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Characterization and Calibration of Acoustic Radar System and Behavior Testing

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Abstract

Bats are well known for their extraordinary abilities to use and exploit echolocation for both collision free guidance and selection and acquisition of food sources. Less well known are the abilities of blind human echolocation experts who are able to detect and discriminate a vast range of objects. The ultimate purpose of this series of research is to have a better understanding of how the echolocation process is done and extract it to have a direct application in radar and sonar system. A research had already finished building an acoustic radar system to simulate the echolocation process; however, the system was not able to do it yet due to some inside problems. The main purpose of this research is to develop the current acoustic radar system and test its behavior to evaluate it whether the system prepared well for further research based on the ultimate goal. A stable, reliable and well calibrated system is a fundamental to all research related to acoustic radar. This research contains two parts, calibration and characterization of system and test radar system behavior. Firstly, the acoustic radar system needs to be characterized and calibrated to be capable of mimicking signals. Subsequently, a series of tests would be conducted to evaluate whether there is need for a further calibration. The series of tests include noise power test, range test, pulse width test and maximum unambiguous test. Noise power test is the most fundamental test for system noise which needed to be conducted firstly. The function of acoustic radar is to detect the range between radar and system, thus range test is necessary. Because the range is calculated by transmitting acoustic pulse from radar, pulse width is an important parameter need to be tested. The last test is to prove this theory. It could tell whether the radar system working correctly by proving this theory.

Keywords: Acoustic, Radar, Test

1. Introduction

Echolocation is an essential ability of various animals and including humans, although very few individuals are able to conduct “active echolocation”. Echolocation is the ability of sensing sound waves reflected back from objects to determine their location. The sounds wave is a type of mechanical vibration through a medium (such as air, which is the case in this research), which propagating by pressure and displacement. Sound is also known as acoustics, which also includes sound, ultrasound and infrasound.

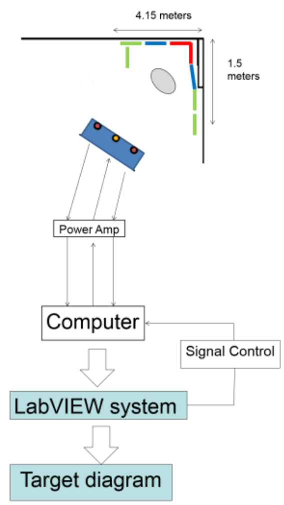
Some animals, such as bats, whale and dolphin, exploit their echolocating abilities to guide themselves to avoid obstacles and to search for food. Among those animals, bat is the most typical example by using ultrasound to guide themselves. Some species of bat have weak sight and others are even completely blind, thus echolocation is an indispensable ability for their survival. On the other hand, less well known example is blind humans. Some blind humans are also experts who are able to detect and discriminate a vast array of objects by using echolocation. Both bats and blind people have the ability to detect different objects; however the accuracy of echolocation identification of human is only 56~86% to bat’s echolocation identification accuracy and is even a little lower than man-made system.

If more details could be found out and system well developed, two improved would happens. Firstly, further research about helping blind humans would be conducted by the acoustic radar system. The study in this field could have a progress. Secondly, man-made system could be improved greatly. As mentioned above, if we could know the bat's echolocation ability better, then we could definitely apply the result to a man-made system.

2. Methodology and Results

2.1 System Design

The radar system contains two parts, hardware equipment and software in the form of the LabVIEW. The configuration of acoustic radar system is shown below in Figure 1.



Legend:

Grey circle	Iron panel, target
Yellow dot	Transmitter
Red dot	Microphones, as receivers
Colorful lines	Absorbers
Blue rectangular	Table

Figure 1: Configuration of Acoustic Radar System and Legend

The LabVIEW system controlled transmitted signal and stored and processed received signals. One transmitter and two receivers were placed in a line, which is orthogonal to the direction between the radar and the target, a panel. A "quiet" corner was constructed by placing foam panels on the wall (These were actually electromagnetic absorber panels, but lab based experiments demonstrated they also worked well at absorbing ultrasound radiation. Power amplifier could amplify both transmitted and received signals. The radar was configured to two receivers and a single transmitter to simulate human's or bat's ears and mouth. To minimize the cross-talk between the transmitter and receivers signal that propagates directly from the speaker to the microphones—sound baffles were placed around the speaker.

2.2 LabVIEW Development

To make the system to be suitable for further research, some significant contributions were made to the system, including increasing stability and controllability and calibrating the cross-correlation output.

2.2.1 increasing stability and controllability

Firstly, controllability was increased by adding more controllable parameters. In a digital system, every sample in a period of transmitted signal needs to be assigned to a certain value. For example, in one PRI, if a total of 2400 samples were detected and 480 of them were assigned by transmitted pulse, thus 1960 samples needed to be padded with zeroes. Next, we set the pulse width as controller in Front Panel in unit of seconds. The number of pulse width samples can be calculated in equation (2), where SR is sampling rate and PW is pulse width. Total samples in one PRI are given in (3). Actual PRF stands for PRF after being calibrated in (4). An indicator was created for maximum unambiguous range in

(5).

$$PW(samp) = PW(sec) * SR(fixed) \tag{2}$$

$$PRI(samp) = [\frac{SR(fixed)}{PRF}] \tag{3}$$

$$Actual\ PRF = \frac{SR\_fixed}{PRF(samp)} \tag{4}$$

$$R_{Max} = \frac{v}{2 * Actual\_PRf} \tag{5}$$

Secondly, system stability was increased by adding an algorithm. Before calibrating the system, when the sampling frequency of the system was set to certain values, the system output appeared to “drift”. That is to say that the peak in the cross-correlation output that indicated a target moved from pulse to pulse, indicative of a problem with the system triggering.

In the National Instrument data acquisition (NI-DAQ) process, analog signals from real world would be converted to digital signals. Data acquisition is a procedure which sampling analog signal. In NI-DAQ process, an actual input of sampling frequency could be revised by a system built-in function; thus, the revised sampling frequency was corresponding to transmitted signals. In the cross-correlation process, because of mismatch between received signal and transmitted signal, the peak would be drifted. In LabVIEW system, input values would be tested and changed by a built-in function when we apply input values to NI-DAQmx.

For example, assume input sampling rate is SR. The testing procedure is given in (6), where Y is integer and z is decimal remainder.

$$Y.Z = \frac{2 * 10^7}{SR} \tag{6}$$

$$SR_{fixed} = \frac{2 * 10^7}{Y} \tag{7}$$

NI-DAQmx will change SR to SR_fixed automatically into system. Because of difference between SR and SR_fixed, peak would shift in the cross-correlation diagram. In this solution, an algorithm was created which is as same as the build-in function before it goes through the build-in function. Thus, Z would be eliminated by the algorithm. Then, it could make sure that when input value goes through the inner function that Z (decimal remainder) would be zero.

As two parts mentioned above converted into LabVIEW interface, the block diagrams is shown in Figure 2.

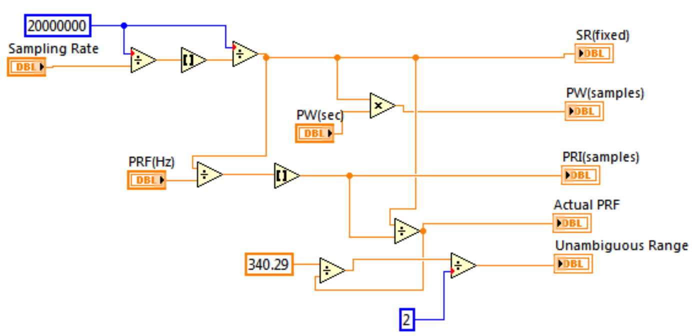


Figure 2: Stability Algorithm and Parameters Calculation

2.2.2 cross-correlation calibration

The idea for cross-correlation in signal processing is to compare the similarity between two signals. The peak occurs when the similarity between the received signal and the transmitted pulse is highest. In LabVIEW, the position in x axis of the peak in cross-correlation results could be the real position of target.

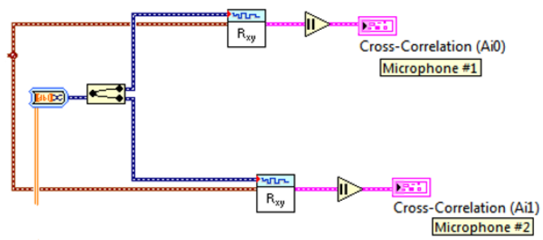


Figure 3: Two Channels Cross-correlation

The red channel is the transmitted signal and the blue channel is the received signal. Before our calibration, the position of x axis was not dynamic, which could not reflect the real position of detected target. Our calibration result is shown in Figure 3, which could reflect real position of target in second. By multiplying half of sound velocity, the x axis could real position in meter.

3. Application and Discussion of Results

After refining the design of the acoustic radar system, a series of evaluation experiments were undertaken. The four tests are, noise power test (I), range test (II), pulse width test (III) and maximum unambiguous range test (IV).

3.1 Noise Power Test

From this experiment, the main purpose is that it should be known whether there was noise coming from the background and if there was noise coming from the digital system (computer or cables lined with computer). If the amplitude of noise was too two high compared with our received signals, then some further calibration needs to be done in our acoustic radar. Thus, system noise needs to be tested and determined whether be in an acceptable range. Before conducting further research, system noise is the first thing that needs to be known. In noise power testing experiment, the testing was conducted under three situations; turn off power amplifier and turn on microphones (I), turn on power amplifier (II) and turn off microphones and turn off both amplifier and microphones (III).

Before testing, an assumption was that the received signal contains two parts. The first part was the echo coming from panel, and the second part was the background reflection. In this test, the amplifier was shut down under testing; instead that pulse was set to 0. When the amplifier did not working, there were no amplified signals transmitted out of amplifier. In other words, there was supposed no echo responses from panel. Thus, the received signal shown in the Table 1 was only outside background noise. When power amplifier was shut down, there was only noise (system noise) going through LabVIEW system. When receivers disconnected, then receivers stop working and no signals could go through those channels. A logical simplified relation is shown in Figure 4.

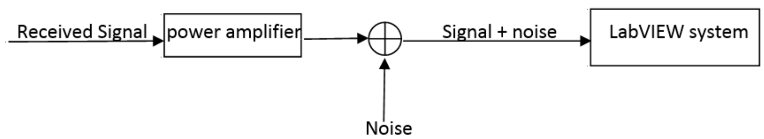


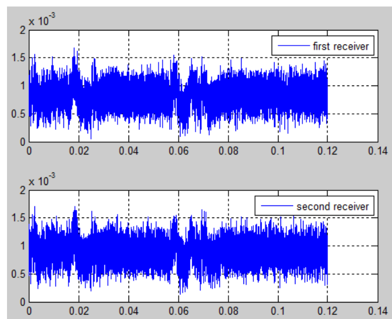
Figure 4: Noise in Receiving Channels

After receiving signal, the noise power is calculated. The calculation is in 2.7 sections.

Table 1: Noise Power and Waveform

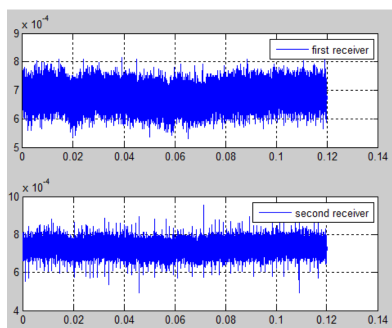
i. Off power amplifier; On microphones

Channel	1st	2nd
Average power /arbitrary linearly	0.21268	0.25098
RMS-value /arbitrary linearly	0.46117	0.50098



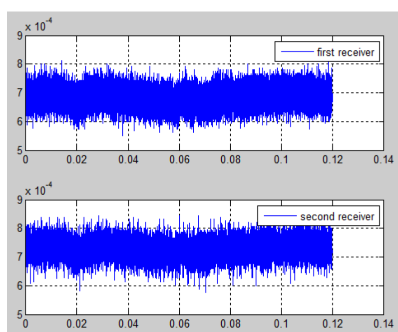
ii. On power amplifier; Off microphones

Channel	1st	2nd
Average power /arbitrary linearly	0.13799	0.15936
RMS-value /arbitrary linearly	0.37147	0.39920



iii. Off power amplifier; Off microphones

Channel	1st	2nd
Average power /arbitrary linearly	0.14000	0.15899
RMS-value /arbitrary linearly	0.37416	0.39873



From the first results, the highest peak around 0.0015, which was smaller compared with regular echo responses amplitude (0.01). Thus, the noises from microphones (receivers on both sides) were acceptable for future experiments.

From the third set of results, even when the amplifier was shut down and disconnected from the two receivers completely, random noise is still showing. In this case, the noise came from the hardware, such as computer, connecting cable or analog-digital converting process.

Compared with first results and third results, there was about 0.09 unit and 0.11 unit noise reduced in first and second channel respectively when disconnected microphones. It proved that even though the amplifier was turned off, the received channel were still connecting inside amplifier; however, it cannot be find that whether amplifying is working slightly or not in both. The received signals are gap proximately equal in two channels.

Compared with second results and third results, two group of RMS values were extremely close, thus, turning off the amplifier has no effect on the received signals. It can be concluded that the two groups of received signals were not being amplified when going through amplifier.

From the above analysis above, there were three conclusions. Firstly, the amplitude of the noise, whether or not from outside background or system, was within an acceptable tolerance. The amplitude of received echo responses were around 0.01 as measured several times before; on the other hand, the highest peak for random noise was about 0.0015 with both system noise and outside background noise. Secondly, when the amplifier was shut down, the received signals were still able to go through the amplifier and go into the LabVIEW system. Thirdly, when turning off the microphones and the amplifier, noise was still in the system. Thus some noise came from the system which was larger than that coming from the background.

3.2 Range Test

In the acoustic radar system, acoustic wave was used to detect range between system and target. The ranging detection was accomplished by measuring time the between transmitting a pulse and receiving its echo response, which is called the timing-lag, t. However, in a real experiment, t is calculated after cross-correlation of the received and transmitted signals. Given a constant acoustic signal velocity, the detected range could be determined by the formula:

$$R = \frac{t*v}{2} \tag{8}$$

In this experiment, it needs to be proved that the real range is equal to the range measured by LabVIEW. The real range is measure by tape; the lagging time is calculated by cross-correlation (position in x axis).

Target was placed in different positions along a line L, and the distance from the center of the panel to the first receiver and the second receiver equaled to each other. The vertical line was determined by the transmitter (middle yellow dot) and the center of panel (center of blue circle). On the other hand, the error could not be eliminated in real testing and it was difficult to set the lines S and L perpendicular to each other. Thus, to fix the problem, L1 and L2 need to be independent and that was calculated to the two detection ranges respectively. Thus, we just need to measure of relative position for the two channels independently.

The detected range by cross-correlation calculation is shown in Figure 6. The peak stands for the target, and the detected range is shows on the x axis (0.44m). However, the digits are not enough to show detected range. Thus, we use MATLAB to measure detected range by plotting the stored data in CSV file.

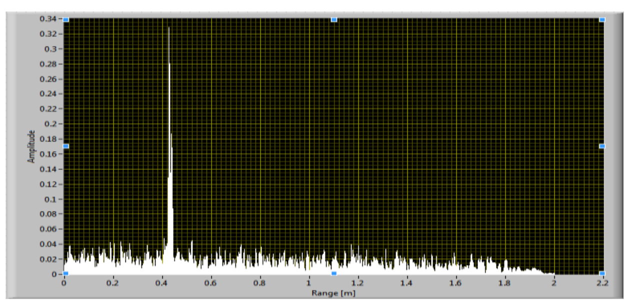


Figure 6: Detected range in LabVIEW Front Panel

An example of a MATLAB plot is shown in Figure 7. Target is marked by the red line. X axis is range in meters; the y axis is the amplitude of the received signals. The position of the vertical line of the waveform along the x axis is the target position, as marked in Figure 7. The waveform is an echo response coming back from the target. In this case, the transmitting signal is up chirp, with a frequency changing from 30000 to 40000 Hz linearly.

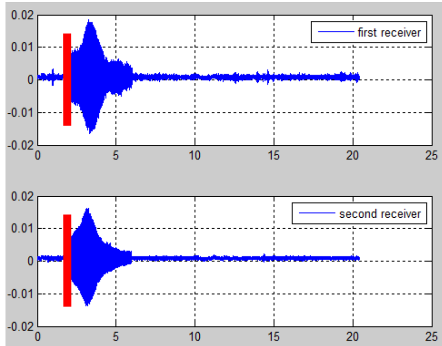
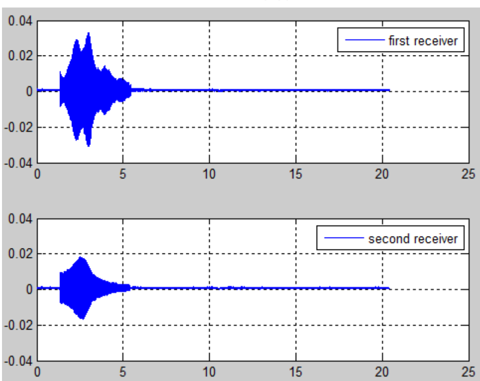
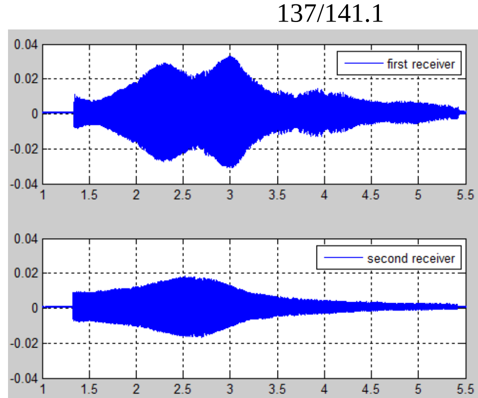


Figure 7: Detected Range by MATLAB Plot

By conducting the experiment, the target (blue panel) was placed at different positions and the ranges were measured using both method. The results are shown below.

Table 2: an example result for measured ranges

Ranges from left channel to target (1st channel)/cm	Ranges from right channel to target (2nd channel)/cm
Received signal from both channel	Zoom-in figures for both channel
135/141	137/141.1
	

From a series of range calculation like the example, as moving further and further away from radar system, the amplitude of received signals got lower and lower. It means that the received signal became weaker when we move target further, because it was more attenuated for acoustic signals than electromagnetic waves propagating through air. Then, the series of range calculation was placed into Figure 8. The x axis is real range and y axis is detected range.

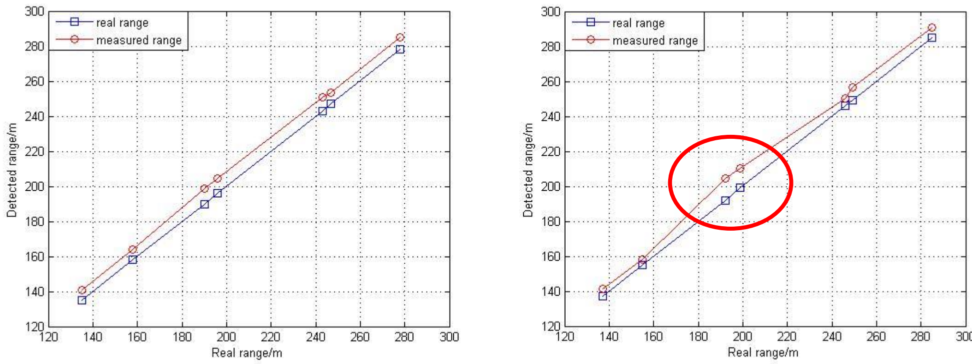


Figure 8: Real Range and Detected Range in Both Channels

The blue line is real range between target and acoustic radar system. Because the blue point is measured by tapes, the values of blue points in y axis are equal to their values in x axis. In other words, the angle between blue line x axis is 45 degree. The blue line is a “standard” line; we use it to compare with detected range. The values for red points in y axis are the detected range and the values for red points in x axis are real range. Red points reflect that the detected range corresponding to the real range. By observing the range-range diagram in both channels, there is a consistent delay in both channels. Furthermore, as marked in second channel, the delay for the real range from 160 to 240 cm, the delay becomes higher than consistent delay in first channel.

In the range testing, it can be concluded that there were consistent delay in both channel; however, the delay in the second channel became higher in some particular position. On the other hand, a further research about the higher delay could be conducted because currently there are not enough data to display how it changes specifically.

As moving target further, received signals became lower. An acoustical wave reflection and refraction could be a reasonable explanation for the phenomenon. Additionally, the amplitude of received signals was higher in the first channel than it in the second channel. There could be two possible reasons. First, a higher power for transmitted signals in first channel could be a reasonable explanation. Second, the angle for the second receiver was not exactly facing on the center of panel.

3.3 Pulse Width Test

In this test, a measurement of received pulse width was undertaken. The testing signal was up chirp. Up chirp is a signal whose frequency increased with time. By testing the pulse width of received pulse, the difference between pre-set value and received pulse could be calculated.

Pulse width of received signal was calculated by measuring plot from MATLAB. In the plot, it could be measured of the position of both tale and head of received pulses by cursor. The pulse width is the difference between two values in x axis. Assume that the position of head is(x_1, y_1), and tale is(x_2, y_2). The example was shown in Figure 6.

Thus, we can calculate Pulse Width: Pulse Width = $x_2 - x_1$

The results of pulse width for both pre-set value and received signal measurement are given below:

Table 3: Pulse Width Comparison

Pre-set Pulse Width /sec	Pulse Width in Channel 1/sec	Pulse Width in Channel 2/sec
0.005	0.00498	0.00497
0.01	0.01001	0.00993
0.024	0.02399	0.02397
0.05	0.04998	0.04997
0.08	0.08001	0.07994
0.1	0.10003	0.10000

In this part, results show that it is only different in fifth digit, when changing pre-set value of pulse width in third digit. The difference between pulse width of received signal and pre-set value changes from -0.7% to + 0.0125%.

Based on the results, one conclusion can be made based on the analysis and results. The absolute value of maximum error in percentage is 0.7%, which is in acceptable tolerance for doing further research based on the same system.

3.4 Maximum Unambiguous Range Test

Last experiment was designed to prove the maximum unambiguous theory. This theory explains the detection of limitation for a radar system. Ambiguous range happens when the target is beyond radar maximum unambiguous range. In this case, radar received the first response, but it had already sent out second pulse. Then, the radar system would identify the response from a second transmitted pulse automatically. Due to the Maximum Unambiguous Range theory, the theoretical equations are shown below. In this test, the equation (9) needs to be proved.

$$R = \frac{v*(i*PRI+t)}{2} \text{ , i=0, 1, 2, 3...} \tag{9}$$

$$R_{Max} = \frac{v*PRI}{2} = \frac{v}{2*PRf}, \tag{10}$$

Among them, R is detected range, when the target is in unambiguous range, I is 0. v is the velocity of the acoustic signal. It is about 340.30m/sec in room temperature. i is a integer when the distance beyond maximum unambiguous range, R_{Max}. t is the detected responding time identified by our system. t is measure between transmitting a pulse and received an echo response.

To increase the distance between target and acoustic radar system, acoustic radar was moved further. In this experiment, target was placed about 250 cm away. The range from target to first reciver was 247 cm and to second receiver was 249.2 cm. Next, we set Pulse Repetition Frequency to 85. The PRF makes Maximum Unambiguous Range to 200 cm by given equation (10), which satisfied to experiment condition. By Cursor measure measurement, we know that the detected range for channel 1 and 2 are 50.81 and 52.6 cm respectively.

From (9),

$$\begin{aligned} R &= \frac{v*(i*PRI+t)}{2} \\ &= i * R_{Max} + R_{Det} \end{aligned} \tag{11}$$

In this experiment, i is equal to 1 because

$$R_{Det} < R_{real} \approx 1 * R_{Max} + R_{Det} \tag{12}$$

The difference between two real range and sum of maximum unambiguous range and detected range is

$$D = (R_{Max} + R_{Det}) - R_{real} \tag{13}$$

Then, we summary two groups of data in two one table:

Table 3: Experiment Data for Both Channels

Channel	Real Range/cm	Detected Range/cm	Maximum Unambiguous Range/cm	Difference
1	247.00	48.81	200.00	1.81
2	249.20	50.60	200.00	1.40

As we mentioned in Range Testing part, there was a slightly difference between detected range and real range. D was caused by system delay.

Moreover, in the peak diagram, there was a peak with a sub-peak showing in first channel, as marked above. By plotting waveform in first channel, the body of waveform had a trough, which is corresponding to sub-peak.

In this experiment, we prove the maximum unambiguous range theory. The results were not exactly as same as the equation (10). The system delay make the ($R_{Max} + R_{Det}$) larger than R_{Real}.

From the sub-peak, any variation in received waveform would connect with the peak value in peak diagram. Additionally, it was correct to measure target range by MATLAB plot rather than cursor in peak diagram, because the location of the peak is not the beginning (head) of waveform. The peak in the diagram is corresponding to the peak of received waveform.

4. Conclusions

In the experiment, the research mainly contains two main parts, system calibration and characterization and behavior testing. In the first part, LabVIEW system was calibration well. In addition, an algorithm in Block Diagram was set up in order to increase controllability and stability. In the second part, we have four experiments to test our system behavior. In the first test, we test noise because noise is the most important for every system. To find out where noise comes from, noise was evaluated under three situations. From the results and analysis, it was concluded that there were two parts of noise. One was from background, the other was from system. In the second experiment, range-detection was tested because the main purpose for every radar system is to measure the range between target and radar. We conclude that there is a consistent system delay for both channels. In third experiment, pulse width was measured and compared. Because acoustic radar system is a pulsed radar system, pulse width is a very important parameter. By comparing measured pulse width and pre-set pulse width, the difference was in acceptable tolerance. In the fourth experiment, maximum unambiguous range theory was proved. In this research, we found out more details about acoustic radar. The testing result shows that the acoustic radar system is qualified to be conducted into more research.

5. Acknowledgement

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