RF-based positioning for Unmanned Autonomous Vehicles

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Contents

1 Project Goals

- Investigate different RF technologies for positioning and evaluate their pros and cons, e.g. WiFi, UWB, BLE, etc.
- Implement an RF based range measurement method
- Compare range measurement using RSSI (Received Signal Strength Indication) and RTT (Round Trip Time)
- Implement a Bayesian filter for positioning using aforementioned range measurement(s)

2 RF-based positioning

RF (radio frequency) based positioning problem is concerned with inferring agent/robot position in space from distance measurements to a number of known static or dynamic beacons/landmarks. For instance, in three dimensional case position can be computed by having at least three distance measurements. Technique for doing this is called multilateration.

The chapter is divided in a following way: first describing general methods of measuring distance between two RF devices/antennas, secondly investigating existing protocols making measurements and lastly selecting an algorithm to iteratively compute and track position of a robot over time.

Requirements for application:

- Ranging max distance - at least 100 meters.

2.1 Range measurement methods

Literature points out two main methods for making distance measurements over RF antennas: RSSI (Received Signal Strength Indication) and time based methods.

2.1.1 RSSI

As the name suggests the received signal strength hints at the power of incoming radio signal. There is non-linear corelation between RSSI and distance between two antennas thus it is possible, for instance, to fit a curve on a measured experimental values. However, the main disadvantage that for commercial protocols the quantity over distance curve flattens out at certain distance and further it's impossible to tell the a difference between different measurements. Due to this limitation the method is not suitable according to application requirements thus later comparison of available RF technologies for positioning will focus mainly on time based methods.

2.1.2 Time based

These methods are based on measuring radio wave propagation time between (or ToF - *Time of Flight*) antennas/devices and calculating the distance by knowing light speed i.e. $d = ct$, where $c = 10e-8$ m/s. One obvious drawback here is that two clock must be synchronized if to infer the distance by ToA (*Time of Arrival*). However, this can be avoided by doing a round trip (in literature referred as TDoA - *Time Difference of Arrival*) and relying solely on one clock. The scheme is illustrated in 1 where T_{prop} is propagation time in which we are interested in for ranging applications. The value can be computed by $T_{prop} = \frac{1}{2}(T_{round} - T_{reply})$. Also, Figure 1 correctly indicates the scale of T_{round} and T_{prop}. Important thing to notice here, if the distances we're measuring are in order of meters, $T_{prop} = d/c$ evaluates to nanosecond scale while for response computer might have to execute hundreds of instructions taking up way more time than the time we're interested in. Thus it's of most importance to know how much time computation takes in the responding device. When selecting/designing a system to use RTT for positioning, responding device must have very

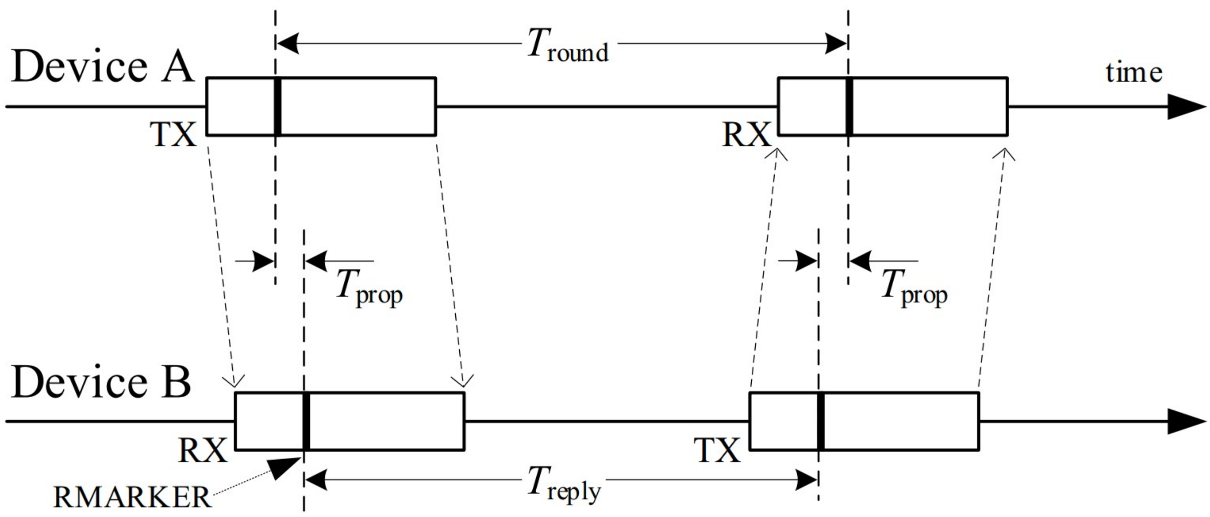

Figure 1: Round trip time.

fine granularity control of computing resources. If one would try to make these computations on OS (Operating system) level, the time jitter introduced by OS scheduling system would be so large that propagation time would vanish in the error of T_{reply} measurement.

2.2 Comparison of RF technologies for positioning

There are many existing protocols/technologies to exchange data between devices over the air i.e. by transmitting it over electromagnetic waves. In this chapter, a few of most popular ones will be reviewed in terms of how suitable each of them is for positioning applications. Namely, paper investigates WiFi, UWB (Ultra Wide Band) and BLE (Bluetooth Low Energy) protocols.

2.2.1 WiFi

FTM RTT: RTT could be obtained by FTM protocol but is difficult to obtain bc hardware support is very limited. Even then requires quite a bit of effort to install required driver, firmaware, kernel version. The distance measurement is not that precise. Best case scenario gives 1-2m accuracy which is nice but more crude estimation would also work.

Positioning base on WiFi signal strength is way easier. Basically could be implemented with any WiFi card without spending additional time on setup. Accuracy is worse 10m. But meets the requirements and prob is worth trying first before going to alternatives. Turns out that the distance to signal curve flattens out at around 20m and cannot measure distances beyond that...

So wifi frequency is max 80MHz which in time based methods alone results in max theoretical distance resolution of 3.5m of time based methods.

2.2.2 BLE

Easily available but no support for precision time stamping...

2.2.3 UWB

How does UWB solve time stamping? THis is very well defined in the official standard 802154z-2020, read the pdf and do a summary.

2.3 Position from distance measurement

However, solution (from 3 beacons) is not unique and adding fourth one allows to come up with a distinctive robot position easier.

3 Implementation

Practical implementation consists of applying EKF for estimation of 3D position in space, writing a simulation to validate the filter implementation, tuning KF parameters (mainly evaluating covariances) by real-world experiments, testing out whole system and evaluating localization accuracy.

3.1 Localization

Describing EKF in detail. Show some code from implementation.

3.2 Simulation experiments

Plots, plots, plots. Noise description?

3.3 Real-world experiments

First, it's important to address the assumption made in the simulation environment. It was assumed that sensor measurement variance is known. For filter to have good convergence properties we would like to know it up to a reasonable accuracy level when in operation. Therefore, the first experiment was conducted to measure the precision of UWB range measurements compared to a ground truth. DTU ASTA's Opticon system was used to generate ground truth labels (limited to 10m range) and two UWB devices, one configured as a tag and another one as an anchor. During the experiment anchor was moved to different position around the track, ground truth distance calculated between devices by taking norm of two position from Opticon and corresponding measurement by the means of UWB antennas was recorded. Figure 3 shows the probability distributions of measured values by real-world experiments in blue and the ground truth in orange.

Looking at the plots one noticeable thing is that mean value of measured values are shifted to the right - meaning sensor gives out bigger distance than it actually is, this could

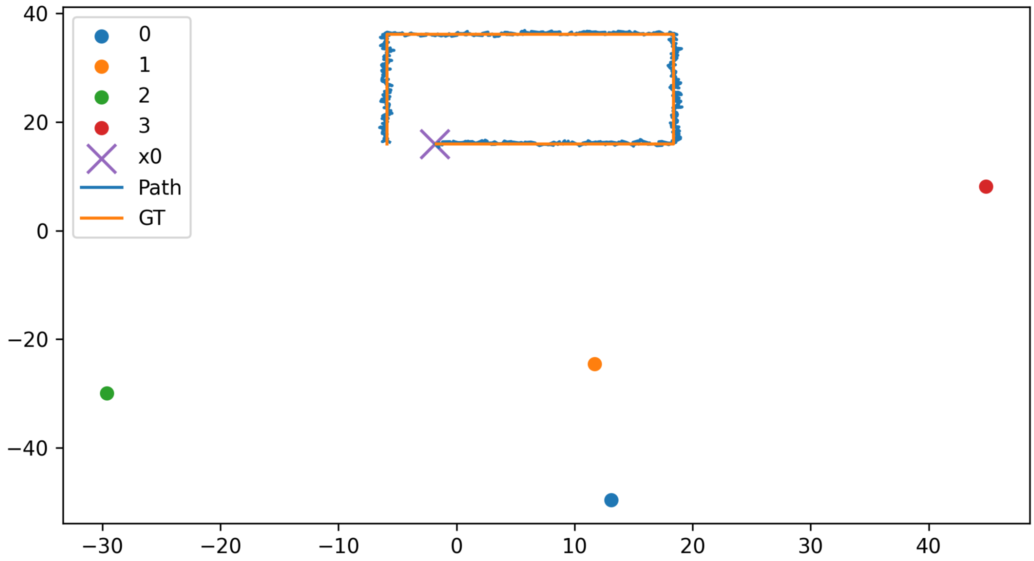

Figure 2: Simulation

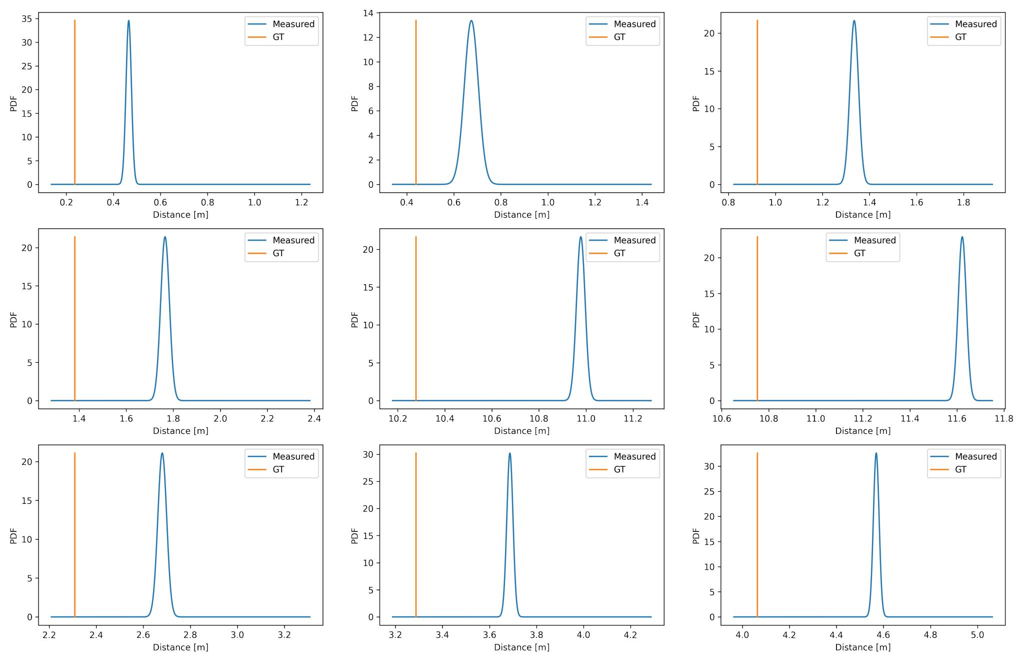

Figure 3: Distance measurements PDFs.

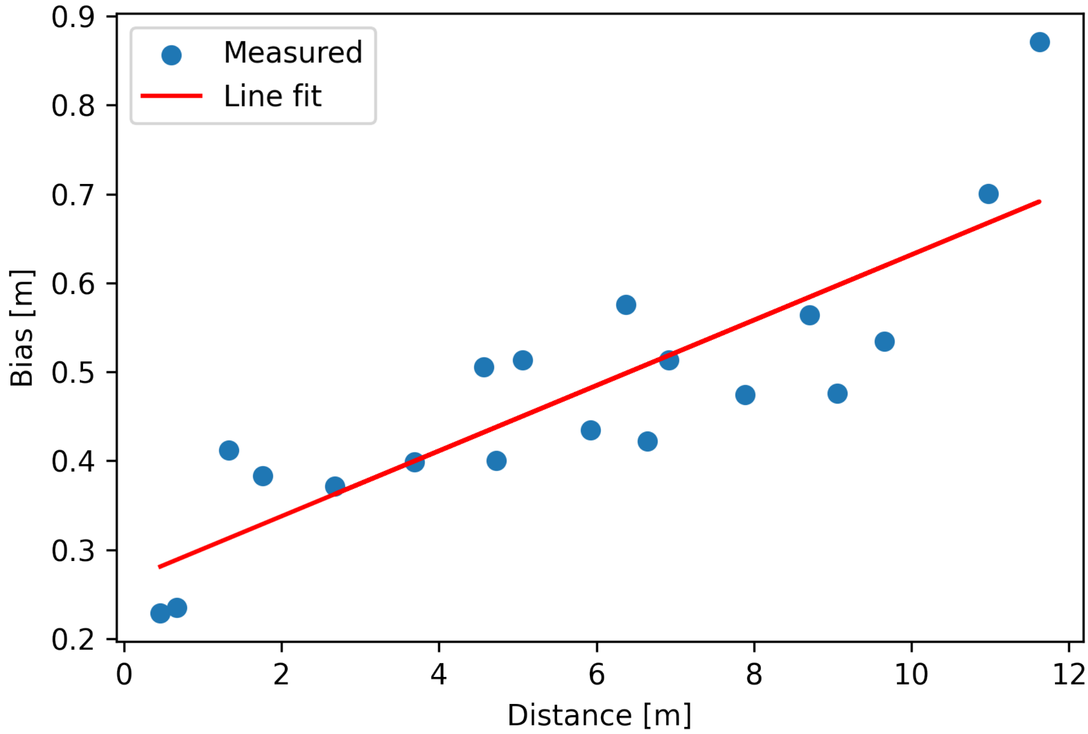

Figure 4: Measurement bias over distance.

be called bias. The relationship of bias and distance is illustrated in Figure 4. Additionally, it can be modeled, at least in this rang, by a line fit, which is shown in the graph too. It approximates the bias reasonably well and will improve localization accuracy in this distance range. In a way, it's calibrating the sensor so that measurements have the same mean value as ground truths.

Next, let's look at the variance and distance relation. The question to ask here if they are dependant on each other or we can use single constant values for all range measurements. Figure 5 shows them on single plot, plus a line fir on the data. It's clearly seen that variance is very low and of the same magnitude through out the data points. Thus, we can conclude that under tested conditions constant variance value can be used in EKF. For instance, an average value of all these variance points.

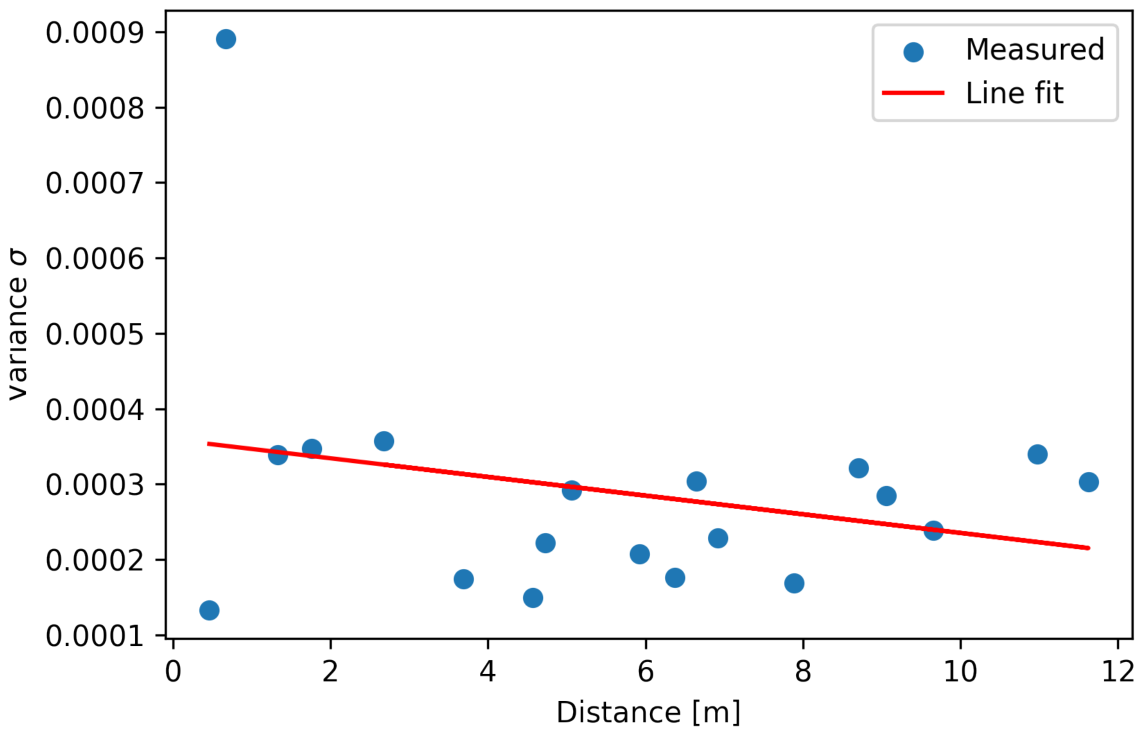

Figure 5: Distance over measurement variance.

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