M1 Electrical Engineering for Communications & Information Processing (EECIP)

Track Electrical and Optical Engineering (EOE)

PHY7509 – Radio Frequency for Connected Objects

Project: Positioning System Project With GPS-WiFi-INS Fusion

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1. Abstract

In modern times, positioning is rapidly growing field in terms of engineering and research. The positioning produces different challenges based on different contexts and environments. This calls for the fusion of different sensors which can be integrated together to find the positioning. In this project, we used five different sensors i.e. Accelerometer, Gyro meter, Magnetometer, GPS sensor, and WiFi sensor to apply sensor fusion. In particular, we studied and experimented the sequential fusion method to find the positioning. INS sensors are generally highly fluctuating and prone to noise. For this reason, we propose to implement averaging in preprocessing stage. Moreover, the sampling frequency of different INS is not synchronous, which is why we added a feature in our software application which allows user to adjust sampling frequency of different sensors based on application. We proposed our algorithm which estimates the distance from Accelerometer and GPS sensor in short time intervals depending on the threshold. At the same time, we fused the magnetometer and gyro meter to calculate the angular movement. Finally, we displayed the results, discussed few, and shared future recommendations. In this project, we generated the Excel and C++ code file which automatically implements the algorithm and everything with just one click functionality.

2. Introduction and Background

Various indoor and outdoor positioning innovative methodologies have been researched and proposed in recent years each having a different approach for integrating seamless combination of sensors and switching mechanism to make the overall positioning system more accurate in dynamic manner. However, we shall see the best possible system in terms of infrastructural sensor availability, reliability, low cost, redundancy. Our approach would be to curb the limitation of one sensor fusion technology with the advantages of the other.

We could briefly explain the sensors we are going to use in our approach:

2.1 OUTDOOR localisation sensors:

GNSS: is widely used in the outdoor environment with 4 satellite constellation system to improve the accuracy. We have a GPS receiving sensor at the mobile device which captures the *almanac and* ephemeris forms of transmitted data.

GPS sensor: Our phone(s) are equipped with GPS receivers that get signals from each GPS satellite. As we know when the signal was transmitted from satellite and the time it gets received, the sensor can tell how far it was from that satellite (even the exact position). We often take three satellites and note their exact position in the sky, relative to the signals received by the sensor it could estimate the device (under test) accurate position in 3 D.

2.2 INS

Inertial navigation is used as a supplementary service in conjugation to other navigation systems. Its also provides higher degree of accuracy when compared to a standalone single system. By proper fusion (combine information) we could reduce errors both in position and velocity. The results achieved are quite stable. Let’s see the sensors used:

- Accelerometer: uses double integration over three axis accelerations to determine trajectory.
- Gyroscope: measures angular velocity giving altitude &orientation (along with accelerometer)
- Magnetometer: gives direction of motion w.r.t north direction.

Accuracy depends on the grade of the material(s) used to fabricate these sensors and the cost relating to it.

Limitations:

(i) Need to know starting point
(ii) Biases in measurement(s) made.

2.3 Indoor localisation sensors:

We will be restricted to talk about WiFi sensor as part of the scope of this project.

WiFi:

We will see the comparison of two indoor localisation techniques (i.e., trilateration and fingerprinting) to estimate the best pin-point location. However, as part of this project, we proposed to integrate the approach we used in Project-1 for indoor positioning based on trilateration of power measurements.

Comparison between two indoor localisation techniques:

Method	*Accuracy level*	*Advantage*	*disadvantage*
Trilateration	*medium*	*Continuous positioning (without calibrating needed)*	*Poor positioning accuracy occurs(by environmental effects)*
Fingerprinting	*high*	*Continuous positioning (environmental factors affect calibration phase).*	*Poor positioning accuracy in environment (where surroundings change frequently).*

The details about the implementation of Trilateration and our proposed variation of this approach is presented in the report of the 1st project.

3. Motivation for Selected approach

The major motivations behind choosing the proposed approach are as follows:

a) A learning opportunity to understand fusion of sensors in a practical world.
b) Experience the working and behavior of INS to find the positioning
c) Experiment around different environments to observe how different sensors behave in different situations
d) To evaluate and compare the different sensors' performance to propose which sensor performs better and in what situation.

4. Proposed Model Space and Validity

We conducted our experiments in different environments i.e. outdoor, indoor, and in transition. Therefore our proposed approach performs well in multiple scenarios.

However, we conducted our experiments by keeping our mobile device in hand in horizontal direction.

In our project, we did implementation through software code, we gives the user to update the following parameters (we introduced) based on the application requirements:

- TOTAL_READINGS (defines the maximum of readings for one sensor)
- ACC_SAMPLING_FREQ,GPS_SAMPLING_FREQ , MAG_SAMPLING_FREQ , GYR_SAMPLING_FREQ
- FOOTSTEP_SIZE (defines the step size value, by default 0.6m)
- GPS_TIME_TRANSITION_MS (defines the range in ms to observe the next GPS recording)
- GPS_ACC_TRANSITION_THRESHOLD (defines the threshold determining which sensor is preferred)
- GYRO_LOWER_THRESHOLD (defines the threshold value for clockwise direction)
- GYRO_UPPER_THRESHOLD (defines the threshold value for counter clockwise direction)
- MAG_THRESHOLD (defines the threshold for magnetometer to handle noise)
- WIFI_POWER_THRESHOLD (defines the threshold to indicate the power level in indoor)

5. Experimental Setup

We conducted our experiments using “Sensor Fusion” mobile application which record the five sensors: accelerometer, magnetometer, gyro meter, GPS, and WiFi at different frequencies.

We conducted our experiments in different environments with different combinations. We also tried different routes to observe the behavior of the proposed approach. Here’s the little summary of different experiments we conducted:

a. Straight outdoor
b. L shape outdoor
c. Straight indoor
d. L shape indoor
e. Straight outdoor - straight indoor
f. L shape outdoor-indoor
g. Straight indoor-outdoor
h. L shape indoor-outdoor
i. Straight outdoor (150m relatively longer distance)

6. Activity Timeline and Experiments

This section describes our experience in this project and our journey from our first measurement to final proposed model.

1st activity: We started with experimentation and observation of working of INS.

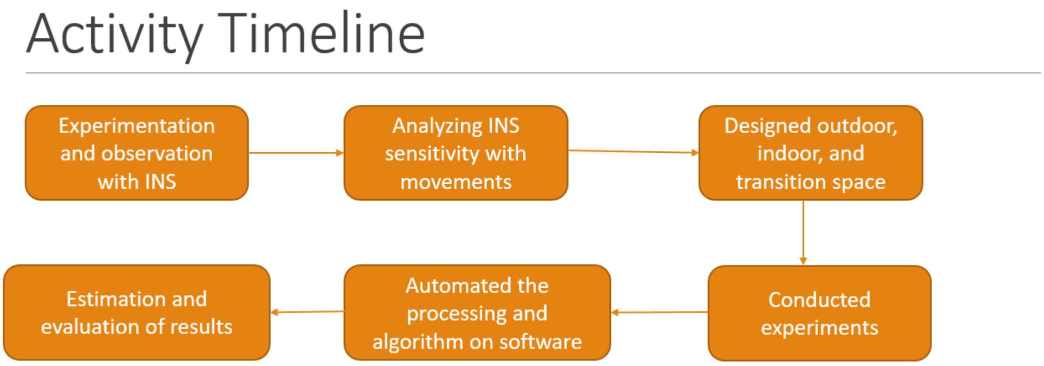
2nd activity: We analyzed the sensitivity of INS sensors with movement in linear and angular directions.

3rd activity: We defined the indoor, outdoor, and transition space for our experiments.

4th activity: In defined spaces, we conducted experiments in different situations and paths.

5th activity: We implemented our solution in a software code, which implements everything in automation. It just needs the log file from the "Sensor Fusion" app. And from that point, it does everything till the point of generating the predicted XY coordinates.

6th activity: Finally, based on our predictions, we evaluated and estimated our results.



7. Key Challenges

As it has been mentioned before that fusion of sensors is no short of challenges. However, for this project we focused on following key challenges and tried to solve them:

a) Noise fluctuations in INS
b) Unavailability of continuous outdoor space with previous WiFi positioning space
c) Non-uniform sampling frequency of INS
d) Processing of the data

8. Solutions for Challenges

As mentioned in previous section, in our project, we tried to focus on four challenges affecting our results.

8.1 Noise fluctuations in INS

The noise fluctations in recordings of different INS sensors were resolved by adding the avergaing of data which smothens the readings. This was done in the code.

8.2 Unavailability of continuous space

Because our indoor positioning based on WiFi signals was proposed in 3rd floor of Telecom SudParis building. Therefore, we couldn't have the significant physical outdoor space connected to this indoor space. To solve this problem, we divided our experiments in different spaces of outdoor and indoor. In some cases, we moved from outdoor to indoor, and vice versa. We added transition regions between these two environments to have more range of spaces for the experiments and validity.

8.3 Non-uniform sampling frequency of INS

As mentioned before, different sensors have different sampling frequency in the Sensor Fusion application. Typically, accelerometer has 5 times more frequency than magnetometer and 10 times more than the GPS. To resolve this issue, we added a feature to the user of our software application to adjust frequency as it is needed for the task. For our experiments, we reduced the accelerometer frequency by 5 times (each recording in 100ms not in 20ms).

8.4 Processing of the data

Even with the few meters and seconds of recording, generate huge amount of data. So processing of data was a challenge from a human experience. To resolve this, we automated this procedure through software. The software gets the log file, extract each sensor data from the file and then use it with fusion algorithm and processing to provide results, wholly automated in one click.

9. Process Flow

This section describes the flow of the process using the algorithm mentioned in section 10. This section helps reader to get the basic overview of how our proposed model works for the user.

Step-1: In sensor fusion application, all 5 sensors record measurements.

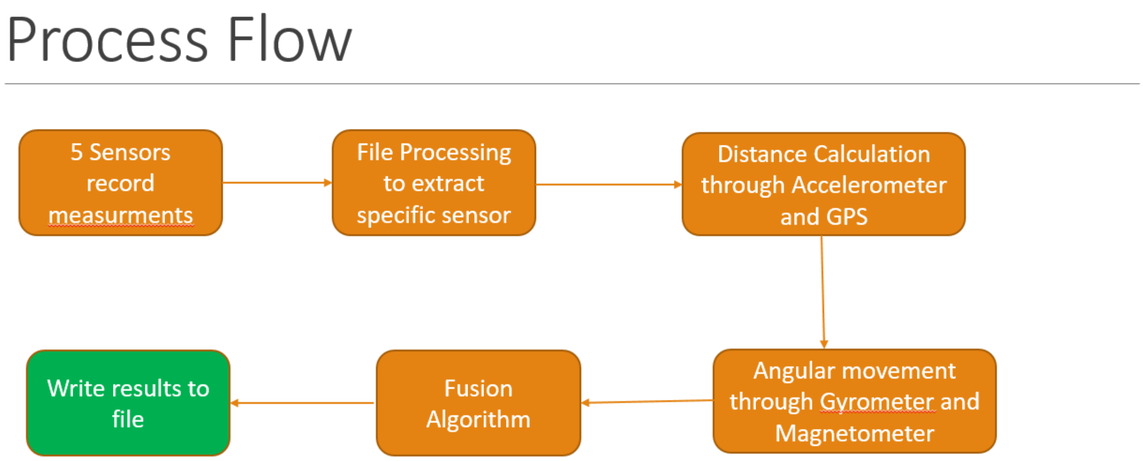
Step-2: This log file containing measurements is passed to the software which extracts the data.

Step-3: Based on accelerometer and GPS (if present), it calculates the distance using fusion algorithm.

Step-4: Based on magnetometer and gyro meter, we calculate the angular movements in our path. Here also, the fusion takes place to evaluate the angular movement.

Step-5: We implement our fusion algorithm to integrate distance and angular movement and find estimated XY values at different timestamps.

Step-6: Finally, these values are automatically written to the file to produce the final results.



10. Algorithm of Model

a) Takes the reference time from the first recording of accelerometer as t=0.
b) Checks if within threshold time (say 1.2s) there is a GPS recording.

c) If yes, calculate the distance based on that GPS recording
d) At the same time, calculate the distance from the accelerometer from initial time to this GPS reading time.
e) To calculate the accelerometer distance, step counter method is used. Acceleration data is extracted through code. The mean is scaled to obtain zero crossings in accelerometer readings. From zero crossing, we calculated number of steps. After obtaining the number of steps, we calculated the distance by multiplying with the step size = 0.6 m.

f) Compare these two distances with GPS_ACC threshold which defines which sensor is to be preferred.
g) If the difference is huge (depending upon threshold), ACC measurement is preferred.
h) Otherwise (depending upon threshold) GPS measurement is preferred.
i) If there is no GPS recording within maximum time jump, distance data is evaluated from the ACC sensor
j) Each distance recording is marked with the timestamp
k) In parallel, using gyrometer (high sensitivity), we determine the angular direction at any timestamp.
l) During this time, the angular movement is determined by the magnetometer.
m) Condition: If gyro indicates movement, consider magneto's angular reading
n) Having distance and angle, find XY using geometry
o) Write XY automatically to Excel file and plot to observe the route
p) If WiFi with known MAC address is detected and power level is within the theshold, the fusion algorithm extracts the positioning information from the code of project 1
q) This is implemented in code, but difficult to experiment since we didn't have the outdoor space near WiFi indoor positioning model.

In this section, we described the basic structure of our algorithm. The results and observations based on this algorithm are mentioned in the sections below.

11. Results

In this section, we will display our results in different contexts to explain the performance of our algorithm.

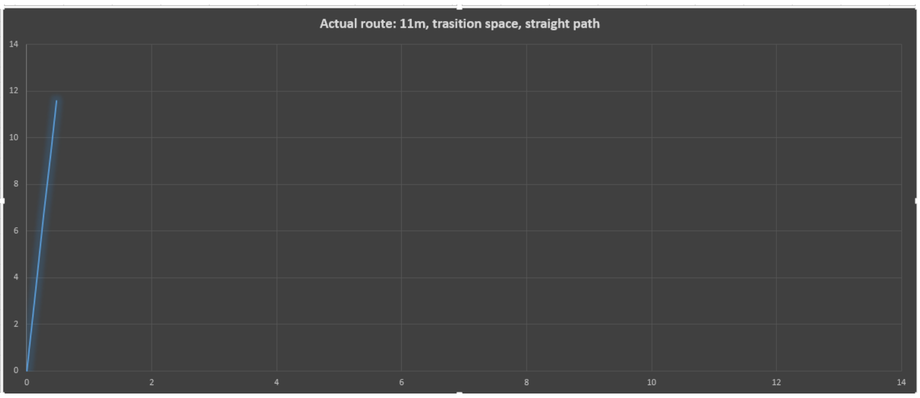
11.1 Experiement-1: 11m, transition, straight path

In this case, our actual distance was 11m in transition environment. In this region we could receive the GPS signals but because of not completely outdoor environment, the values would have been misleading. Our algorithm produced the following result:

```
Overall Predicted distance= 11.584540m
Predicted Acc distance= 9.000003m
Predicted GPS distance= 20.320969m
```

As you can see, GPS distance was very faulty. But our algorithm adjusted and gave final result of 11.5m (actual was 11m).

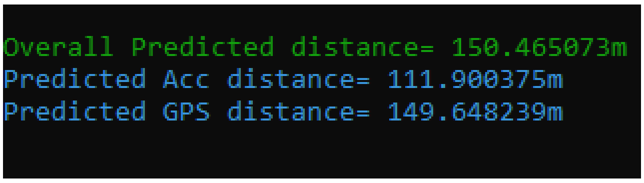
The route predicted in this case is shown below:



As it is visible, the distance was approximately well estimated and there is a slight variation of 0.6 meters in opposite axis. This is a very small error. The estimated results are fairly accurate here. Let's discuss second experiment.

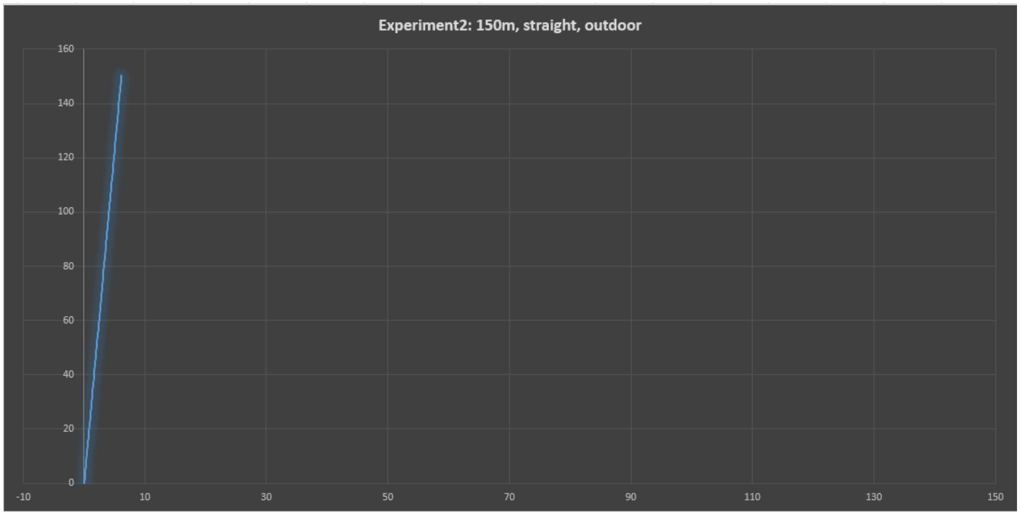
11.2 Exeriement-2: 150m, outdoor, straight path

In this case, our actual distance was 150m in outdoor environment. In this region we could receive the GPS signals clearly because of outdoor environment. Our algorithm produced the following result:



Here the accelerometer displayed error as it is relatively longer distance. As it was completely outdoor, GPS signals were correct, but here again our fusion algorithm adjusted and this time it preferred the GPS results more (not completely) and final result of 150.5m was almost perfect (actual was 150m).

The route predicted in this case is shown below:



As it is visible, the distance was approximately well estimated and there is a slight variation of 7meters in opposite axis. This is a very small error in longer distance. The estimated results are fairly accurate here as well. Let's discuss third experiment.

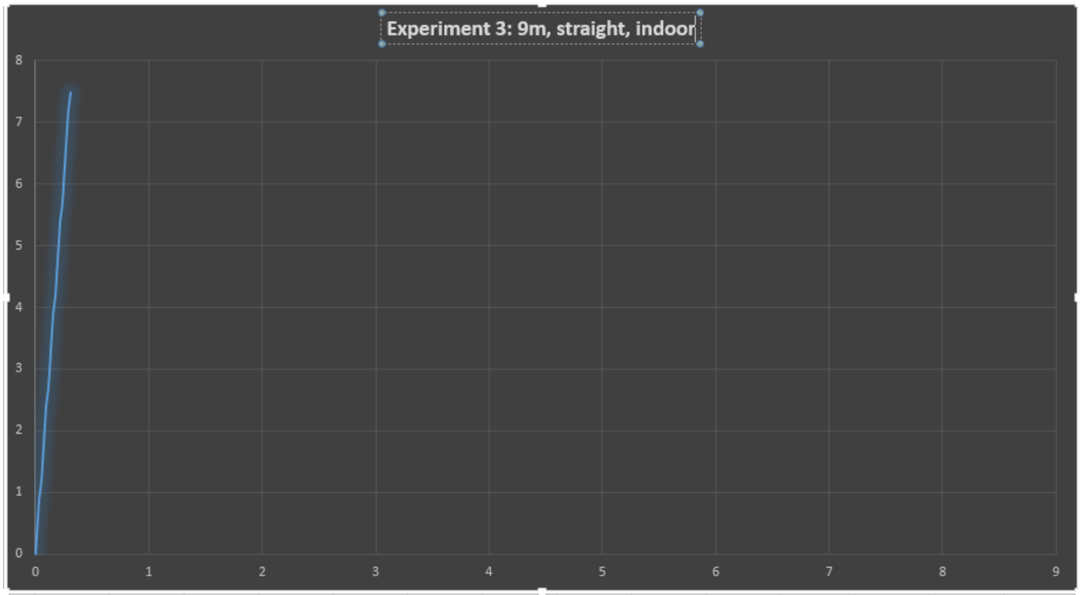
11.3 Experiment-3: 9m, straight, indoor

In this case, our actual distance was 9m in completely indoor environment. In this region we could not receive the GPS signals of totally indoor environment. Our algorithm produced the following result:

```
Overall Predicted distance= 7.800002m
Predicted Acc distance= 7.800002m
Predicted GPS distance= 0.000000m
```

Here the GPS shows no distance because as stated we were in complete indoor environment. But here again our fusion algorithm adjusted and this time it preferred the accelerometer results and final result of 7.8m was almost perfect (actual was 9m).

The route predicted in this case is shown below:



As it is visible, the distance was approximately well estimated and there is a slight variation of 0.03 meters in opposite axis. This is a very small error. The estimated results are fairly accurate here. Let's discuss fourth experiment.

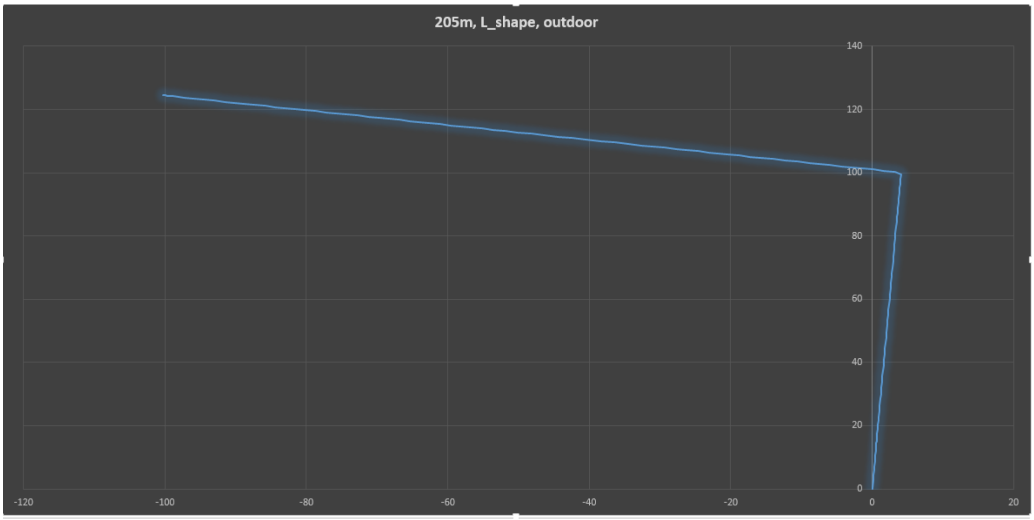
Experiment-4: 33m, L shape, outdoor

In this case, our actual distance was 205m in outdoor environment but our trajectory was L-shaped. In this region we could receive the GPS signals clearly because of outdoor environment. Our algorithm produced the following result:

```
Overall Predicted distance= 207.007156m
Predicted Acc distance= 153.300797m
Predicted GPS distance= 207.260468m
```

Here the accelerometer displayed error (150m vs 205m actual) as it is relatively longer distance. As it was completely outdoor, GPS signals were correct, but here again our fusion algorithm adjusted and this time it preferred the GPS results more (not completely) and final result of 207m was almost perfect (actual was 205m).

The route predicted in this case is shown below:



As it is visible, the distance was approximately well estimated and trajectory is almost L shapped but have clockwise shift. This is a marginal error in trajectory. The estimated distance and trajectory still give fairly accurate result here as well. Let's discuss fifth experiment.

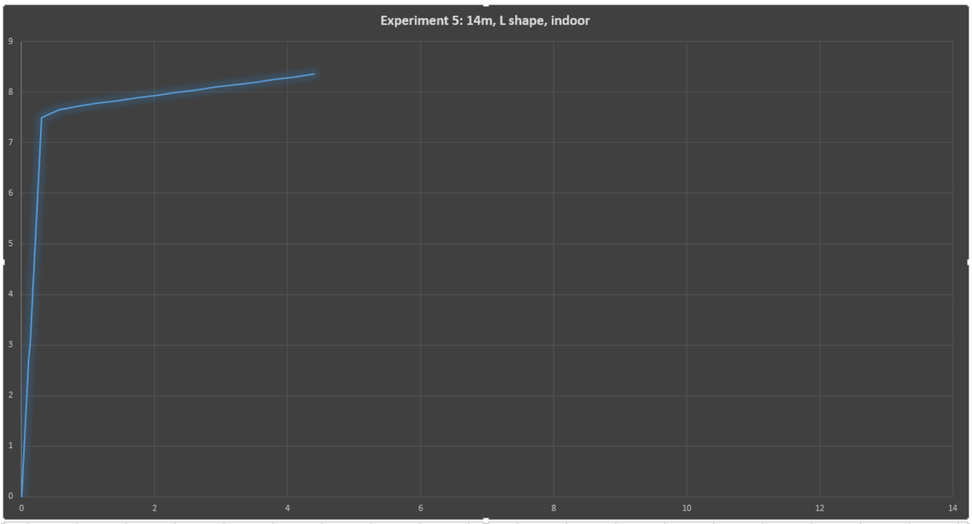
Experiement-5: 14m, L shape, indoor

In this case, our actual distance was 14m in completely indoor environment but our trajectory was L-shaped. In this region we could not receive the GPS signals of totally indoor environment. Our algorithm produced the following result:

```
Overall Predicted distance= 12.300005m
Predicted Acc distance= 12.300005m
Predicted GPS distance= 0.000000m
```

Here the GPS shows no distance because as stated we were in complete indoor environment. But here again our fusion algorithm adjusted and this time it preferred the accelerometer results and final result of 12.3m was almost perfect (actual was 14m).

The route predicted in this case is shown below:



As it is visible, the distance was approximately well estimated and trajectory is almost L shapped but have counterclockwise shift. This is a marginal error in trajectory. The estimated distance and trajectory still give fairly accurate result here as well. Let's discuss sixth experiment.

Experiment-6: Indoor with known WiFi AP

In this experiment, we tested by keeping an indoor AP as a reference for known AP which can be used to find the positioning through our Project_1 WiFi positioning model.

In our experiment, we moved near that AP to observe if our application detects it and if the power level is within the required threshold of positioning.

```
Known Wifi AP within threshold power level is detected, can use project-1 algo to find positioning with Inertial sensors. wifi_power_level =-43.000000

Overall Predicted distance= 16.800005m
Predicted Acc distance= 16.800005m
Predicted GPS distance= 0.000000m
```

As shown below, it can be observed that our application detected at around 7s from the start time and it indicated this to processing unit that this power level (-43dBm) is within threshold to be used for the evaluation of positioning in a completely indoor environment.

Here also, as you can see, the GPS has no measurements since we are in completely indoor with good WiFi strength received. Meantime, accelerometer did predicted its estimation of distance which can be fused with WiFi model.

12. Observations and Remarks

The key observations from the results in this project are:

a) For every 15m, on average accelerometer step counter gives an error of 1m.

b) In longer distances, accelerometer gets more and more inaccurate with step counter

c) It is compensated by the GPS in outdoor but in indoor the WiFi positioning isn't as accurate as GPS, so in indoor, longer distances are less reliable.

d) Magnetometer is very sensitive to relative motion of device with the body which needs to be modeled with detailed experiments and with different human beings

e) Gyrometer is highly sensitive and gives clear indication of angular direction even with slower speeds. This is helpful in fusion algorithm.

13. Limitations of Proposed Model

The proposed model has following limitations

a) The current implementation is limited and valid with the horizontal plane placement of the mobile device

b) This model is not perfect in removing the noise from INS. The current implementation implements only averaging at this time.

c) Because of limited time and scope, current algorithm couldn't model lot of humans' data which will improve much better modeling in future if implemented with different humans.

14. Future Variations

Following are the few future recommendations regarding our proposed model:

a) The noise can be filtered from the data
b) The magnetometer can be modeled more accurately with recording from multiple humans
c) Can be extended for any position of mobile device in a generic manner.

15. Conclusion

In this report, we discussed the literature background of widely known positioning sensors. We presented our model specifications and validity. We presented the experimental details and setup. Following on, we described our timeline of the project and what challenges we experienced. The solutions for those challenges especially for the processing of the huge amount of data. We proposed the solutions for these challenges. We presented our proposed algorithm and displayed results indicating the performance of our approach especially different transition environments. At the end, we commented on the results and discussed few limitations in our approach and what future modifications can be employed to enhance performance.

16. Software Tools

Alongside this report, we are attaching the software tools we used during this project and which can be used by another user.

16.1 Excel files (ACC, GYR, MAG, GPS, WIFI)

Our software code automatically extracts the sensor data from the log file and provide separate auto-generated Excel files for each sensor for better analysis.

16.2 Excel files (XY Data)

Our software code automatically produces the predicted XY positions at different stamps in auto-generated file after applying fusion algorithm.

16.3 C++ (Fusion_Project)

This is our software implementation of the whole project. It's a simple one-click automated code. It just takes the "Sensor Fusion" application log file as an input and does everything from that point on its own, and by applying algorithm, it automatically generates the estimated positions of the user at different timestamps.