Detecting the DOA for Robots with Wireless Antennas

Jiejie Wei*, Bumsik Kim† and Zhe Yan†
Department of ECE, Stony Brook University
NY,Stony Brook, 11790
Email: *jiejie.wei@stonybrook.edu, † bumsik.kim@stonybrook.edu‡ zhe.yan@stonybrook.edu

***Abstract*—The technology of robot grows everyday, which leads the need for a good design in their localization. Our project is to develop algorithms and protocols for the localization of sensors and mobile robots. The main problem is to find the direction and distance of the robot. We will use Multiple Signal Classification(MUSIC) algorithm to determine the direction of arrival(DOA) of robots, and we will estimate the distance between each of the robots based on the path loss of our received signal strength. Noise during the signal processing will be considered during our simulation. In our first semester of research, we are going to simulate the random location of robots and test the power received in ideal case.**

I. Introduction

A. Background

There are many robots created to improve quality of our life, so the AI of robots can make a great contribution. What's more, we may want to easily find a specific room location even when we are not familiar with the place. We can navigate our outdoor position with GPS, but it is hard for us to know our indoor position with our smart devices. All of these problems lead to the topic on how to implement the localization of our robots.

In terms of localization, our method to find direction first and measure the distance along with the direction. There are several algorithms of direction of arrival, we choose to use MUSIC algorithm , stands for MUiltiple SIgnal Classification, one of the high resolution subspace DOA algorithms, which gives the estimation of number of signals arrived, hence their direction of arrival. Compare with other algorithm, it is able to estimate frequencies with accuracy higher than one sample, because its estimation function can be evaluated for any frequency. This is a form of superresolution. MUSIC estimates the frequency content of a signal or autocorrelation matrix using an eigenspace method. This method assumes that a signal, $x(n)$, consists of p complex exponentials in the presence of Gaussian white noise. Given an $M \times M$ autocorrelation matrix, $\mathbf{R}_x$, if the eigenvalues are sorted in decreasing order, the eigenvectors corresponding to the p largest eigenvalues (i.e. directions of largest variability) span the signal subspace. The remaining $M - p$ eigenvectors span the orthogonal space, where there is only noise. Note that for $M = p + 1$, MUSIC is identical to Pisarenko harmonic decomposition. The general idea is to use averaging to improve the performance of the Pisarenko estimator. The equation of MUSIC will be described later. [**?**]

After the procedure of DOA, we will estimate distance based on path loss[2] with noise of Rayleigh fading and Gaussian white noise. Path loss is the reduction in power density of an electromagnetic wave as it propagates through space. This term is commonly used in wireless communications and signal propagation. Although path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption, we decide to use simple version of pass loss equation without considering so many effects, which is commonly used and called free space propagation. The simplified equation will be described later.

In terms of noise simulation, we decide to use the effect of Rayleigh fading,a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. Rayleigh fading models[3] assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution the radial component of the sum of two uncorrelated Gaussian random variables. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. In addition to Rayleigh fading noise, we also add Gaussian white noise, which is also known as normal distribution white noise. It is very commonly used in signal processing because of the central limit theorem, it states that averages of random variables independently drawn from independent distributions converge in distribution to the normal, that is, become normally distributed when the number of random variables is sufficiently large. A random variable with a Gaussian distribution is said to be normally distributed and is called a normal deviate if mean of the distribution is 0 and its standard deviation is 1.

B. Related Work

Daniel B. Faria[4], published a report, "Modeling Signal Attenuation in IEEE 802.11 Wireless LANs", presented experimental data that validates the use of the log-distance model both inside and outside a standard office building. In his project, path loss models are used to approximate signal attenuation as a function of the distance between transmitters and receivers, being an important building block for both research and industry efforts. Based on experiments with off-the-shelf 802.11 hardware, they had shown that the log-distance path loss model with log-normal shadowing can be used to estimate signal attenuation both inside and outside an office building with moderate accuracy. As a result, we will not consider the environment effect of indoor and outdoor in our project.

R.C. Smith and P. Cheeseman in 1986, and the research group of Hugh F. Durrant-Whyte in the early 1990s[5], proposed an algorithm called simultaneous localization and mapping (SLAM),which is the computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.

Leonard, J.J. and Durrant-Whyte, H.F.[6], proposed a report of mobile robot localization by tracking geometric beacons in 1991. The algorithm is based on an extended Kalman filter that utilizes matches between observed geometric beacons and an a priori map of beacon locations. Two implementations of this navigation algorithm, both of which use sonar, are described. The first implementation uses a simple vehicle with point kinematics equipped with a single rotating sonar. The second implementation uses a 'Robuter' mobile robot and six static sonar transducers to provide localization information while the vehicle moves at typical speeds of 30 cm/s.

II. Overview

Signal will fade during the transmitting and power will somewhat loss no matter what kind of transmitter be used. As a result, we can estimate the distance between the receiver and transmitter if we know the properties of the wireless signal. Meanwhile, the phase of signal will shift when receiver get a signal, which related to their direction of arrival. In this case, out project decide to use the MUSIC algorithm and path loss to estimate direction and distance between multiple robots.

Due to the interaction of noise, one of the biggest challenge is to recover the original signal with considering white noise and Rayleigh fading noise. To easily understand the effect of these noise, the following figures are the simulation of some common signals when addictive noise is applied.

To simulate our signal processing, we are going to use Matlab to model signals and apply them in simulation field, then we will integrate them with MUSIC algorithm and finally get DOA location, which will be described in detail later.

III. Architecture

A. Formula

- To simplify our simulation, we decide to use a simple version of path loss, which is:

$$L(d) = 10 * n * log_{10} d + C \tag{1}$$

  where L is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for system losses.

- Rayleigh distributed probability density function is:

$$p_R(r) = \frac{2r}{\Omega} e^{-r^2/\Omega},\ r \geq 0 \tag{2}$$

  where R is random variable, $\Omega = E(R^2)$.

- The probability density function p of a normal distribution random variable z in our case is:

$$p_G(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} \tag{3}$$

  where z represents the grey level, μ the mean value and σ the standard deviation

- The frequency estimation function for MUSIC is:

$$\hat{P}_{MU}(e^{j\omega}) = \frac{1}{\sum_{i=p+1}^{M} |\mathbf{e}^H \mathbf{v}_i|^2}, \tag{4}$$

  where $\mathbf{v}_i$ are the noise eigenvectors and

$$\mathbf{e} = \begin{bmatrix} 1 & e^{j\omega} & e^{j2\omega} & \cdots & e^{j(M-1)\omega} \end{bmatrix}^T. \tag{5}$$

IV. Evaluation

We use simple version of signal modelling only considering path loss with some noise signal.

The following graphs are 4 simulation results that randomly allocate 4 robot objects and one signal power vs. distance simulation figure :

V. Conclusion

According to our simulation result, we can see that due to the small distance between four antennas in one robots, we can only see the three range circle for each robot instead of 12, which make sense since this indicates that the distance of four antennas will not effect our distance measurement much.

In terms of power vs. distance result, we can see that when distance is greater than about 380-600 meters, the signal strength will be less than -75db, which is the medium quality of signal. As a result, we can conclude that in our case, the largest range that can be acceptable is approximately 450 meters, and we will get high quality signal when it is greater than -55db, which means robot can get good quality about ninety percent within 50 meters of a transmitter.

We will also have a better understanding why the noise is a big challenge in our project, since received signal with noise gives us a signal strength with big tolerance, for example, it's about 220 meters tolerance when calculating medium quality range, which will cause a big difference when evaluating the location.

The future plan is to be more proficient using MUSIC algorithm and enhance our methodology of distance calculating. As we can see, the current simulation indicates we will have a big tolerance of distance.

REFERENCES

[1] Wikipedia. Charge-coupled device — wikipedia, the free encyclopedia, 2015. [Online; accessed 11-December-2015].

[2] sensorwiki. Temperature sensors, 2011/04/14. [Online; accessed 11-December-2015].

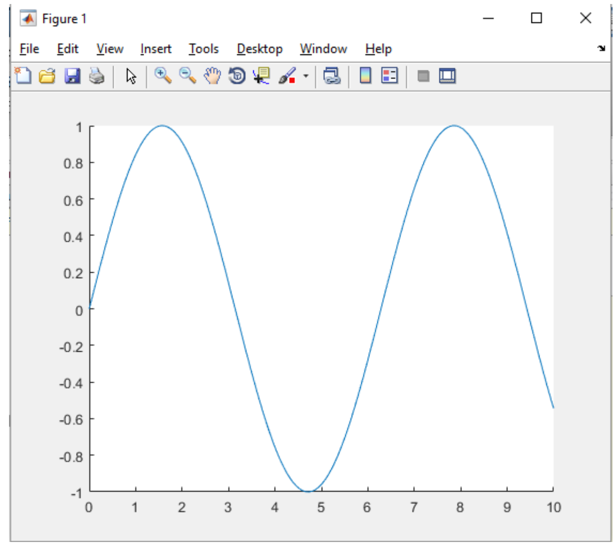

Fig. 1. sin waveform

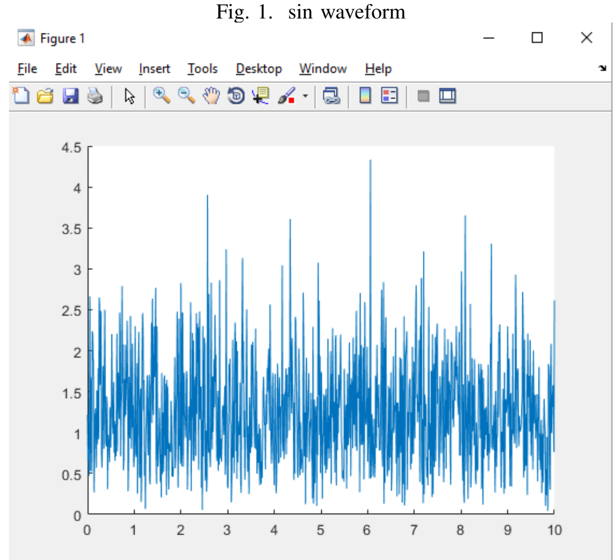

Fig. 2. Rayleigh fading noise

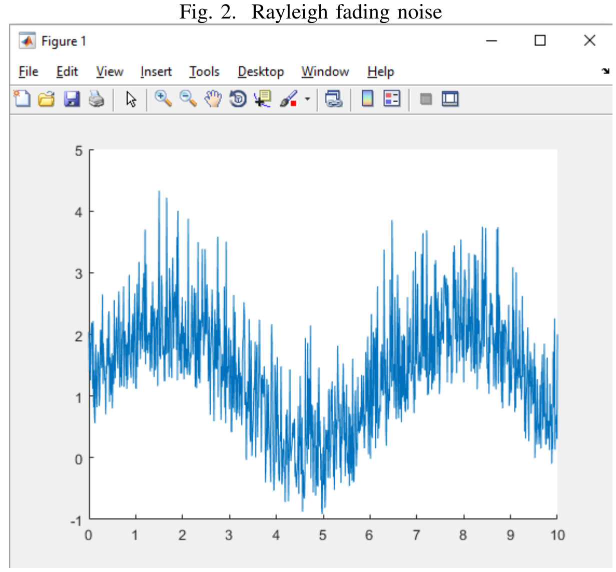

Fig. 3. sin waveform added with Rayleigh fading noise

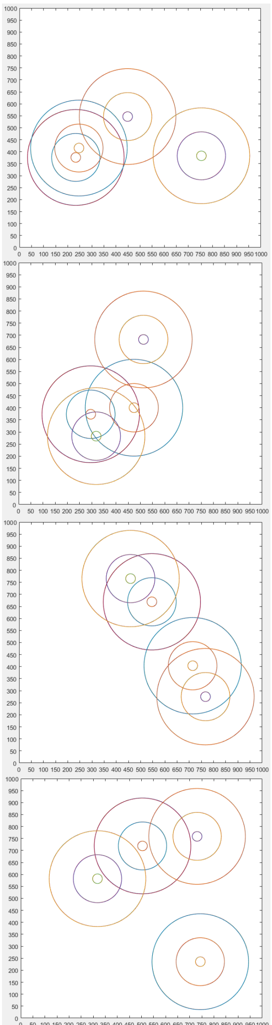

Fig. 4. Four sample simulations

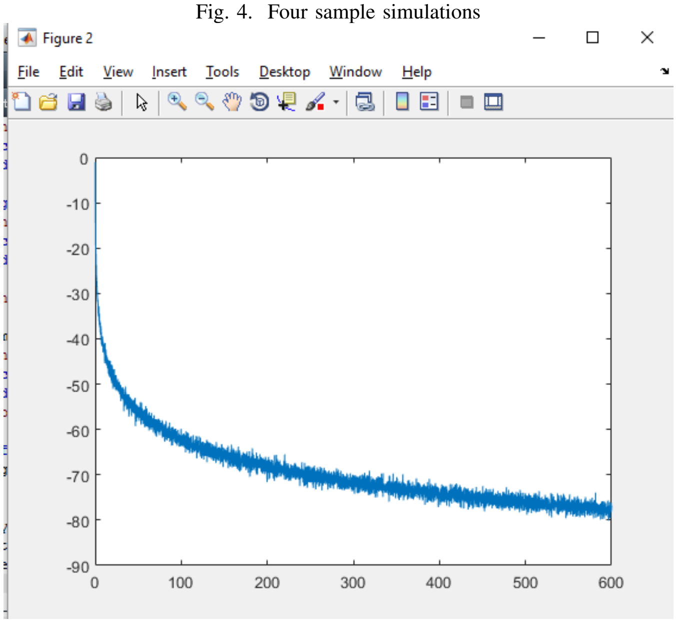

Fig. 5. Power vs. Distance