Hydrophone*

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ABSTRACT

A requirement for the Naiad AUV (Autonomous Underwater Vehicle) is to have a passive broadband sonar. Also according to the mission specifications of the ROBOSUB competition the AUV is required to listen to a pinger and locate its position. All these functionalities can be implemented using an array of hydrophones. For the Naiad AUV, 4 hydrophones arranged in a rectangular array were used. The Time Difference Of Arrival (TDOA) technique was used to accurately locate the pinger.
The multilateration algorithm takes the time of arrival of the signal at each hydrophone as input and calculates the position of the pinger. A CAN message is sent containing the relative position of the pinger in 3 dimensions.

1. INTRODUCTION

A hydrophone is a device that uses a microphone to listen to sounds under water. Hydrophones are based on the idea of piezoelectric transducers that produce electrical signals in response to a pressure change. As sound is a pressure wave, the hydrophone generates an electrical signal proportional to the amplitude of sound.
For the Naiad AUV it was decided to use an array of 4 hydrophones arranged in a rectangular pattern. The hydrophone circuit amplifies the received signal and then performs full wave rectification. The signal is then passed through low pass filter and through a Schmitt trigger. The result is that it generates pulses when the input signal crosses a threshold.
The hydrophone software uses external interrupts to get triggers from the circuit and records the time the signal arrived. When the signal is received at each hydrophone the multilateration algorithm calculates the pinger location based on the time difference of the arrival of the signal at each hydrophone. It then sends out a message containing the pinger location in 3 dimensions.
The initial plan was to implement the hydrophone software on the Generic CAN Controller. However, the simulations of the multilateration algorithm done in MATLAB showed that the AT90CAN128, which has a maximum frequency of 16MHz, shows that is too slow. Hence the calculated position would have a large error. Thus even though the multilateration algorithm is implemented and tested in Ada, it was not tested on AT90CAN128. Due to the financial situation of the project, it was put on hold.

*This report was written during the fall of 2013 in an advanced level project course at Mälardalen University, Sweden.

2. METHOD

The method used for finding the pinger location is called multilateration. As described in [2], it uses the difference in time at which the signals arrive at each hydrophone to localize the sound source. With the use of 2 hydrophones the location is narrowed down to a hyperboloid. One additional hydrophone gives an extra hyperboloid and the intersection of the two hyperboloids helps narrow down the location of the pinger to a curve. With one more hydrophone, another unique curve is obtained and the intersection of the two curves gives the estimate location of the sound source. The x-,y- and z- coordinates of the pinger are calculated considering one of the hydrophones as the origin.
With [1] as guideline and starting reference, the formulas were derived firstly for the simplest case of hydrophones arranged in a square array. However due to the design constraints of the AUV, the hydrophones could only be placed in a rectangle. Hence the formulas were derived for the x,y and z co-ordinates of the sound source. Afterwords the formulas were simplified so as to avoid float errors. Hence all the quantities are calculated as numerator and denominator and divided in the end.
The inputs to the formulas are:

1. Length and width of the rectangular array of hydrophones.
2. Velocity of sound in water.
3. Time of arrival of signal at each hydrophone.

3. IMPLEMENTATION

The implementation has the following parts :

3.1 Hydrophone array

The hydrophones that have been used in the Naiad AUV are made by Aquarian Audio Products. It has sensor that is capable of picking up sounds from below 20Hz to over 100KHz.

Based on the arrival time of the signals of each hydrophone, the sound source can be able to located. When multiple sound sources are present, a beamforming technique can be used to locate the individual sound sources.
With an array of 4 hydrophones, the sound source can be localized. The arrangement chosen is a rectangular array of hydrophones. The length and width of the rectangle is 20mm and 15mm respectively. Since the hydrophone array should detect sound frequencies of upto 30kHz, and considering the speed of sound in water to be 1500 m/s, the minimum distance between the hydrophones can be calculated by:

$$\frac{1500}{30000 * 2} = 25\text{mm}.$$

The advantages of chosing a rectangular array are:

1. The multilateration algorithm is simplified.
2. It was easy to mount the hydrophones on the AUV.

The disadvantages of the rectangular arrangement is that the accuracy of the algorithm decreases as the source comes closer to the plane of the hydrophones.

3.2 Hydrophone Circuit

The hydrophone circuit includes three smaller circuits, namely:

- *Bridge amplifier circuit.*
- *Low pass filter.*
- *Schmitt trigger circuit.*

3.2.1 Bridge amplifier circuit

The hydrophone circuit is powered by the +12 and -12 Volt feed from the Power supply board. The amplifier circuit used OP amp named OP42GPZ - OP AMP. This op-amp is a fast precision JFET(The junction gate field-effect transistor)input operational amplifier.
According to typical performance characteristics and electrical characteristics, the gain bandwidth of this product is 10 MHz. This band width is suitable for hydrophone circuit. In the rectifier circuit care has been taken to attain a high precision signal by using a Schottky diode, that is characterized by a low voltage drop and fast switching time. The result that has been achieved by using a Schottky diode is more accurate than using other types of diodes.

3.2.2 Low pass filter

Since the low pass filters only allows low frequencies to pass and attenuates frequencies higher than the cutoff frequency,this means that the Hydrophone circuit will pass just a limited range of frequencies to avoid noises or other sounds. Any noise on the hydrophone circuit will decrease accuracy.

3.2.3 Schmitt trigger circuit

The operational amplifier used in the circuit is the TL084BCNG4 - IC, op-amp. This operational amplifier designed with high slew rates 13V/μs, supply voltage +12 and -12 Volt and 3 MHz bandwidth that covers the frequency range of the hydrophone circuit. The Schmitt trigger that will be achieved from circuit will be records the time the signal arrived by the hydrophone software by using external interrupts.

3.3 Hydrophone software

The hydrophone software should accept the pulses generated by the hydrophone circuit as input and output the location of the sound source on the CAN bus. The hydrophone software can be divided into 3 modules:

1. **External Interrupt:** The hydrophone circuit generates pulses when it gets a sound signal that is above the threshold. The hydrophone circuit is connected to the external interrupt pins of the CAN micro controller. The external interrupt is configured to generate an interrupt on the rising edge. The time of the interrupt occurrence and the number of the hydrophone is pushed in a queue. Whenever the read data is called the data is removed from the queue and returned in FIFO order.
2. **Multilateration Algorithm:** The multilateration algorithm is initailized by passing the velocity of sound and the length and width of the rectangular array of hydrophones. After initialization the algorithm is executed by calling the *run* function. The *run* function takes the time of arrival of the signals at the hydrophones as input. Care must be taken to ensure that the order of the time of arrival is correct. For example Ti is the time for the hydrophone at (0,0) while Tl is the time for the hydrophone at (l,b). The algorithm returns the sound source location in x,y and z co-orfinates in millimeters. A boolean variable is also returned to tell if the position is correct or not.
3. **The main program:** The main program initializes the CAN drivers and the external interrupts. It then reads data from the queue of the external interrupts. When it has the data for all the hydrophones it calls the *run* to start the multilateration algorithm. If the valid position is returned it is put out on the CAN bus.

3.4 Multilateration algorithm simulation

Since the clocks in any microcontroller has a maximum frequency,a simulation was done in MATLAB to analyse how the clock resolution effects the algorithm. The simulation takes the following inputs the length and width of the rectangular array of hydrophones, the velocity of sound and the location of sound source in 3 dimensions with one of the hydrophones at the origin. Then it calculates the time it will take for the sound from the source to reach the hydrophones. The time is then rounded off to the desired accuracy (currently it is set to micro seconds). By using the rounded off times the location of the sound source is re-calculated. The errors in the original position and calculated position can be observed.
From the simulations it was observed that the AT90CAN128

which has an external clock of 16MHz is too slow to get a fairly accurate estimation of position.
It was observed that the minimum clock required to have acceptable errors in localization is 1 GHz. Hence the code was not tested on AT90CAN128.

4. RESULT

As mentioned in the previous sections, due to financial constraints and unavailability of the hardware, the complete system was never tested. However the implementation of the multilateration code in Ada was tested by supplying it values for the time it takes for the sound to reach the hydrophones. The values of the times were obtained from the simulation which was done in MATLAB. The multilateration code in Ada was able to locate the sound source. The accuracy of the location depends on the resolution of the clock used to measure the time at each hydrophone.

5. CONCLUSION AND FUTURE WORK

Due to limitations presented in the report, hydrophone circuit was not tested. Multilateration software was tested in Ada on PC. Simulations showed that the 16MHz clock of AT90CAN128 is not fast enough to get desired accuracy in multilateration algorithm.
Future work includes designing the hydrophone circuit with a faster microcontroller with atleast 1GHz clock frequency. The API for multilateration algorithm can then be used in the code for that microcontroller.

6. REFERENCES

[1] R. Bucher and D. Misra. A synthesizable vhdl model of the exact solution for three-dimensional hyperbolic positioning system. *VLSI Design*, 15:507–520, 2002.

[2] Multilateration wiki. `http://en.wikipedia.org/wiki/Multilateration`. Accessed 2014-01-10.