Orientation and Displacement Detection for Smartphone-Device Based Inertial Measurement Units

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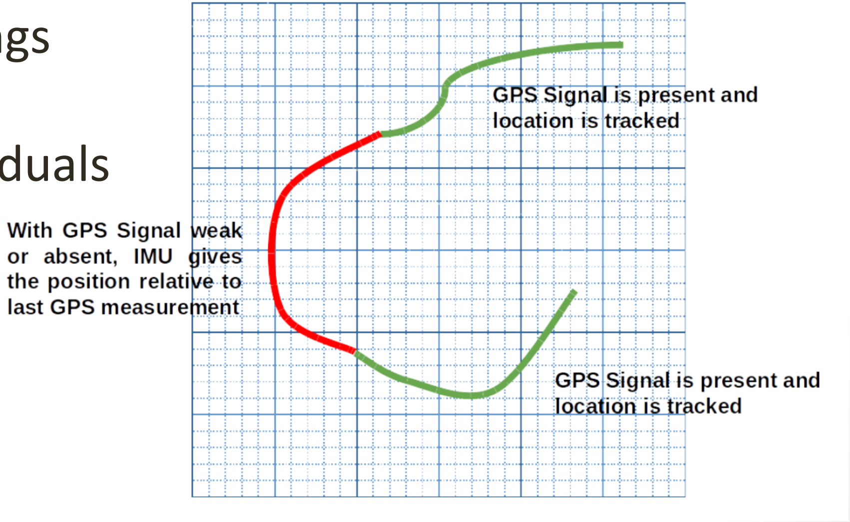
Introduction

- Project objectives:
  - Displacement detection
  - Integration with GPS data
  - Estimation of location in access-denied areas
- Displacement detection with smartphone-based IMU
- Integration in MATLAB
- Location estimation with MATLAB

Need for this Project

- Applications in pedestrian tracking
- Movement history and precise location detection

- Applications
  - Surveying in tunnels, buildings
  - Patient location in hospitals
  - Movement history for individuals



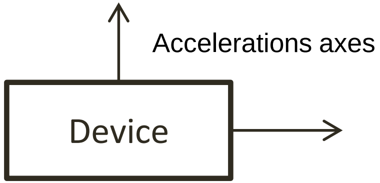
Problem Statement

- Use Inertial Measurement Unit to detect displacement accurately
- Correlate displacement with known GPS measurements to correct drift
- Estimate GPS coordinates for locations where GPS cannot be used
- Combine data to yield complete mapping/tracking solution

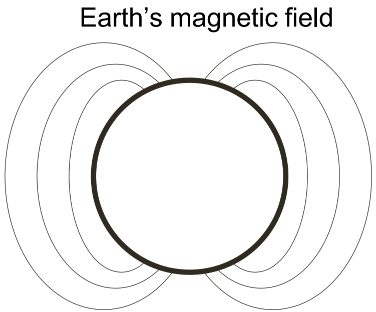
Inertial Measurement Unit

- Smartphone-device based IMU
- Modern smartphones have Accelerometer, Gyroscope, Magnetometer

- Accelerometer
  - Accelerations in 3 axes



- Gyroscope
  - Angular rotation rate in 3 axes

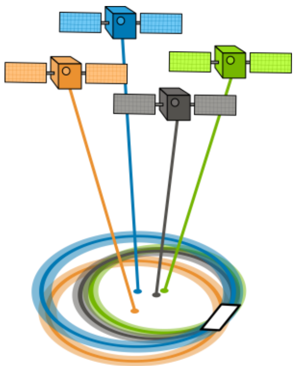


- Magnetometer
  - Magnetic field strength in 3 axes

Global Positioning System

- Geosynchronous satellites orbiting Earth
- Triangulation with 3 or more satellites gives precise coordinates
- Requires direct Line-of-Sight

- GPS signal is weak or nonexistent in access-denied areas
  - Inside buildings
  - Tunnels
  - Electromagnetic interference
  - Canopy cover



Orientation detection

- Accelerometer is based on local axes
- Orientation detection is necessary to yield Earth-Frame Accelerations

- We take three orientation measurements
  - Heading calculation - done with Magnetometer and Accelerometer
  - Accelerometer-based Euler angle calculation
  - Gyroscope-based Euler angle calculation

- The three measurements are combined

Heading Calculation

- Magnetometer determines strength of magnetic field
- Can be used to determine direction of North
  - smartphone calibrates for Magnetic north

- Magnetometer needs to be corrected for device rotation

$$E = uG \times uB \qquad N = uE \times uG$$

- With compensation, we find plane orientation

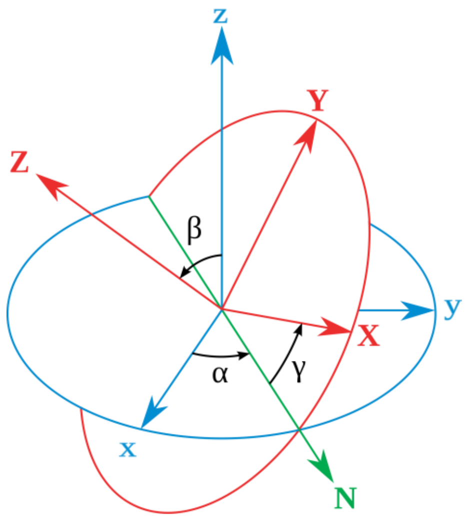
Acceleration-based Euler Angles

- Euler Angles
  - Roll - γ
  - Pitch - β
  - Yaw - α
- Use accelerometer to calculate Roll and Pitch (Yaw cannot be calculated)

$$Roll = -\arcsin uG_y$$

$$Pitch = -\arcsin uG_x$$

- These values can be used to correct gyroscope readings

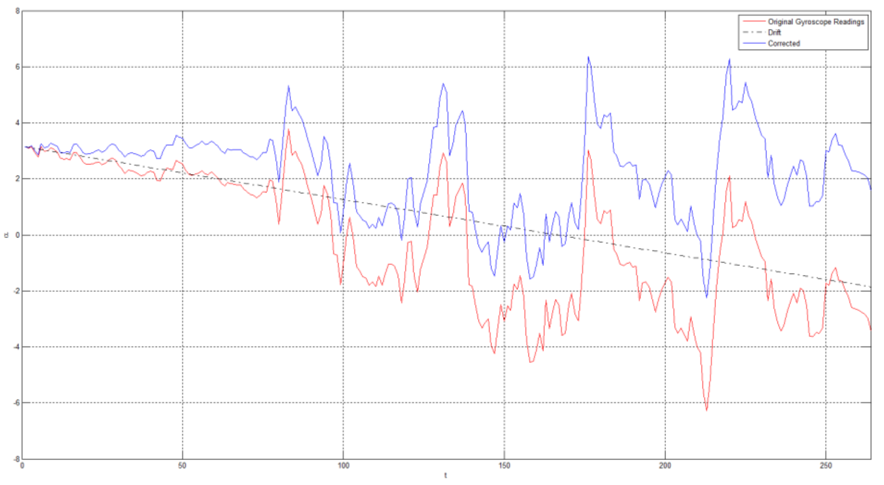


Gyroscope-based Euler Angles

- Gyroscope gives rate of rotation

- These can be integrated over time to yield rotation matrix
- Rotation matrix yields Euler angles

- Gyroscope calculations drift
- They are corrected with accelerometer-based Euler angles



Gyroscope Drift Correction

- Drift correction is necessary

- Complementary filter

$$\theta = 0.98 * (\theta + gyr \cdot dt) + 0.02(acc)$$

- Combined gyroscope and accelerometer-based calculations
  - Gyroscope is short-term
  - Accelerometer is long-term
- Gyroscope drift is corrected with this approach

Displacement detection

- Once orientation has been determined, we proceed to displacement detection

- Acceleration in body frame is known
- We need the Direct Cosine Matrix to obtain accelerations in Earth Frame

Direct Cosine Rotation Matrix

- Calculated from Roll, Yaw, and Pitch

$$W = \begin{bmatrix} C_\alpha C_\beta & C_\alpha S_\beta S_\gamma - S_\alpha C_\gamma & C_\alpha S_\beta C_\gamma + S_\alpha S_\gamma \\ S_\alpha C_\beta & S_\alpha S_\beta S_\gamma + C_\alpha C_\gamma & S_\alpha S_\beta C_\gamma - C_\alpha S_\gamma \\ -S_\beta & C_\beta S_\gamma & C_\beta C_\gamma \end{bmatrix}$$

- Acceleration calculated by multiplying Accelerometer with DCM

$$Acc_{earth} = Acc_{body} \cdot W$$

Acceleration correction

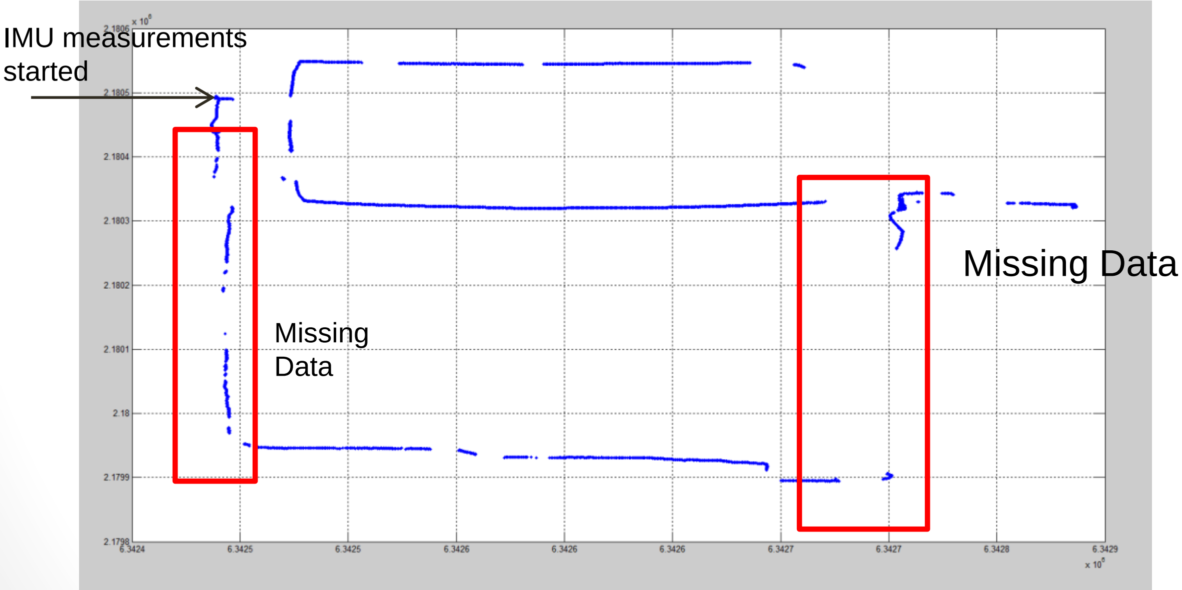
- We can correct acceleration values
- Necessary because smartphone accelerometers are cheaper and noisier

- We use step-detect filter
- Correlate with user’s height
- Obtain approximate displacement and derive for acceleration

- Corrected accelerations are used for net displacement

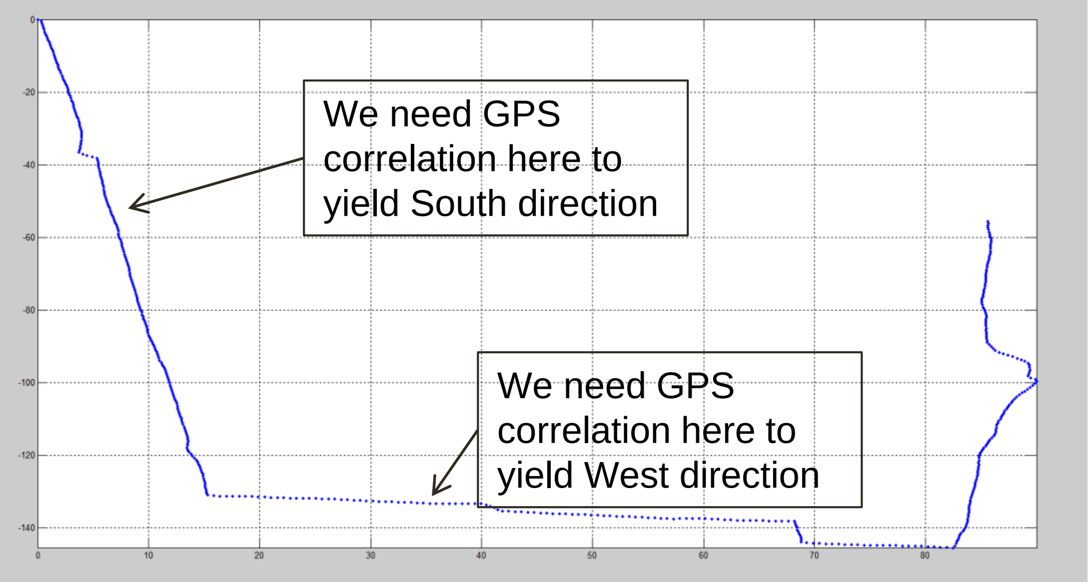
GPS Measurements

- GPS measurements are taken and data points obtained
- Sample GPS plot shown below



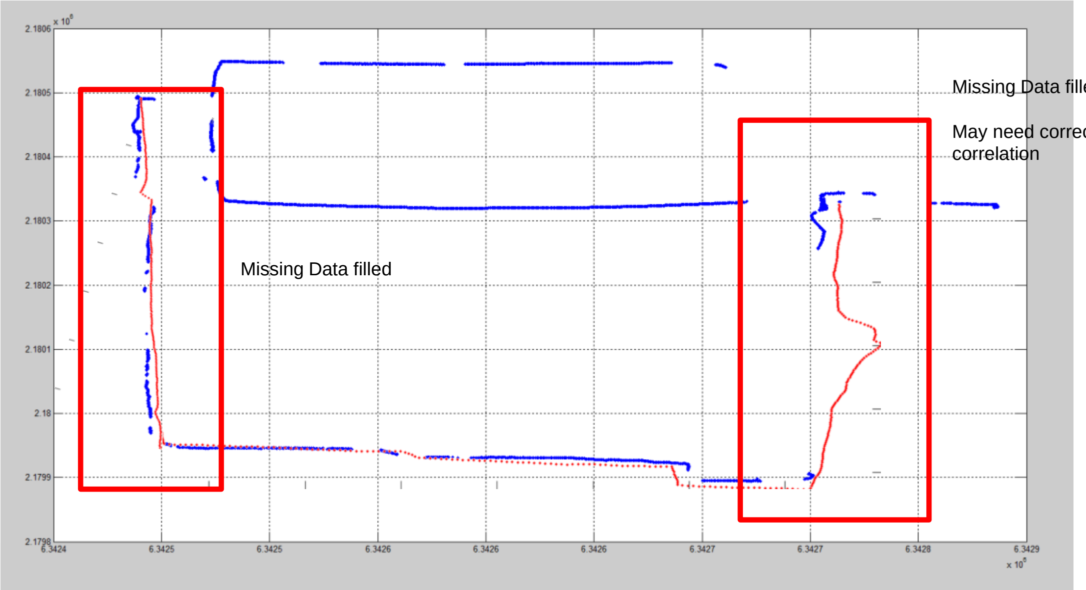
Sample IMU Data

- Sample IMU data is shown:



GPS/IMU Integration

- Some data points are correlated
- Complete tracking is shown:



Missing Data filled

May need correction for final correlation

Results

- Using smartphone, we can estimate missing coordinates in access denied areas
- IMU data is reliable even with cheaper sensors
- Although quantitative error was not measured, qualitatively, data fits

Challenges and Future Work

- May need better sensors for IMU
- A Kalman filter would work better than complementary, but improvements will be negligible
- Quantitative testing

Conclusions

- We have presented and Orientation and Displacement Detection algorithm
- Estimates missing data points/coordinates in GPS data
- Can aid in surveying in access-denied locations
- Can aid in pedestrian tracking