Report for Experiment 0/1

Speed of Sound in Air

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GE:1111 Engineering Computational Problem Solving

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Introduction

The purpose of this investigation was to determine the speed of sound in air using MATLAB. To do this an ultrasonic transmitter and receiver were used which emit/receive sound waves. The emitter was wired to a function generator where 4 pulses of a 10V 40kHz sinusoidal wave was generated. This pulse then was transmitted via the ultrasonic transmitter and then received by the receiver whichs output was hooked up to channel 1 on the oscilloscope. Additionally the oscilloscope had the transmitted signal on channel 2. Additionally an external trigger was applied to the oscilloscope to indicate the sampling start period. Now with the given transmitted pulse and received scope on the oscilloscope one can look at the time delay between the two. This time delay is important as one way to calculate the speed of sound is by taking the travel distance and diving it by time. Therefore by obtaining various travel distances and travel times one could theoretically graph distance over time and perform a linear regression whichs slope is the speed of sound.

During this investigation a procedure similar to this is done throughout experiment 1 the ultrasonic transmitter and receiver are facing each other aligned with a measuring tape. This tape then allows one to find the travel distance and then by counting the number of time slots of the oscilloscope one can find the travel time. This procedure was repeated for a various distances with its respective time recorded. Using this information in MATLAB a linear regression was then created using the polyfit function and the slope of this function was the found value for speed of sound.

The next part of this investigation involved creating an ultrasonic distance sensor based upon a given time input. This setup consisted of a transmitter receiver facing the same way on the same measurement line of the ruler. In order to create this distance sensor the same idea is used as in investigation one except now the unknown value is distance. The speed of sound is known from this first investigation and the time is input although this is twice the time. The reason this is twice the time is this is the time to both transmit and receive therefore the time needs to be over two. Finally this then yields an equation time over two times velocity which equals the distance.

The final part of the investigation involved finding the travel distance based on a different method of the amplitude propagation. Known by the power law power in an area decreases as distance increases. Therefore based on the amplitude one can predict the distance. It is known the amplitude is equal to a constant multiplied by distance to the nth power. Therefore if one collects amplitudes and distances and takes a log of the given equation then a linear fit can be made using polyfit. Then this polyfit can be used to find n and the constant which solves the overall equation.

Results

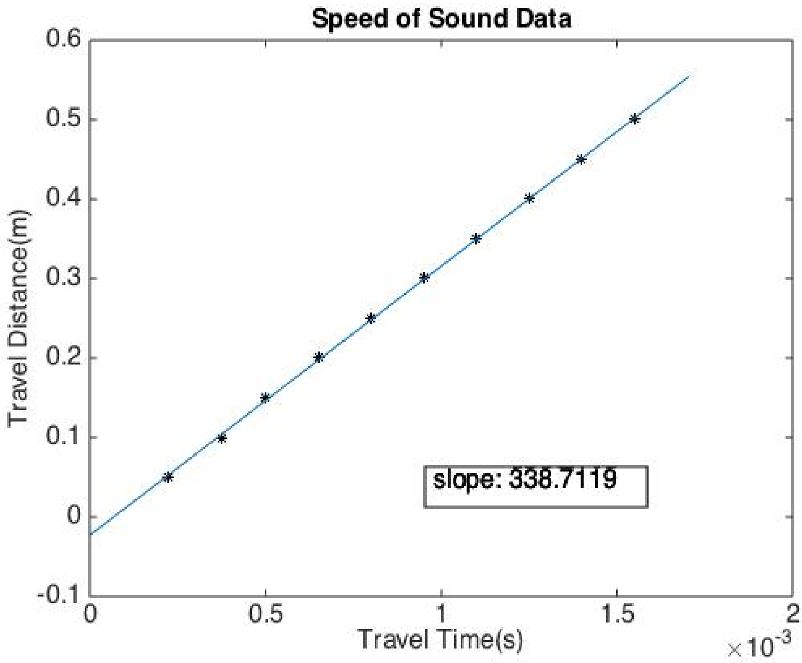

Figure 1: Speed of Sound Data Linear Regression

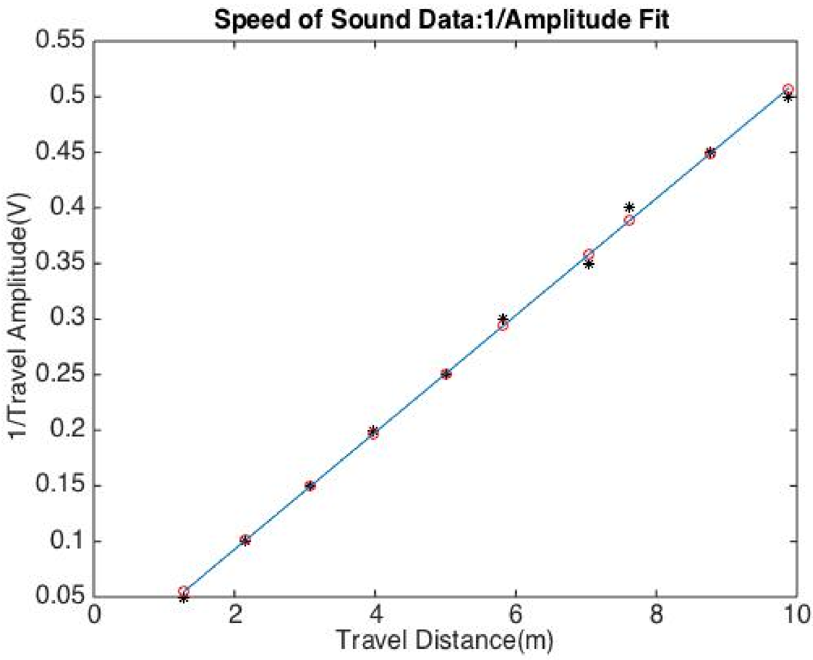

Figure 2: Amplitude/Distance Data Linear Regression(Slope: .0527 B:-.0126

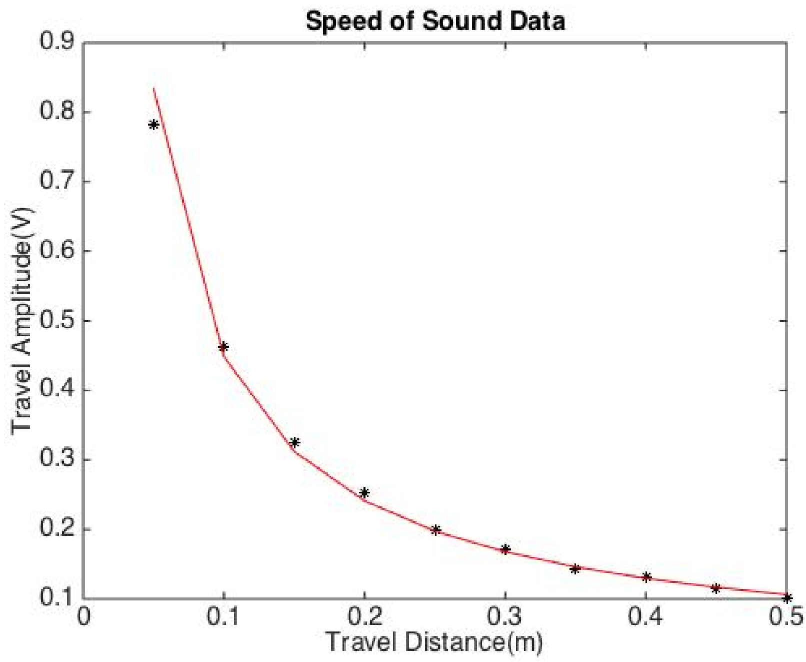

Figure 3: Amplitude/Distance Power Regression(N: -.8951 C:.0571)

Speed of Sound Data		
Time(s)	Distances(m)	P-P Amplitudes(v)
0.8339	0.05	0.8339
0.4484	0.1	0.4484
0.3119	0.15	0.3119
0.2411	0.2	0.2411
0.1975	0.25	0.1975
0.1677	0.3	0.1677
0.1461	0.35	0.1461
0.1297	0.4	0.1297
0.1167	0.45	0.1167
0.1062	0.5	0.1062

Figure 4: Speed of Sound Raw Data Table

Matlab Calculated Values	
Speed of Sound(m/s)(m)	338.7119
Bias in Speed of Sound(b)	-0.0231
1/Amplitude/Distance(v^-1/m)(m)	0.052666
Bias in 1/Amplitude/Distance(b)	-0.0126471
Power Law N Value	-0.8951
Power Law Constant	0.0571

Figure 5: Speed of Sound Matlab calculated values

Figure 1 was plotted in order to find the speed of sound in air by finding the slope of various distances and times this gives velocity. Therefore to find this slope in matlab a vector of distances and times were created and a linear fit was generated as velocity is linear with distance and time. The value for the speed of sound was determined to be $338.71\frac{m}{s}$. Figure 2 was graphed to highlight the relationship between distance and 1/amplitude. Looking at the dots in figure 3 it can be seen that amplitude power decays when compared to distance. Therefore the equation distance=1/amplitude can be generated from that. This mean then that the equation distance equals x where x is 1/amplitude should have a linear fit. This was then tested by graphing distance versus one over amplitude (Fig. 2). Multiple values for the polynomial that fit figure 2 where made although a linear fit did the perfect job to reflect the data(Slope .0527$\frac{V}{m}$). To highlight the fit of the plot red circles are used to represent points on the fit that closely match the values of the given data. Figure 3 was plotted in order to find an alternative way to find distance when compared to amplitude. Since amplitude is power decays when compared to distance the modelling equation cx^ncan be used. Since various distances and amplitudes are known the c and n can be solved. By taking the log of this equation the log of the amplitude should equal the log of c + n times the log of the distance. This closely resembles the equation of a straight line therefore a linear fit of the log of distance and the log of the amplitude should find the constant and n. Once this fit is made the slope represents n and the b factor is the log of the constant. This then gives the modeling equation amplitude equal $e^{log(c)}x^n$ where all the factors are now known.

Analysis

The known value for the speed of sound is 340.28 $\frac{m}{s}$ when comparing this to the 338.71$\frac{m}{s}$ found in the first plot we find these values are very close to each other. Highlighting the linear fit of distance of time does give the velocity for a function. One reason for these values possibly being off is the speed of sound does vary based upon temperature. In the second part of this experiment a distance sensor which predicted distance based on a given time interval was designed and implemented. This was created by multiplying the velocity found of sound found for the first part of this investigation with time over two. The reason time is over two is we only want the distance to the object not to and from. Looking at the one experiential pair for a time of .000650s the distance is .1139m it was actually .1100m. Overall the distance sensor works up to the magnitude of a few millimeters where it begins to lack preciseness. One reason that these values may be off is due to the precision of the oscilloscope time delay.
In the second part of this experiment where amplitude is modeled as a function distance it was found that it does power decay with time. When looking at the optimal polynomial coefficient for modeling distance with 1 over the amplitude it was found that a first degree optimally modeled this situation. This agrees with the real world scenario as distance should be linear with one over the amplitude since amplitude equals constant over distance. The relationship between amplitude and distance is a power law. One expects that constant over distance should be the amplitude therefore a power of one should be used in the equation theoretically. Comparing this to the experimental value of -.89 we find this close to the true value validating the modelling equation. A possible reason that this value may be off is due to the transient noise and not enough points measured in the primary decaying portion of the function.

Conclusions

Through this laboratory investigation the speed of sound was able to be determined using an ultrasonic transmitter and receiver. By determining the time delay at known distances between the transmitter and receiver the speed of sound was able to be determined using a linear regression. Since velocity equals distance over time this then gave the speed of sound found in the experiment to be $338.71\frac{m}{s}$. The true speed of sound is 340.28 $\frac{m}{s}$ this is close to the experimental value although it may have been off due to the factor of temperature which changes the speed of sound. Through this then a practical application of this work was the creation of a distance sensor using this velocity value. By multiplying velocity and time over two the distance then could be determined. This factor of two is present to represent the travel distance not the time of arrival. Using this formula for a time delay of .000650s it was determined to be .1139 m away although in practicality it was .1100. This program did provide resolution to the millimeter range although be off due to the error in the velocity value. This distance sensor created has real application to robotics as they can be readily used to detect obstacles and move around them. Lastly this investigation was able to confirm the power law fit of amplitude and distance. To verify this a fit linear fit was confirmed experimentally also to fit 1/amplitude and the distance. In theory the power of distance should be 1. Although by plotting taking various amplitude and distance pairs and taking logarithms to find the power it was found that the power was .89. This is once again close to 1 although was off due to lack of modelling points for the primary decay of the function. This portion of the experiment has real life applications to the modeling of radio waves trying to figure if a transmission can be heard above the noise level based on the distance.

Questions

1. The transmitted pulse is the blue pulse earlier in time and the received pulse if the green pulse received later in time. The reason I known is the trigger initiates sampling once the transmitter begins sending out a pulse. Therefore the signal closer to the 0 time axes is the transmitted signal. Additionally this then highlights the green signal is the received signal as it takes time to receive the pulse.

2. It take an object about the size of the whole aperture and possibly a little bigger to block the beam. It does not really matter where the object as long as it is blocking the transmitting aperture or receiving aperture it will not receive the signal. The ultrasonic transmitters does behave similarly to that of a laser pointer. The ultrasound gets through some objects as the radiation patter either is larger than that of the object or the sound waves are small enough to penetrate the object.

3. The ultrasound can transmit through different materials it just matters then density of the material.

4. The time delay in these two pulses is .00035 seconds. You measure the beginning of the pulse from the begins transition to zero and the end at point A.

5. The offset between the base and the transducer will not effect the value of the speed of sound as there is a bias included in the fit for the speed of sound.which will account for this factor

6. In this graph x is the time delay, y is distance, m is the speed of sound and b is the bias or error. In figure three b is approximately .2 and m is approximately 320 meters per second.

7.One can find the speed of sound of the excel treadling by looking at the modelling equations slope. This way of modelling is better than just taking one distance value and diving it by a time since it provides multiple values reduces outliers weight in answer, provides an average of all the real calculated speeds of sound for each value therefore a more precise value and provides more true data for analysis.

8. By changing the voltage from 10v to 5v the received and transmitted waves got smaller. This was expected as less energy is sent out which means less will be then received.

9. No the speed of sound does not matter on the wave amplitude the velocity of the medium is constant which is air.

10. The speed of sound velocity does not matter on the frequency of the transmitted wave as the medium will have a constant velocity which is air.

11. One would expect as the energy of the wave spreads out that it will power decay as you get farther from a source. If a wave was sampled at 1 meter from the source it would get $1/100cm^2$ of the wave and then 2m one would find that the received wave from is $.005cm^2$. This can be generalized to the equation energy = constant over distance where n is one.

12. The power relation that is found between distance and voltage is a power of .913. This is consistent with my answer from question 11.

1. The best fit of amplitude and distance in matlab was $.0571x^{-.8951}$ while in excel it was $.0275x^{-.913}$. These values for n are off due to the different ways of calculating the power fit. Also since n is off c will skew due to this factor additionally.
2. Excel probably calculates the value for its power law using a least squares fit which is an overdetermined system which is optimized to fit given constraints of the data.

3. To get a linear regression one would have to plot the natural logarithm of y against x. (polyfit(log(y)/log(exp(1),x,1).

Lab 0

Any introduction for this data has already been done in the first part of this investigation so see above introduction

Results/Analysis

The same procedure done in MATLAB was also done in excel to highlight the different computational tools available to fit data. The speed of sound from excel was found by to be $337.86\frac{m}{s}$ by plotting various distances and times. Comparing this to the oracle value of 340.28 $\frac{m}{s}$ this value isn't far off and only about a $\frac{m}{s}$ of from the matlab calculated slope. The reason for the differences on the matlab and excel slope is each program has a different computational tool used to calculate slope. Additionally in excel various factors of the transmitted wave were changed like the frequency and transmitted power. When halving the transmitted power to 5 V the value of the speed of sound became $333.33\frac{m}{s}$ about 4 meters$\frac{m}{s}$ off from the excel value. Although this does not indicate that the speed of sound changes with time this maybe be due to noise in the data that have skewed the values. Physically the velocity of sound stays the same as the medium determines the sound and not the wave transmitted through it. The speed of sound was determined as 20kHz to be 309.07$\frac{m}{s}$ and 333.33 $\frac{m}{s}$ at 60kHz once again noise could have skewed these values and due to the limited precision of the oscilloscope some time values could be incorrect. Once again stating that the velocity of the speed of sound is not effected by the frequency of the wave. The same algorithm used in MATLAB was also used in excel so for a given for a time delay of .000650s it was determined to be .1139 m away although in practicality it was .1100m. Finally a plot was created for the power law fit of amplitude and distance and the equation was determined to be $.0275x^{-.913}$. In matlab the equation was $.0571x^{-.8951}$ highlight n was off only by .02. The reason that excel and matlab have different values once again is based upon how excel and matlab get there fits. Matlab used a linear fit which was then used to find the values for c and n while excel used least squares and found the governing equation for the overdetermined system.

Conclusion

Overall it was determined the any computational tool can help fit data in order to find if a governing equation does match a factor or not. Excel was a useful tool in this experiment and was able to correctly link the experimental values to the theoretical values. Some reasons for error in these values though were the small precision of the oscilloscope time intervals and additionally transient noise. In the future to reduce this a narrower band pass filter should be placed on the received pulse and additionally the oscilloscope should feature a computer UI for counting time delays.

10V 40kHz Speed of Sound			
Distance(m)	Time(Seconds)	Amplitude Measured(V)	Total delta V
0.05	0.000225	0.3906	0.7812
0.1	0.000375	0.2312	0.4624
0.15	0.0005	0.1625	0.325
0.2	0.00065	0.126	0.252
0.25	0.0008	0.1	0.2
0.3	0.00095	0.08594	0.17188
0.35	0.0011	0.071	0.142
0.4	0.00125	0.06562	0.13124
0.45	0.0014	0.057	0.114
0.5	0.00155	0.05062	0.10124
0.55	0.0017	0.04312	0.08624

Figure 6: Speed of Sound Excel

10V 20kHz Speed of Sound	
Distance(m)	Time(Seconds)
0.05	0.000125
0.1	0.000275
0.15	0.0004
0.2	0.000675
0.25	0.0007

Figure 7: Speed of Sound 10V 20kHz

10V 60kHz Speed of Sound	
Distance(m)	Time(Seconds)
0.05	0.0002
0.1	0.00035
0.15	0.0005
0.2	0.00065
0.25	0.0008

Figure 8: Speed of Sound 10V 60kHz

5V 40kHz Speed of Sound	
Distance(m)	Time(Seconds)
0.05	0.000225
0.1	0.000375
0.15	0.000525
0.2	0.000675
0.25	0.000825

Figure 9: Speed of Sound 5V 40 kHz

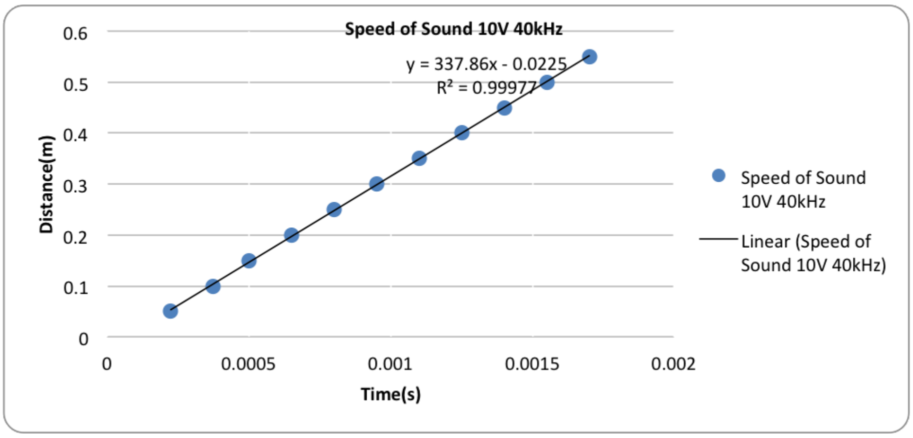

Figure 10: Speed of Sound 10V 40 kHz

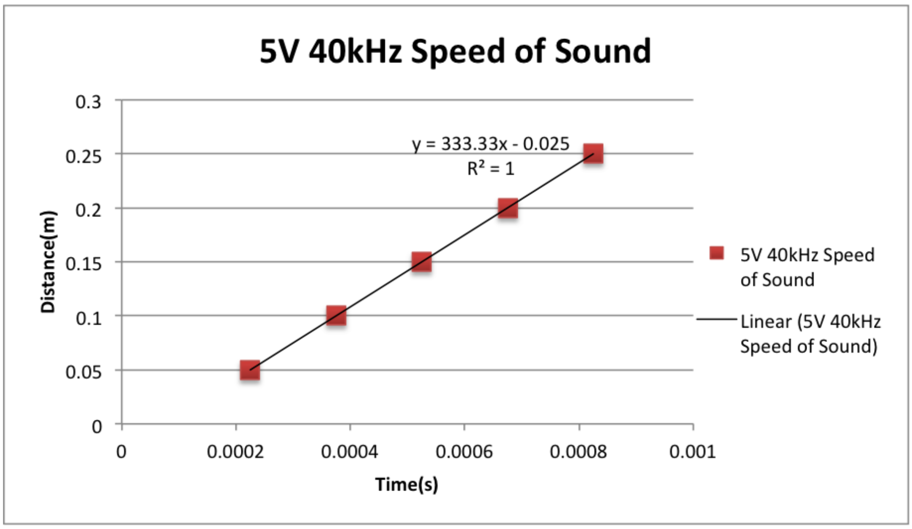

Figure 11: Speed of Sound 5V 40 kHz

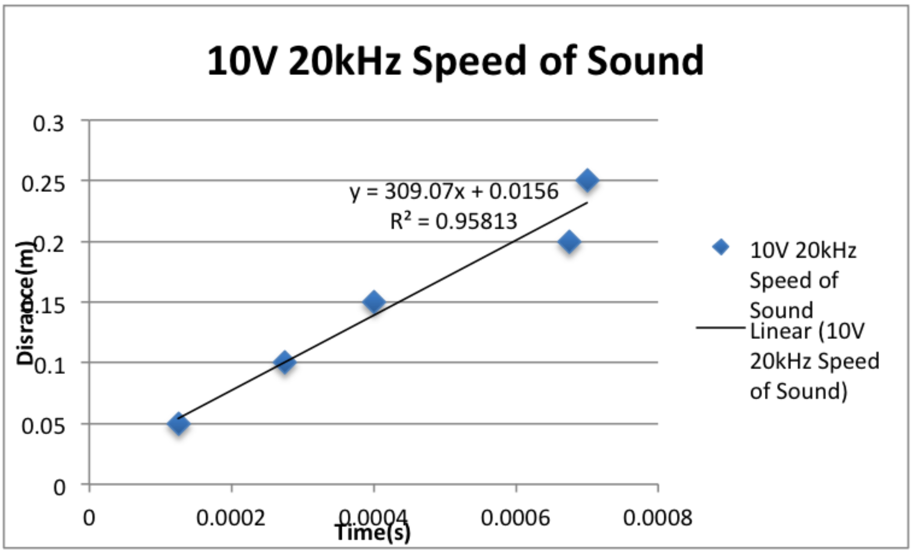

Figure 12: Speed of Sound 10V 20 kHz

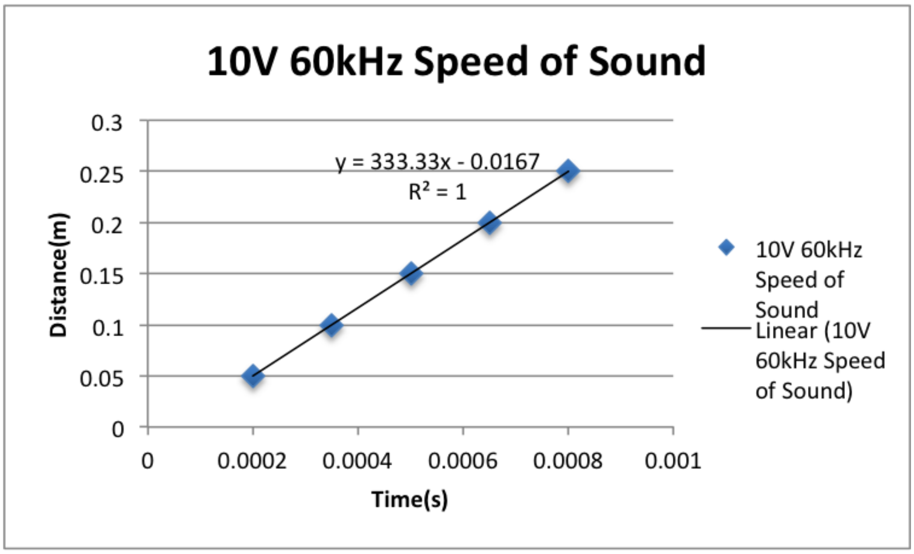

Figure 13: Speed of Sound 10V 60 kHz

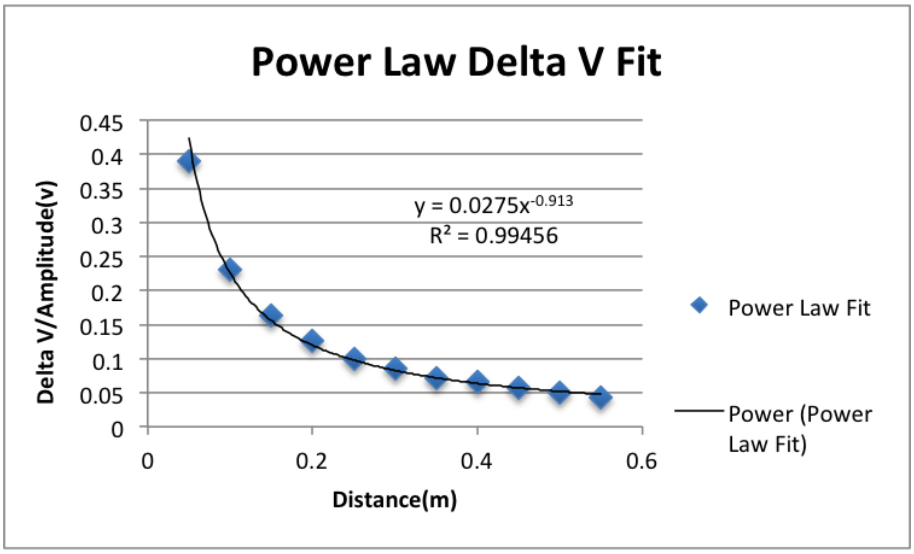

Figure 14: Power Law Fit Distance and Amplitude

Appendices

Matlab Code

```
logC=est3(2);%finds log of c
c=exp(log time=[0.000225 0.000375 0.0005 0.00065 0.0008 0.00095 0.0011
0.00125 0.0014 0.00155]; %time table matrix
 distance=[0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5]; %distance
data matrix
 amplitude=[0.7812 0.4624 0.325 0.252 0.2 0.17188 0.142 0.13124 0.114
0.10124]; %amplitude data matrix
 sosData=[distance; time; amplitude]; % makes a larger matrix out of
the three matrices above
 disp sosData %displays the combined matrix
%plot(time, distance, 'k*'); %plots time v distance with points
 %title ('Speed of Sound Data:     ...');
 %xlabel('Travel Time');
% ylabel('Travel Distance'); % ^^ labels and titles for above plot

 est=polyfit(time, distance, 1); %creates a best fit line
 polyval(est, time); % evaluates best fit line values
 Time=[0:110]*max(time)/100; %creates time axis for plot


 %Finding the velocity
 plot(time, distance, 'k*', Time, polyval(est, Time)); %plots values
above
 set(gca, 'FontSize', 16);%Titles Plot
 title ('Speed of Sound Data', 'FontSize', 16);
 xlabel('Travel Time(s)', 'FontSize', 16);
 ylabel('Travel Distance(m)', 'FontSize', 16);
 annotation('textbox', [.5 .2 .1 .1], 'String', ...
                   ['slope: ',num2str(est(1))], 'FontSize', 16);


 est=[est(1),est(2)]; %linear regression

 figure %Add in mutiple plots
plot(time, amplitude, 'k*');%Plots Amplitude and TIme to see relation
title ('Amplitude vs. Time');%Tites Plot
ylabel ('Amplitude ');
xlabel ('Time');

%Part 6 PolyVal fit increasing m although m=1 is best
x=1./amplitude;%creates a vector of 1 over all the values of the
amplitude
est2 = polyfit(x,distance,1)%fits a linear regression to this data
figure%Add in mutiple plots
plot(x,distance, 'k*')%Plots the data
figure%Add in mutiple plots
plot(x,distance,'k*',x,polyval(est2,x),'or',x,polyval(est2,x),%Plots
the regressione evaluted at selects points
set(gca, 'FontSize', 16);%Titles Plots
 title ('Speed of Sound Data:1/Amplitude Fit ', 'FontSize', 16);
 xlabel('Travel Distance(m)', 'FontSize', 16);
 ylabel('Travel Amplitude(V)', 'FontSize', 16);
```

```
n=est3(1);%Finds N through this
logC=est3(2);%finds log of c
c=exp(logC);%finds c by taking e^log
amp=c*(distance.^n)%Tests modeling using expemiental data

plot(distance,amplitude,'k*',distance,amp,'r')%Compares real data to
model
set(gca, 'FontSize', 16);
 title ('Speed of Sound Data', 'FontSize', 16);
 xlabel('Travel Distance(m)', 'FontSize', 16);
 ylabel('Travel Amplitude(V)', 'FontSize', 16);


C);%finds c by taking e^log
amp=c*(distance.^n)%Tests modeling using expemiental data

plot(distance,amplitude,'k*',distance,amp,'r')%Compares real data to
model
set(gca, 'FontSize', 16);
 title ('Speed of Sound Data', 'FontSize', 16);
 xlabel('Travel Distance(m)', 'FontSize', 16);
 ylabel('Travel Amplitude(V)', 'FontSize', 16);
```

Distance Sensor Code

```
time=input('Enter value for time (s):') %user imputs value for time in
seconds
range=est(1)*(time/2)-.01; %halves time value as this is the time to
and from the object and * by velocity of sound in air
disp('Range (m) =') %display range calculation \/
disp(range)
```