Canada Wide Science Fair

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Benjamin Schmidt is the winner of this year's Special Award from the Canadian Acoustics Association for his project - Robotic Sound Localization.

Benjamin Schmidt earned the Canadian Acoustical Association Award ($400) for "An outstanding project related to Acoustics, the science of sound," and a Senior Engineering Science Honourable Mention ($100). Benjamin is a student at Centre Wellington District High School, Fergus, Ontario. Ben was a member of Team-Canada at the Intel Science and Engineering Fair this spring in Portland, Oregon. He was awarded Acoustical Society of America First Award ($500) (Each winner also receives a one-year ASA membership). Society of Exploration Geophysicists Award of Merit ($250), for projects that display excellence related to the geophysical sciences.

Editor's Note: We are very happy to note that Benjamin Schmidt submitted a brief summary of his project work that won the prize at the fair. His full article is reproduced below.

ROBOTIC SOUND LOCALIZATION*

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Editor's Note: The submission by Benjamin Schmidt was reformatted and edited to fit in to the Journal format.

ABSTRACT

The purpose of this project was to build a system capable of estimating the direction of a sound source using a static array of sensors without measuring time delays. Such a system would aid in tracking a robotic vehicle over a short range and is a prototype for a radio-based tracking system. The project consisted of several parts, the first of which was the construction of an adjustable sound source, providing a constant amplitude and variable voltage. After testing many designs, a crystal earphone and a square wave tone source were used as the sound source. Next, a sound sensor consisting of a microphone and a housing to make the microphone response directional were constructed. Circuitry to convert the amplitude of the sound into a DC voltage, to be able to read by a microcontroller, was built. Several designs for directional sound sensors were tested. By rotating the sensor and sampling at different angles, the data that would be generated by a group of sensors pointing in different directions, was simulated. A static array based on the simulations, consisting of seven sensors arranged radially at 35° intervals, were used for the final design. A second-order polynomial regression was used as the basis of an algorithm to estimate the angle to the sound source. Experiments to determine the effect of the signal frequency, sampling protocols and microphone housing design on the accuracy of the angle estimates, were conducted. The best results were obtained for a frequency of 2.15 kHz. At distances of 50cm-100cm, the final array design was able to locate the direction of the sound source with an accuracy of about ±3°.

1.0 Introduction

Using only auditory cues, humans can easily locate the source of a sound. Most of the time one doesn't even notice when people orient themselves towards a speaker. Sound localization can be accomplished without head movement using binaural hearing. Two basic mechanisms are usually applied in source localization by human ears - interaural time differences (ITD) and interaural level differences (ILD). An automated system capable of similar localizing of sound sources would have many applications, including short-range tracking of mobile robots. The purpose of this project was to create a stationary tracking system capable of estimating the azimuthal angle of a receiver relative to a sound source.

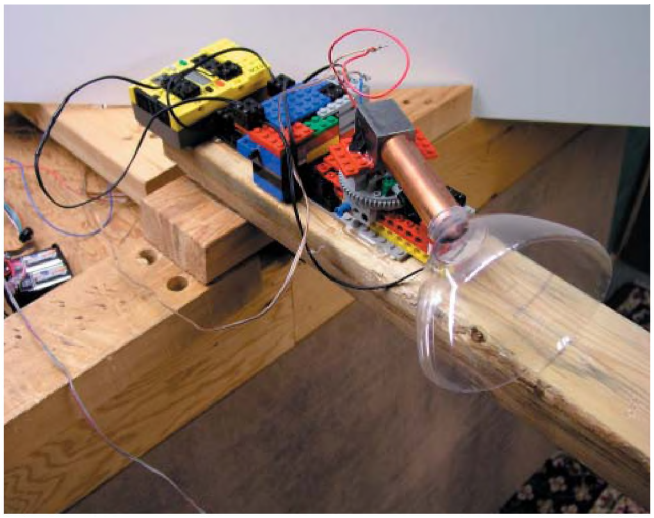


Figure 1. Tone Source Set-up

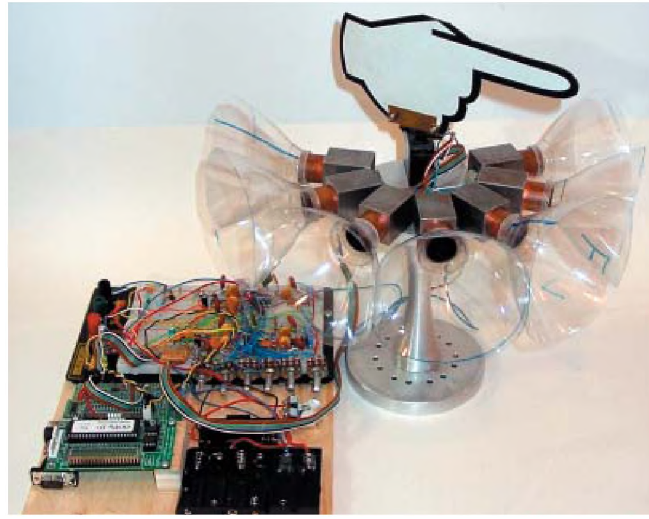


Figure 2. The Sensor Array

The system used, was based on an ILD approach, using the directional differences in sound amplitude detected by each sensor in a static array to determine the angle relative to the sound source.

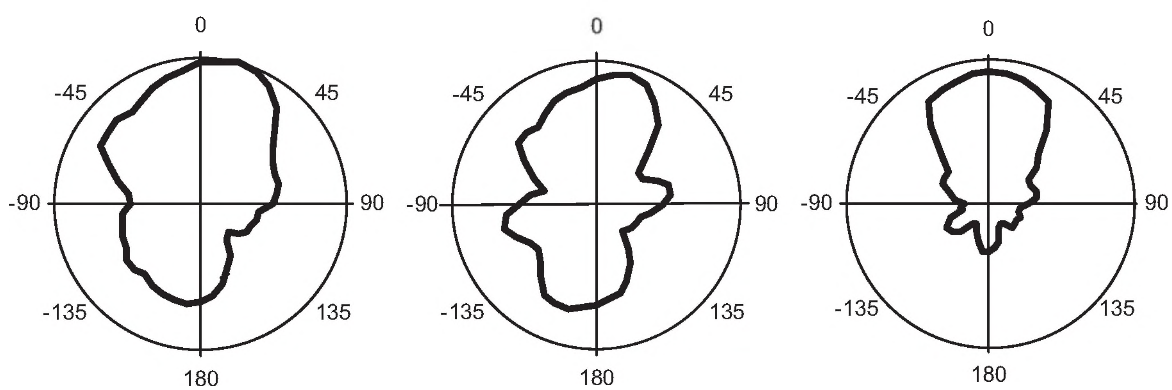
2.0 Procedure

First, a reliable tone source was constructed and tested. The test source had fixed amplitude, a controllable frequency and an omnidirectional speaker housing. The final design used a variable-frequency square wave generator and a crystal earphone as the sound source. Next, the required circuitry was designed and tested to convert the amplitude of sound waves detected by a microphone into a DC voltage that could be read as an input by a computer. One also needed a housing for the microphone that ensured that its sensitivity was directional. Because of the complexity of interactions between factors such as reflections, refraction, interference and resonance, it was necessary to test the housing designs experimentally. A computer-controlled turntable allowed one to test the proposed designs at specific angles relative to the sound source. The basic housing structure had a single opening, a short tube of adjustable length, and space for a cone and/or baffle. The directional characteristics of different housing designs using various funnel sizes, tube lengths and signal frequencies, were tested.

Using the data from the turntable experiments, one was able to simulate static arrays of different numbers and arrangements of sensors. An algorithm that fitted the signal strength data from specific, known angles to a parabolic curve was developed. The maximum value of the regression estimated the angle to the sound source. Based on the simulation results using a single microphone, a static radial array of seven sensors, spaced 35 degrees apart, was built. The accuracy and precision of the estimated azimuthal angle using the same funnel sizes, tube lengths and signal frequencies that had been tested on the turntable were also measured.

3.0 Results and Discussion

Figure 3 shows examples of data collected using the turntable. The graphs show the responses of three sensor designs incorporating different microphone housings.



(a) No Tube or Cone **(b) Tube** **c) Tube and Cone**

Figure 3. Sample Angle Versus Intensity Graphs For Three Sensor Designs.

Angle Relative to Sound Source	Number of Sensors Used for Polynomial Regression				
	3	4	5	6	7
0°	-2.9 ± 2.9	-28.1 ± 11.9	5.7 ± 3.6	-5.5 ± 5.0	8.9 ± 4.3
17.5°	21.3 ± 2.9	-68.9 ± 5.9	37.9 ± 11.4	13.6 ± 9.2	20.7 ± 23.5

Table 1. Mean Estimated Angles ± S.D. Using Different Numbers Of Points For Calculation.

Tube Length (cm)	Cone mouth Diameter (cm)	Estimated angle to sound source (Actual Angle: 0 degrees)	Estimated angle to sound source (Actual Angle: 17.5 degrees)
4.0	10.5	-3.0 ± 1.6	15.7 ± 2.5
5.0	10.5	-1.5 ± 1.2	30.6 ± 10.5
5.0	8.0	1.7 ± 2.9	-38.4 ± 374.8
5.0	2.0	2.5 ± 6.8	64.6 ± 197.2
8.0	8.0	9.5 ± 16.3	29.7 ± 23.5
8.0	10.5	3.3 ± 3.4	27.0 ± 8.4
8.0	10.8	0.5 ± 2.4	28.1 ± 23.3
8.0	2.0	-12.0 ± 93.0	-28.4 ± 24.4
4.0	8.0	1.3 ± 5.5	3.2 ± 7.5
4.0	10.8	1.8 ± 1.6	-47.6 ± 131.0
4.0	8.0	1.9 ± 2.2	15.0 ± 8.1
4.0	10.5	-1.3 ± 1.5	10.2 ± 2.9
4.0	10.8	-0.2 ± 2.4	15.8 ± 2.0

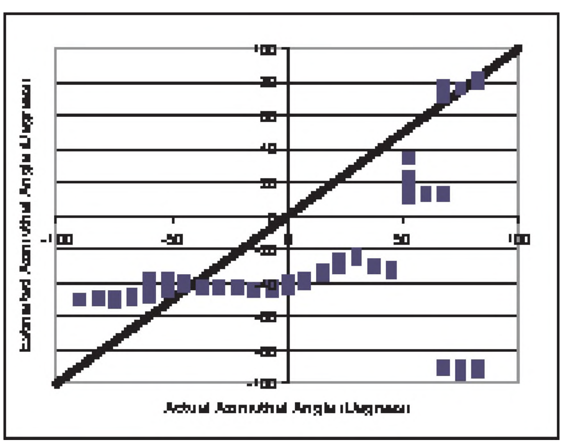
Table 2. Calculated angles and standard deviations for different combinations of cones and tubes.

Intensity was measured as the peak amplitude of the incoming signal. Sound source was located at 0 degrees and the source frequency was 2150 Hz.

The plot shown in Figure 3c was obtained using the design that was selected for the static array. The housing had a 2 cm wide tube that was 4 cm long, and a 7 cm long funnel that was 10.5 cm wide. Between –52.5 degrees and +52.5 degrees the signal amplitude is a smooth curve that resembles a parabola. Therefore, a quadratic function can be used to model the data, and its maximum value will be near zero degrees.

Many simulations, using both turntable and static array data, were conducted. Table 1 shows the results of an experiment using different numbers of sensors for the angle estimation. Data in Table 1 was generated using a static radial array of 7 sensors spaced 35 degrees apart. Distance from source to array was 50 cm and each trial consisted of 100 observations.

If seven detectors are spaced 35 degrees apart, three sensors will always fall within the range of the curve (±52.5 degrees). However, the use of data from sensors other than the three that register the largest response decreases the accuracy and precision of the system. The relationship between signal frequency and the accuracy of the estimated angle using the static array was complex. The directional gain of the sensors, and the resulting accuracy of the estimated angle, would



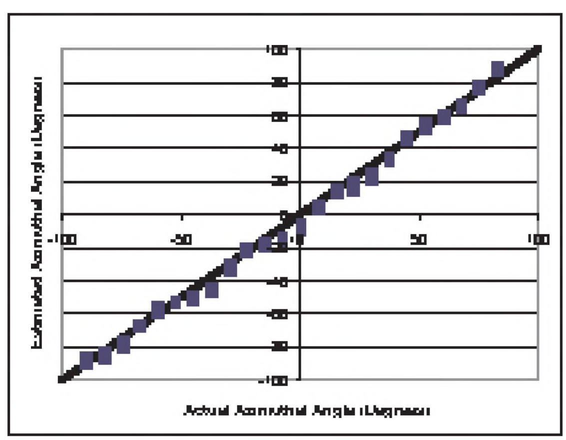


Figure 4. Actual versus estimated angles using two sensor housings: tube only (L) and tube and funnel (R). The black line represents perfect estimation.

depend on the dimensions of the cone and tube relative to the wavelength of the sound. Testing demonstrated that 2150Hz generated the most accurate results. This frequency was related to the structure of the sensor, the length of the tube (4 cm) being approximately ¼ wavelength. Having selected a frequency for the sound source, the array using the same combinations of cone and tube dimensions that had been tested on the turntable was tested. The design selected based on the results from a single sensor (4 cm long tube, 10.5 cm wide funnel) produced the most accurate and precise angle estimated (Table 2). This confirmed the trends seen in the turntable experiments. The conditions for the data shown in Table 2 were: distance to sound source 100 cm, and the sound frequency 2150 Hz. Each treatment consisted of 20 observations. Data was generated using a static radial array of 7 sensors, 35 degrees apart.

At a distance of 50 cm, the final array design could locate the direction of the sound source with an accuracy of about ±3 degrees (Figure 4). Data, shown in Figure 4 was based on 10 samples at each angle (-90 degrees to +90 degrees) in 7.5 degree increments, taken at a distance of 50 cm and at a frequency of 2150 Hz.

The system was very susceptible to environmental noise. Use of multiple samples compensated for some of the noise, but this did not eliminate biases introduced by such acoustical effects as reflected signals from fixed surfaces in the vicinity of the array.

4.0 Conclusions

The current investigation has shown that it is possible to determine the direction of a sound source with a single static array of directional sensors. Because it does not move, it can calculate the position more quickly than a rotating detector and it is not subject to mechanical failure. The accuracy of this system is comparable to that reported for humans (Yost 2000). It may be possible to further refine the system using genetic or neural programming instead of polynomial regression, improving the sensor design, or incorporating phase and timing measurements into the calculations. Furthermore, it should be possible to use a similar process with directional radio antennae. Such a system would have a greater range, and could be used to track wildlife, cell phones or a robot exploring on the surface of another planet.

Acknowledgements

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