NA 568 - Mobile Robotics Group 23 Project Proposal

William Cohen, Hannah Denomme, Samuel Gonzalez, Shubham Patil, Ruifeng Xu

We propose to perform localization and mapping of a drone in an indoor environment using IMU and relative WiFi signal strength (RSS) sensor measurements. The novelty of our project stems from generating a 3D point cloud of RSS signal strength that is unique to the drone's surroundings. This map of landmarks will be used to correct the integration of IMU data yielding a better estimate of robot location than solely relying on the RSS and IMU data alone.

To achieve this, we will process the IMU data with an invariant extended kalman filter and correct it against the RSS measurement and a model that uses the inverse square strength of the "distance" between the drone and the known global location of our WiFi router. When our measured RSS value disagrees with the model within a given tolerance, a landmark will be recorded in a point-cloud map and a particle filter will be run over it to estimate the most probable location of the drone. This estimate will then be used to correct for drift in the IMU.

In short:

1. <Agreement between model and RSS – No particle filter> Use beacon-range correction, based on known global location of WiFi, in IEKF (localize)
2. <Disagreement between model and RSS – No particle filter> Use last known position + integration of IMU to provide new map location and RSS value (update map)
3. <Agreement between model and RSS – Particle filter> No change
4. <Disagreement between model and RSS – Particle filter> Use particle filter (MAP estimator) to localize position based on time-series of last measured RSS values

To validate our theory we will generate a virtual indoor environment using the programs available from the DeepLocNet paper [2]. A virtual drone running our algorithm will then be flown over the map where we can fine tune its parameters as needed and assess its performance with RSS mapping turned on and off. Next we will test our algorithm in the real world using a Crazyflie 2.1 and a payload consisting of an ESP8266 wifi module connected to a MPU6050 IMU. The builtin Crazyflie AHRS utilizes multiple sensors to correct for error and its measurements will serve as the ground truth position of the drone. We will run our algorithm on the payload and compare it to the ground truth measurements.

[1] P. Kabamba and A. Girard, "Navigation," in *Fundamentals of Aerospace Navigation and guidance*, Cambridge University Press, 2014, pp. 78–112.

[2] K. N. McGuire, C. De Wagter, K. Tuyls, H. J. Kappen, and G. C. de Croon, "Minimal navigation solution for a swarm of tiny flying robots to explore an unknown environment," *Science Robotics*, vol. 4, no. 35, 2019.

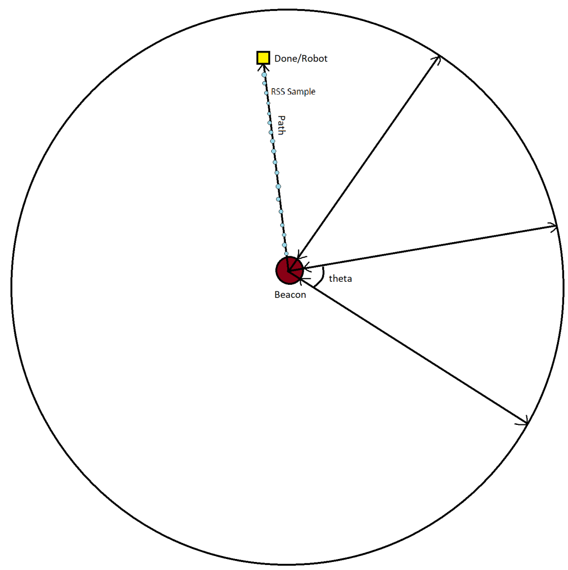
[3] S. S. Dhanjal, M. Ghaffari, and R. M. Eustice, "DeepLocNet: Deep observation classification and ranging bias regression for radio positioning systems," *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2019.

Using a known distance to a beacon to improve localization has been well studied[1]. This works well in situations where the model for estimating distance from a beacon is accurate and is well defined, such as in GPS triangulation. Generating a model for how the signal of a beacon falls off is not always feasible or may require extensive computation that makes it not suitable for real-time localization. Specifically accurately modeling how WiFi signal strength propagates through a room cannot be achieved by only using the inverse square law because the signal can reflect off of walls or be occluded by obstructions in the room. InsThe propagation of a WiFi signal can be reasonably modeled
In order to accurately estimate the propagation of a WiFi signal in an indoor environment can be achieved by using stochastic processes such as of the motley keen path loss algorithm can when estimating a

Sam Notes:

Intuition is that IMU is prone to drift while dead reckoning. Assuming that the signal density of a 3D point in space is relatively constant it can be used to correct the drift in the IMU measurements. This algorithm can be used to improve the position estimation of robots in home environments using existing wifi signals (people don't move their routers or change the geometry of their house often). It may also be extended by adding multiple beacons. Limitations of the algorithm is that we don't account for dynamic signals such as interference from electronic devices, microwaves, etc. Could be mitigated by using a moving average of RSS sample signal strength over time

1. Use the wifi beacon as the origin and build up a map of RSS by traveling along a straight line away from the beacon. IMU dead reckoning along with gradient of signal can be used to infer distance to beacon. (The gradient should help account for drift moving away from the beacon). Once a desired distance has been reached, turn around and follow the path back to the beacon. RSS values of the return path can be averaged with previous values.
2. Rotate the drone by theta and repeat step 1 following another ray reaching out from the origin. (In this step we only can use the IMU measurements. This shouldn't be too big of an issue for small theta because there won't be that much accumulated error)
3. Repeat steps 1&2 until a sufficiently dense point cloud is generated
4. Use a particle filter on the RSS point cloud to estimate the location of the robot. This can be combined with the IMU data to correct for drift.
5. Evaluate the algorithm by instructing the robot to move to another location and comparing its estimated location to its ground truth location.
6. Compare the results of using only the IMU and IMU with RSS.



Done/Robot
RSS Sample
Path
theta
Beacon

References:

Papers:

1. https://www.science.org/doi/pdf/10.1126/scirobotics.aaw9710?casa_token=Yq9e0024IiMAAAAA:9Um1UVdeuUgdcRQ55gIXtng0DqyrYMGhbqwtpWrrUJoVq-2-OrwJzJcv2x4dk3k3R6tK78Xrj6d7
2. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5152728
3. https://link.springer.com/content/pdf/10.1007/s10514-013-9356-x.pdf
4. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6225059
5. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9107480
6. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9155463
7.

Simulation Software:

ROS: https://www.ros.org/

Keywords:

RSS (Relative Signal Strength)
Backscatter (w.r.t. WiFi/Navigation)

Things to do:

1. Research on type of noise model for WiFi
2. Learn about ROS

Brainstorm Idea (Send to Professor)

Use Wifi Signal strength for localization/mapping:

- Inspired by SGBA paper that uses gradient of wifi signal strength (RSS) gradient to return to connected area when drones fly out of range
- Objective: Demo the algorithm running on a real drone. (We have access to one)
- Technical Approach: Combine particle filtering of RSS data with IKF of IMU data. Will use ROS simulator to develop algorithm before running on hardware
- Novelty: Need to read up more on backscatter
- Expected Outcomes: We expect to get better localization results when combining wifi RSS data with IMU data

Will’s Thoughts

Process looks like:

1. Measure IMU + Wifi Signal Strength
2. Transmit packet <IMU, WiFi>
3. Prediction with IMU data (IEKF)
4. Correction with Wifi Data
    a. Does this need a particle filter? If we have an appropriate model, we should be able to approx distance with just the signal strength
    b. Extension with non-homogenous signal strength could require use of particle filter/map
5. (Stretch?) Use IEKF IMU localization (with camera?) to map WiFi signal strength of existing area, then use map to navigate -> This could provide some of our “**Novelty**” as the mapping in the original paper was focused on image data and only used the signal strength to descend towards areas with higher signals to return “home”
6. (Stretch) Visual tracking at low refresh rate so we have 2 correction models for relative position while in-view of the base station. This could be feasible as there should be a model, based on my interpretation of the paper, that is designed to recognize crazyflies in images

Notes:

1. The movement along straight lines may not be necessary, as we can have a rough calibration of the wifi strength v. distance by taking ~ 50 measurements in concentric circles by hand. We could measure each point and calibrate the distance that way
2. It is possible with the above calibration that we find the signal is non-circular, which may require use of a more complicated method to localize based on the signal strength (particle filter or something else)