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Robot Name: Echo

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Abstract

This paper describes the proposal, development, and final outcome of the development of an autonomous mobile acoustic source locator named Echo. The objectives of this project are to design and construct a quadrapedal walking robot capable of taking in audio signals via a microphone array, filtering those signals to detect a particular unique signal and then locating that signal. While the functioning of Echo is governed by the onboard microcontroller board the acoustic data processing is handed off to a nearby personal computer connected wirelessly. This computer sends no commands to Echo, only a location that Echo's programming tells Echo to walk to.

Executive Summary

I greatly underestimated the difficultly of this project. Likewise I didn't allow enough time to account for unforeseeable setbacks. I have the habit of biting off more than I can chew and with this project this has certainly been the case.

Chief among the set-backs were the inability to communicate via the RS232 serial connection to the Blue SMiRF Bluetooth modem and the inability to send commands to the SSC-32 that the servo controller could recognize. In addition four of the pins connected to Port D were dead; I therefore needed to write an additional program to enable Port F to accommodate PWM signals in order to drive the required number of servos. Likewise one servo began to fail just as Echo was beginning to walk. This servo started generating an excessive amount of heat, swapping out the electronics and motor on the servo solved the heat issue, perhaps only temporarily, but the servo still would not hold a position.

As I was unable to get the BlueSMiRF operational in the allotted time frame the acoustic source location function was placed on hold as the program required was deemed too computationally expensive for the ATxMega128a1. In addition access to an oscilloscope was limited therefore hindering testing at the odd hours I've been keeping.

Walking in real time is much more difficult than I anticipated. The math itself was easy enough to figure out, however the math rarely translates exactly to the real world without modification. Furthermore the lack of balancing input complicates the required adjustments.

I Introduction

Acoustic location has numerous applications in areas such as passive sonar, search and rescue operations, and security systems. With a number of conceivable instances where such applications would be under conditions deemed either hazardous or tedious it makes sense to construct some autonomous robotic entity to perform them. Therefore, the objective of this project is to construct an autonomous system named Echo to detect a certain periodic acoustic signal and then travel to the source of that signal.

Echo utilizes four legs to traverse its environment. Ideally Echo would be able to travel over rough terrain; however that seemed a bit too ambitious for an initial attempt and the main focus is on Echo's acoustic source location.

Echo passively listens to the ambient environment until it detects a particular acoustic signal. This signal activates Echo's search program where Echo transmits the signal from the microphone array via Bluetooth to a nearby computer. This computer is programmed with an algorithm that returns a distance and heading to Echo again via Bluetooth. This algorithm is based on the method proposed by Stanley T. Birchfield, termed accumulated correlation, seems a promising method due to its purported comparable accuracy to the traditional beamforming with a significant reduction in computation.

This process runs continuously until the distance is reduced to a certain value and the program terminates. This allows for course correction as opposed to having Echo receive the directions and then tracking its own displacement.

In addition Echo also has a “wander” mode in which it walks around the environment for a period of time avoiding obstacles. This serves primarily to create the illusion of aimless wandering.

Ideally Echo will avoid obstacles while tracking down the sound source; however the interactions of the sound waves and those obstacles may impose limitations.

The remainder of this document details the specifics of Echo's systems with an increasing level of detail followed by an overview of Echo's programming and concludes with a review of Echo's performance in the field.

II Integrated Systems

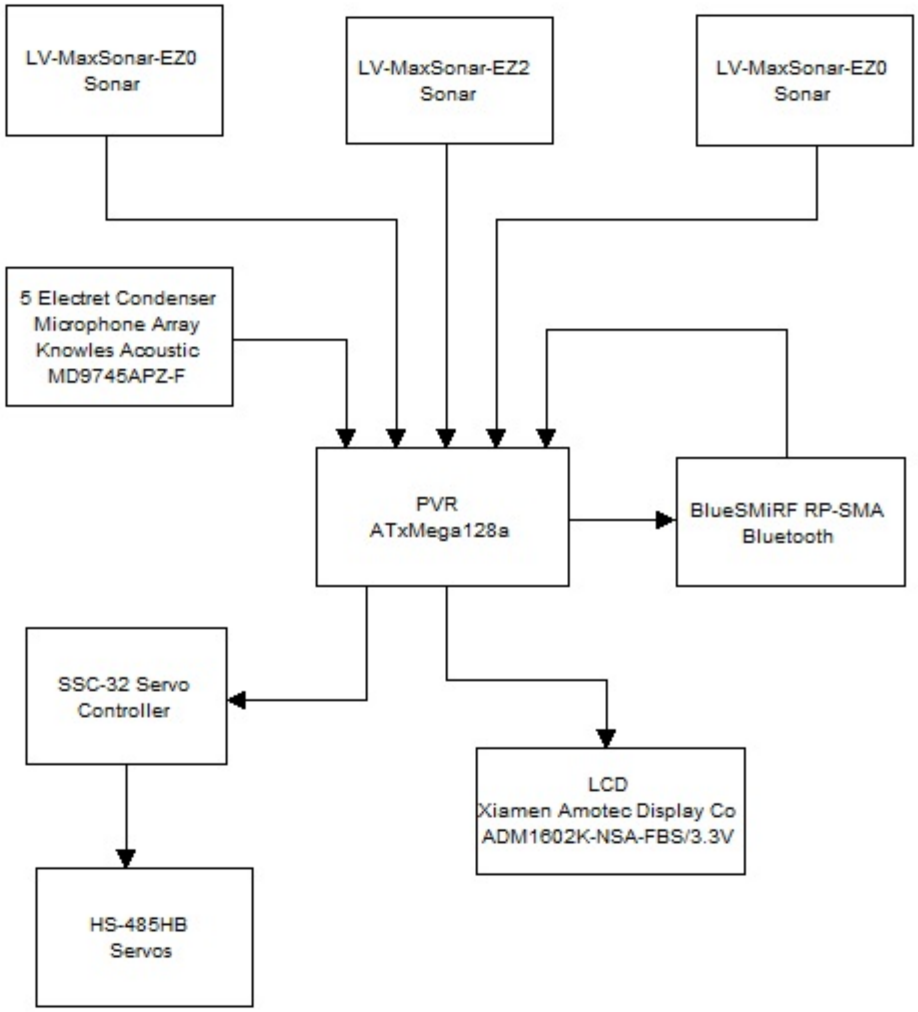


Figure 1: Block Diagram

III Mobile Platform

Echo's platform was designed in SolidWorks and cut from a sheet of balsa wood on a T-Tech PCB milling machine.

The original design made heavy use of splines that refused to translate and scale properly from the drawing file to the file read by the T-Tech. To circumvent this problem the platform design was overlain with a number of straight lines spaced 0.031 inches apart (the radius of the tooling bit). The points formed from intersections of these lines and the original splines were then connected with straight lines resulting in an acceptable approximation to the original design.

Each piece was then sanded, stained, and finished with Helmsman Spar Urethane.

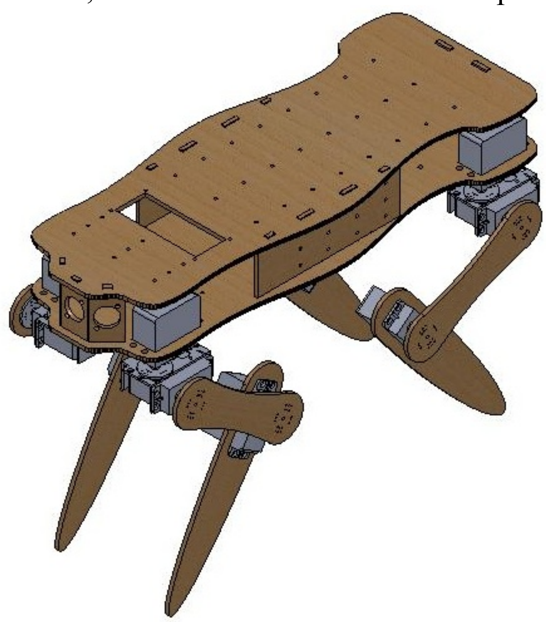


Figure 2: Isometric View of Mobile Platform Assembly

Echo was modeled after a German Sheppard dog, hence the appearance in the figure above. While Echo was able to stand in this configuration walking was extremely difficult due to balancing issues. Ultimately the "dog walk" was dropped and legs spread to enable locomotion.

IV Actuation

Actuation is achieved via 12 HS-485HB servos controlled either by the SSC-32 Servo controller or the PVR board if need be.

Echo's gait was based on a modified butterfly swimming stroke. It would lift each leg individually; rotate forward about the attachment point on Echo's body, then contract to provide traction. Once each leg has moved forward, Echo would rotate each servo attached to the body effectively pulling Echo forward.

Initially turning was achieved by simply stepping forward with the legs on only one side. As time progressed this is to be replaced by a more effective method with the legs on one side stepping forward while the legs on the opposite side step backward enabling Echo to turn further with each turn.

V Sensors

For obstacle avoidance Echo is equipped with three sonar range finders. One LV-MaxSonar-EZ0 High Performance Sonar Range Finder is aimed directly forward along Echo's lateral axis. On either side, set back 45 degrees, is one of two LV-MaxSonar-EZ2 High Performance Sonar Range Finders. This configuration provides Echo with an approximate 140 degree field of sense. The sonar beams overlap enabling Echo to distinguish between a partially obstructed path and a totally blocked path.

For acoustic source location, Echo is equipped with a microphone array consisting of five Knowles Acoustic Electret Condenser Microphones (Model number MD9745APZ-F). These microphones produce an electrical signal in response to acoustic vibrations. These signals are then amplified by a low power, single-supply, rail-to-rail operational amplifiers (TI's MicroAmplifier Series OPA344PA) so as to be detectable. The amplified signals are assigned to an array and then passed to a personal computer via a BlueSMiRF RP-SMA Bluetooth Modem. The computer then runs an algorithm that returns a direction and heading. This direction and heading is then passed to Echo via Bluetooth.

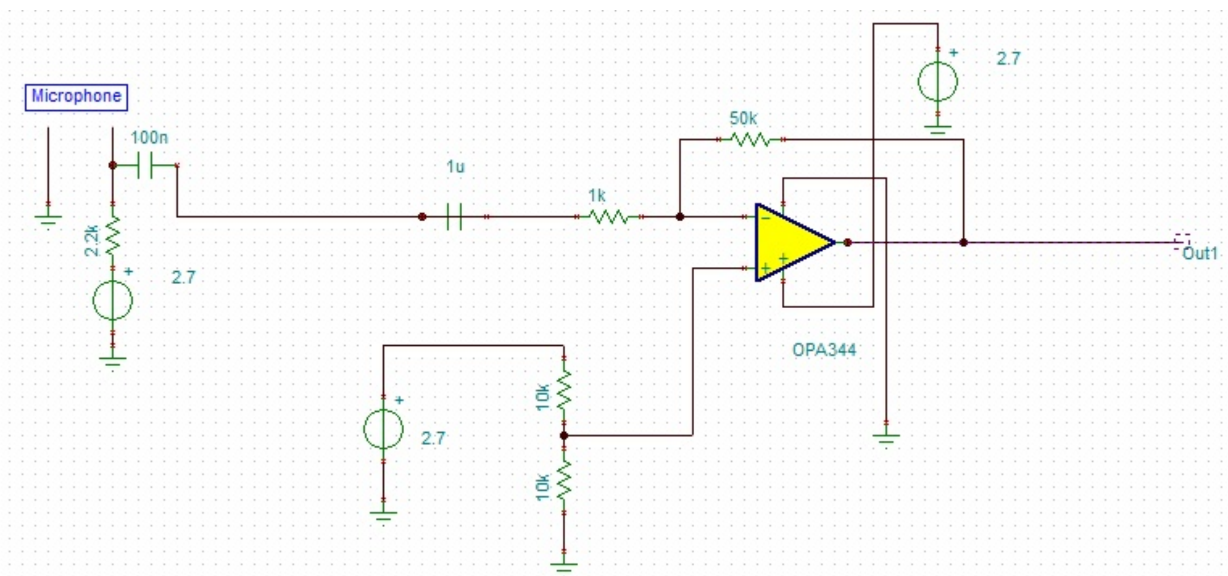


Figure 3: Microphone and Amplifier Circuit Diagram

VI Behaviors

Echo has two main functions, avoid obstacles and acoustic source location. The two are related once Echo acquires the location of a source and then proceeds to avoid obstacles on its way to this source.

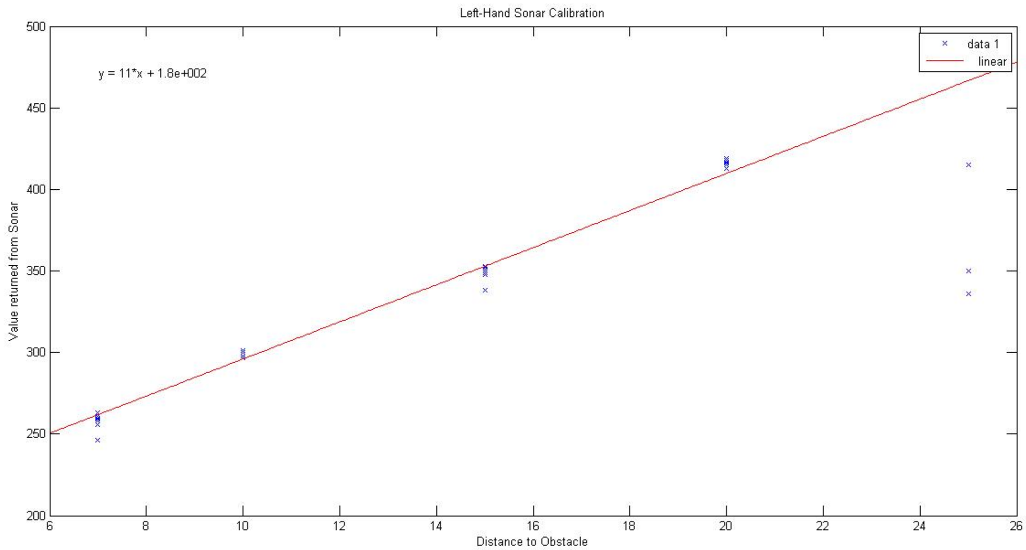
The LCD is an efficient way to provide feedback, especially when other indications of recognition are subtle.

Echo "hears" the world through three sonars. I'm slightly disappointed in the response time of the current sonar routine as Echo appears slow to react to non-static obstacles, such as a person stepping in front of Echo.

Otherwise Echo is a dutiful solider who attempts to locate a sound source and walk to its point of emanation.

VII Experimental Layout and Results

In order to effectively avoid obstacles the sonar needed to be calibrated.



The equation for the best fit line was determined and the voltage output was related to the distance to an obstruction by the equation below.

$$V = 11d + 180$$

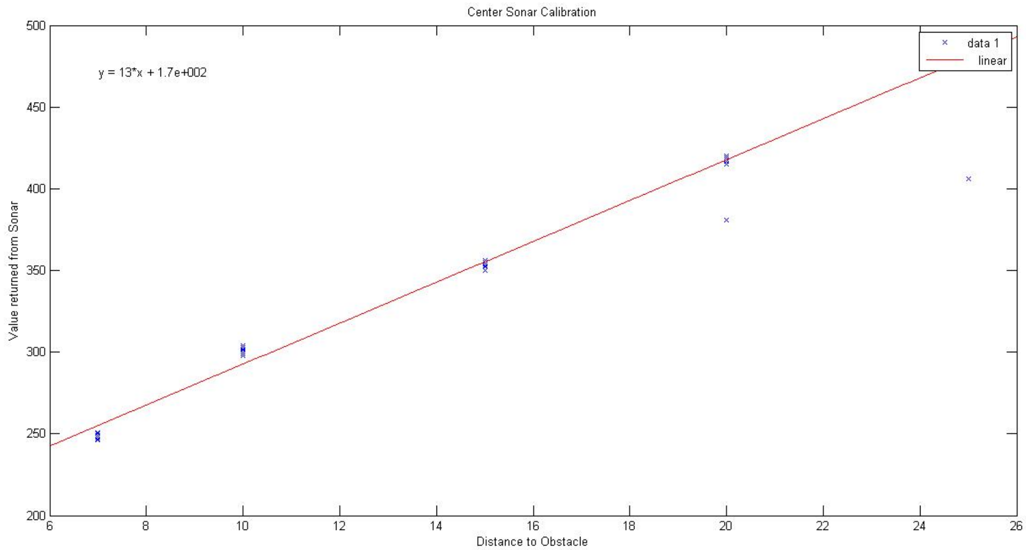
Where d is measured in inches from a wall.

Extrapolating,

At 6 inches V=246, which fits with the measured data for obstacles within the 6 inch range.
At 9 inches V=279.

Therefore the thresholds will set as such.

V=250 is to be set as the red light limit, ideally this corresponds to 6.36 inches.
V=280 is to be set as the yellow light limit, ideally this corresponds to 9.09 inches.



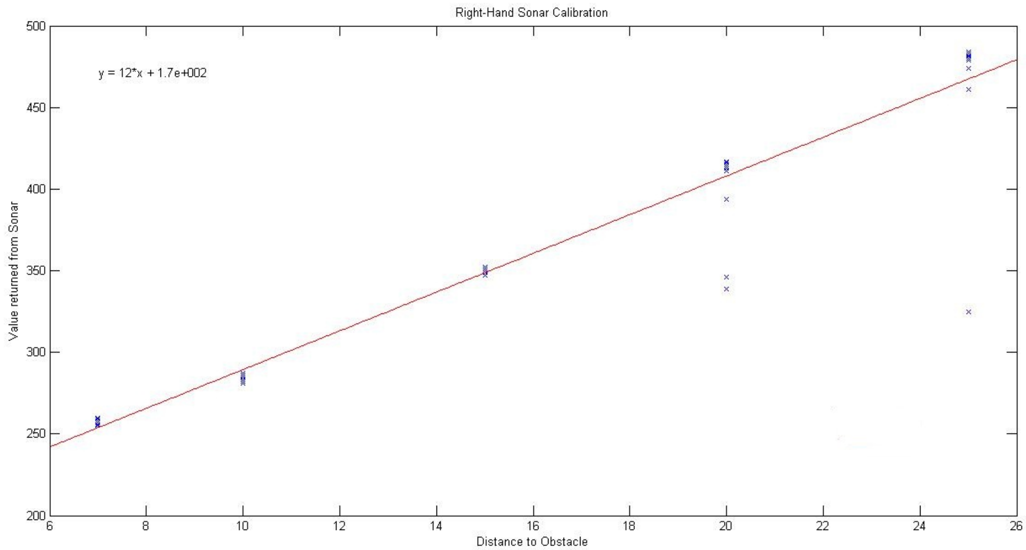
$$V = 13d + 170$$

Extrapolating,

At 6 inches V=248, which fits with measured data within the 6 inch range.
At 9 inches V=287.

Therefore the thresholds will set as such.

V=250 is to be the red light limit, ideally corresponding to 6.15 inches.
V=280 is to be the yellow light limit, ideally corresponding to 8.46 inches.



$$V = 12d + 170 \qquad for\ d > 6\ inches$$

Extrapolating,

At 6 inches V=242, which fits with measured data within the 6 inch range.
At 9 inches V=278.

Therefore the thresholds will set as such.

V=250 is to be set as the red light limit, ideally corresponding to 6.67 inches.
V=280 is to be set as the yellow light limit, ideally corresponding to 9.16 inches.

VIII Conclusion

The term conclusion seems premature at this point. The fact that Echo does not behave as desired indicates that work on Echo has not concluded. Though the class is ending I intend to continue working on Echo until I'm satisfied.

For the class I wish I had devoted my time to either an acoustic source location robot or a walking robot has a combination of the two proved to require more time than the class allotted. Granted in hindsight there was a period of time that I devoted to design deliberation that if I had just jumped in head first could have proved beneficial to completing on time.

As an aerospace engineering student I've experience with the mechanical side of design, but very little with the software and electrical side. During this project that has proved to be my Achilles Heel as it was. In the past my experience with programming was with the FORTRAN language and with MATLAB, this project was my first real experience with programming in the C language. This represented a considerable challenge for me. In addition this was my first experience with micro-controllers, although it will not be my last. This class has instilled in me an interest in a new hobby.

IX Documentation

Data sheets for the components used can be found at the following links

PVR board

SSC-32	http://www.lynxmotion.com/images/html/build136.htm
BlueSMiRF	http://www.rovingnetworks.com/documents/RN-41.pdf
Antenna	http://www.sparkfun.com/datasheets/Wireless/Antenna/DA-24-04.pdf
Servos	http://www.servocity.com/html/hs-485hb_servo.html
Microphone	http://www.knowles.com/search/prods_pdf/MD9745APZ-F.pdf
OPA 344	http://focus.ti.com/lit/ds/symlink/opa344.pdf
Sonars	http://www.maxbotix.com/uploads/LV-MaxSonar-EZ0-Datasheet.pdf http://www.maxbotix.com/uploads/LV-MaxSonar-EZ2-Datasheet.pdf
LCD	http://www.sparkfun.com/datasheets/LCD/ADM1602K-NSW-FBS-3.3v.pdf

X Appendices