Measuring distances using audio

REF [1] Time-of-Flight Measurement Techniques for Airborne Ultrasonic Ranging for reference  
[2] Fast processing techniques for accurate ultrasonic range measurements

Measuring distance using ultrasonic signals offers an inexpensive solution to the indoor localisation problem. Measurements of the distance of an object from fixed landmarks can be used to calculate the precise location of that object. The basic idea is to send an acoustic signal through the air from a transmitter to a receiver. The time it takes for the signal to reach the receiver is known as the time of flight (TOF), which can be used to measure the distance by the following equation:

Where is the distance, is the time of flight and is the speed of sound in air. Many ultrasonic applications use a single transducer, which both emits and receives, to calculate the distance to an object by emitting a signal and measuring the time it takes for an echo to be received. The distance is calculated similarly to the calculation above, but having the result, as the signal has travelled the distance to the object and back; . For this comparison, we will consider the measurements are using the second technique, which allows us to know when the signal was sent, although in more complex ranging systems that use independent transmitters and receivers, synchronisation becomes an important factor, which we will examine later.

The accuracy of the distance measurement depends on the accuracy of the measurements of the TOF and the speed of sound in air. Choosing the measurement technique of the TOF depends on a number of factors such as cost, ease of implementation, environment. We will examine some common methods used for these TOF measurements. Methods are usually compared by the accuracy, or error in the distance measurement, repeatability, or the variance in repeated measurements, cost of implementation and performance under noise.

Time Domain methods with single frequency signals

The first method we look at is thresholding. A signal is sent, and the time of flight is the time it takes for the amplitude of the echo signal to surpass a certain threshold. The threshold is usually selected to be well above the noise standard deviation. This method is relatively straightforward and does not require complex circuitry or calculations, and can be implemented with inexpensive transducers. Its limitation is it naturally introduces a bias into the measurement. If the threshold level is set to low, noise interference can cause false positive to be detected. Increasing the threshold will improve detection of real echoes, however the time it takes for the incoming signal amplitude to surpass the threshold will be delayed further. This is especially true if too low a sampling frequency is chosen. Although noise and sampling frequency selection are issues that all TOF measurements must deal with.

Curve fitting is a method of TOF estimation that attempts to fit a parabolic curve to the echo signal envelopes leading edge to provide a measurement without bias. This uses threshold estimate as above, but then fits a parabolic curve in the form where is the estimation of the result of simple thresholding and is estimated from a second derivative approximation around this threshold point. A nonlinear least-squares method is then applied to fit the curve, and the vertex of the parabola is used as the measurement of the TOF.

Sliding window is a method that can be used to make detection more robust. A window of length N is slid through the echo signal one sample at a time. As the window slides through the sample, it counts the number of samples which exceed the threshold value. If this count exceeds second threshold the signal is considered present and the TOF estimate is produced.

Cross-correlation is an unbiased measure of TOF. The echo signal is correlated with a matched filter that contains the waveform and the delay will be the peak. This method has a few drawbacks in comparison with those outlined above. In real-time processing, the entire echo must be observed before the correlation process can being which can add a significant delay to producing the estimate. It is also computationally much more complex than the previous methods. However, this method should significantly reduce noise interference.

A study performed by [2] shows that Correlation gives by far the best results in terms accuracy, which is what would be expected, however the less complex methods offer some acceptable performance results at much lower cost. Curve fitting performing best when it came to bias and total error, where as sliding window performed best with standard deviation.

Other methods of measurement

TDOA(this is what we use? FM?RF?) AOA RSS CSI

Time difference of arrival (TDOA) can be used as part of a multilateration system to predict the location of an object. A transmitter sends a signal which is received at receiver stations 1 and 2, which are at known locations. When both receivers have received the signal, the can cross-correlate them to determine the time shift between the two waves which is the difference in time it took the signal to at each station. This time shift can be used in equation 1 to get a measure of distance. As both stations are fixed, we now have an infinite number of points along a curve that satisfy the transmitters location. If we had a second pair of stations, we would get a second curve of possible locations that intersects the first. This produces a small number of locations that the transmitter could be.

“Accuracy of multilateration is a function of several variables, including:

The antenna or sensor geometry of the receiver(s) and transmitter(s) for electronic or optical transmission.

The timing accuracy of the receiver system, i.e. thermal stability of the clocking oscillators.

The accuracy of frequency synchronisation of the transmitter oscillators with the receiver oscillators.

Phase synchronisation of the transmitted signal with the received signal, as propagation effects as e.g. diffraction or reflection changes the phase of the signal thus indication deviation from line of sight, i.e. multipath reflections.

The bandwidth of the emitted pulse(s) and thus the rise-time of the pulses with pulse coded signals in transmission.

Inaccuracies in the locations of the transmitters or receivers when used as a known location”

Angle of Arrival (AoA) is used to determine the direction a received signal arrives at an array. It is measures by taking the TDOA between elements within the array. For example, let’s consider an array of two microphones separated by half the wavelength of an incoming sinusoidal wave. If the wave was emitted from directly in front of the array, there would be no phase difference between the two measured waves. However, if the wave was emitted from the right of the array, the microphones would receive the signals half a wavelength apart, resulting in a phase difference on 180. If this was used alongside the multilateration system we described earlier, we could immediately disregard many of the values of the curve produced.