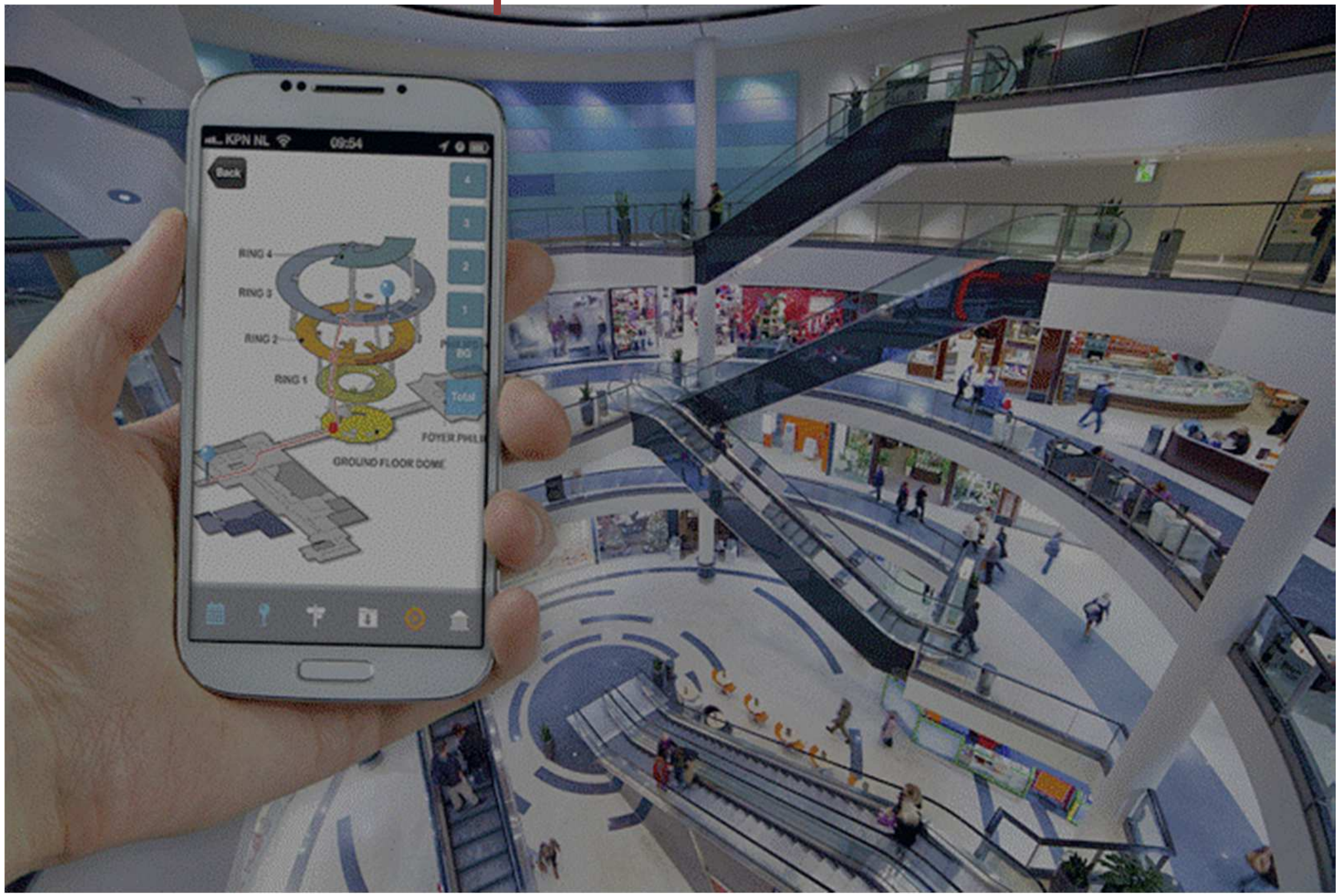
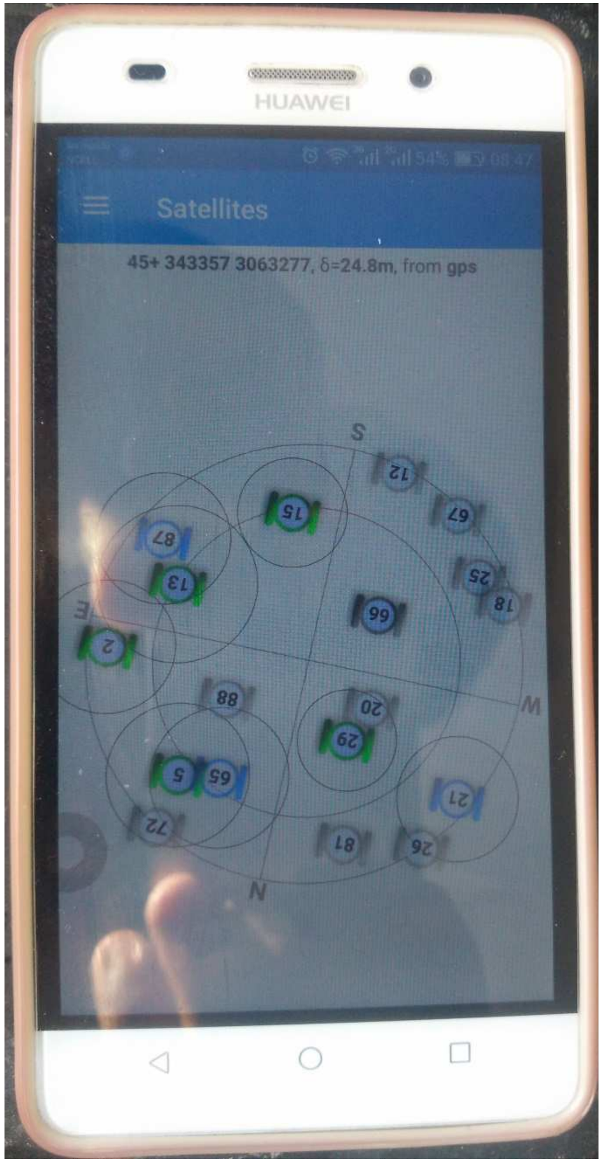
# Utility of Sensor Fusion of GPS and Motion Sensor in Android Devices In GPS-Deprived Environment




*Suresh Shrestha, Amrit Karmacharya, Dipesh Suwal*

# Introduction

- The use of Global Positioning System (GPS) signals to deliver location based services
- Implemented by smart phones
- Smart city



# Introduction

- antennae needs a clear view of the sky

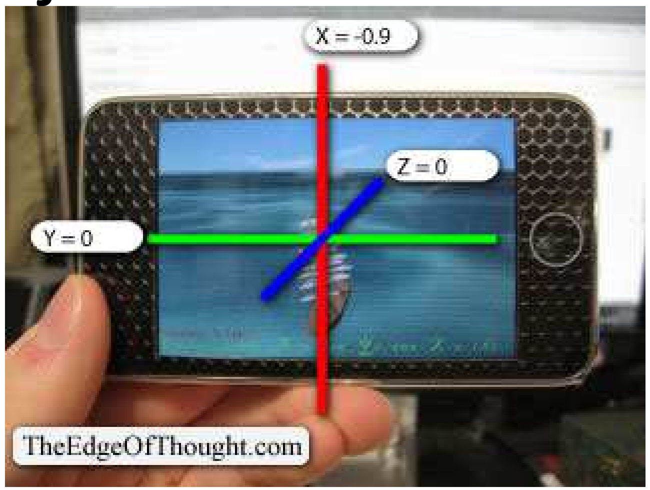
- GPS-deprived conditions
  - Urban settlements
  - Indoor(inside hotels,malls)

# Application in GPS

- GPS accuracies of smart phones have not been studied nearly as thoroughly as typical GPS receivers
- Median horizontal error in static outdoor environment is around 5.0 to 8.5 m.
- In dense and crowded areas with more buildings it is even worse.
- Most android devices are equipped with motion sensors
- This can be used to complement GPS accuracy

# INS (Inertial Navigation System)

- continuously updates the position, orientation and velocity of the moving object from motion sensor readings.




- typically contain
  - gyroscope : measuring angular velocity
  - accelerometer : measuring linear acceleration
- immune to jamming and deception

# Drawbacks of INS

- Measurement of acceleration and angular velocity cannot be free of error.

- Integration drift

- unrestrained positioning errors in the absence of coordinate updates from external source
- GPS can be used for updating

- Solution
  - Hybrid Positioning System


integrate other non-GPS methods in GPS-denied environments in order to enhance the availability and robustness of positioning solutions

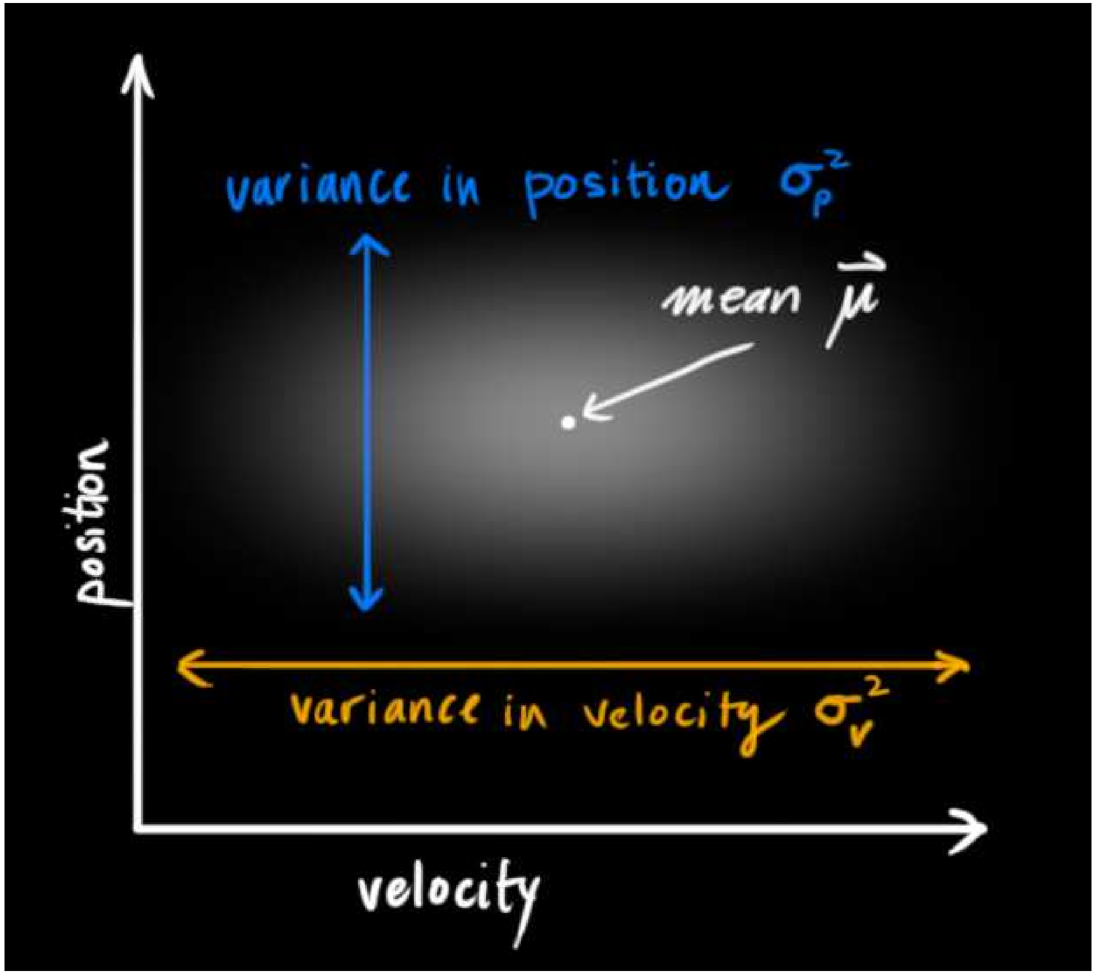
# Kalman Filter

- **Estimating Algorithm**
- uses a series of measurements (with some inaccuracies) observed over time
- produce more precise estimates by reducing noise

# Algorithm

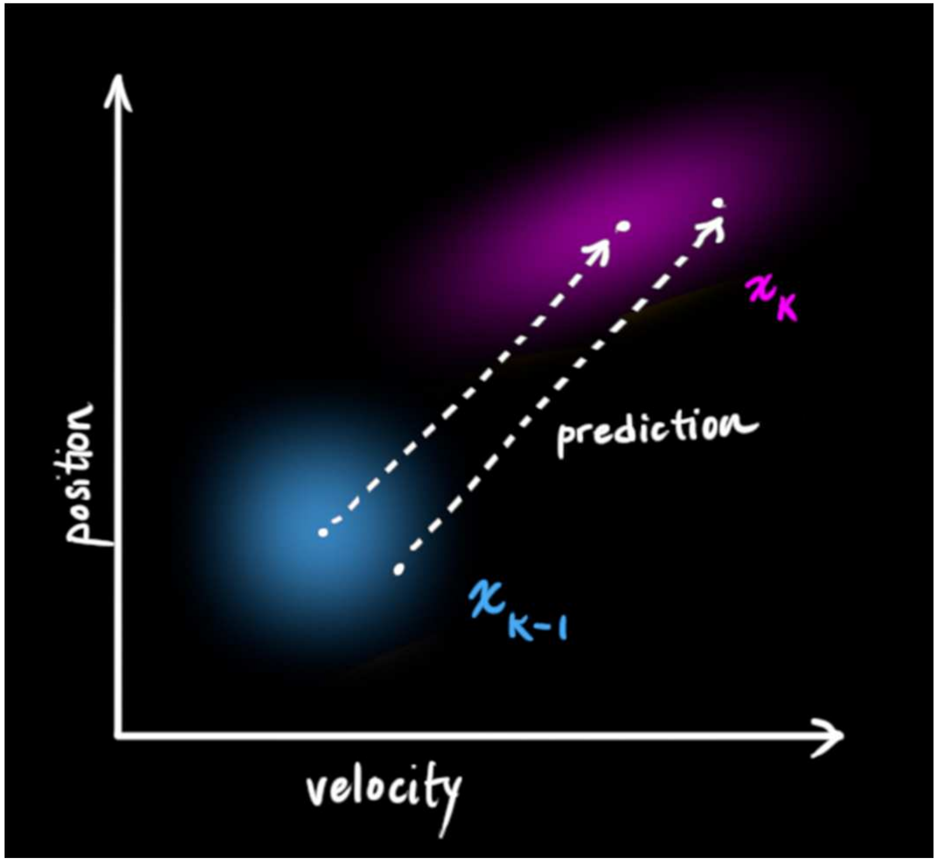
- The algorithm works in a two-step process.
  - Prediction Phase: Kalman filter produces estimates of the current state variables, along with their uncertainties.
  - Update Phase: Once the outcome of the next measurement is observed, these estimates are updated using a weighted average, with more weight being given to estimates with higher certainty.
- The algorithm is recursive. It can run in real time, using only the present input measurements and the previously calculated state and its uncertainty matrix; no additional past information is required.

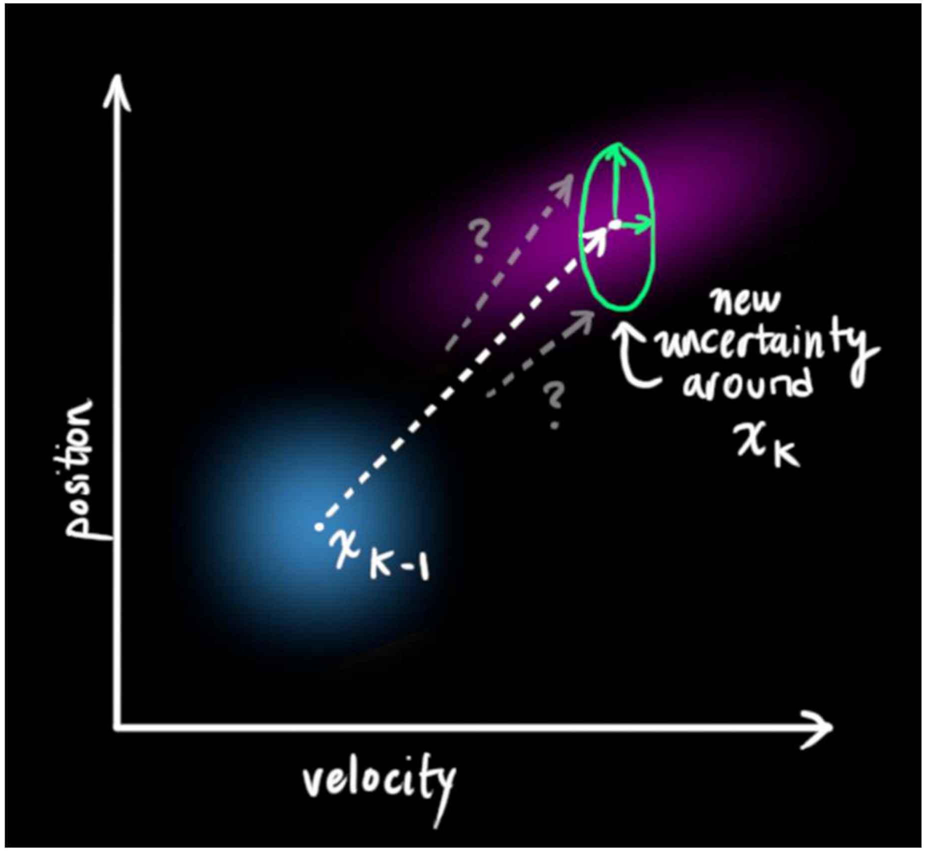
# Observed Point and Variance




*Source: http://www.bzarg.com/p/how-a-kalman-filter-works-in-pictures/*

# Prediction Phase

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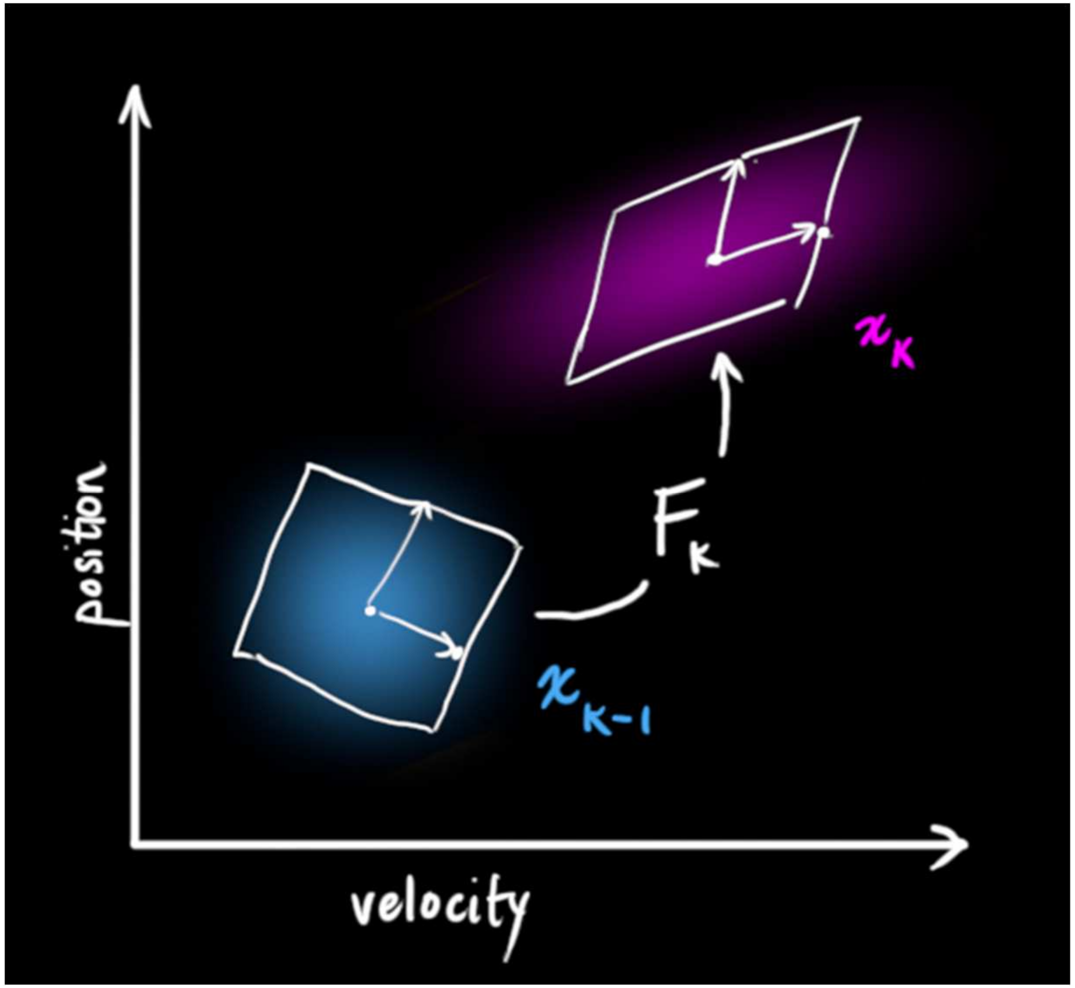
# Transformation

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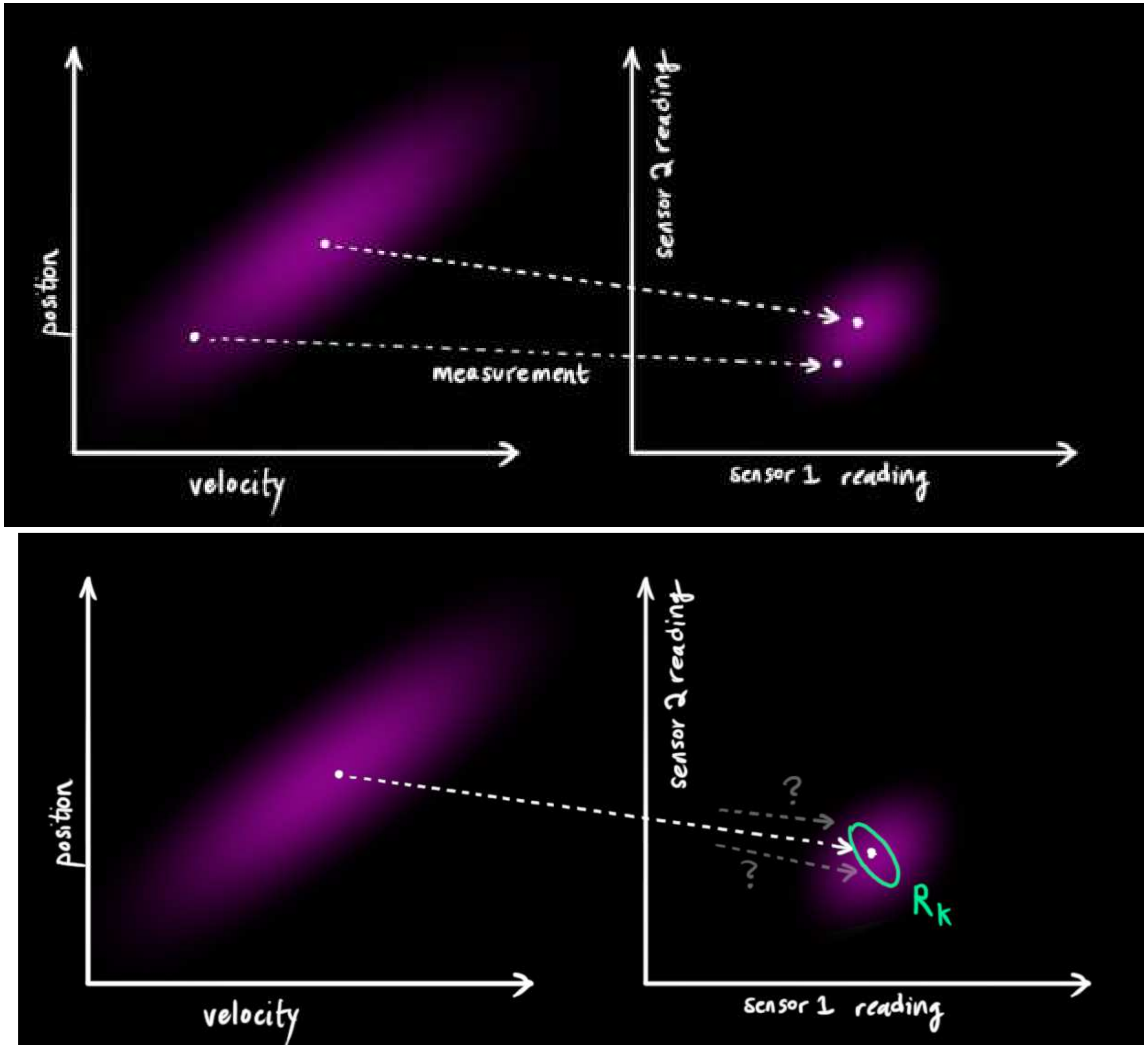
# Update Phase

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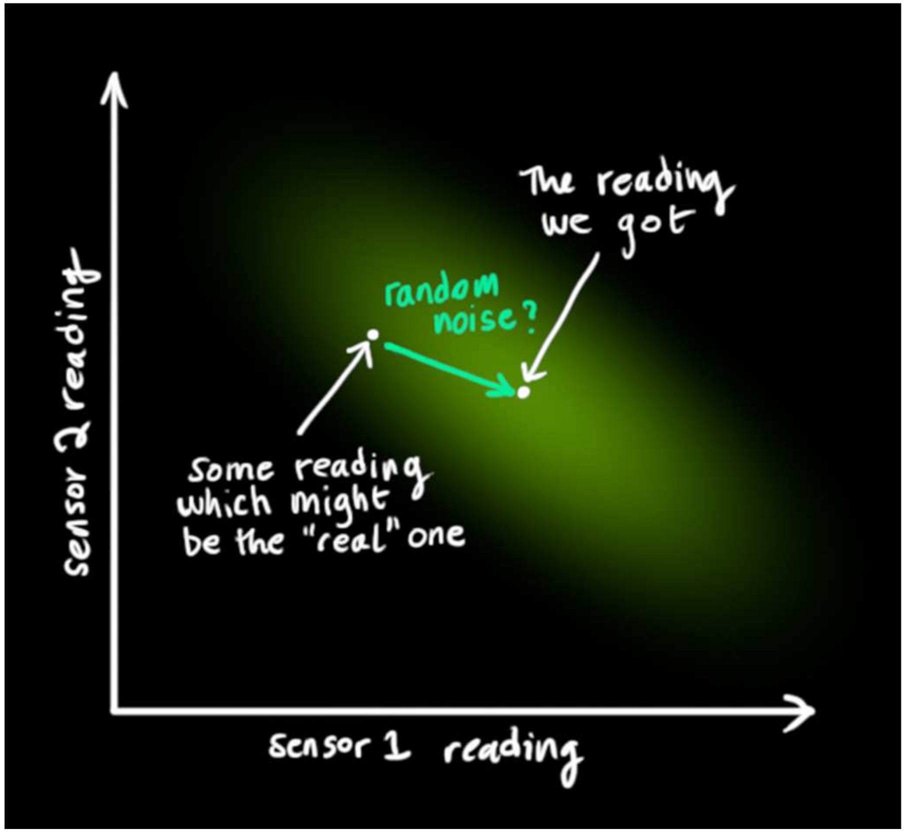


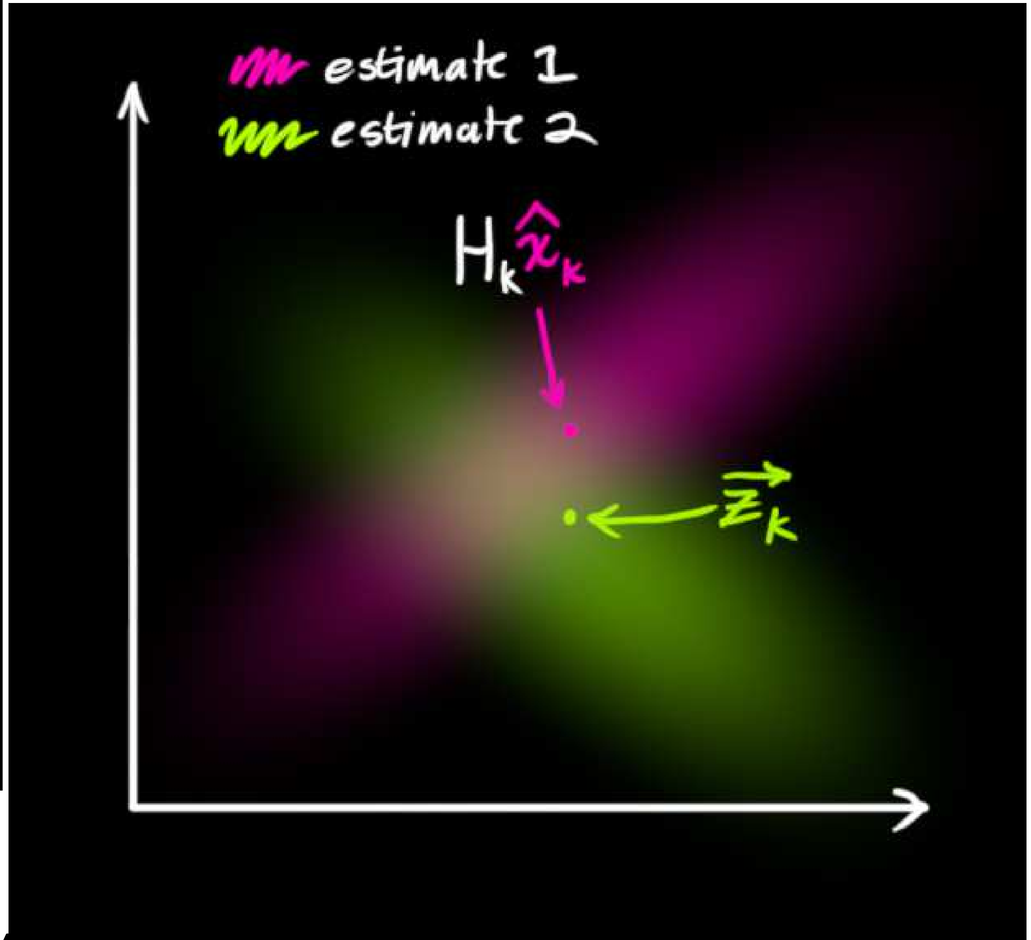


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# Kalman Filter Parameters

***Model*:**

$$x_k = Ax_{k-1} + Bu_k$$

$$z_k = Cx_{k-1} + v_k$$

***Predict*:**

$$\hat{x}_k = A\hat{x}_{k-1} + Bu_k$$

$$P_k = AP_{k-1}A^T$$

***Update*:**

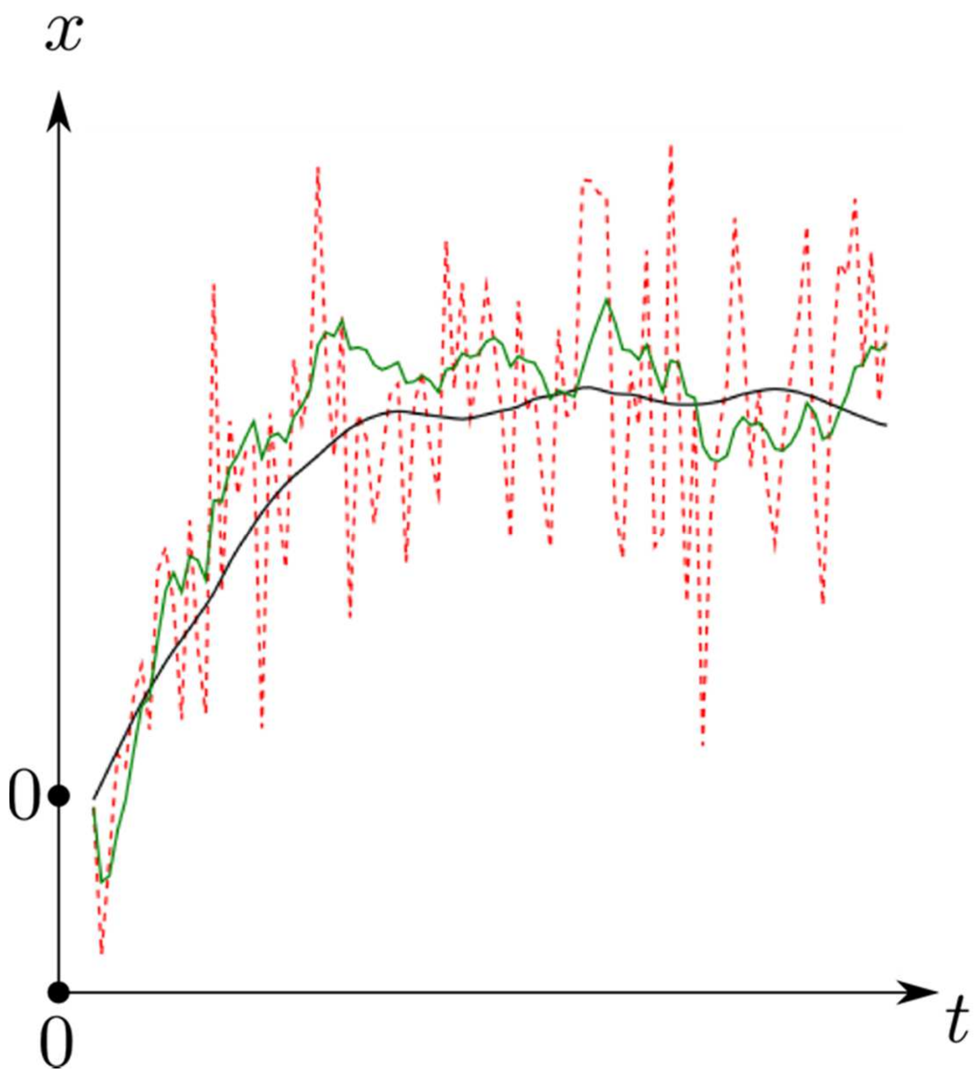
$$G_k = P_kC^T(CP_kC^T + R)^{-1}$$

$$\hat{x}_k = \hat{x}_k + G_k(z_k - C\hat{x}_k)$$

$$P_k = (I - G_kC)P_k$$

- The algorithm works in a two-phases
- prediction phase, old position will be modified according to the physical laws of motion.
- Next, in the update phase, a measurement of the position is taken from the GPS unit.

# Data View




- Black: predicted,
- green: filtered
- red: observations

# Experiment



# Android devices used

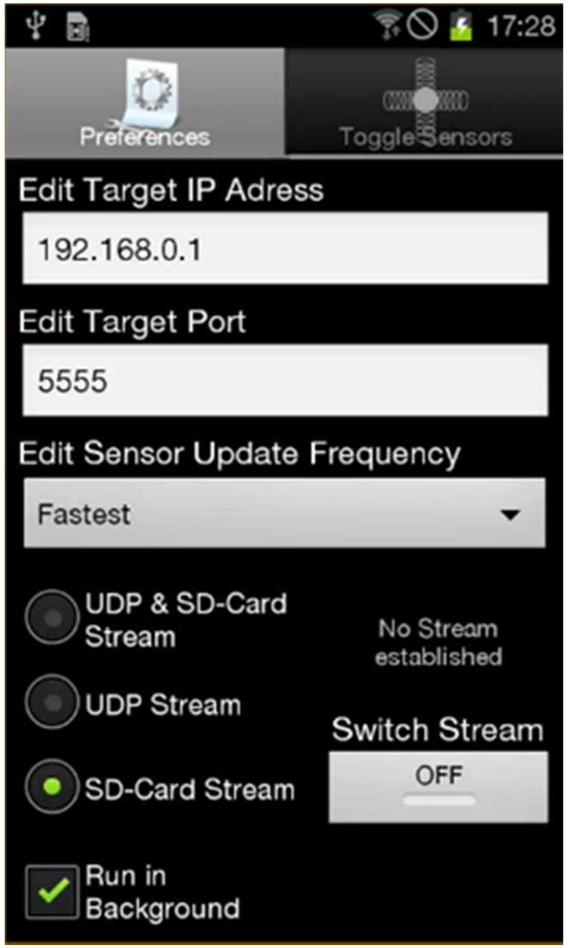

# Experiment

- The algorithm is supposed to be hard coded to the device but for demonstration we have extracted the data from android device sensors in csv format.

Data and Observation from android device

| timestamp | gps | easting | northing | accelerometer | x | y | orientation | x | y | z |
|---|---|---|---|---|---|---|---|---|---|---|
| 1467528475 | 1 | 9522455.035 | 3201110.468 | 3 | -0.201 | 2.72 | 81 | 241.812 | -16.062 | -1.031 |
| 1467528476 | 1 | 9522455.035 | 3201110.468 | 3 | -0.172 | 2.614 | 81 | 243.5 | -15.688 | -0.734 |
| 1467528477 | 1 | 9522455.035 | 3201110.468 | 3 | -0.575 | 2.72 | | | | |
| 1467528478 | 1 | 9522455.035 | 3201110.468 | 3 | -0.421 | 2.519 | 81 | 241.453 | -14.656 | -2.375 |
| 1467528479 | 1 | 9522455.035 | 3201110.468 | 3 | 0.23 | 2.509 | 81 | 226.203 | -16.328 | 2.234 |
| 1467528480 | 1 | 9522455.035 | 3201110.468 | 3 | 0.393 | 2.413 | 81 | 175.016 | -11.812 | 3.578 |

# Data logging

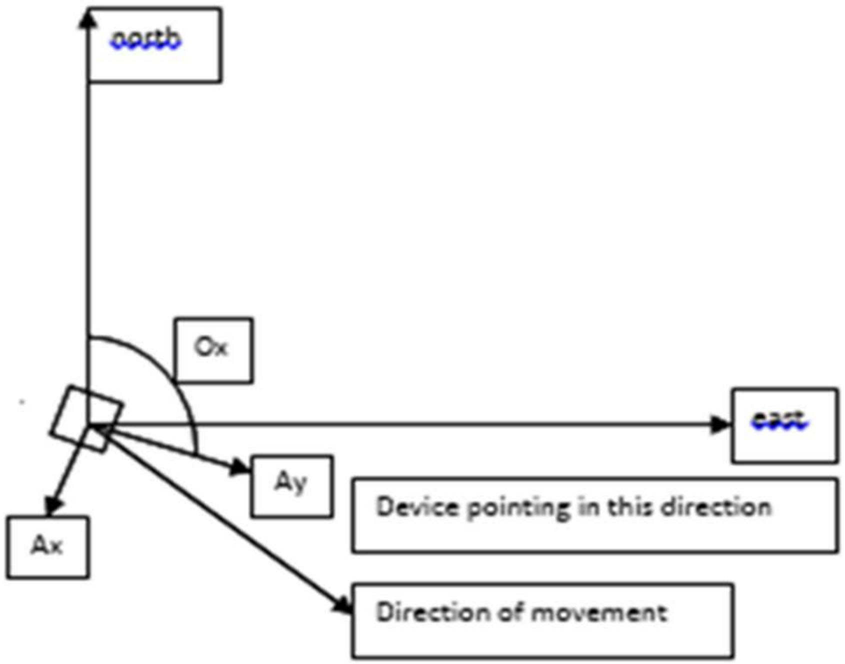
# Motion Sensors

XY direction of accelerometer is different from that of gyroscope/magnetometer.

Accelerometer measures Ay in forward direction of device and Ax perpendicular to it

Gyroscope/Magnetometer gives Ox as bearing from north

The formula converts device




$$Ae = Ay \sin Ox + Ax \sin Ox + 90$$

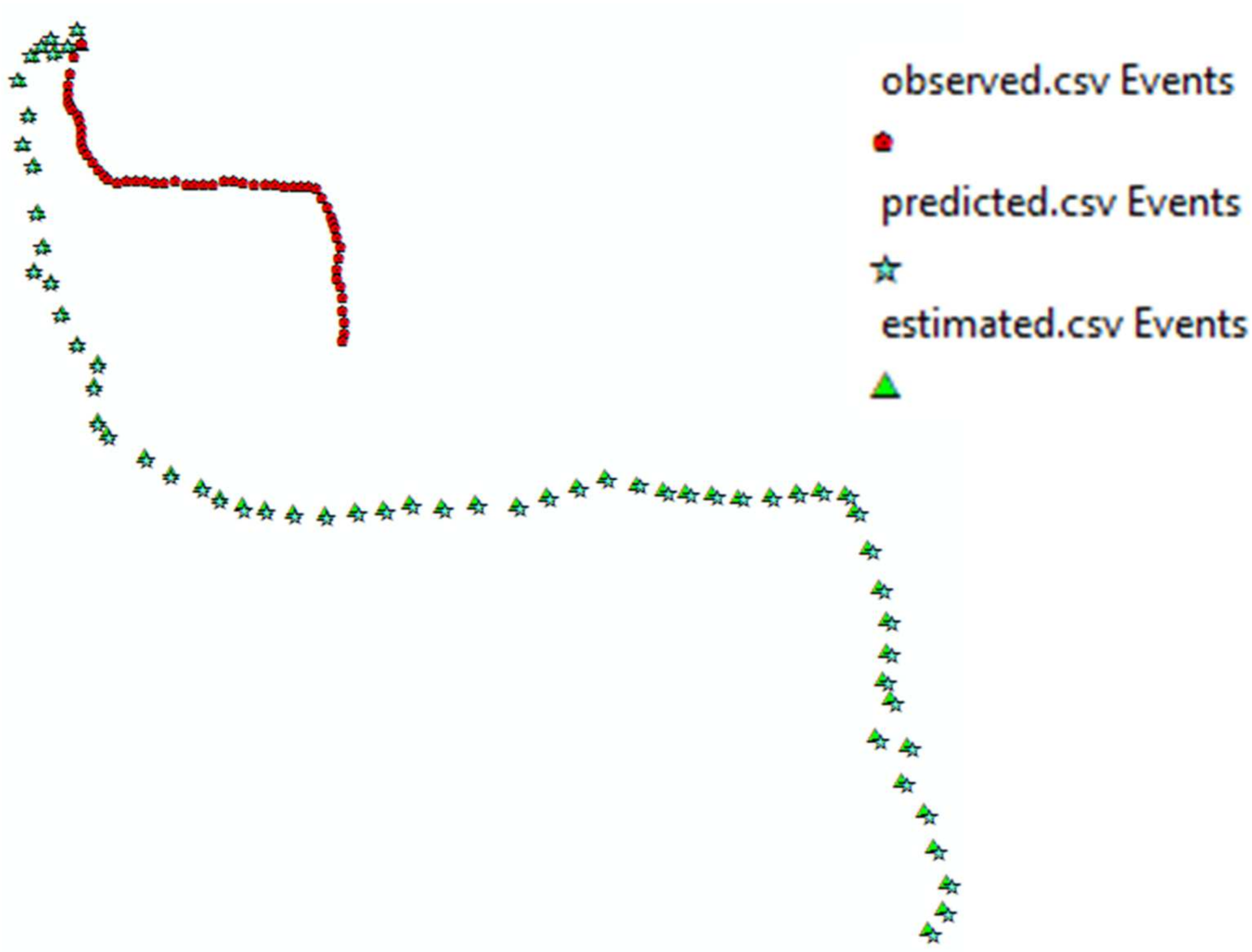
$$An = Ay \cos Ox + Ax \cos Ox + 90$$

# Data Calculation

| Predict Phase | | | | | | | | | | | update | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ae | An | ue | un | dt | de | dn | e | n | p | | g | ek | nk | pk |
| | | | | | | | | | | | | 9522455 | 3201110 | |
| -2.3025 | -1.461997878 | 0 | 0 | 1 | -0.53279 | 2.906915403 | 9522454.502 | 3201113 | 1 | | 0.166667 | 9522455 | 3201113 | 0.833333 |
| -2.2626 | -1.320289794 | -2.30247 | -1.462 | 1 | -2.38847 | -0.154997878 | 9522452.647 | 3201110 | 0.833333 | | 0.142857 | 9522453 | 3201110 | 0.714286 |
| -0.575 | 2.72 | -4.56508 | -2.78229 | 1 | -4.85258 | -1.422287672 | 9522450.182 | 3201109 | 0.714286 | | 0.125 | 9522451 | 3201109 | 0.625 |
| -2.0116 | -1.573595548 | -5.14008 | -0.06229 | 1 | -5.35058 | 1.197212328 | 9522449.684 | 3201112 | 0.625 | | 0.111111 | 9522450 | 3201112 | 0.555556 |
| -1.9702 | -1.570479215 | -7.15165 | -1.63588 | 1 | -7.03665 | -0.38138322 | 9522447.998 | 3201110 | 0.555556 | | 0.1 | 9522449 | 3201110 | 0.5 |
| -0.1819 | -2.438019318 | -9.12182 | -3.20636 | 1 | -8.92532 | -1.999862435 | 9522446.11 | 3201108 | 0.5 | | 0.090909 | 9522447 | 3201108 | 0.454545 |
| 1.8288 | -3.218743832 | -9.3037 | -5.64438 | 1 | -10.1752 | -4.011381754 | 9522443.746 | 3201104 | 0.454545 | | 0.083333 | 9522445 | 3201104 | 0.416667 |
| -0.1194 | -3.40799247 | -7.4749 | -8.86313 | 1 | -7.4319 | -7.158625586 | 9522445.599 | 3201098 | 0.416667 | | 0.076923 | 9522446 | 3201098 | 0.384615 |
| 1.43606 | -3.57962314 | -7.59434 | -12.2711 | 1 | -8.25984 | -10.46111806 | 9522444.548 | 3201093 | 0.384615 | | 0.071429 | 9522445 | 3201093 | 0.357143 |
| 0.36262 | -6.358782287 | -6.15828 | -15.8507 | 1 | -6.17728 | -12.6662412 | 9522446.52 | 3201089 | 0.357143 | | 0.066667 | 9522447 | 3201090 | 0.333333 |
| 0.29013 | -4.694678368 | -5.79566 | -22.2095 | 1 | -5.73366 | -19.85852348 | 9522447.186 | 3201080 | 0.333333 | | 0.0625 | 9522448 | 3201081 | 0.3125 |
| -0.9389 | -3.425647136 | -5.50553 | -26.9042 | 1 | -4.93103 | -25.22370185 | 9522448.211 | 3201074 | 0.3125 | | 0.058824 | 9522449 | 3201076 | 0.294118 |
| 1.46995 | -2.172849049 | -6.44439 | -30.3298 | 1 | -6.84189 | -29.07984899 | 9522446.746 | 3201070 | 0.294118 | | 0.055556 | 9522447 | 3201071 | 0.277778 |
| 1.97443 | -4.349837928 | -4.97444 | -32.5027 | 1 | -4.55294 | -30.15169803 | 9522449.814 | 3201068 | 0.277778 | | 0.052632 | 9522450 | 3201069 | 0.263158 |
| 2.84058 | -3.501945002 | -3.00002 | -36.8525 | 1 | -3.19652 | -34.60653596 | 9522451.615 | 3201062 | 0.263158 | | 0.05 | 9522452 | 3201064 | 0.25 |
| 2.46587 | -2.10772523 | -0.15944 | -40.3545 | 1 | -0.59994 | -38.79348096 | 9522454.435 | 3201057 | 0.25 | | 0.047619 | 9522454 | 3201058 | 0.238095 |
| -0.4516 | -3.37694788 | 2.306439 | -42.4622 | 1 | 2.976939 | -40.89620619 | 9522458.234 | 3201053 | 0.238095 | | 0.045455 | 9522458 | 3201055 | 0.227273 |
| 0.70475 | -4.72114041 | 1.854855 | -45.8392 | 1 | 2.635355 | -43.58365407 | 9522457.67 | 3201049 | 0.227273 | | 0.043478 | 9522458 | 3201051 | 0.217391 |
| 1.80332 | -2.504461411 | 2.559607 | -50.5603 | 1 | 2.617107 | -49.01829448 | 9522458.097 | 3201043 | 0.217391 | | 0.041667 | 9522458 | 3201045 | 0.208333 |
| 4.88537 | -2.200655558 | 4.362924 | -53.0648 | 1 | 3.898424 | -50.42625589 | 9522460.046 | 3201040 | 0.208333 | | 0.04 | 9522460 | 3201042 | 0.2 |
| 3.83663 | -1.976189092 | 9.248299 | -55.2654 | 1 | 9.521299 | -53.12491145 | 9522466.782 | 3201036 | 0.2 | | 0.038462 | 9522466 | 3201038 | 0.192308 |
| 4.17855 | -0.496479474 | 13.08493 | -57.2416 | 1 | 13.17593 | -55.13960054 | 9522471.439 | 3201033 | 0.192308 | | 0.037037 | 9522471 | 3201035 | 0.185185 |

This calculations are performed by pyKalman Module in python

# Result



observed.csv Events
predicted.csv Events
estimated.csv Events

# Results and Conclusion

- The acceleration in z direction is greatly affected by gravity (9.8 $m/s^2$). Component of this acceleration affects other axes as well resulting error in position.
- Requires more sensitive motion sensors

# Conclusion

- various potential application areas such as robotics, shopping malls, museums, underground areas, city area, etc
- With increased computational power on handheld devices, a propagation-based technique could be implemented to determine the position of the device.

Thank You