ECE 113 - Project

Spring 2019

Received signal based Source Localization

In this project, you will estimate the location of a source emitting signals, by processing the signals received by sensors located on a drone. You can use signal processing techniques seen in class, or more advanced techniques that you can find in the literature, in order to denoise the received signal or to estimate the motion/location of the source. In particular, you are invited to read the two articles we are joining to this statement.

Background

An approach to determine the location of a source is to utilize the information of the signal strength of the transmitted signals as observed through a noisy channel by a sensor. The received signal strength information can be converted to distance estimates, from which the target position is determined. Source localization has been one of the central problems in many fields such as radar, sonar, telecommunications, mobile communications, and sensor networks. Time-of-Arrival, time-difference-of-arrival, received signal strength, acoustic energy, and angle-of-arrival of the emitted signal are commonly used measurements for location determination. In this project, you will focus on positioning with the use of received signal strength measurements. Received signal strength is the average power received at a sensor where the power is originated from the emitting source. It is commonly assumed that the received power follows an exponential decay model which is a function of the transmitted power, path loss constant and distance between the source and sensor. The channel between the source and the sensor is considered to be a noisy channel, i.e., the channel adds Gaussian noise to the received signal at the sensors.

Mathematical Interpretation

Let $\mathbf{x} = [x\ y]^T$ be the source position to be determined and $\mathbf{x}_l = [x_l\ y_l]^T$ be the known coordinates of the l^{th} senssor, $l = 1, 2$. The distance between the source and the l^{th} sensor, denoted by d_l, is simply

$$d_l = \sqrt{(x - x_l)^2 + (y - y_l)^2}, \quad l = 1, 2. \tag{1}$$

Denote the source transmitted power by P_t. In the absence of disturbance, the average power received at the l^{th} sensor, denoted by $P_{r,l}$, is modeled as

$$P_{r,l} = \frac{K_l P_t}{d_l^{\alpha}}, \quad l = 1, 2, \tag{2}$$

where K_l accounts for all the other factors which affect the received power while α is the path loss constant. We consider $\alpha = 2$ in free space, and let $K_l = 1$.

Project Problem

There are two separate projects to choose from. You can only submit one project. The first project can be chosen by all the students who are enrolled in the Digital Signal Processing class, while the second project can only be chosen by the students who are enrolled in both the Feedback Control Systems and the Digital Signal Processing classes. Both projects are equally valued: 5 bonus points.

Project I

Consider the setting of the source and the drone as shown in the figure below:

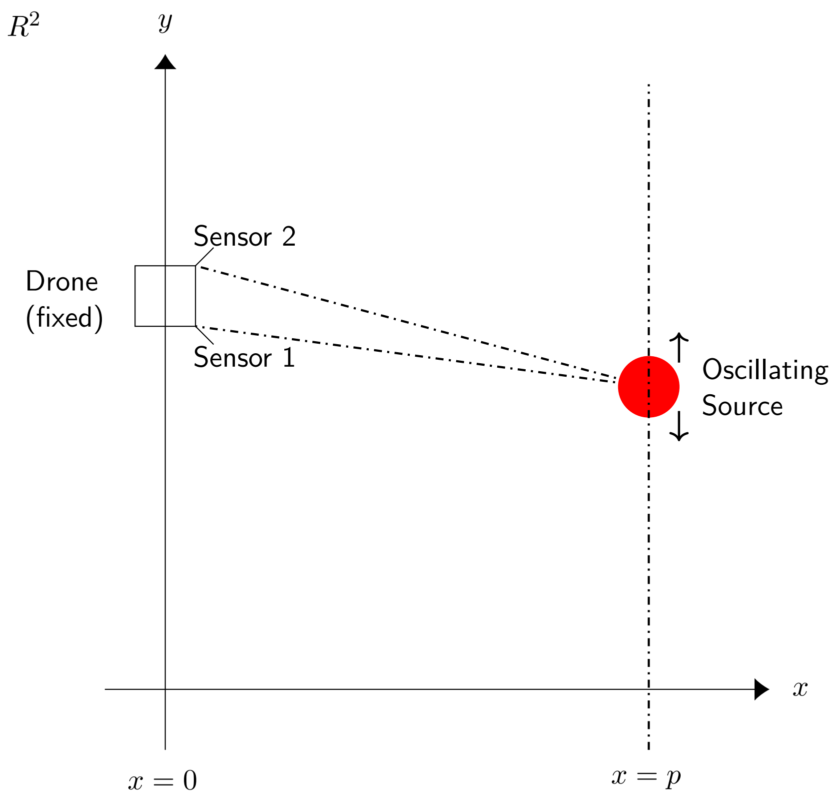

Figure 1: Fixed Drone, Moving source

The drone is stationary here and it has a panel of two sensors on it to receive the signals. The coordinates of the drone and, hence, of the sensors are known. Sensor 1 is at $(0, h_1)$ and Sensor 2 is at $(0, h_2)$, where $h_1 = 4$m, and $h_2 = 4.5$m. The source is oscillating along the line $x = p$, where $p = 2$m is known. The oscillatory motion of the source can be modeled using the following equation:

$$y(t) = A\sin(\omega_2 t + \phi) + b \tag{3}$$

$$\text{where} \begin{cases} A & \text{is the amplitude} \\ \omega_2 & \text{is the angular frequency} \\ \phi & \text{is the initial phase and} \\ b & \text{is the mean height of the oscillating source.} \end{cases}$$

The source of the signal emits a continuous-time signal of the form:

$$\text{transmitted\_signal}(t) = 10\sin(\omega_1 t), \tag{4}$$

where $\omega_1 = 2\pi$ rad/sec. Therefore, the time period is 1 second. The signal is sampled at $T_s = 5$ ms to get the discrete-time signal "transmitted_signal[n]". In this part of the project, the task for the drone is to estimate the parameters of equation (3), i.e., the equation values of A, b, ω_2, and ϕ. This can be done by applying signal processing techniques like DFT on the signals received by both the sensors.

An example of the transmitted signal, and the received signals at both the sensors is illustrated in the figure below:

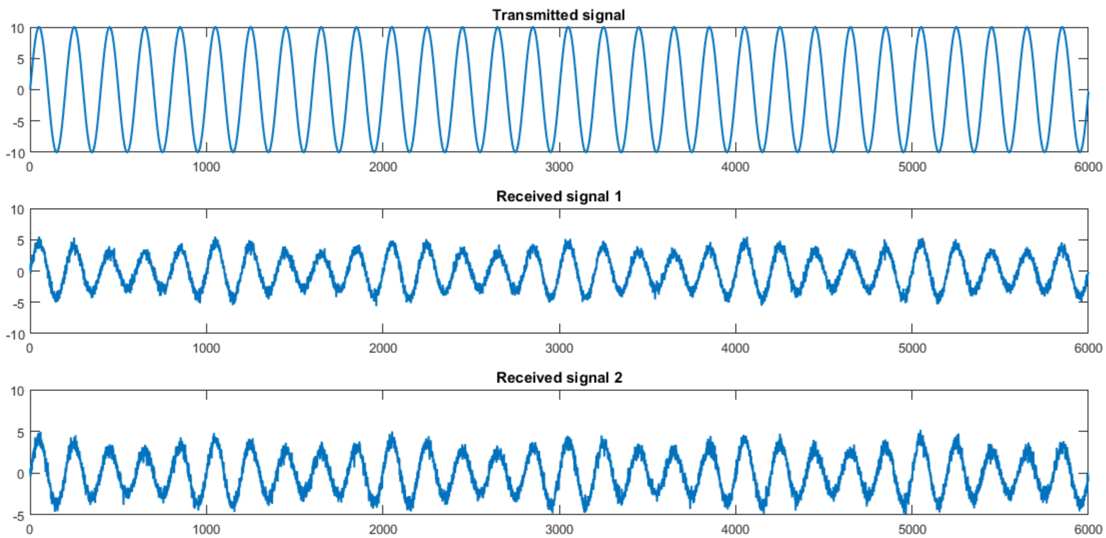

Figure 2: An example of received signals are sensor 1 and sensor 2.

You are provided with samples of the signals received by each of the sensors.
The tasks for this part of the project are the following:

- The signals received by both sensors are noisy due to the channel noise. So the first task is to denoise the received signals at both the sensors. (Hint: You have learned some filters in the class like moving average filter, exponential smoother, etc. that can help in denoising the signals. There are several sophisticated techniques in the literature that can efficiently denoise the signals with a minimum loss of information about the transmitted signal.)
- To propose an algorithm that can estimate the parameters of the oscillatory motion equation in (3). (Hint: Try to think how can you predict the oscillatory motion by observing the decay pattern in the amplitude of the received signal?)

Project II

Consider the setting of the source and the drone as shown in the figure below:

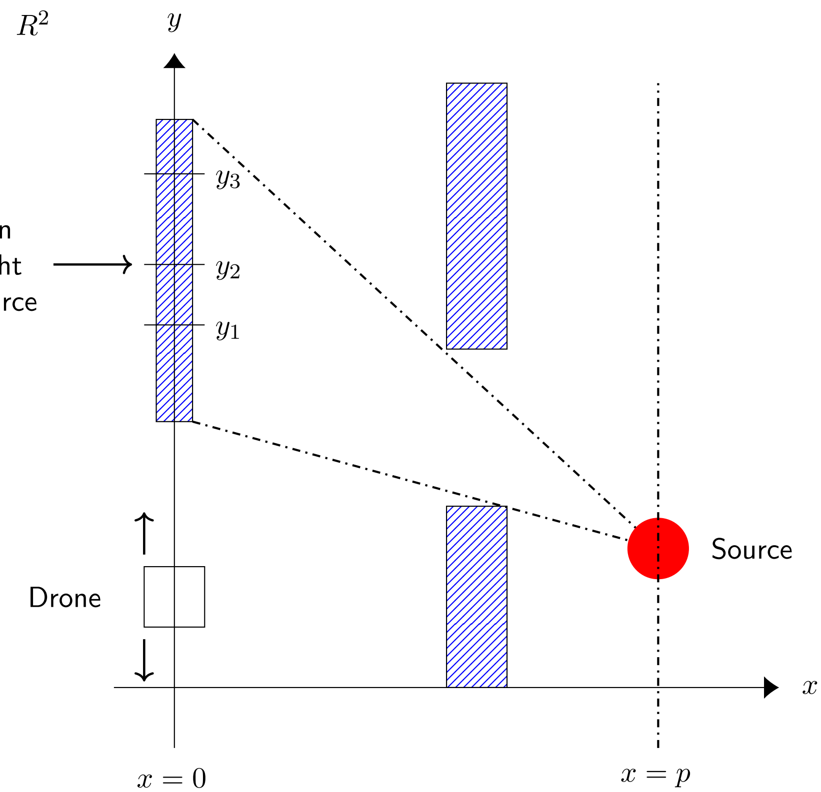

Figure 3: Moving Drone, Fixed Source

The shaded blocks between the source and the drone represents a 'signal blocker' which does not allow the signals to be transmitted through it. In other words, one can interpret it as, the drone's sensor will receive the transmitted signal only if it is in the line-of-sight of the source. Otherwise, the sensor will record the noise in the channel.

Now consider that the source is stationary and it emits a continuous-time signal:

$$\text{transmitted\_signal}(t) = 10\sin(\omega_1 t),$$

where $\omega_1 = 2\pi$ rad/sec. Therefore, the time period is 1 second. The signal is sampled at $T_s = 5$ ms to get the discrete-time signal "transmitted_signal[n]". The source is not continuously emitting the signals but it is emitting for a window of 15 seconds at every 5 seconds. One such example of the transmitted signal is shown below:

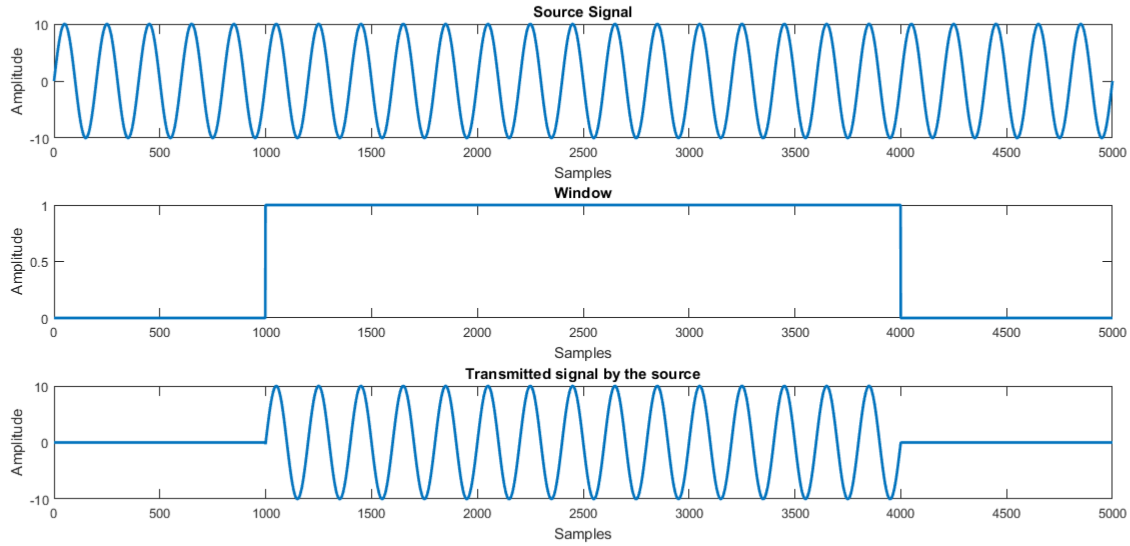

Figure 4: Transmitted signal by the source

Now, consider that in 2-dimensional space, we have the information that the source can be anywhere on the line $x = p$, where $p > 0$ is unknown. We will try to estimate the exact location of the source in this part of the project. This can be done with a drone that has only one sensor on it and has one-degree of freedom for the motion, say, along the line $x = 0$. Therefore, by taking multiple observations of the transmitted signals from the source at different locations along the line $x = 0$, we will be able to estimate the location of the source.

The tasks for the project are the following:

- To design a controller that sweeps the line $x = 0$ while recording the incoming signals. You can stop at different points along the line $x = 0$ to record the incoming signals or continuously record it as the drone moves.

- To design an algorithm that can estimate the coordinates of the source from the observed signals. (Hint: These signals are noisy observations, so you can design a filter that can denoise the received signals, and then design an algorithm to estimate the location of the source.)

Included in the project distribution is a Simulink model (sensor_model.slx) containing the single-input, single-output sensor sub-system that models the signal-occluded scenario depicted in Figure 3. Specifically, the sensor block tracks the height of the drone as input, and outputs the received signal from the periodically-intermittent source if and only if the signal source is in line-of-sight of the drone.

Submissions

DEADLINE: Friday, June 14^{th} at 11:59 pm. Late submissions will NOT be accepted.

- Zip the files `code.m` and `Report.pdf` and upload it on CCLE in the assignment "Project" in the folder Week 8. Your code MUST be ready for run without making any edits or debugging it, and it must print the required results on the command window along with generating necessary plots.

- `Report.pdf` containing NOT MORE than 3 pages (less than this is also fine; we appreciate efficiency).

For the students taking the Project II which is a bonus project for both the classes, you must submit your SIMULINK simulation and the Report file for the Feedback Control Systems class and the MATLAB code where you have implemented the signal processing and the Report for this part of the project, separately.

Include the following in the report.

- Briefly explain the denoising technique you have used and the reason for using the technique. You must also include a comparison between the different denoising techniques you have tried for the project.
- Explain clearly how did you make a hyperparameter choice (if any). For example, for computing the N-point DFT, what is the best value of N you have chosen.
- A table showing the measurement estimates of the parameters to determine the location/motion equation of the source. If you have tried multiple techniques for this, enlist the estimated values from all the techniques and report the best one.
- Answer the following question: Why do you think this technique works the best? (This is an open-ended question)