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# Ultrasonic Sensor Network: Target Localization with Passive Self-Localization

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Project Report  
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## Abstract

A flying robot is localized using ultrasonic sensor network distributed on the ground. This requires localization of sensor nodes first. In absence of RF link between target and sensors, weighted Multi-Dimensional Scaling (MDS) with Gradient Descent is used to localize the sensors from outlier free data obtained from generating a locally linear manifold. After initialization, an Extended Kalman filter (EKF) is used to estimate robot's position alongwith other unknown parameters. Outliers, which are numerous because of large distances and noise involved, are detected by checking innovation to be within range. Variable length observation vector helps select the good sensor observations from the available many.

## 1 Introduction

Absolute positioning of flying robots is extremely important for free range path tracking, reactive navigation, as well as automatic control [1]. With flying robots, localization systems using inertial sensors and GPS suffer from problems in some scenarios like inverted flights and acrobatic maneuvers [1]. Using computer vision suffers from slow update rate.

Deploying ultrasonic sensor networks to solve this problem offers an attractive solution, providing high update rate, high accuracy and robustness using redundancy in the sensors. Each sensor is equipped with an ultrasonic receiver, some computing power, and a wireless link to central computer. A pulse emitted from the transmitter on the flying robot, is received by some of the sensors who report the pulse arrival time to the central computer. In absence of RF-link between ultrasonic transmitter and sensors, time-of-flight (TOF) information is not available, and the position is estimated using pulse arrival times.

Ultrasonic sensors have been use in localization of robots [2,4,5,6]. Problems addressed include estimating variable speed of sound, and combining data from different types of sensors,etc. However, in almost all of them, the following problems are

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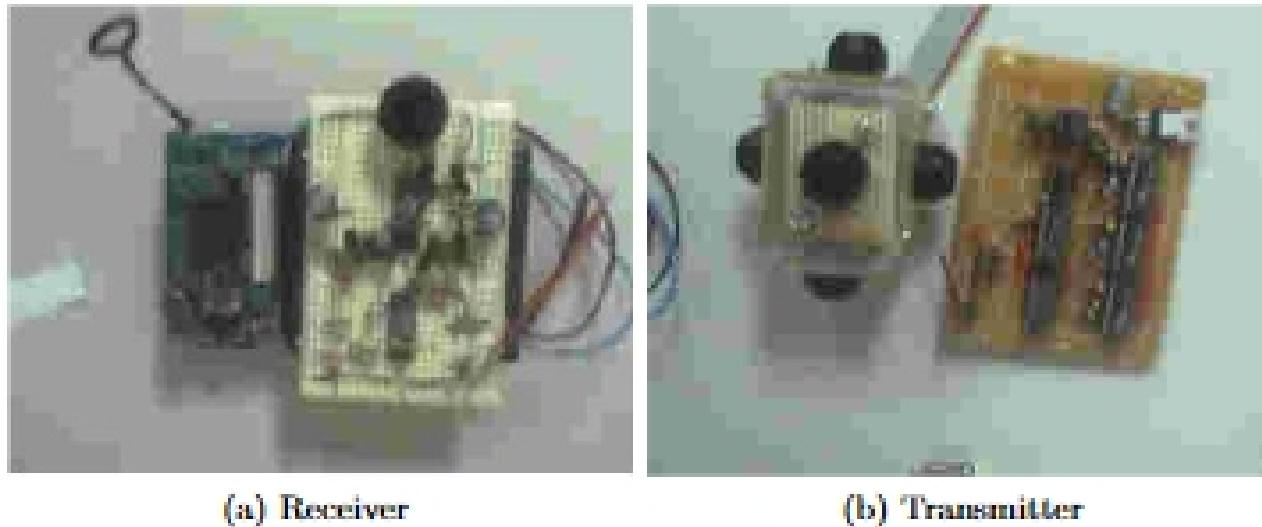


Figure 1: Receiver and Transmitter circuits

not addressed: a) Very unreliable arrival times because of large distances involved and noise, resulting in a large number of outliers, b) Unknown ultrasonic sensor node locations, c) No RF-synchronization between transmitter and receiver. Using redundancy from higher number of sensors, allows to reliably estimate the position if the robot in these scenarios.

Most sensor network algorithms require knowledge of sensor node locations, which is not always practical. Network localization algorithms exist, but some of them need special beacon nodes with known locations, and others need nodes to communicate with each other using sound and RF signals. Passive sensor network localization techniques are promising. Bayesian network [6] approach to passive localization is not applicable in practical scenarios of single target localization because the pulses are not well dispersed (in fact they lie on a particular trajectory) and only a small subset of nodes receive the pulses.

We use Weighted Multi-Dimensional Scaling (WMDS), with minimization over pulse arrival time as well. Outliers are removed by finding a 3-dimensional locally linear [3] manifold in a subset of space of arrival times from all the sensors. Once the sensors are localized, the algorithm switches to Extended Kalman Filtering (EKF) mode for position estimates of the target. A variable length observation vector is used and consistent innovations from each subset of available observed arrival times are used to update the position.

## 2 Localizer Structure

The localization system consists of  $M$  beacons (6 in our specific experiment), and a transmitter array placed on the flying robot which sends a 40kHz ultrasonic pulses (Figure 1(b)) at every 20 ms. Note that there is no RF-Synchronization between the flying robot and the sensor nodes. The sensor nodes are located at  $\vec{s}_i$  with  $i = 1, \dots, M$ . The nodes are placed on uneven ground with approximately known locations  $\vec{s}_i^0$ .

The sensor nodes ((Figure 1(a))) consist of a ultrasonic receiver, signal from which is amplified, filtered and rectified using low-noise analog circuitry and fed to sensor microprocessors which have adaptive pulse energy and noise energy thresholds to detect pulses. The time of arrival of pulses alongwith pulse energy and width is reported to the central computer over wireless network (using Crossbow radio).

The large distances involved (50 ft.) and the noise from flying robot (helicopter) result in poor reception of pulses at the ultrasonic sensors. There are numerous missing pulses and erroneous pulses. The amplitude of the pulse received varies a lot because of many factors like transmitter and receiver angle, shadowing, multi-path interference, etc. Although it has some correlation with the distance from transmitter, the amplitude of the pulse cannot be taken as a feature for distance. The arrival time of the pulses is accurate (to  $150\mu\text{sec}$ ), and is taken as the feature vector for observation.

### 3 System Model

For the  $n^{\text{th}}$  pulse, the arrival time at sensor  $m$  ( $= 1, \dots, M$ ) is given by

$$t_m(n) = t_0 + nT + D_m(n)/c \quad (1)$$

$$D_m(n) = \|x(n) - s_m\| \quad (2)$$

$$D_{k_1}(n) - D_{k_2}(n) = c(t_{k_1}(n) - t_{k_2}(n)) \quad (3)$$

where,  $T$  is the beacon firing cycle time (variable),  $t_0$  is the firing time of first pulse,  $c$  is the speed of sound in air (variable but can be modeled).  $D_m(n)$  is the euclidean distance of the target when  $n^{\text{th}}$  was fired from sensor  $m$ . Note, that in third equation, taking differences of the distances between two sensors results in cancellation of firing time of the pulse. Thus, if we are using more sensors, then the time-of-flight is not needed.

### 4 Algorithm

The localization process consists of two parts

1. : Pulse Detection: The noise level and the pulse energy level vary. To take care of this, and ensure that low energy pulses are also detected, we put a adaptive threshold based on total signal energy and pulse energy.

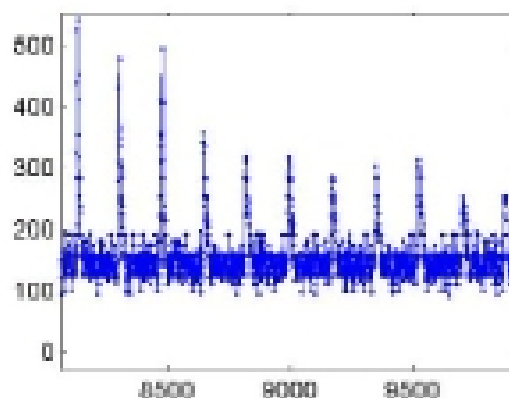


Figure 2: Received signal from 10 ft at the Sensor

2. Sensor Localization: Given approximate location of the sensors placed randomly on the field and unknown position of the target, the task is to accurately find the position of the sensors. There are a lot of outliers in the data because of false pulses and missing pulses.
3. Realtime Target Localization: Once sensor node locations have been determined, the position of the target should be determined in realtime. Only