# The Performance Analysis of Seamless Navigation Systems using Smartphones

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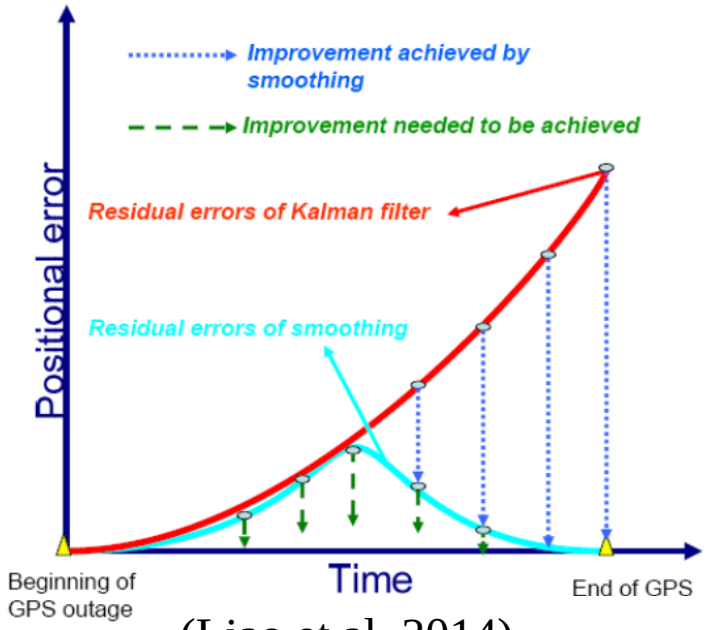
# Outline

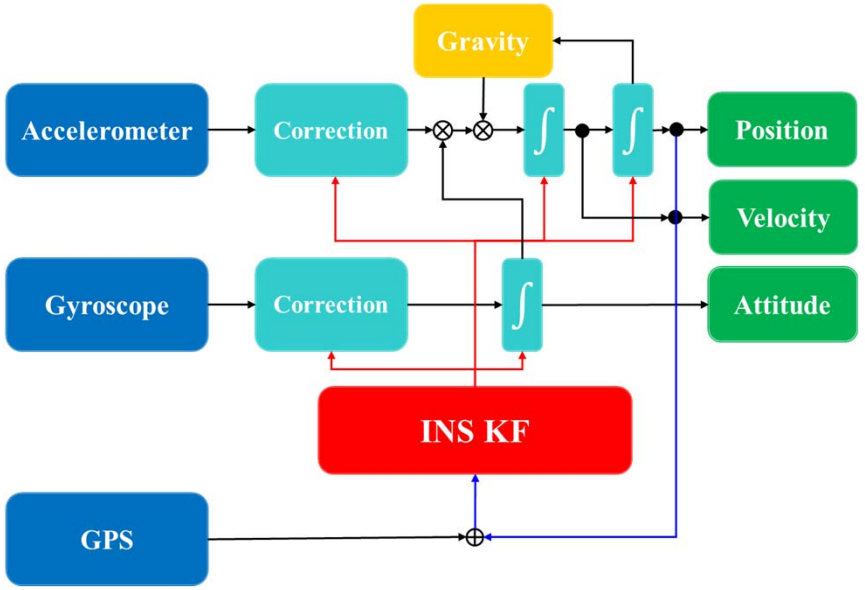
- Introduction
- Objective
- Methodology
- Experiment
- Conclusion

# Introduction

- Global Navigation Satellite System (GNSS)
- Inertial Navigation System (INS)
- Loosely Coupled scheme (LC)
- Seamless navigation system




(Liao et al, 2014)



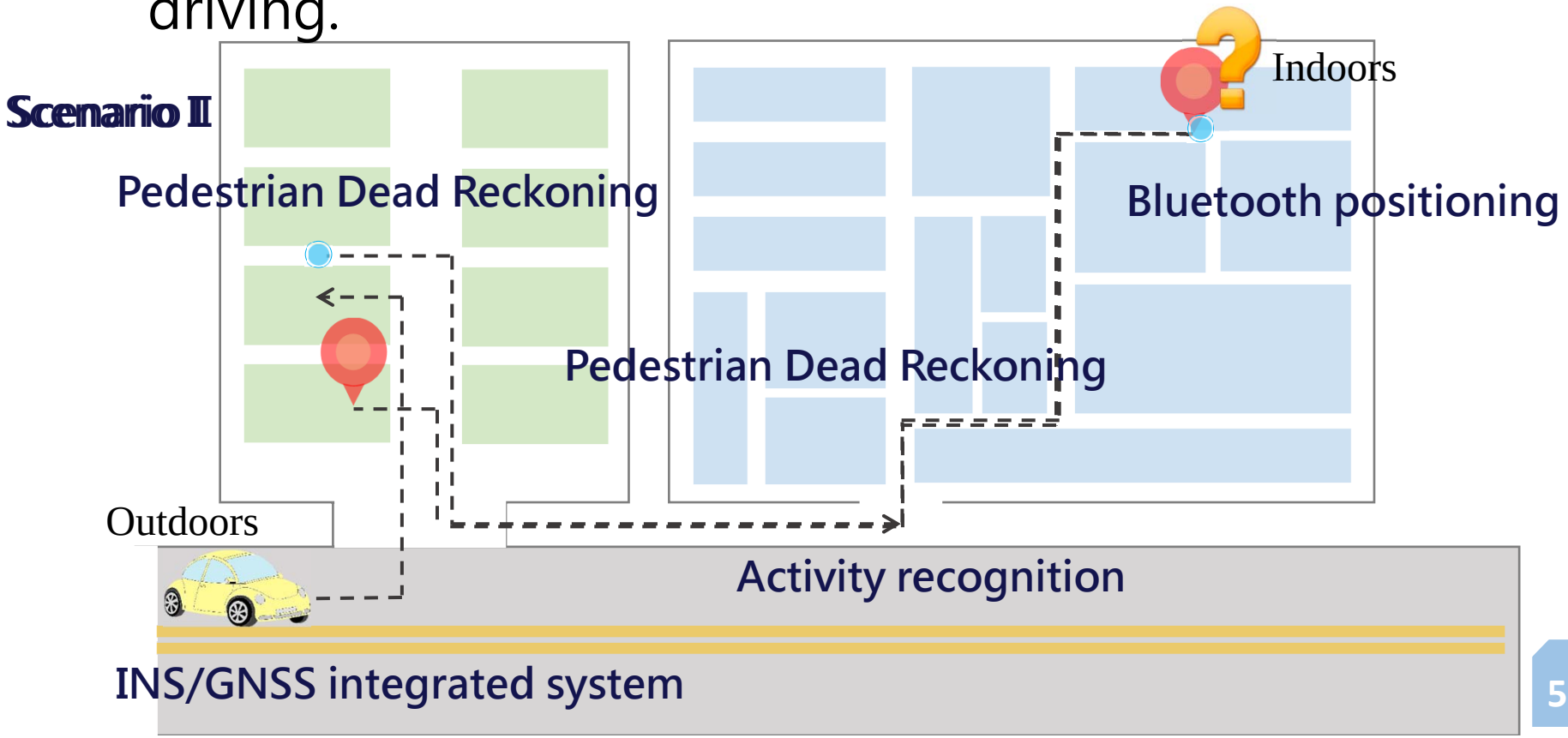

(Duong, 2013)

# Introduction

- Pedestrian Dead-Reckoning (PDR)
- Activity recognition
- Bluetooth positioning technique (Beacons)
- Smartphones

# Objective

- Developing a mobile application that enables to provide robust and uninterrupted positioning information during indoor and outdoor environments that is functional for walking and driving.



# Methodology

**INS/GNSS integrated system**

**PDR**

**Activity recognition**

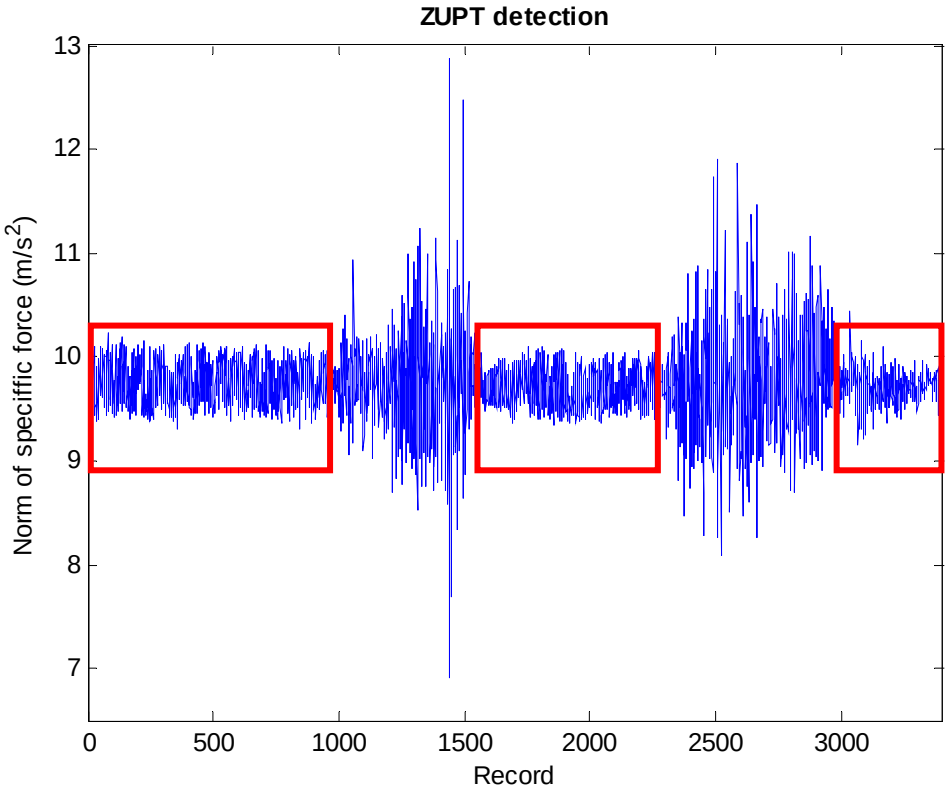
**Bluetooth positioning**

**Proposed Personal Navigation System (PNS)**

**Algorithm for pedestrian and vehicle**

# INS/GNSS integrated system

- State: position, velocity, attitude, the bias of accelerometer and the bias of gyroscope.
- Measure
- Constrai
  - Non-H
  - Zero V

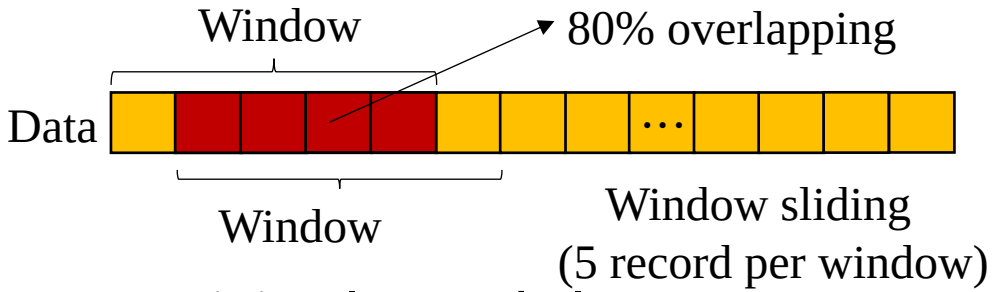



Duong, 2013)

# Pedestrian Dead Reckoning (PDR)

- Stance detection: maximum value, frequency constraint, maxima constraint

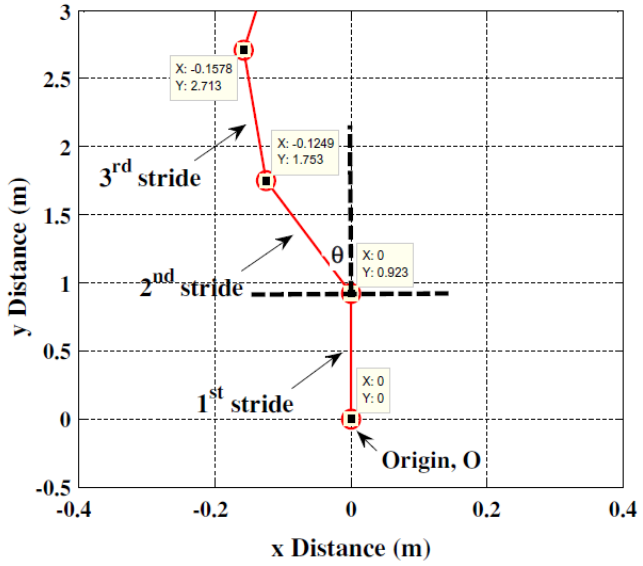
$$a(t) = \sqrt{a_x^2(t) + a_y^2(t) + a_z^2(t)} - g$$




- Step length estimation: empirical model (Chen et al., 2011)

$$SL = \left[ 0.7 + a(H - 1.75) + b \times \left( \frac{(SF - 1.79) \times H}{1.75} \right) \right] \times k$$

- Heading estimation
  - magnetometer
  - gyroscope

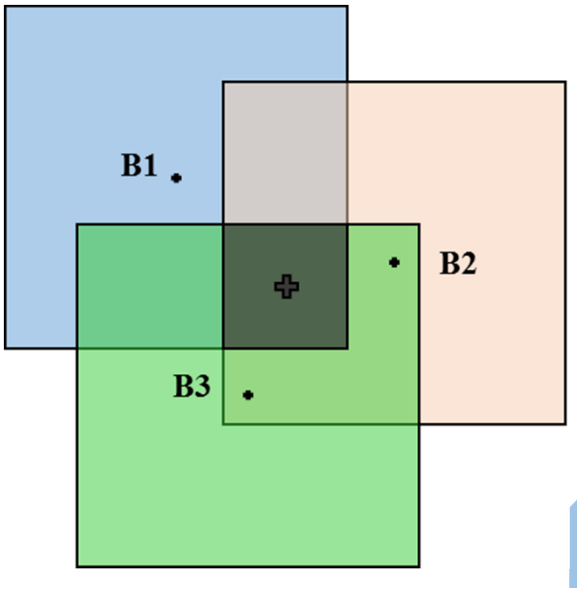


# Activity recognition

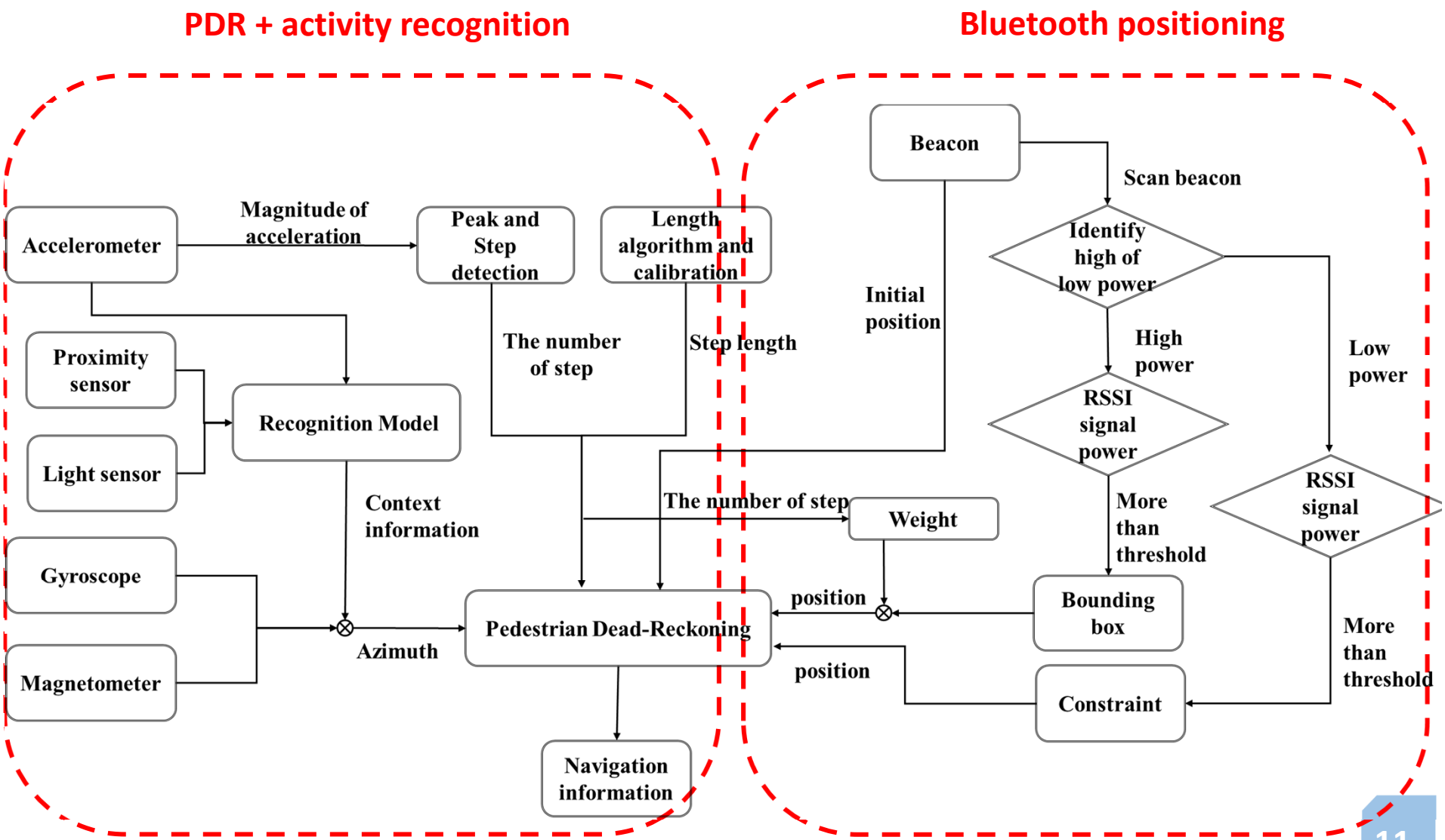
- Data: Accelerometer, light sensor, proximity sensor
- Feature: Mean and RMS
- Classifier: Decision Tree (DT)

# Bluetooth positioning

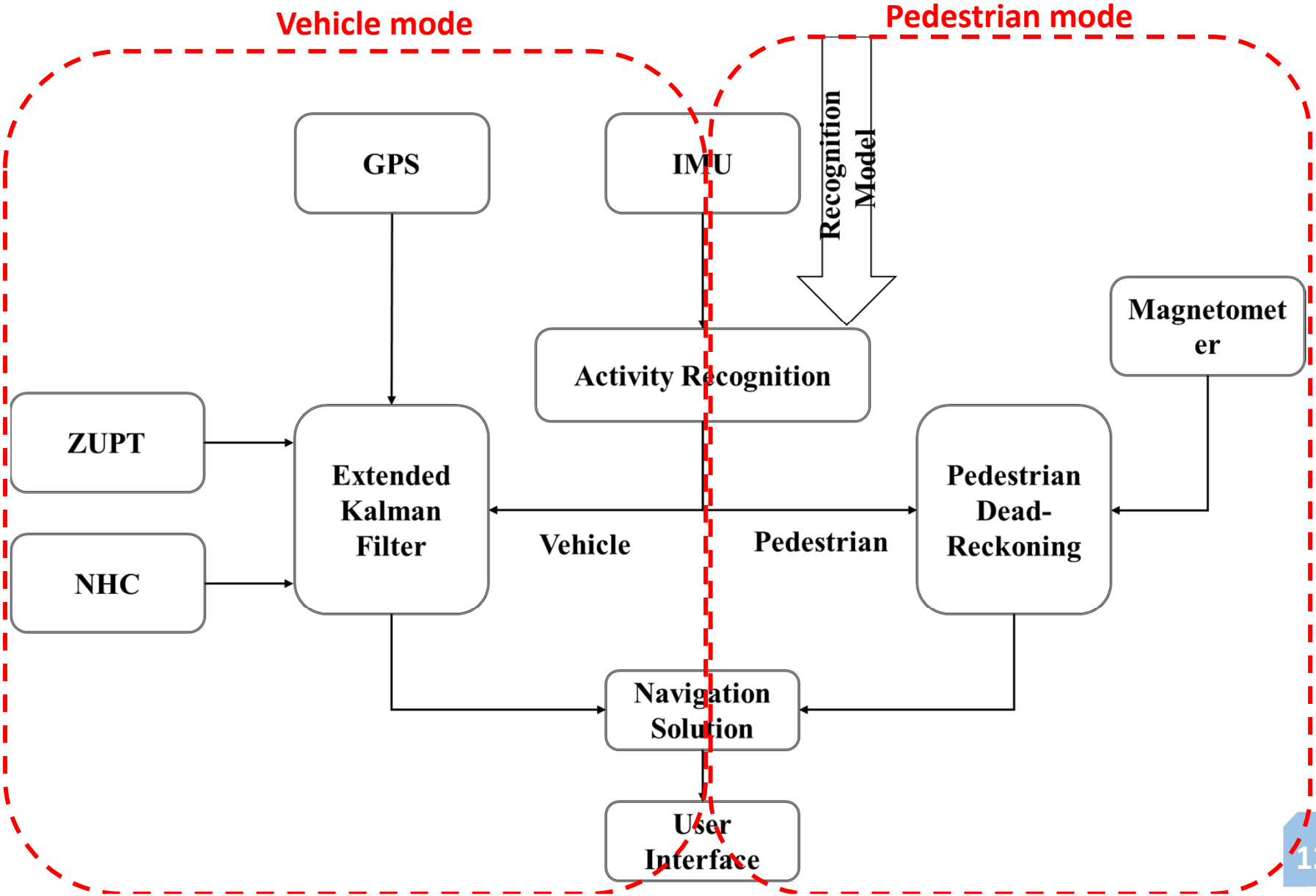
- Bluetooth Low Energy (BLE) is the new specification version 4.0 of Bluetooth.
- Beacons.
- Low cost, low power consumption, easy deployment and supported by smartphones.
- Positioning techniques
  - Bounding box



# Proposed PNS



# Algorithm for pedestrian and vehicle



# Experiment

**Performance analysis for activity recognition**

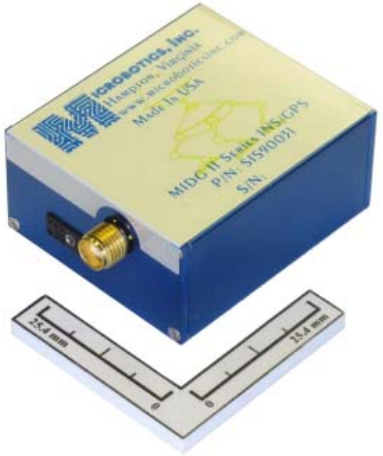
**Performance analysis for PDR**

**Performance analysis for Bluetooth positioning**

**Performance analysis for INS/GNSS integrated system**

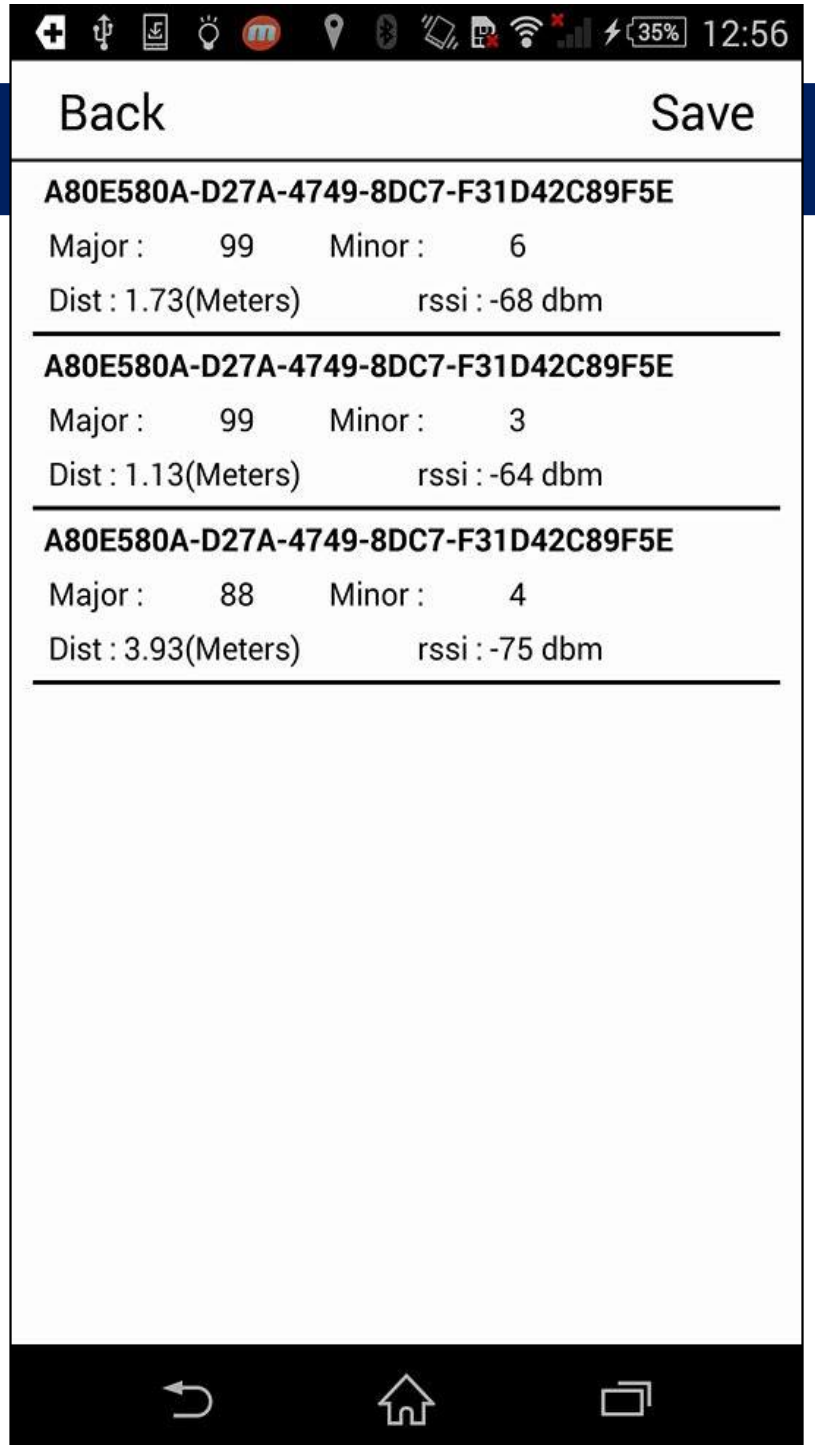
# Experiment setting

- Test product : SONY Z3
  - Sampling rate: 20Hz
- Reference solution: IMU MIDG II
  - Sampling rate: 50Hz
- THLight's Beacons

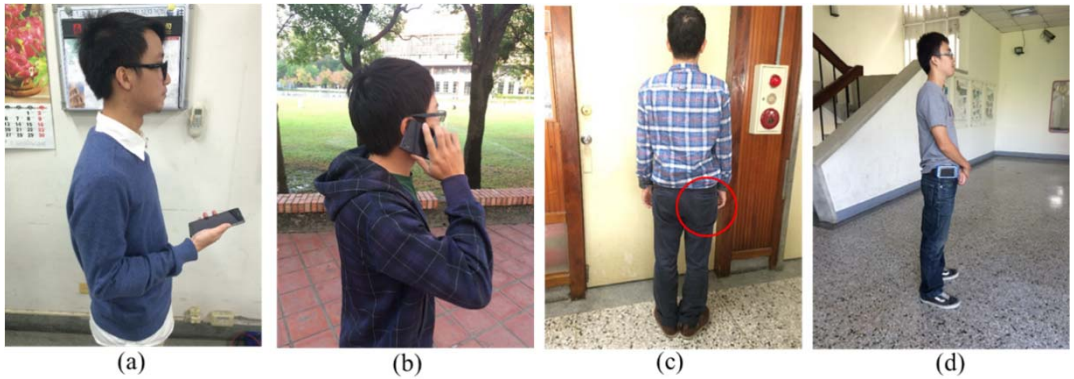

# Point APP

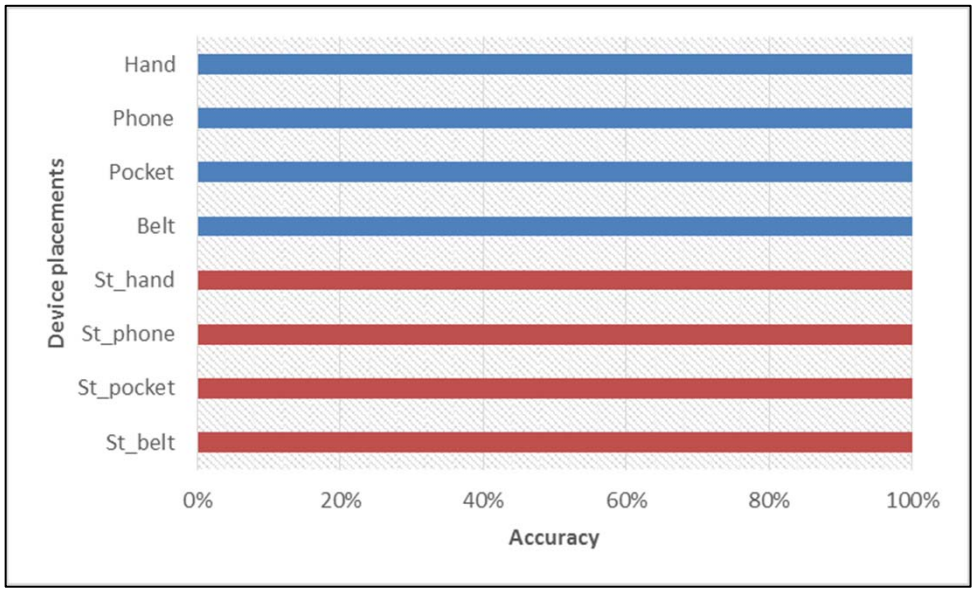

46% 13:13
POINT
Integated Navigation
Indoor Navigation
Sensor Log
Beacon Log


35% 12:56
Back
Save
A80E580A-D27A-4749-8DC7-F31D42C89F5E
Major : 99 Minor : 6
Dist : 1.73(Meters) rssi : -68 dbm
A80E580A-D27A-4749-8DC7-F31D42C89F5E
Major : 99 Minor : 3
Dist : 1.13(Meters) rssi : -64 dbm
A80E580A-D27A-4749-8DC7-F31D42C89F5E
Major : 88 Minor : 4
Dist : 3.93(Meters) rssi : -75 dbm

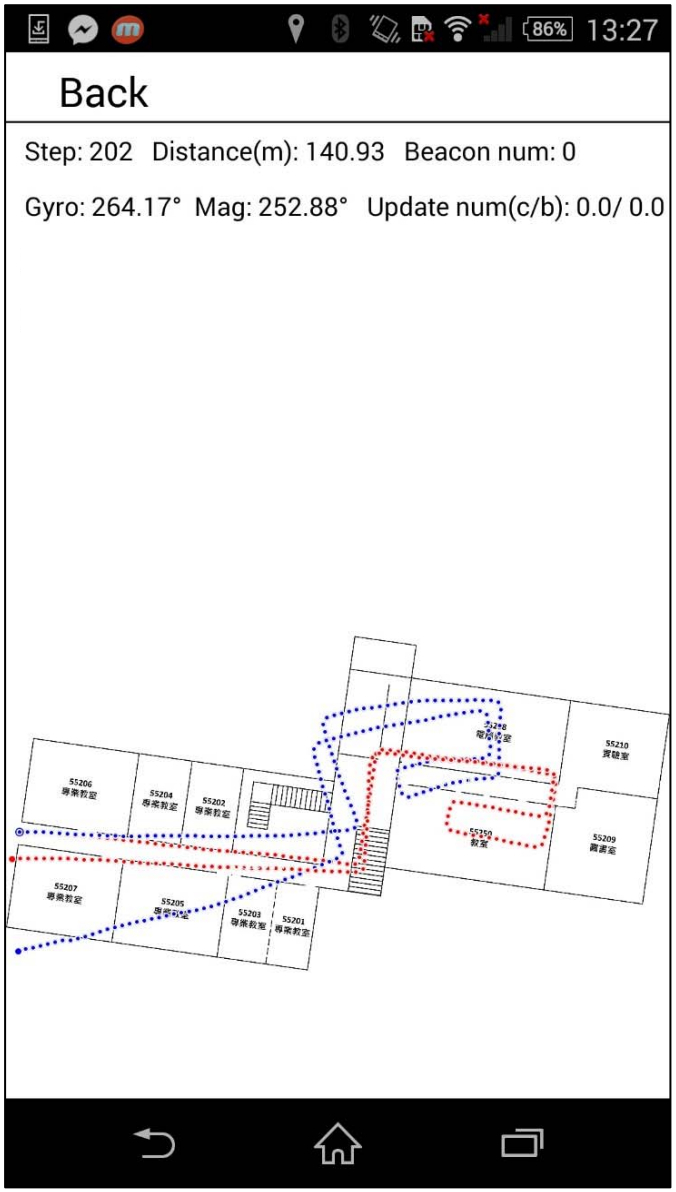
# Experiment for activity recognition

- Five participants (4males and 1 females).



# Experiment for PDR



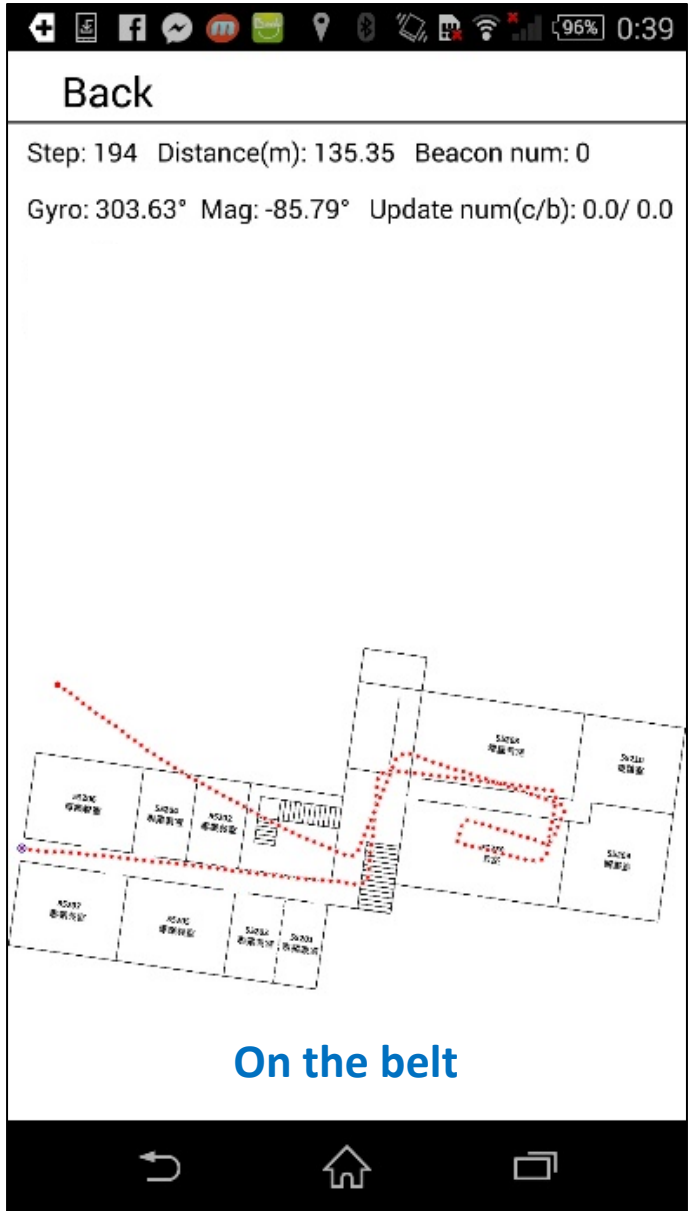

- The mean relative precision are about 4.93% and 2.46% for magnetometer and gyroscope, respectively.

$$Misclosure = \sqrt{(x_{end} - x_{init})^2 + (y_{end} - y_{init})^2}$$

$$\text{Re}\,lative\ error = \frac{\sqrt{(x_{end} - x_{init})^2 + (y_{end} - y_{init})^2}}{D}$$

| Subjects | Estimated distance (m) | Magnetometer | Gyroscope | Magnetometer | Gyroscope |
|---|---|---|---|---|---|
| | | Misclosure (m) | | Relative Precision (%) | |
| 1 | 134.38 | 11.36 | 3.19 | 8.45 | 2.37 |
| 2 | 140.93 | 10.58 | 2.72 | 7.51 | 1.93 |
| 3 | 135.35 | 3.74 | 3.72 | 2.76 | 2.75 |
| 4 | 137.73 | 3.72 | 5.00 | 2.32 | 3.63 |
| 5 | 137.65 | 4.94 | 2.22 | 3.59 | 1.61 |
| Mean | 137.20 | 6.88 | 3.37 | 4.93 | 2.46 |

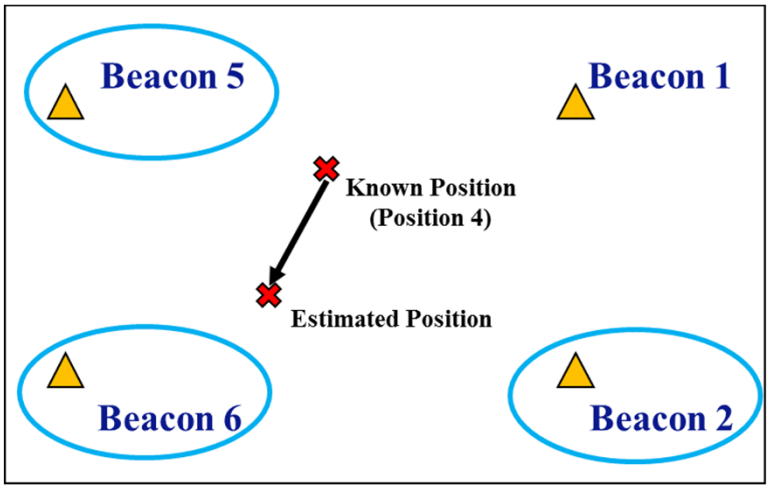
# Experiment for PDR

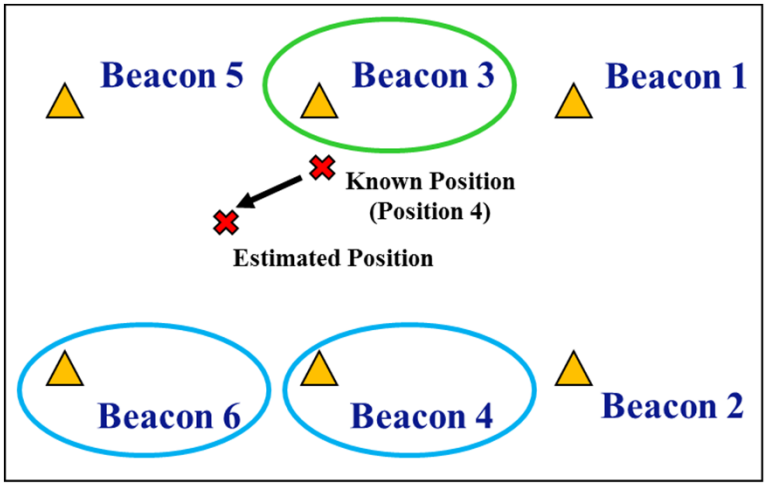


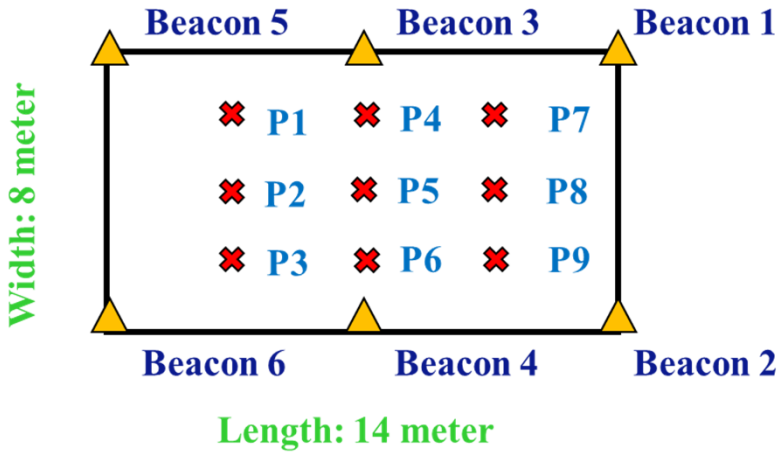

- The results of smartphone in the pocket and on the belt, are worse than others which are because of the vibration.

| Posture | Estimated distance (m) | Misclosure (m) | Relative Precision (%) |
|---|---|---|---|
| In hand (reading) | 138.41 | 1.80 | **1.30** |
| Close to ear | 138.84 | 0.97 | **0.70** |
| In the pocket | 130.00 | 7.39 | **5.68** |
| On the belt | 135.35 | 14.59 | **10.78** |

# Experiment for Bluetooth positioning

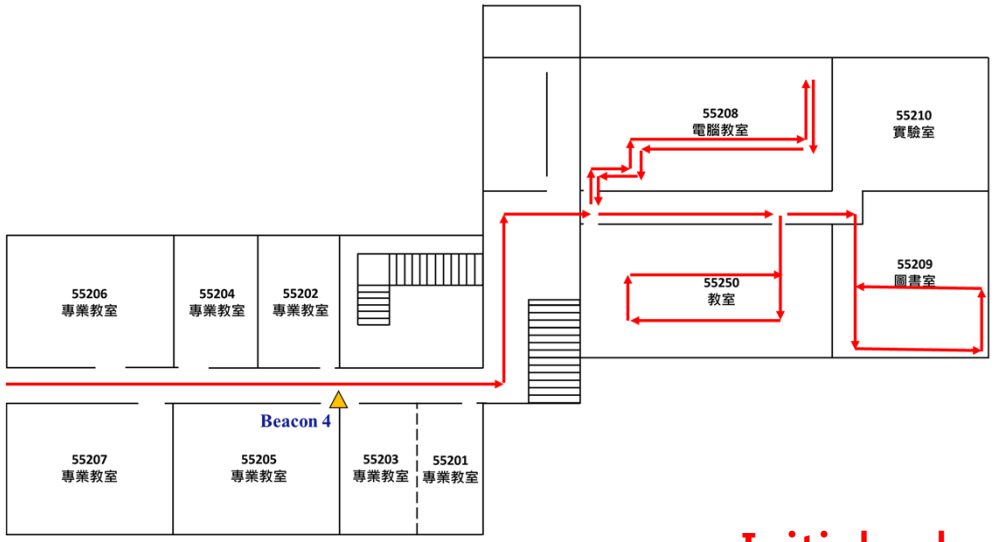


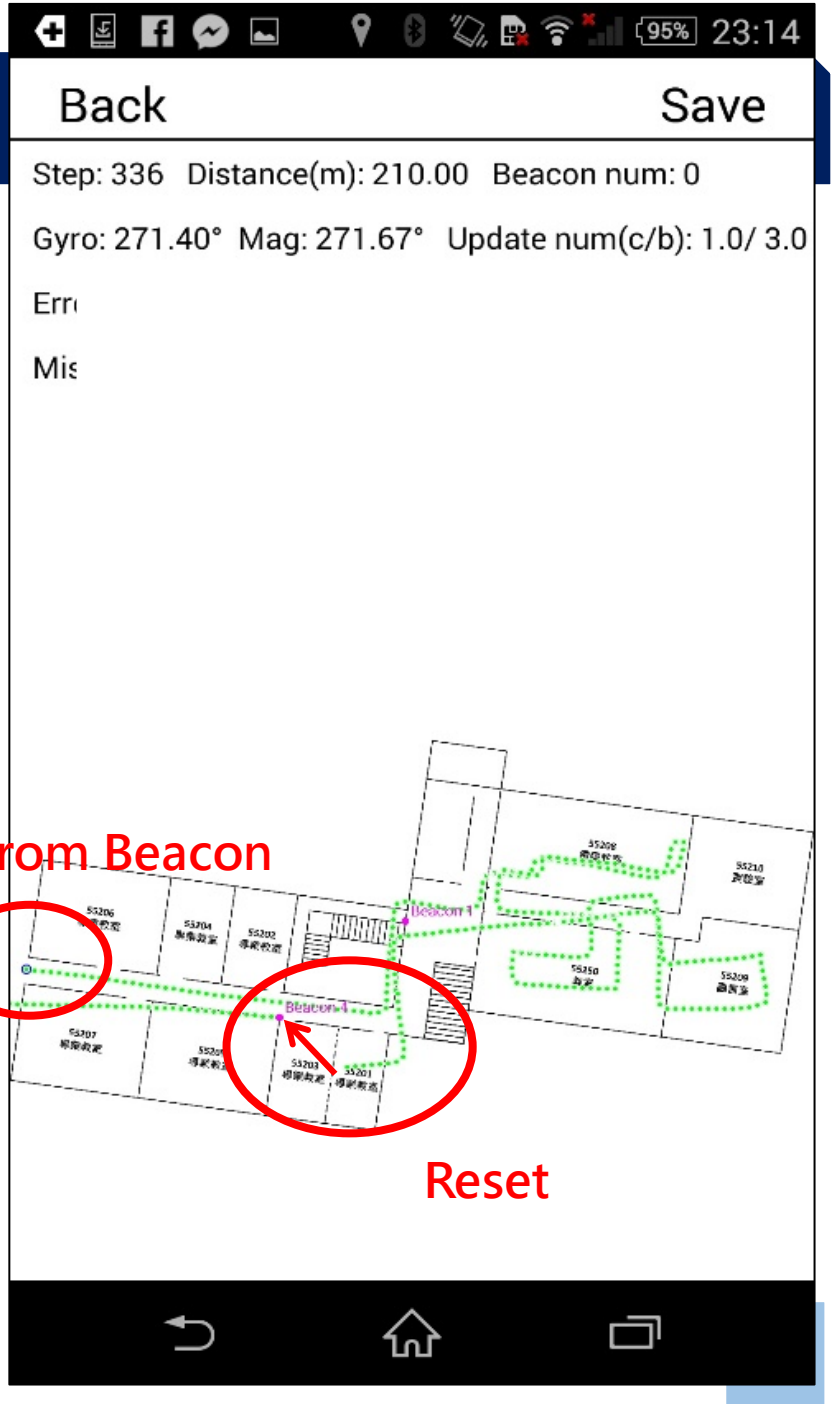




| bounding box | | | | |
|---|---|---|---|---|
| Subject | Four Beacons | | Six Beacons | |
| | N | E | N | E |
| Mean Error | 1.74 | 2.23 | 1.21 | 2.12 |

# Experiment for PD




Initial value from Beacon




Reset

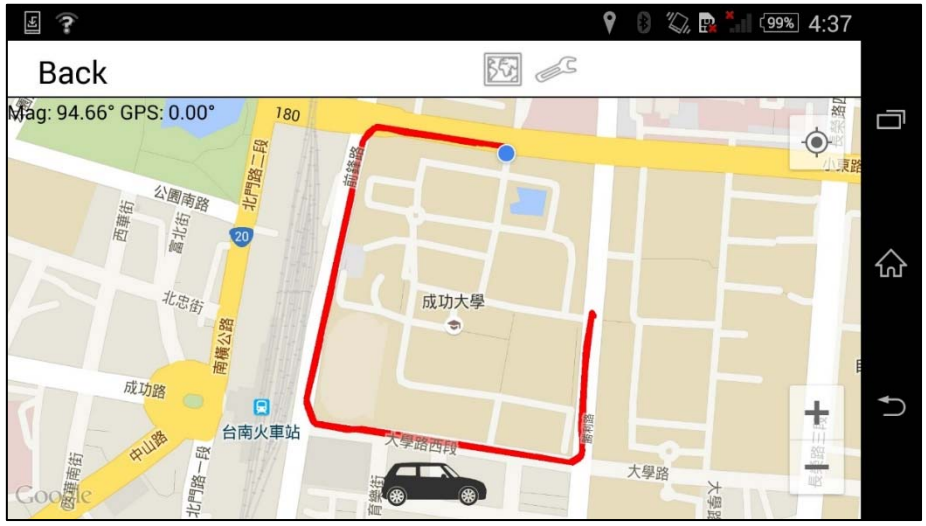
# Experiment for INS/GNSS integrated system



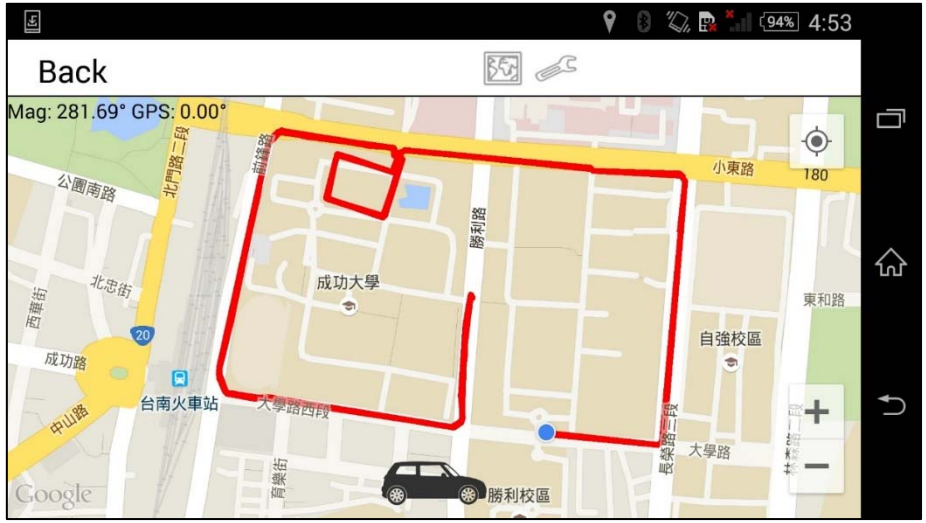
Without NHC+ZUPT With NHC+ZUPT

| | Whole trajectory | | | Section of open sky | | | Section of underground | | |
|---|---|---|---|---|---|---|---|---|---|
| Direction | N | E | H | N | E | H | N | E | H |
| Max | 17.13 | 17.13 | 15.68 | 13.57 | 8.35 | 7.89 | 39.76 | 17.13 | 15.68 |
| Min | 0.11 | 0.02 | 0.08 | 0.19 | 0.06 | 0.08 | 0.11 | 0.02 | 0.93 |
| RMSE | 8.47 | 7.96 | 7.78 | 6.61 | 4.26 | 4.08 | 9.79 | 10.10 | 9.91 |

# Switching for vehicle and pedestrian







# Conclusion

- The proposed multi-sensor activity recognition based on DT can achieve the accuracy of about **100%** that is efficient in recognition of different device placements.
- The densities of beacons have a very important influences on the results of beacons positioning. The position errors commonly are less than **2 meter**.
- The mean relative precision of PDR is less than **2.5%.**
- Beacon is capable of providing the initial position of user in indoor environment and aid the PDR for improving the solutions.

# Conclusion

- ZUPT and NHC constraints improve the solutions of INS/GNSS integrated system during GPS outage.
- The errors of INS/GNSS integrated system about 10 meter in 2D directions no matter in open sky or underground environments.
- The development of proposed algorithm can achieve seamless navigation with personal navigation system, INS/GNSS integrated system, activity recognition and beacons positioning technology.

# Thank you for your listening