600.446 CIS II Paper Critical Summary
Group 12: Hydrophone-based Localization of Snake Robot End-Effector

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Filonenko, Viacheslav, Charlie Cullen, and James D. Carswell. “Asynchronous ultrasonic trilateration for indoor positioning of mobile phones.” Web and Wireless Geographical Information Systems. Springer Berlin Heidelberg, 2012. 33-46.

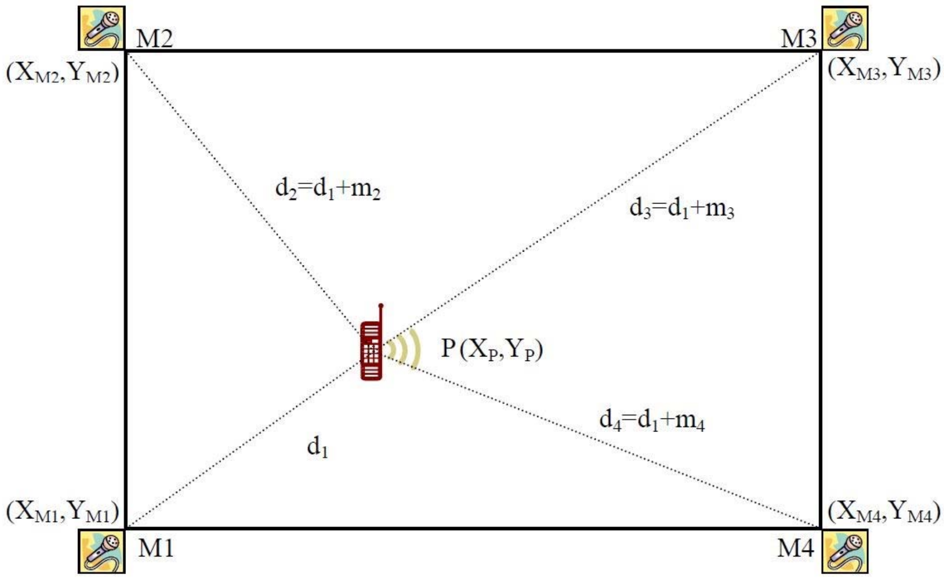
Reasons for selecting paper

My project involves using ultrasound from multiple sources to locate the tip of the APL snake robot in the body. While this paper presents the use of ultrasound for localization of mobile phones in air with low frequency ulrasound (22kHz), the methods tested are generally applicable to any application based on time of flight localization. It is particularly relevant that the methods shown are based on time differences rather than absolute times, because sound propagation is sufficiently fast in tissue that not accounting for communication time between different components could add significant error. By using time differences, the communication time between components is canceled out.

My actual localization method is slightly modified from the method presented to take advantage of the known geometry of the ultrasound probe, but the method in the paper stands as a good baseline for comparison.

Summary

The paper details a method for using the speaker of a cell phone and multiple microphones in a building to determine the location of the cell phone. To do so, the cell phone emits pulses of ultrasound and the microphones, which are at known locations, pick up the sounds and note the time. It was found that typical cell phone speakers are capable of producing 22kHz sounds without significant distortion which is conveniently above the range of normal human hearing so as to be inaudible to people in the area. The method used to locate the phone differs from previous attempts in that it uses the difference in the time of flight of ultrasound pulses to each microphone rather than the absolute time of flight to each pulse, thereby removing the need to synchronize the clocks of the cell phone and each microphone. The paper gives a fairly detailed overview of current methods of indoor cell phone localization methods and discusses the drawbacks of different technologies. Most notably radio-frequency based localization methods suffer from poor accuracy with the best accuracy presented was 1 meter. Ultrasound based methods on the other hand have so far been able to produce accuracies of a few centimetres. The method presented improves upon existing ultrasound approaches because it is able to be used on a smart phone, whereas previous methods required specialized hardware. The authors also briefly discuss the decision to use the time of flight of the ultrasound rather than the measured sound intensity, citing collected data showing that intensity was not a reliable measure of distance. The presentation of the method is organized around a specific example of a rectangular room with a microphone in each corner and a cell phone located at an unknown location in the room. In the example, all locations are treated as two dimensional points in a plane. Since there are only two unknowns, the x and y values of the phone, it is noted that only two time differences, corresponding to three microphones are needed. However, the authors use four to demonstrate the use of least square methods to find the most probable values and the standard deviation from the mean.



From geometry they found the equations:

$$m_2 = \sqrt{(X_P - X_{M2})^2 + (Y_P - Y_{M2})^2} - \sqrt{(X_P - X_{M1})^2 + (Y_P - Y_{M1})^2}$$

$$m_3 = \sqrt{(X_P - X_{M3})^2 + (Y_P - Y_{M3})^2} - \sqrt{(X_P - X_{M1})^2 + (Y_P - Y_{M1})^2}$$

$$m_4 = \sqrt{(X_P - X_{M4})^2 + (Y_P - Y_{M4})^2} - \sqrt{(X_P - X_{M1})^2 + (Y_P - Y_{M1})^2}$$

They then added a residual term for each of the above equations and performed non-linear least squares to minimize the residuals. Their choice of method for least squares was doing a first order Taylor expansion of the above equations with derivatives with respect to X_P and Y_P and then use Euler's method to find the minimum. To test their method, the authors drew a room on graph paper and roughly measured by hand the distances to each corner from a given point chosen to be the location of the "cell phone". This was repeated 6 time and it was found that the algorithm performed with less than 1

Analysis

While the algorithms and reasonings behind method decisions are well presented in the paper, the testing methods are woefully innacurate. It is almost unacceptable that testing was done by simulating the situation by hand when it could have easily been done in computer simulations to perform thousands of tests instead of six. Measuring distances "by hand" also removes the ability to quantify the amount of error introduced. No discussion of these problems were made and indeed the paper makes no mention of typical time of flight measurement errors in real life systems. As such this method cannot really be compared to previous systems. The calculated standard deviations also do not make sense in a practical application as the introduced error would likely not be normally distributed as a significant portion would be from blocking obstacles that would increase time of flight, thereby skewing error. Finally, the authors fail to mention any possible extensions to their methods. In particular, there is no reason that the same algorithm could not be used in a three dimensional space so long as there were at least four microphones.