MEMS Sensors For Wearable & IoT
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About TomTom

World leader in location and navigation products and services

3500 employees worldwide

Headquartered in Amsterdam
TomTom Organization & Product Portfolio

- Consumer
- Automotive
- Fleet Management
- Enterprise and Government
Sensor Trends for Wearable

Sensor Inputs
- Accelerometer
- Magnetometer
- Gyroscope
- Ambient Light
- Proximity
- Pressure
- Touch
- Haptics
- Fingerprint
- Health
- UV Light
- Humidity
- Environmental
- Microphone
- GNSS
- WiFi
- BLE
- NFC

Low Power Functions
- Motion / Geofencing
  - Significant Motion
  - Significant Stillness
  - Geofence Monitor
- Building Floor Detection
- Personal Health / Fitness / Activity
- Contextual Awareness
- Haptic Feedback
- Sensor Dead Reckoning
- Biometrics and Fingerprint
- Wakeup / Unlock
- HRM and Glucometer
- Gestures
- Smart TV Remote Control
- CO / Pollutant Detection
- Multi-Media Video / Audio

Examples
- Carry Method
- User Posture
- Device Transport
- Step Counting
- Indoor Location
- Fused Location
- Map Matching
- Shake
- Flip
- Tap
- Flick / Swipe

Source: BRCM
Location and Sensing Are at the Heart of Wearable

- **Geofencing**
- **Fused Location**
- **Activity Recognition**
- **Location History**
What is Geofence?

- A Geofence is a virtual perimeter on a geographic area. When a mobile device enters, exists, stays inside or outside the Geofence, the action is known as a geofence event and a notification indicating the event is generated from the application software.
- Apple iOS5.1 even adds Geofence indicator on the UI and Android already supports Geofence API since JB.
- Geofencing application examples:
  - Fleet management
  - Internet of things (IoT)
  - Location Based Service (LBS)
    - Mobile advertising
    - Child location services
    - Auto check-in at venues
  - Agriculture
Contextual Awareness

- Geofence is a key component of Contextual Awareness
- Low power Geofencing is further achieved by activity detection.
  - high powered GNSS receiver will be used as needed.
  - Inertial MEMS sensor based activity detection helps to hibernate GNSS receiver when stationary or low user dynamics.
Fused Location
Use All Sources of Location Information

Other Technologies
WWAN
MEMS

Outdoor
GNSS

Indoor Map
WWAN DB

WiFi AP DB
Beacon DB

GNSS Predicted Orbits

INDOOR WLAN
BLE Beacon
Motion Sensors: from 3 to 9 axis

- Wearable seen as next big thing for sensors in consumer after smart phones and tablets.
- Discrete accelerometer used today in most wearable for activity recognition. More advanced application is to tightly coupled GNSS receiver with accelerometer for power saving and step length improvement.
- Sensors supplies push use of 9-axis combo (accelerometer + gyroscope + magnetometer)
  - Are combo sensors low-power enough yet?
    » Gyro can help to reduce the false arm of activity recognition but it consumes too much power which is not good for battery limited product like wrist band.
    » High powered Gyro must be used as needed.
  - eCompass can help to improve heading in standstill condition.
    » eCompass heading is only valid when user dynamics is low
    » eComass can be switched off most of the time.
Sensor Power Usage

- When sensors are on, there is an incremental power cost.
- Power, for purpose of sensor assisted/oriented applications, is used by the sensor hardware, sensor output data rate (ODR), the applications running on application processor (AP).
- This incremental power is only spent when
  - GNSS is in challenged environments
    » In this case, it is worthwhile to spend this incremental power, to maintain accuracy and meet end user expectations.
    » Complex activity detection is required.
Key Performance Index for Fitness

- Cross Track Error (CTE)
  - CTE is the Euclidean distance between reported fix to truth track
  - The higher CTE the higher distance travelled error
- Position Fix yield rate
  - Fix yield rate is defined by total reported fix divided by total fix attempts
  - The higher fix yield rate the more robustness
  - GPS is not the only source for position fix. IMU can help wearable to achieve 100% fix yield rate in difficult and/or indoor environments.
- Heading Error (HE)
  - Angular difference between reported heading and truth orientation
  - HE is not a critical for wearable as they are not aiming for turn-by-turn navigation
  - HE is a critical factor for post processing
- Distance travelled accuracy
Sensor Assisted Navigation

- Navigation performance is augmented by sensors
  - Outdoor in vehicle: GNSS + IMU
  - Outdoor pedestrian: GNSS + IMU + Magnetic
  - Indoor: WLAN + IMU + Magnetic + Pressure
- Fix accuracy
  - Improved position smoothness and accuracy in conditions when GNSS is very weak or only WLAN/BLE Beacon indoor positioning is available.
- Sensor assisted power saving
  - Overall location system power usage is significantly reduced when device is hard stationary, e.g., the user walks indoor and sets the device with location applications running on a desk.
- Improved post map matching
  - Reduce wandering effect when device is in challenged GNSS environments
  - Improved heading accuracy
  - Improved position accuracy
- Pedestrian Dead reckoning (PDR)
Step Length Augmentation

The Problem

The Solution

GNSS works poorly in the presence of blockers (overheads roads, tunnels, buildings, mountains)

Accelerometer based step length helps to improve distance, speed and position.
Adaptive Step Length

- Motion mode classification
- Step detection
  - Time domain: Peak detection and/or zero crossing
  - Step frequency is derived from frequency domain (STFFT)
- Step length estimation
- GNSS/Step length integration
  - Knowing step frequency is a key to derive step length
  - Step length could be further calibrated by GNSS based distance
  - Calibrated step length can help to refine distance accuracy in GNSS difficult areas.
  - Ground track performance can be further refined by step length to reduce cross track error.

Step detection: time domain

Step frequency: frequency domain
GPS/Step Length Integration

Step length vs Frequency

- Step length
- 線性(Step length)
Conclusion

• Current sensor fusion algorithm are not accurate enough to enable IoT and wearable applications.
  – 6 and 9 axis systems suffer from gyro drift and magnetic interference
  – Power consumption is still very high

• Dedicated sensor processor is the trend
  – Android KitKat OS making sensor hub mandatory to support activity monitoring with mobile phone.
  – M7 sensor hub in iPhone5S allowing continuous activity monitoring.

• Sensor and Data
  – Data is the heart of the IoT
  – The data starts at the sensors. It’s the sensor that generates the data.
  – Today’s big data: accelerometer based activity recognition and pedometer
  – Future big data: accel + gyro + Mag based precise activity recognition