FLOOR LOCALIZATION WITHOUT CALIBRATION OR ADDED INFRASTRUCTURE

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Main Idea

- A fundamental goal of indoor localization technology is to achieve the milestone of combining **minimal cost** with **accuracy** sufficient enough for general consumer applications.
- In this presentation, we will explain a Wi-fi-based indoor localization system for multi-story buildings. The System presents a method for **simultaneously** mapping the signal environment to **get signal positions** and **positioning** one or several users from offline data in multi-story environments without requiring any calibration or added Infrastructure.
- It is an **inexpensive** solution with **minimum set-up** and maintenance expenses, is scalable, and **robust to environmental changes**.
- This approach lends itself well for **crowdsourcing future data.**

Main Idea (cont'd)

- Our goal is to build an **objective function** F to **minimize**, where the arguments to the objective function include **scan positions**, **access point positions** and access point parameters, As a result locating scan positions, access point positions and parameters simultaneously.
- We will use the barometer to get pressure value which exist in many devices to get an initial estimate of the floor number, Also we will estimate the initial scan positions with the GPS readings, At end we will initialize the APs positions with the scan position in which that AP is strongly heard.
- Now, we have initial values for our arguments and an objective function to be minimized. After finishing the optimization phase we will have the best arguments values which can be used to localize the user device for later scans.
- So that is the main idea, Now lets discuss the optimization phase in details.

Process Steps

1. Collecting data from sensors.
2. Filtering the collected data.
3. Building the optimization problem with the initial values.
4. Solving the optimization problem and get the optimal argument values.
5. Using the APs locations to estimate the floor of later scans.

1. Collecting data

- Collect data which represent the visible APs with their RSS values, pressure value from the barometer, scan GPS readings, ... etc.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
scanId	type	scantime	gpsvalid	gpslatitude	gpslongitude	gpsaccuracy	gpsage	bssid	ssid	rssi	wifilatitud	wifilongit	wifiaccura	cpslat	cpslon	cpsacc
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	84:b5:9c:e	LU weblog	-73	55.71102	13.21021	24	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	84:b5:9c:e	eduroam	-73	55.71102	13.21021	26	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	84:b5:9c:e	LND_INTR	-74	55.71102	13.21021	25	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	00:0b:0e:f	eduroam	-77	55.71088	13.21035	23	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	78:19:f7:7	LND_INTR	-79	55.71123	13.20998	23	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	84:b5:9c:e	LU weblog	-79	55.71099	13.21023	16	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	00:0b:0e:f	LND_INTR	-79	55.71089	13.21036	27	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	ac:7f:3e:e	UA-WiFi (	-80	55.71108	13.20999	20	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	28:8a:1c:f	LND_INTR	-80	55.71096	13.21	28	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	28:8a:1c:f	eduroam	-80	55.71095	13.21001	26	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	28:8a:1c:f	LU weblog	-80	55.71096	13.21001	27	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	78:19:f7:7	eduroam	-80	55.71125	13.20998	22	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	78:19:f7:7	LU weblog	-81	55.71122	13.20998	22	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	00:0b:0e:f	LU weblog	-82	55.71089	13.21037	23	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	a8:d0:e5:3	eduroam	-82	55.71088	13.20992	21	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	84:b5:9c:e	LND_INTR	-83	55.71101	13.21025	17	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	b4:75:0e:c	tonet7	-84	55.71084	13.20964	52	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	ac:a3:1e:d	eduroam	-84	55.71127	13.20963	20	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	28:8a:1c:f	LU weblog	-84	55.71094	13.21009	16	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	ac:a3:1e:d	scutb	-85	55.7111	13.20968	20	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	ac:a3:1e:d	LU weblog	-85	55.71126	13.20964	19	55.71102	13.20989	52
5725538	wifi	2/9/2016 12:34	1	55.71102706	13.20977956	3	0	84:b5:9c:e	eduroam	-85	55.71099	13.21021	16	55.71102	13.20989	52

1. Collecting data (cont'd)

R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
wifiId/blu	scannerId	wifiIndoo	freq	gpsaltitud	floor	btAge	clLat	clLon	clAcc	pressure	nbrofStep	refpointLa	refpointLo	slamFloor	indoorWi	indoorWi	indoorWifiAccuracy	
4.53E+08	1	0	5220	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.53E+08	1	0	5220	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.53E+08	1	0	5220	106			55.71053	13.20749	68	980.96	0	0	0	1				
45502280	1	0	2412	106			55.71053	13.20749	68	980.96	0	0	0	1				
3.95E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.53E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				
3.95E+08	1	0	2412	106			55.71053	13.20749	68	980.96	0	0	0	1				
3.95E+08	1	0	2462	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.52E+08	1	0	5300	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.52E+08	1	0	5300	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.52E+08	1	0	5300	106			55.71053	13.20749	68	980.96	0	0	0	1				
2.16E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				
3.95E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.07E+08	1	0	2412	106			55.71053	13.20749	68	980.96	0	0	0	1				
1.94E+08	1	1	2412	106	0		55.71053	13.20749	68	980.96	0	0	0	1	55.71107	13.20975	0	
4.53E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				
6.96E+08	1	0	2412	106			55.71053	13.20749	68	980.96	0	0	0	1				
6.87E+08	1	0	5580	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.52E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				
7.67E+08	1	0	5580	106			55.71053	13.20749	68	980.96	0	0	0	1				
6.87E+08	1	0	5580	106			55.71053	13.20749	68	980.96	0	0	0	1				
4.53E+08	1	0	2437	106			55.71053	13.20749	68	980.96	0	0	0	1				

2. Filtering data

- Access points scanned less than 5 times are removed from the APs list, As they could be outside the building or smart devices set to work as access points.
- Scans with less than 3 visible APs are filtered out from the data to not affect the optimization problem badly.

3. Building the optimization problem

- Let scan 3D position is Sj and AP position is Tj, Then we have

$$\mathbf{s}_j = [s_{x,j} s_{y,j} s_{z,j}]^T \qquad \mathbf{t}_i = [t_{x,i} t_{y,i} t_{z,i}]^T$$

- Our target function consist of many terms, each terms is responsible of part in estimating the positions correctly.

$$F = F_{pow} + \lambda_1 F_{GPS} + \lambda_2 F_{acc} + \lambda_3 F_{\Delta},$$

where λ1, λ2, λ3 are scaling parameters > 0 that determines how important each part is in the target function.

- Lets discuss every term in the target function in details.

3.1 Building the optimization problem – Fpow term

- How to calculate ?
  1. For every scan **Si** which heard some APs called **Tj** , we calculate the distance between the two positions by

$$d_{ij} = \sqrt{(\mathbf{s}_j - \mathbf{t}_i)^T(\mathbf{s}_j - \mathbf{t}_i)}.$$

  2. Calculate the estimate RSS from the loss model by knowing the distance from step 1.

$$P_{ij} = C_i - 10\gamma_i \log_{10}(d_{ij}) + n_{ij}C_{floor} + X_{ij}$$

     - Ci is the measured power at one meter from an access point (-37dB)
     - γi is the path loss exponent which depends on the environment whether outdoor or indoor (2.5)
     - nij is the number of floors separating access point i and scan j,
     - Cfloor is the floor dampening constant for passing through one floor (-15dbm)

  3. Our target is to minimize the squared residuals between actual RSS values and estimate RSS values for all APs.

- What is its role?
  - **When we minimize the squared residuals between actual RSS values and estimate RSS values for all Aps then that means we have calculated the distance between the APs and the scans in the best way.**

3.2 Building the optimization problem – Fgps term

- How to calculate ?

$$F_{GPS} = \sum_{j \in J_{GPS}} \frac{1}{\lambda_j} \left(\mathbf{g}_j - [s_{x,j} s_{y,j}]\right)^T \left(\mathbf{g}_j - [s_{x,j} s_{y,j}]\right)$$

where gj represent the GPS readings of the scan number j, And λj is the accuracy in meters for the horizontal plane.

- What is its role?
  - To ensure that GPS 2D position is not so far from the source position to make sure that we go in the correct direction of estimating the scan position.

3.3 Building the optimization problem – Facc term

- The time stamps of each scan is also available, as well as the ID of the receiver. It is reasonable to assume that receiver positions pertaining to the same device, close in time, should be close spatially. Let j = {j1 j2 j3} be a set of three scan indices that comes from the same receiver device, and has the three indices consecutively in time, and less than ten seconds apart. Let Jacc be the set of all such triplets j.

$$F_{acc} = \sum_{\mathbf{j} \in J_{acc}} (\mathbf{s}_{j_1} - 2\mathbf{s}_{j_2} + \mathbf{s}_{j_3})^T (\mathbf{s}_{j_1} - 2\mathbf{s}_{j_2} + \mathbf{s}_{j_3})$$

- What is its role?
  - To prevent possible jumps in the consecutive scans due to estimating their positions wrongly.

3.4 Building the optimization problem – FΔ term

- In real situations floor changes often at the same 2D position, assuming a fixed place for the staircases or elevators, So we will make use of that situation.
  - Let j1,j2 be a indices of a pair of consecutive scans from the same user that have different z-coordinates, and JΔ be the set containing all the pairs of such scan indices.
  - f(·) is a identity function if [sx,j1sy,j1] are within 15m of [sx,j2sy,j2], and constant 0 otherwise

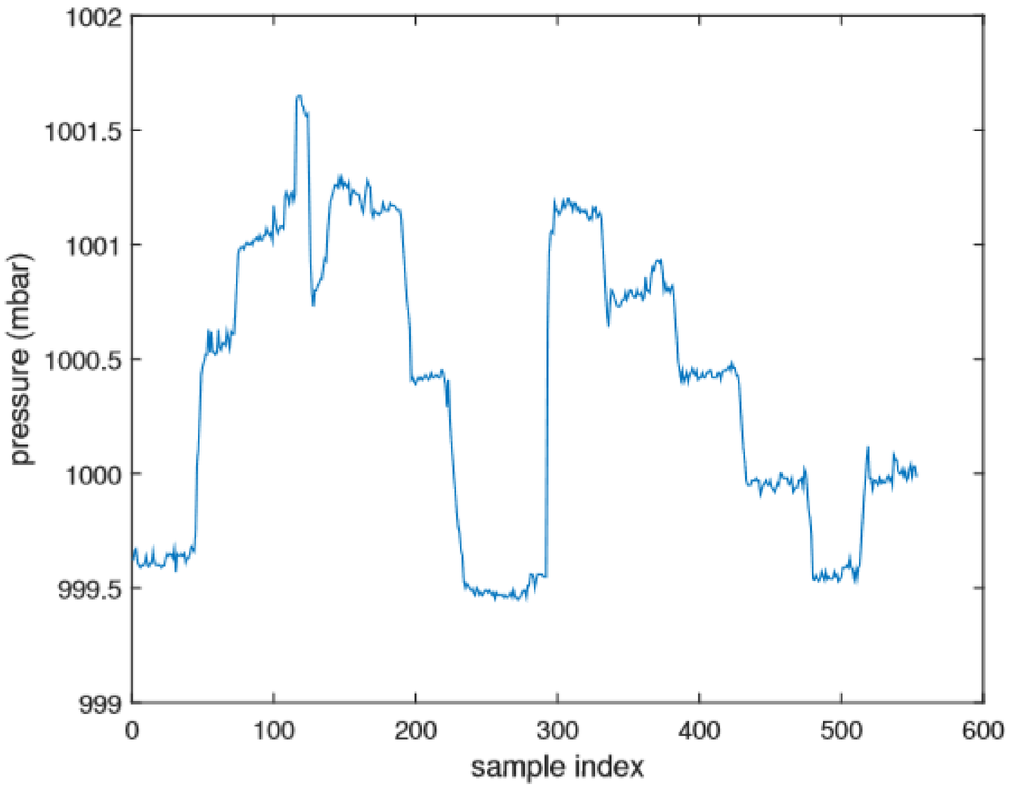
$$F_\Delta = \sum_{j_1, j_2 \in J_\Delta} f\left(\left(\mathbf{s}_{xy,j_1} - \mathbf{s}_{xy,j_2}\right)^T \left(\mathbf{s}_{xy,j_1} - \mathbf{s}_{xy,j_2}\right)\right)$$

- What is its role?
  - To prevent possible jumps in the positions when changing floor Up/Down.

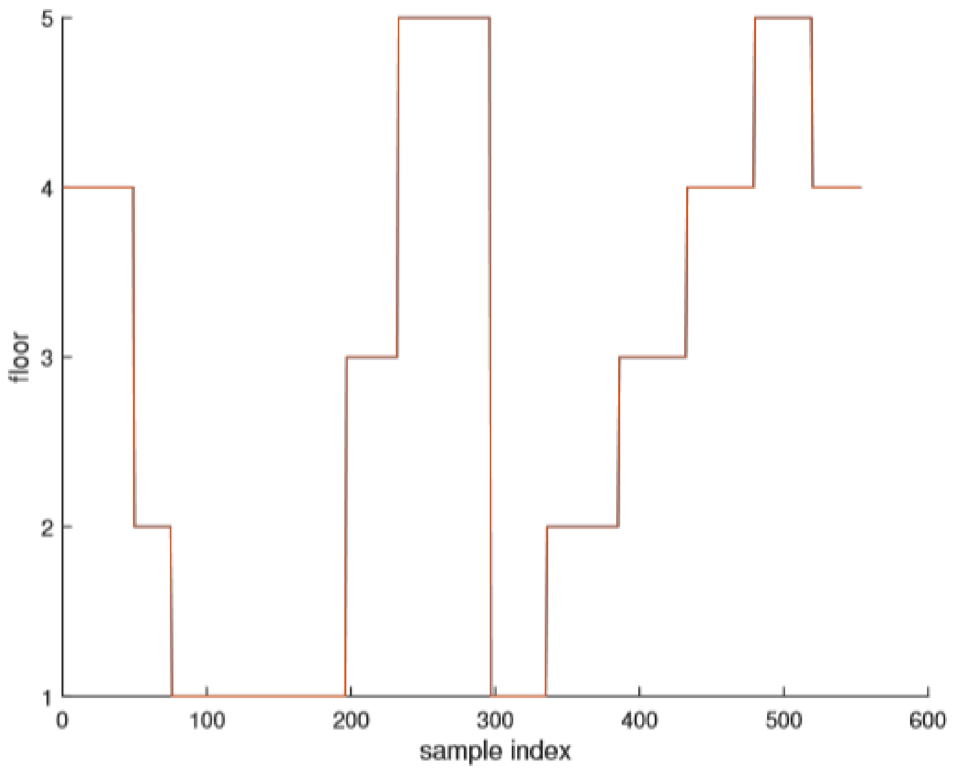
3.5 Building the optimization problem – Target Function

2. Optimization scheme
   - We get the overall objective function $F = F_{pow} + \lambda_1 F_{GPS} + \lambda_2 F_{acc} + \lambda_3 F_{\Delta},$
     where λ1, λ2, λ3 are scaling parameters > 0 that determines how important each part is in the target function.
   - By solving this optimization scheme we get all the positions and parameters, but it remains to find good initializations for x, y, z positions.
     - For **x and y** we can get good initialize for them from **gps readings** stored in the database.
     - For **z (Floor)** we will use the smartphone **pressure sensor "barometer".**
       - **Air pressure can not be used to explicitly determine exact height but It is possible to study the change in air pressure to try and determine when a floor change takes place.**
       - The pressure signal is convolved with the derivative of a Gaussian kernel to detect strong changes in pressure to detect the floor change.
       - **Note that user must enter the starting floor number in the beginning of the session. So we can trace after it by the air pressure change and detect the floor estimate**.

Relationship between air pressure and change in height



(a) Pressure data from consecutive scans



(b) Ground truth floors for consecutive scans

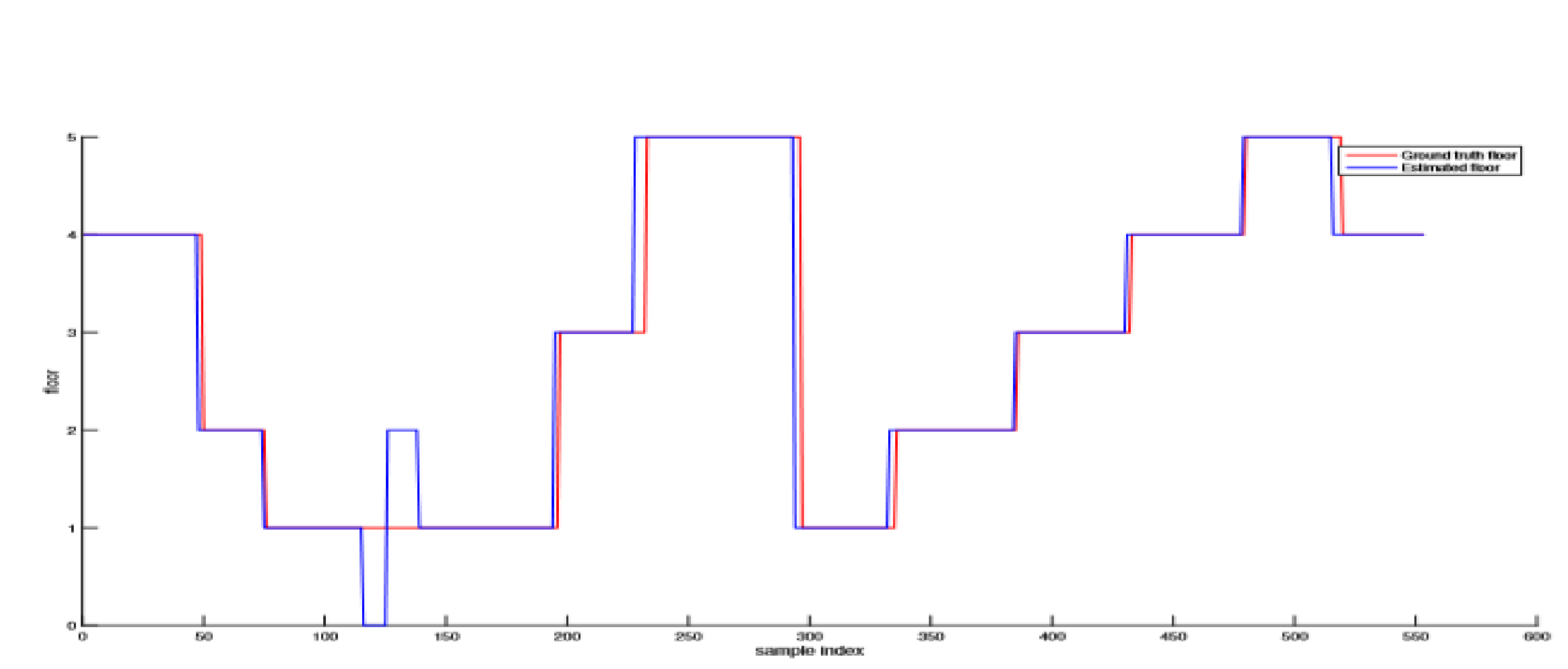
How to get floor estimate form pressure data?

- We assume the spacing between each floor h, is uniform in each separate building. Then we determine its value from the difference in heights by solving

$$h^* = \underset{h \in [2.5\ \ 5]}{\operatorname{argmin}} \sum \left| d_i - round(d_i/h) \cdot h \right| .$$

- Once the floor spacing has been estimated, every difference in height is discretized into a number of floor changes and we can know what is the current floor value.

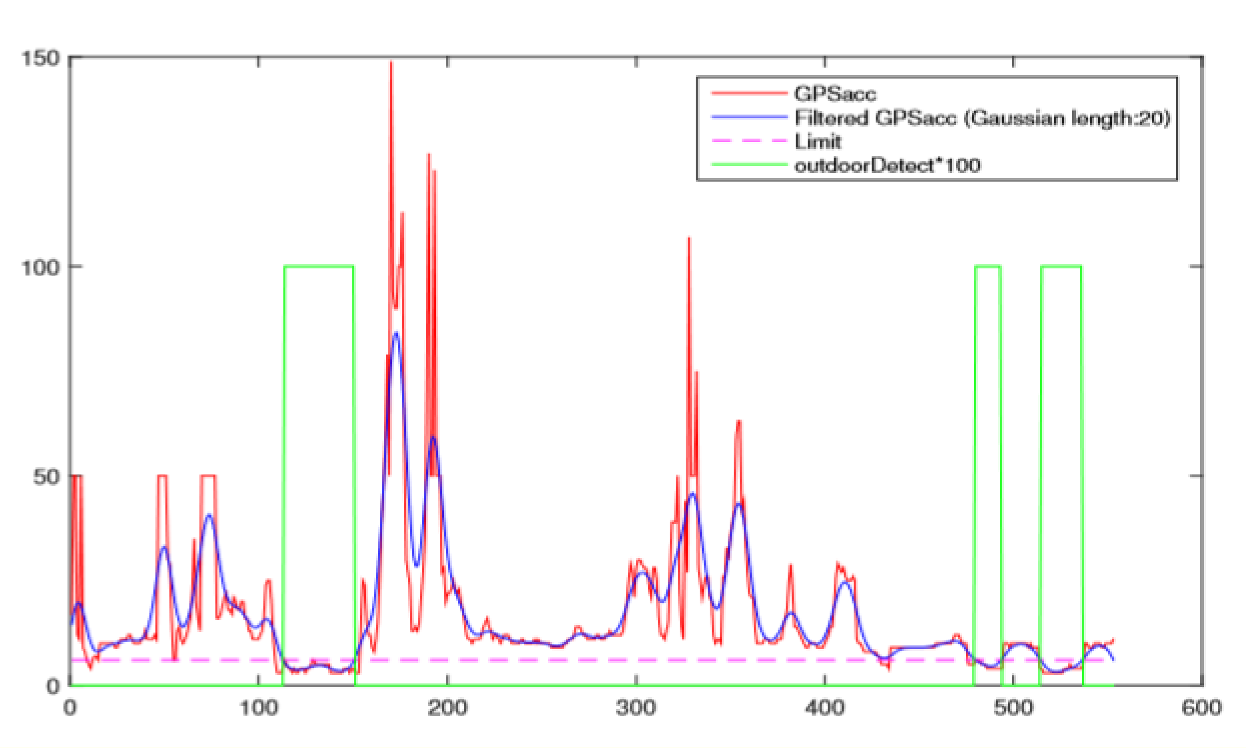
Floor Estimate Error



- There is a faulty detection at sample indices 120-130. The user went outside for some time which led to noise in the signal. The noise might have come from the doors opening and closing, wind outside, uneven ground or other sources. Whatever the cause in this case, we have found that outdoor pressure readings generally contain a lot more noise than indoor readings. I

How to improve Floor Estimate

- To reduce error occurred we should disregard all pressure changes that take place while outdoor to avoid large pressure changes and the winds.
- To determine when the user is outdoors we can use the GPS signal which has a strong connection outdoors as the receiver has LOS or a multipath component to the GPS satellites, So GPS accuracy is improved when outdoors.



To Summarize the process

- we make iteration over floor detection and optimization scheme.
  - So we can list all the steps:
    1. Use pressure sensor where available to get a floor estimate using the methods.
    2. Optimize over all positions and access point parameters using the estimated floors and the methods of optimization.
    3. For each floor, check for 5x5m2 tiles where scans are similar to each other inside the tiles. These tiles will become representative of that floor, So we can predict which floor a new scan will lie probably.
    4. For each interval of scans, each scan in that interval will compare how similar it is to each tile. If similar enough, it will cast a vote for that tile, and by that cast a vote to which floor it belongs to.
    5. Majority vote determines which floor each interval belongs to. This gives what floor each scan belongs to.
    6. Floors of access points are set to the same as the floor of the scan with the strongest RSSI value to it.

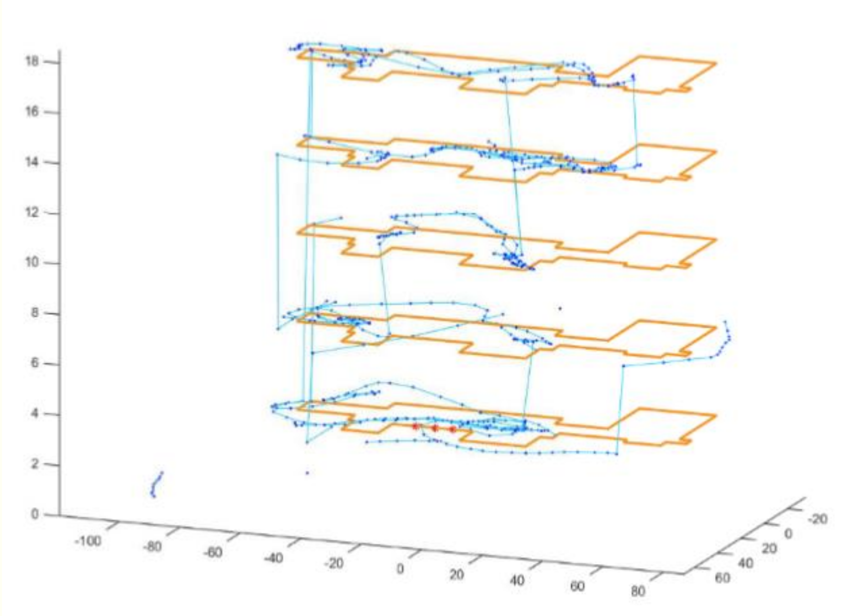
    Notice that Steps 2-6 are iterated until convergence.

Results

- Testing the system on two Multi-story building and achieving the following results

Building	Corrected Floor scans	Ratio
M.C	2913/3070	94.7%
E-house	2706/2770	97.7%

- Using the system for tracking it achieved well on Multi-story buildings.



Implementation

- We didn't find the implementation of the system online, So we implemented it, As calibration Free system is very commonly to use to adapt with the environmental changes.
- We try to use **Pulp library in python** but ended up with bad results as the results are integers and far away from our target real x and y coordinate.
- Then we achieved our goals using **Scipy library in python** and some preprocessing.
- **You can see all files including source code and data files from here.**
- **Also you are welcomed to run and test the code on colab form here.**

ANY QUESTIONS ?
THANK YOU