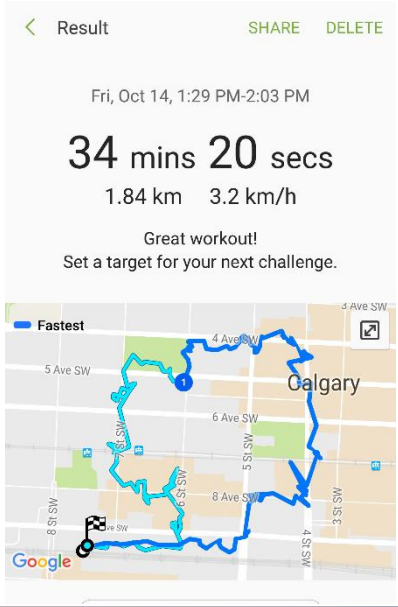
Fitbit Surge



Apple Watch 2



S Health Gear S2



Coursa Sports on Moto 360

Wearable Energy Saving Example

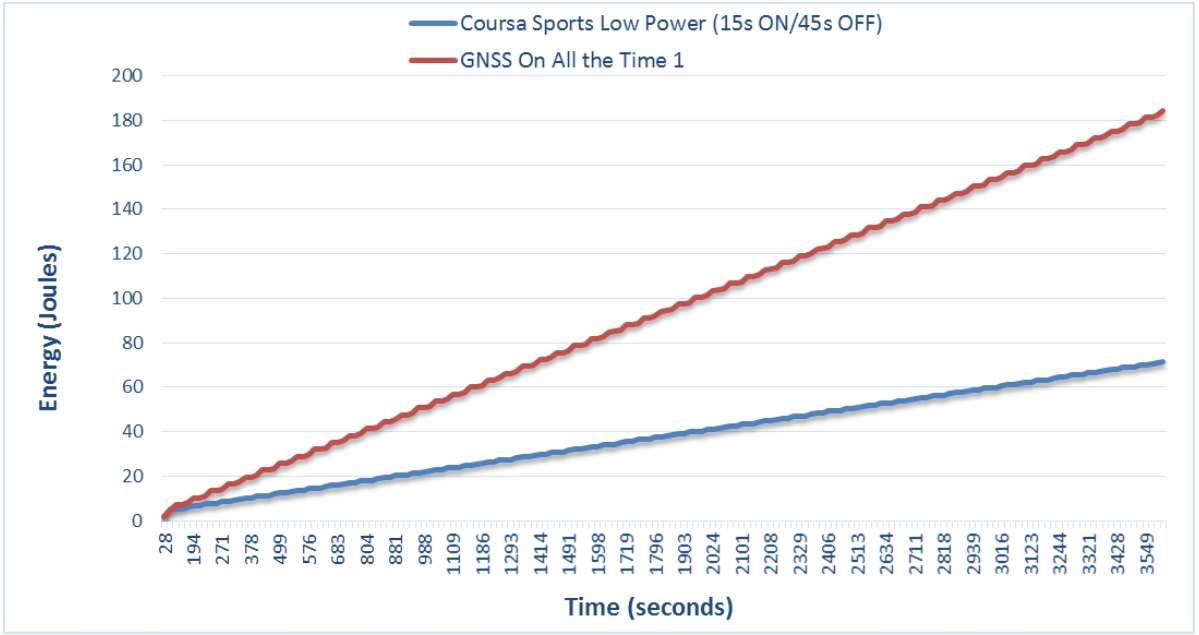
sensing the FUTURE

How much energy can Coursa Sports save in comparison to GPS on all the time?

uBlox MAX-M8C operating in continuous mode @ 1 Hz

	Time to Fix (s)	Current Consumption (mA)	Voltage (V)	Power (mW)
Initial acquisition	28	21	3	63
Hot start reacquire	1	21	3	63
GNSS tracking @ 1Hz		17	3	51
6 axes Sensors + Coursa SW		3	1.8	5.4

Energy savings for Coursa Sports Low Power Mode



Time (minutes)	Coursa Sports Low Power, Energy Savings
2	24%
5	46%
10	54%
20	58%
30	60%

Coursa Sports on Android Phones

sensing the FUTURE

- 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

sensing the FUTURE

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

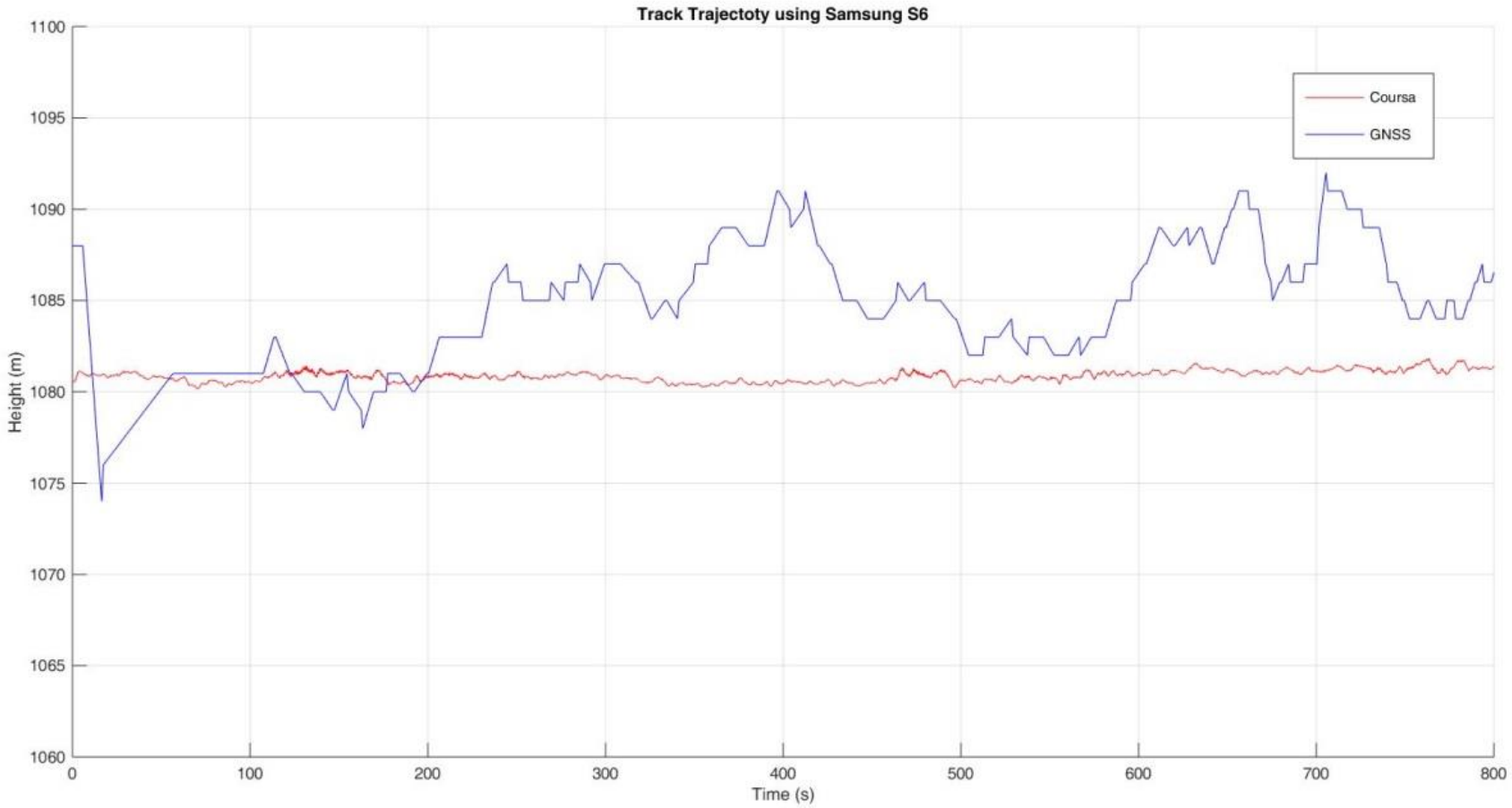
Coursa Sports (Low Power Mode)

GPS used in duty cycle

Example 4: Coursa Sports Height on the Flat Track

sensing the FUTURE

Track is flat with nearly no height gain/loss
Coursa Sports is much more accurate than GPS on all the time

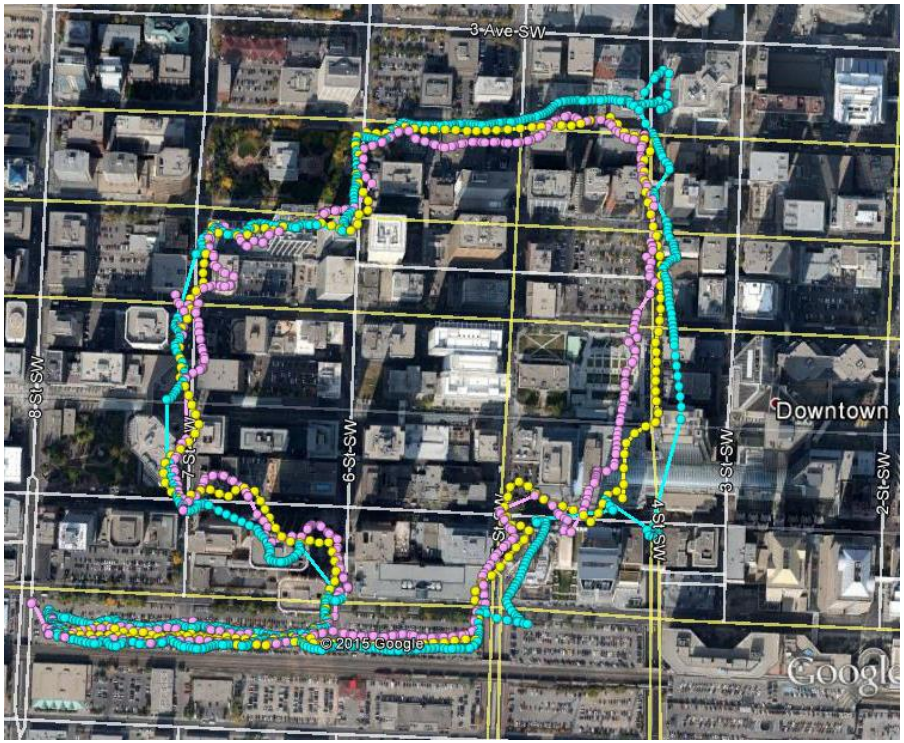


Example 5: Coursa Sports Performance Mode on S6 Phone in Downtown

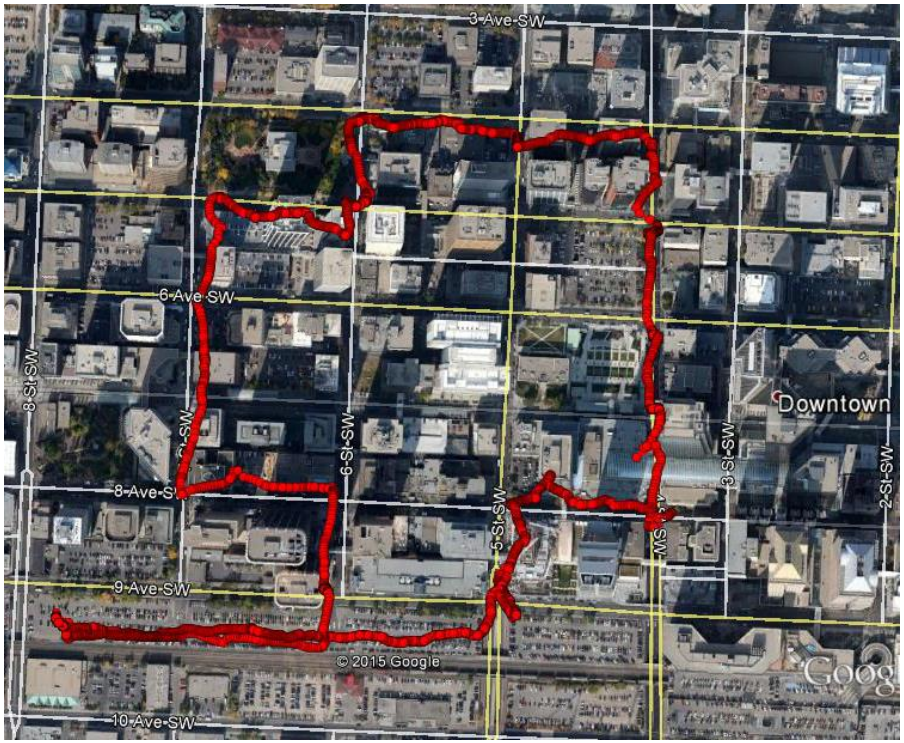
sensing the FUTURE

- 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



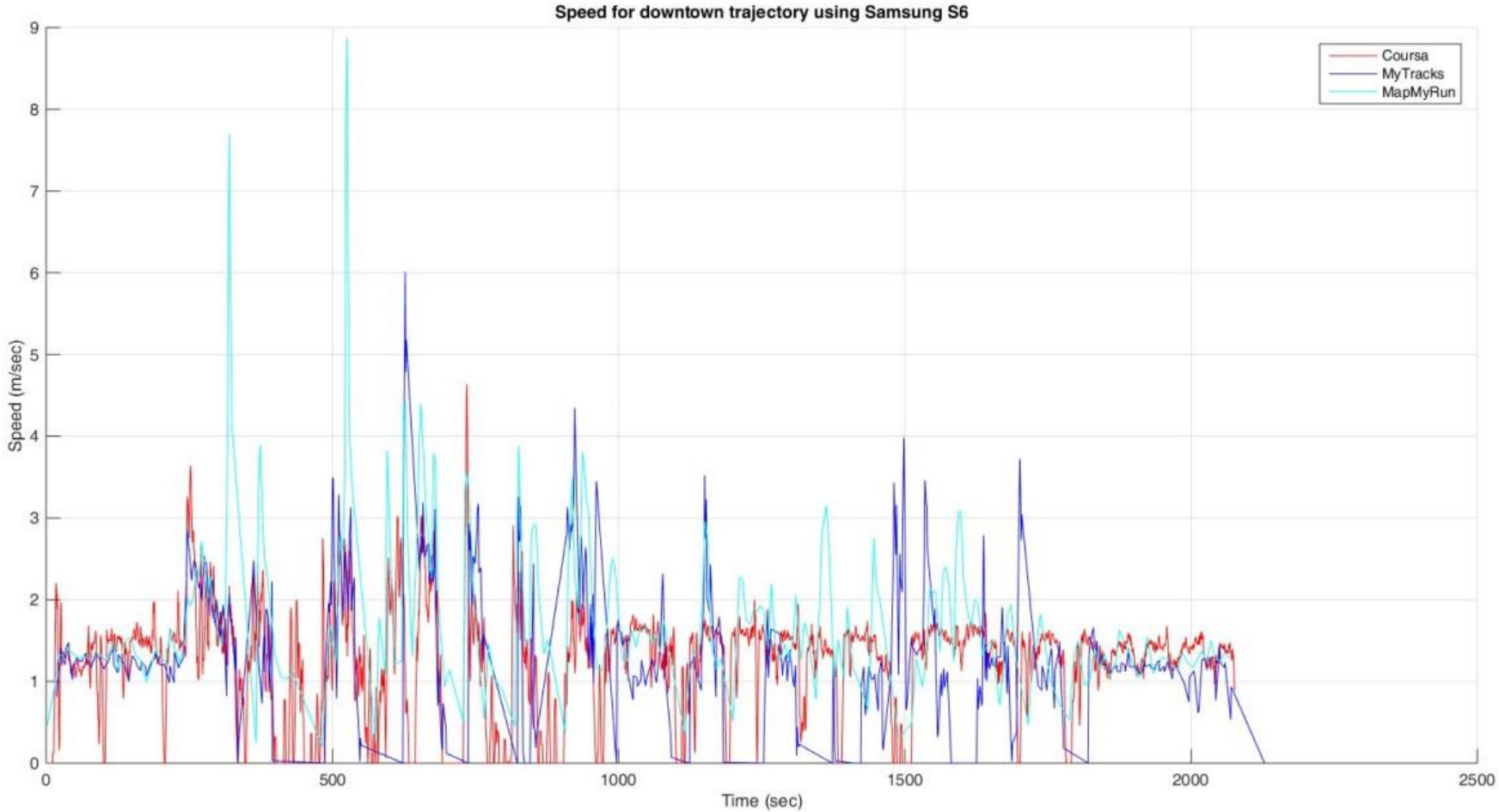
Coursa Sports (Performance Mode)



Example 5: Coursa Sports Speed in Downtown

sensing the FUTURE

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

sensing the FUTURE

- 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)

	Distance/Speed Errors w.r.t. Distance Travelled
Coursa Sports Low Power (25% duty cycle)	7%
Coursa Sports Balanced (50% duty cycle)	5%
Coursa Sports Performance (no duty cycle)	4%
GPS on all the time at 1 Hz	8%

Comparing Coursa Sports to the Apple Watch Series 2

Apple Watch 2 Benchmark

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- 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

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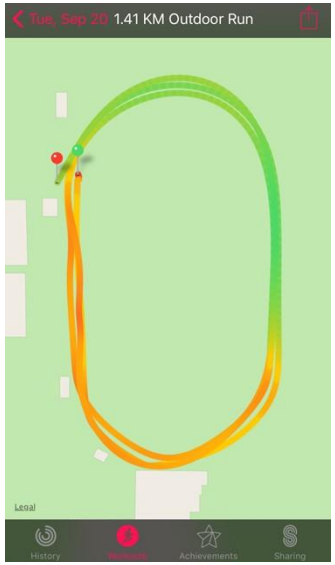
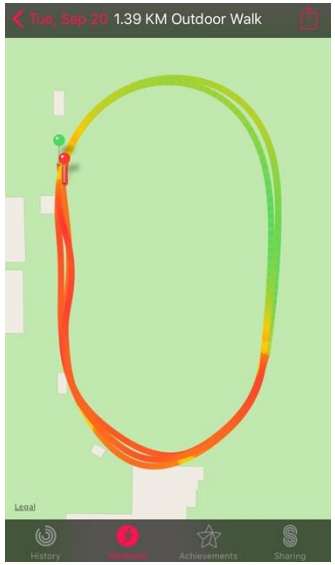
- Apple has done a good job integrating GPS hardware on their Watch 2
  - Accuracy of GPS position & velocity similar to Android phone performance
    - Positions within 5 meter accuracy (correct side of road)
    - Initial acquisition time within a few seconds
  - Better positioning accuracy and acquisition 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

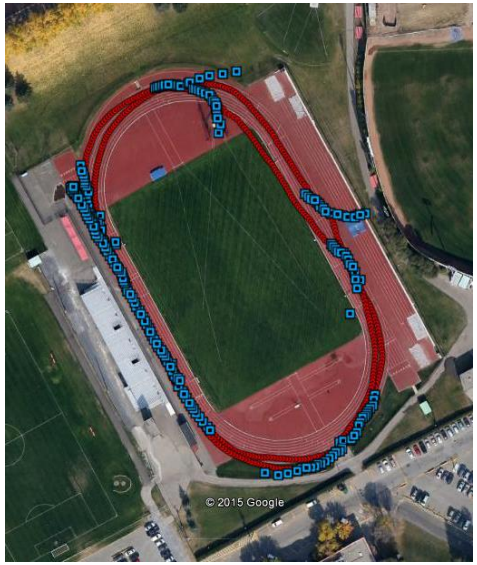
4.4% error



3.0% error



3.7% error



- **Coursa Sports**
- **Duty Cycled GPS**

Distance Benchmark Set by Apple

sensing the FUTURE

- Accuracy benchmarking of Coursa Sports performed using several Android devices

	Average Distance Errors w.r.t. Distance Travelled
Apple Watch 2 GPS on all the time	3-4%
Android Phone GPS-only	8%
Coursa Sports Performance on Android (GPS on all the time)	4%
Coursa Sports Balanced on Android (50% duty cycle)	5%
Coursa Sports Low Power on Android (25% duty cycle)	7%

Route Comparisons

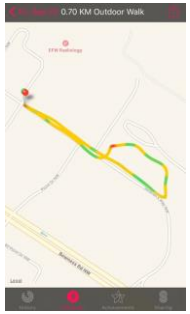
sensing the FUTURE

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

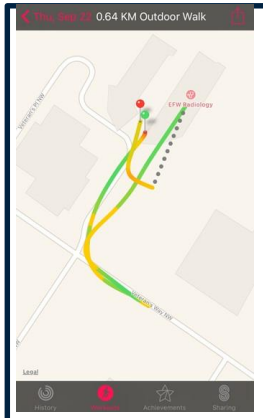
1) Apple Watch smooths GPS errors





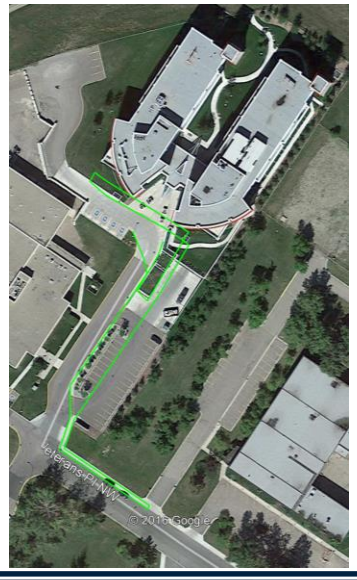
2) Apple Watch smooths some real turns, even in open sky.

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

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- 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

sensing the FUTURE

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

	Distance Performance	Route Performance	Power Performance
Apple Watch 2	The benchmark, good distance estimation	Smooth in open sky and in mild multipath. Does not bridge GPS outages. Problems with turns.	5 hours with GPS ON
Android Phone GPS-only	2x worse than Apple Watch	Subject to GPS multipath errors and does not bridge GPS outages.	4-6 hours with GPS ON, depending on device
Coursa Sports	Can get Android devices to similar performance as Apple Watch in Coursa Sports Performance Mode	Smooth in all conditions & bridges GPS signal outages. Can get better path than Apple Watch 2 in signal loss scenarios and during turns.	3 hours more than Apple Watch 2 and Android mobile devices in Coursa Sports Low Power Mode

Coursa Sports Software & Integration

Cross-Platform SW Availability

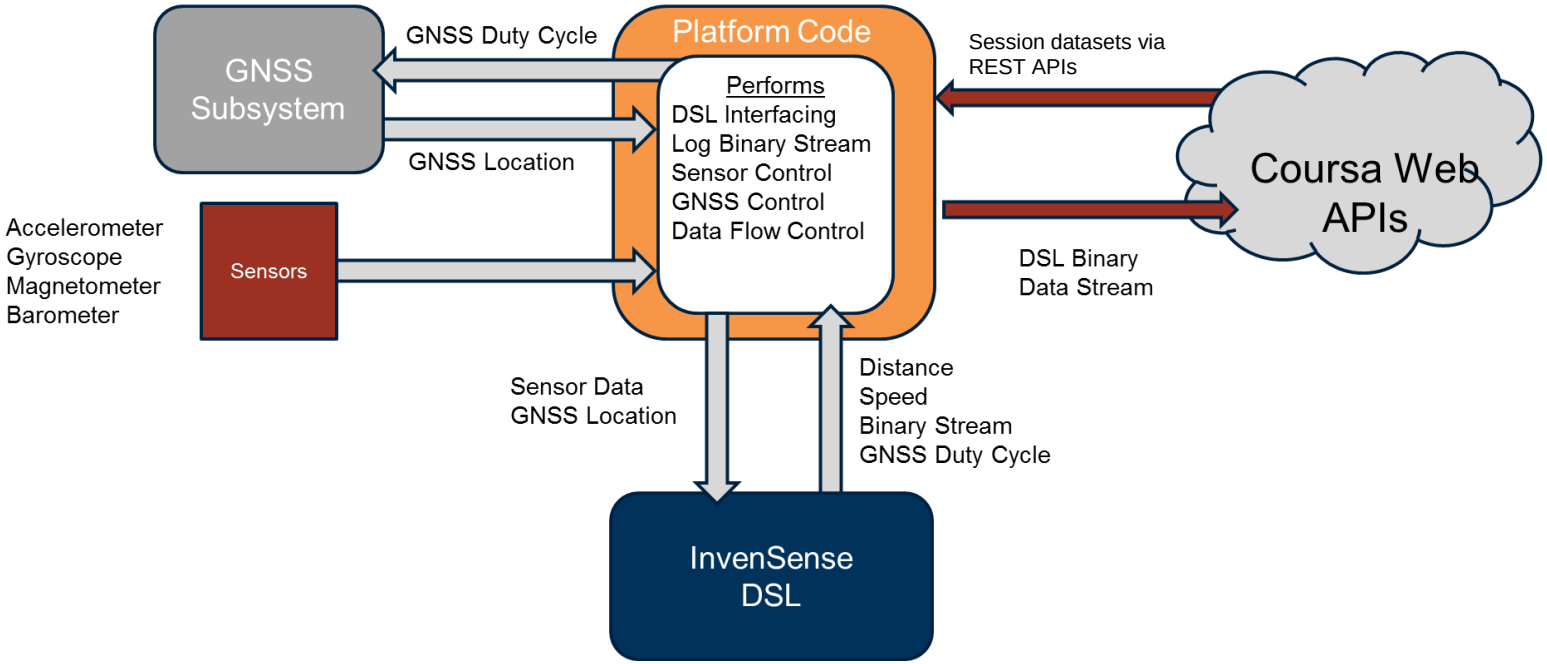
android wear

	MIPS	Code (KB)	Data (KB)
Real-Time Software Requirements	<6	115	50

Application Processor or Microcontroller

Embedded Library for OEMs or SDK for App Developers

Coursa Sports Architecture



- 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

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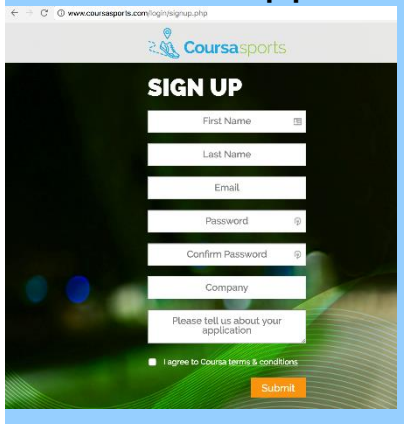
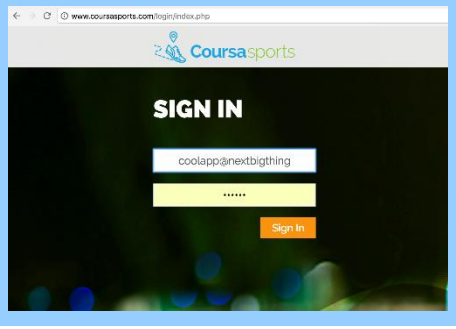
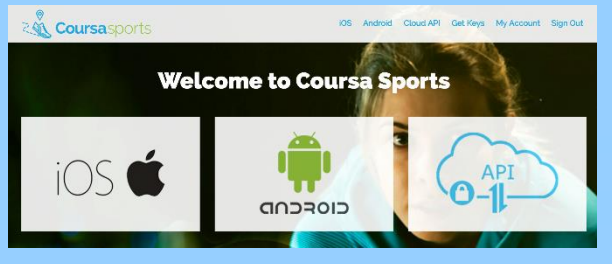
1] Request access to SDK & wait for approval



2] Login to download Android & iOS SDK



3] Integrate iOS & Android SDK using the SDK key granted to the account
Verify distance & speed



4] Use unique user id's and upload data to the Coursa Sports servers

5] Use the API key to download processed route data from Coursa Sports servers

6] Test and verify implementation

Coursa Sports Eval App

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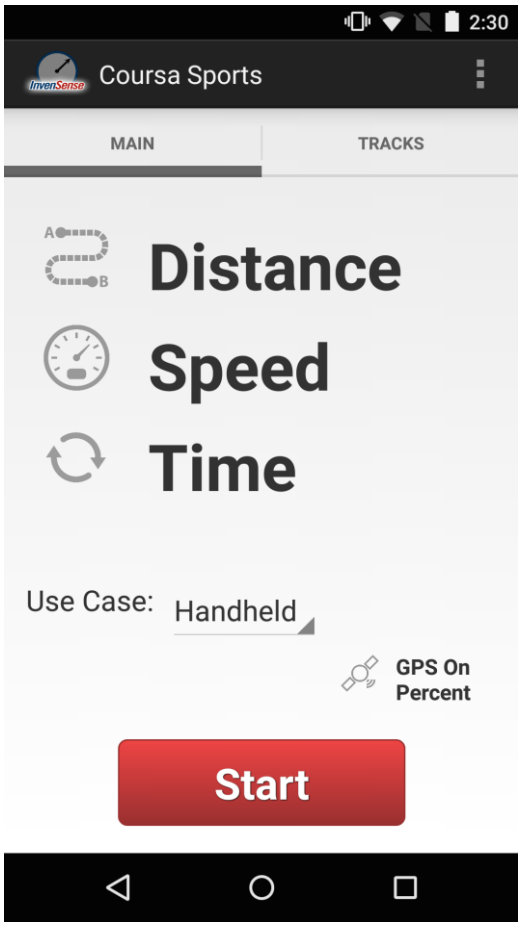

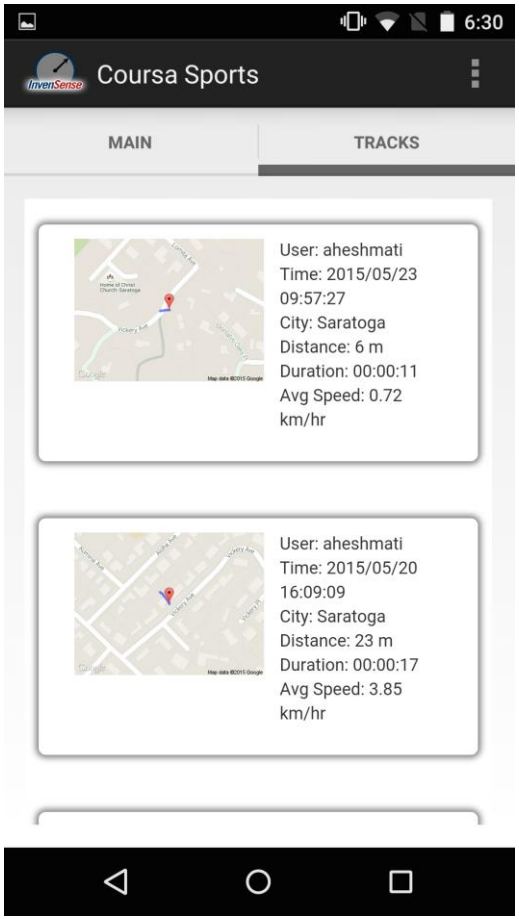

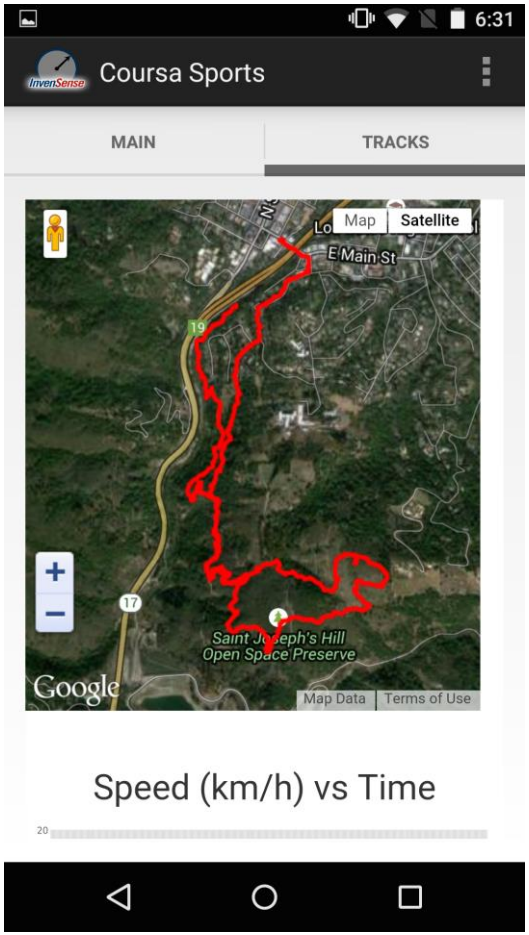

Eval app available for demo on Android, Android Wear and iOS devices

Thank You