

LADAR Basics

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TABLE OF CONTENTS

		<u>Page</u>
I.	Introduction.....	1
II.	Background.....	1
III.	Objectives.....	2
IV.	Hardware Characterizations.....	2
	A. APL-1.....	2
	B. DAQCard 700.....	6
	C. Sagebrush Model-20.....	7
V.	LADAR System.....	8
	A. Description.....	8
	B. Function.....	8
	C. Sample Data.....	11
VI.	Conclusion.....	13
Appendix A: APL-1 Log Sheets		
Appendix B: DAQCard 700 Log Sheets		
Appendix C: Sagebrush Model-20 Log Sheets		

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1.	THOR.....	1
2.	APL-1.....	3
3.	DAQCard 700.....	6
4.	Sagebrush Model-20.....	7
5.	APL-1 LADAR System.....	8
6.	Exact Scan Program Input/Output.....	9
7.	Continuous Scan Program Input/Output.....	9
8.	Non-XYZ Roof Data.....	10
9.	True XYZ Roof Data.....	10
10.	Photograph of Roof.....	11
11.	Non-XYZ Short Range of Roof with Colored Range.....	11
12.	True XYZ Long Range Scan of Roof.....	11
13.	Photograph of Aquila UAV Radar Antenna.....	12
14.	Non-XYZ Scan of Radar Antenna with Colored Range.....	12
15.	True XYZ Scan of Radar Antenna.....	12

I. Introduction:

Laser detection and ranging, known as laser radar or LADAR, is a technology that uses laser light to measure the distance to an object. LADAR works on the principle that when light is shined onto an object a portion of that light is reflected back. The time between when the laser is fired and when the reflected light is received is used to determine the distance away a target is. The distance away can be modeled as a point in space. If the laser is scanned over an entire object a 3D image, or point cloud, of the object can be created. A 4D image of the object can be created if intensity is factored into the equation. The intensity is measured by the amount of light reflected back to the receiver.

II. Background:

LADAR is currently being developed and tested for use by the United States Army. In military use, a LADAR system can be integrated into a missile seeker. The LADAR in the seeker will continuously scan the area in front of the missile. The point cloud created by the LADAR can be analyzed by a computer in the seeker to determine if any known objects are in the field of view. The computer compares the point cloud to a database containing friendly and enemy targets. The seeker can be either set up to scan everything until it locates any enemy target or it can be setup to locate only a particular target. Once the seeker has found the target it is looking for the LADAR data is transmitted to the ground station and a soldier verifies that what the LADAR sees is actually what the soldier is looking for. Once the target is verified the soldier can deliver the command to destroy the target. This setup is known as man in the loop (MITL) and is used to verify that the correct target is being destroyed.



Figure 1. THOR

An example of a seeker currently under development is the Tactical Hardware and Operational Refinement (THOR) seeker system. The THOR seeker system uses a 1064 nm laser beam that is divided into multiple beams of near equal power by going through a binary diffraction grating (BDG). The single beam is divided into multiple beams so the scan can be done in a shorter period of time. The beam is scanned across an area using a

two-axis gyro stabilized gimbal and an elevation scanner. The elevation gimbal is used to set the depression angle and stabilization during the scan. The azimuth gimbal and the elevation scanner work together to scan an entire area. The amount of time it takes to scan an entire area is approximately one second, but varies depending on the desired field of view.

III. Objectives:

The main objective of this paper is to teach someone with no experience in LADAR the basics of LADAR systems. This will be done by using the APL-1 (a laser rangefinder) in conjunction with a pan and tilt gimbal and a data acquisition (DAQ) card. This paper will thoroughly characterize each piece of equipment separately. After the equipment is characterized it will be tested to further determine how it operates and how well it will operate in the LADAR scanner configuration. Log sheets for the tests performed can be found in appendices A, B and C. In the end, the APL-1 will be used with the DAQ card and the pan and tilt gimbal to make a laser radar scanning system. The LADAR scanning system will produce a 3D image that can be rotated and viewed from all angles.

IV. Hardware Characterizations

A. APL-1

1. Description

The APL in APL-1 stands for Applied Physics Lab and goes along with the idea of it being designed primarily as a research tool. The APL-1 was designed by H.N. "Buck" Burns. Buck Burns is the president of H.N. Burns Engineering Corporation, a company that specializes in laser radar analysis and design. The APL-1 is a laser rangefinder. The difference between a laser rangefinder and a LADAR scanning system is that a laser rangefinder can only see the single spot it is pointed at while a LADAR scanning system can see the entire area in front of it. A LADAR scanning system uses a scanner to move the laser beam up, down, left and right, giving it a wide field of view. While the APL-1 is only a laser rangefinder, with the help of a Sagebrush Model-20 and a DAQ system it can be used as a laser radar scanning system.



Figure 2. APL-1

The APL-1 is setup as a bistatic laser rangefinder. This means that the transmitter and receiver are not located at the same point. Unlike the monostatic system, where the transmitter and receiver are at the same point, the bistatic system requires focus adjustment for best results. The bistatic system is also limited on minimum range since the gap between the transmitter and receiver is more significant as the target moves closer, eventually causing the beam to not reflect into the receiver.

The laser in the APL-1 is a Class I laser and considered to be eye safe with the transmitter lens on. If the transmitter lens is off it is a Class III laser and is not considered eye safe. The APL-1 uses a 905nm wavelength InGaAs laser with a beam divergence of 3.3 mr. (milli-radian) and a peak power of 1.25 watts. The pulse repetition rate of the laser can be either internally or externally triggered with TTL level signals. If the internal triggering is selected a clock pulse of approximately 1 KHz from a 555 timer wired as an astable multivibrator will be used. The laser outputs a 20ns pulsewidth (FWHM, Full Width Half Maximum) on every rising clock pulse.

The APL-1 optical receiver uses an EG&G C30902E silicon avalanche photodiode (APD) to receive the reflected photons. The APD circuitry includes a temperature-compensated bias supply circuit and a low-noise transimpedance amplifier (Signetics NE5212). The APD has an active diameter of .5mm with a receiver lens that has a 75mm focal length. This yields a field of view (FOV) of 6.67 mr. In order to have a constant APD gain over temperature, the APD bias voltage must be increased by 0.7V/deg Centigrade. The APD bias circuit uses an LM355 to detect temperature. The LM355 is a precision Kelvin thermometer with a scale factor of 10 mV per degree Kelvin. The temperature offset is applied to the APD gain along with the slope and offset bias through a series of operational amplifiers and transistors.

The power supply on the APL-1 takes an input of 12 volts and generates plus-and-minus 5 volts for the logic circuits and plus-and-minus 12 volts for the analog circuits. It also makes the high voltages required by the laser transmitter and APD bias circuits.

2. Function

The APL-1 determines the distance away an object is by using time of flight (TOF). TOF is the amount of time between when the laser beam leaves the transmitter to when it enters the receiver. Using the speed of light the TOF can be converted into a distance. In order to determine the TOF, the APL-1 generates a start and a stop pulse. When the laser in the APL-1 turns on it draws a large amount of current. A current sensor detects this current and sends a start pulse to the range counter module at almost precisely the time the laser is turned on. The laser outputs a 20 ns wide pulse and turns off again. This pulse is output through the transmitter lens and goes on to the target. The beam hits the target and a portion of the transmitted photons bounce back to the APL-1. The reflected photons go through a spectral filter which filters unwanted light, such as solar rays. After the spectral filter the photons go through the receiver lens and into the APD laser detector. The APD outputs an electrical signal that is dependent on the amount of photons received. This electrical signal then goes through the transimpedance amplifier, video amplifier (gain of 21), and the threshold detector. The threshold detector compares the receiver's signal and generates a stop pulse when the voltage goes over a certain threshold (normally 20 mV to 40 mV). When the received signal goes over the threshold voltage a stop pulse is sent and the TOF is determined.

The range counter module in the APL-1 measures time between the start and stop pulses and outputs an analog voltage proportional to the distance to the target. The range is determined by an analog value output at the range output on the APL-1. The range output is linear and outputs 10 volts for maximum range. The maximum range is selectable via 2 dip switches to 100, 1,000 or 10,000 meters by setting both switches to position 1, 2, or 3 respectively. These switches change the resistor and capacitor values, changing the time constant of the RC circuit, which changes the maximum range. If the received pulse is valid (within range) the internal piezoelectric speaker will make a short beep

3. Inputs & Outputs

Laser Current Out – This outputs the current used by the laser in a ratio of 1 volt per watt. Measure this signal with an oscilloscope.

Laser Trigger Out – This is a TTL level output that shows the laser trigger clock. If the internal trigger is being used, this will output the clock produced by the 555 astable multivibrator circuit. If the external trigger is being used it will output the external clock source. Measure this signal with an oscilloscope.

Ext Trigger In – This is a TTL level input that triggers the laser to pulse.

Rx Out – This is the inverted output of the optical receiver after it has gone through the transimpedance amplifier. The non-inverted output goes on to the video amplifier. The inverted output can be observed here and not disturb the non-inverted output. Measure this signal with an oscilloscope.

APD Bias Out – The APD Bias voltage is available for observation on this connector. This signal can be measured with a voltmeter.

Post Amp Out – This is the output of the optical receiver after it has gone through the transimpedance and video amplifiers. Measure this signal with an oscilloscope.

Threshold Out - This is the threshold voltage output. This voltage is nominally between 20 and 40 mV. This signal can be measured with a voltmeter.

Stop Pulse Out – This is the output of the ECL-level stop pulse. Measure this signal with an oscilloscope.

Ramp Out – This is a buffered version of the voltage on the range ramp capacitor. Measure this signal with an oscilloscope.

Range Out – This voltage is an analog indication of the distance to the target. The output is linear with a maximum of 10 volts. This signal can be measured with a voltmeter but is best viewed on an oscilloscope using the strobe output as a trigger.

Strobe Out – The strobe signal is a TTL-level, 40 ns pulse that indicates the ranging event has been completed and that the analog range voltage is stable and ready for digitization. Factory set as negative going, but has been changed to positive going by changing the position of the jumper W1 on the range counter card. Measure this signal with an oscilloscope.

Range Valid – The range valid signal is a TTL-level signal that indicates whether a valid laser return was sensed during the range gate interval. Logic high indicates a valid return. Measure this signal with an oscilloscope.

Range Gate – The gate signal is an ECL-level signal used to observe the range gate circuit function. The gate signal goes from ECL high to ECL low when the laser is fired (start pulse) and returns to an ECL high when the maximum range is exceeded or when a stop pulse is received, whichever comes first.

4. Laboratory Tasks

- Set Maximum Range
- Check Power Supply
- Verify Specifications
- Alignment & Focusing
- Range & Slope Adjustment
- Time of Flight Accuracy
- Laser Trigger Delays
- Use APL-1 With External Trigger

- Find Minimum Range
- Find Maximum Range

B. DAQCard 700

1. Description

The DAQCard-700 is made by National Instruments. The card has 8 digital outputs, 8 digital inputs, and 16 analog inputs. The analog to digital conversion used on the card is successive approximation. The card also has three clocks that are programmable and can be used for a variety of purposes. The card connects to a computer via PCMCIA.



Figure 3. DAQCard 700

2. Function

In order to log the APL-1 data on a computer, it needs to be hooked up to a DAQ card. The outputs that need to be read from the APL-1 are the range voltage and the strobe. The range voltage is the voltage output that corresponds to the distance away the target is. The strobe output is a 40 nanosecond pulse that lets the user know when the range voltage is ready. The DAQCard 700 will be used to monitor the range and strobe output of the APL-1. Using these two outputs an accurate range reading will be taken using the DAQ card.

3. Software

The DAQCard 700 will be controlled using a C++ program. All of the interfacing to the card is provided by National Instruments in header files. The NI-DAQ help provides all of the information needed to use the National Instruments functions correctly.

4. Laboratory Tasks

- Analog & Digital Read Times

- Clock Tests
- Analog Conversion Accuracy

C. Sagebrush Model-20

1. Description

The Sagebrush Model-20 is the pan and tilt gimbal that will be used to turn the APL-1 laser range finder into a laser radar. The Model-20 uses a stepping motor system with an accuracy of 0.1 degrees and a slew rate of 60 degrees per second. It is designed for payloads of 20 pounds or less, so it will have no problem with the APL-1. The Model-20 is controlled through the serial port of a PC.

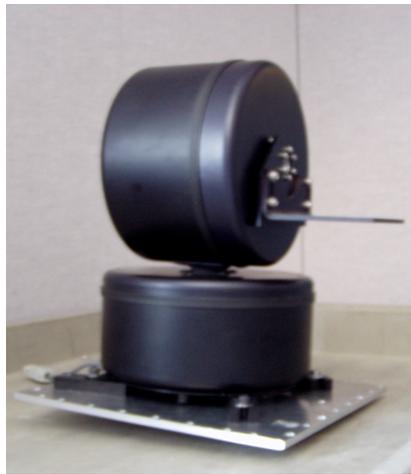


Figure 4. Sagebrush Model-20

The Model-20 is not designed to scan over an entire area, which is what it will be doing in this setup. The Model-20 is designed more for applications such as positioning a camera and other tasks that are not time critical. For this reason the scan times will be very long.

2. Function

The Model-20 comes in two versions, one that uses a stepper motor and one that uses a servo. The Model-20 being used in this paper is the stepping motor version. This version uses a stepping motor to move the elevation and azimuth gimbal. The Model-20 has a home location which is located at 0 azimuth, 0 elevation. In order to move the gimbals to other locations the Model-20 is told through software to move to positions that correspond to the number of steps required. For instance, azimuth 100 would be 100 steps away from home azimuth. There are approximately 197 steps in every degree, so 100 azimuth would move the gimbal approximately one half of a degree from the home position.

3. Laboratory Tasks

- Control Model-20 With Computer
- Test Model-20 Accuracy
- Test Model-20 Speed

V. LADAR System

A. Description



Figure 5. APL-1 LADAR System

The LADAR system consists of the APL-1, the Sagebrush Model-20, the DAQCard 700, a Dell Inspiron 9100 laptop, and a tripod. The APL-1 is mounted to the Sagebrush with 2 bolts. The Sagebrush is mounted to an aluminum plate with 4 bolts. This plate is mounted to the tripod. The APL-1 and the Model-20 both have their own power supplies. One dual power supply could be used in the place of the two. The Model-20 is controlled through the computer's USB port using a USB to serial converter. The DAQCard 700 is connected to the computer through a PCMCIA slot. The APL-1 is connected to the DAQ with strobe pulse connected to pin 45 (Clock2), and the range output connected to pin 5, analog input number one.

B. Function

The APL-1 LADAR system scans in two ways. The first way is for the Model-20 to move a small amount, stop, take a range reading and repeat until the scan is complete. This way of gathering data is time consuming but accurate. The range data can also be averaged over several pulses to help with the accuracy. The user can specify the exact angular elevation and azimuth resolution in this way also. The series of questions asked by the program is shown below.

```

How would you like to scan? Enter a 1 for continuous or a 2 for exact.
2
Enter the depression angle in degrees:
-4
Enter the degrees of elevation to be covered: (1-70)
10
Enter the degrees of azimuth to be covered: (1-360)
30
Vertical Lines:
20
Horizontal Lines:
60
Average range data over how many pulses? Enter a 1 for no averaging.
30

Calculated Angular Azimuth Resolution: 8.727 milliradians.
Calculated Angular Elevation Resolution: 8.727 milliradians.

Scanning_

```

Figure 6. Exact Scan Program Input/Output

The second way of gathering data is to have the Model-20 move across the entire azimuth without stopping and take range readings the entire way across. The position of the Model-20's azimuth and elevation are recorded using a function in the C++ program. Once the azimuth has reached one limit, the elevation will increase by the given amount and the azimuth will pan to the other azimuth limit. The second way of gathering data is almost three times faster than the first. Because the Model-20 never stops moving during data acquisition this way, the data cannot be averaged and readings may not be as accurate. Because the range data is taken as the Model-20 is panning, the angular azimuth resolution is not a set rate. It depends on the speed of the computer, how fast the DAQ card can do analog to digital conversions, how many degrees per second the Model-20 is set to move, and the pulse repetition rate of the APL-1. The series of questions asked by the program is shown below.

```

How would you like to scan? Enter a 1 for continuous or a 2 for exact.
1
Enter the depression angle in degrees:
-4
Enter the degrees of elevation to be covered: (1-70)
10
Enter the degrees of azimuth to be covered: (1-360)
30
Vertical Lines:
50
Gimbal speed in degrees per second (1 - 60):
30

Calculated Angular Elevation Resolution: 3.491 milliradians.

Scanning_

```

Figure 7. Continuous Scan Program Input/Output

When taking range data the DAQCard 700 is used. When the LADAR program is ready to take a reading of the range voltage the DAQ's clock 2 is used. The counter in clock 2 is preset to a number. Each time the clock 2 input receives a clock pulse this

number is decremented. The strobe pulse is connected to the clock 2 input. In the LADAR program, the counter of clock 2 is continuously read until its number is decremented. Immediately after this decrement the range voltage conversion is processed and stored. This yields a time of less than 500uS from the strobe pulse to a completed conversion and ensures that our range voltage was converted while it was still stable.

In the LADAR program Gnuplot is used to view the LADAR data while a scan is still in progress. After each completed horizontal scan, all of the data taken so far is output to a Gnuplot script. This Gnuplot script is automatically opened in Gnuplot after the first horizontal row is completed. At the end of the Gnuplot script is code that tells Gnuplot to pause for two seconds and re-read the file. This causes the 3D image made by Gnuplot with the LADAR data to be continually updated and viewable during a scan. After the LADAR scan is complete, the LADAR data is saved into the file that is being continually read without the re-plot script at the bottom. Because the re-plot script is no longer in the data file, Gnuplot plots the data one final time and stops.

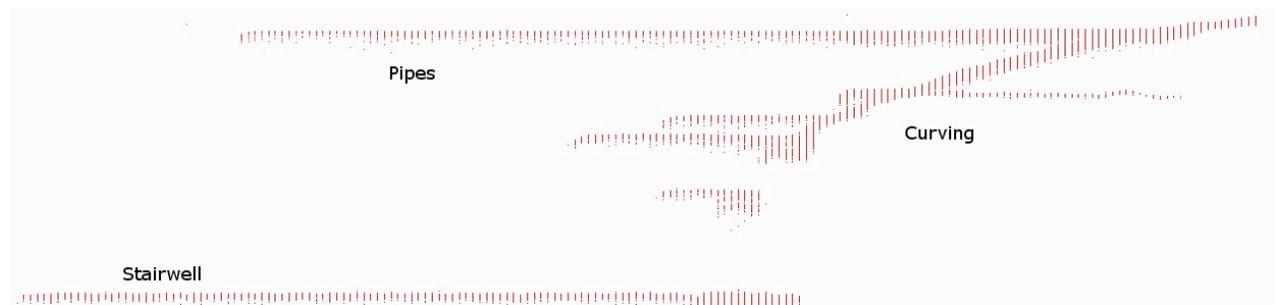


Figure 8. Non-XYZ Roof Data

If the LADAR range data is simply plotted in a Cartesian system the picture will be distorted. The image is incorrect because the LADAR range data is plotted without taking into account the angle that range was taken at and determining the true XYZ of that point. Not converting the data to true XYZ causes some objects to be the incorrect size and causes flat surfaces to curve. Figure 8 is a scan of a roof (tilted 90 degrees counterclockwise) in uncorrected form. Notice how the roof curves drastically. Also notice how the pipes that are close to the LADAR are seen as taller than the stairwell on the opposite side. By using trigonometry, the true XYZ coordinates of the point from the APL-1 can be determined. When in true XYZ the X, Y and Z coordinates will give the distance away the point is from the origin for each of the axes. In this particular setup that distance is given in meters. Notice the true XYZ scan of the roof in figure 9.



Figure 9. True XYZ Roof Data

C. Sample Data



Figure 10. Photograph of Roof

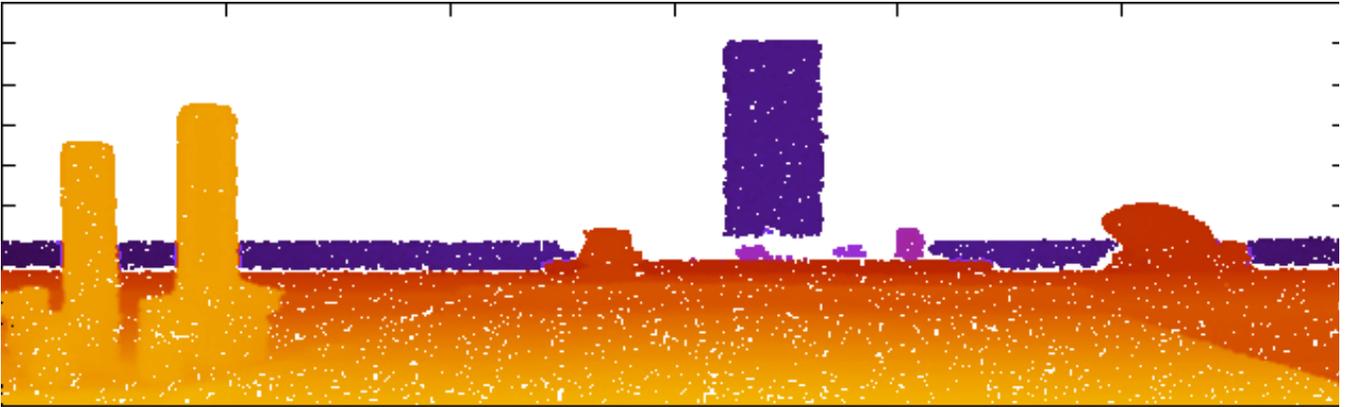


Figure 11. Non-XYZ Short Range Scan of Roof with Colored Range

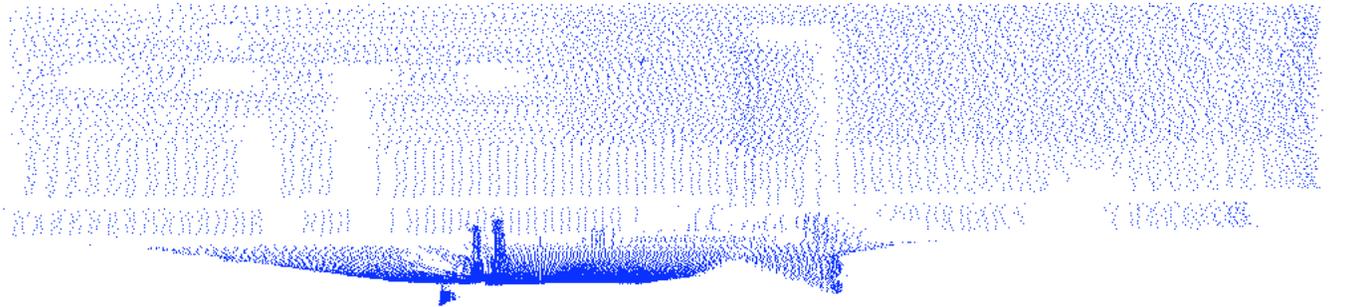


Figure 12. True XYZ Long Range Scan of Roof



Figure 13. Photograph of Aquila UAV Radar Antenna

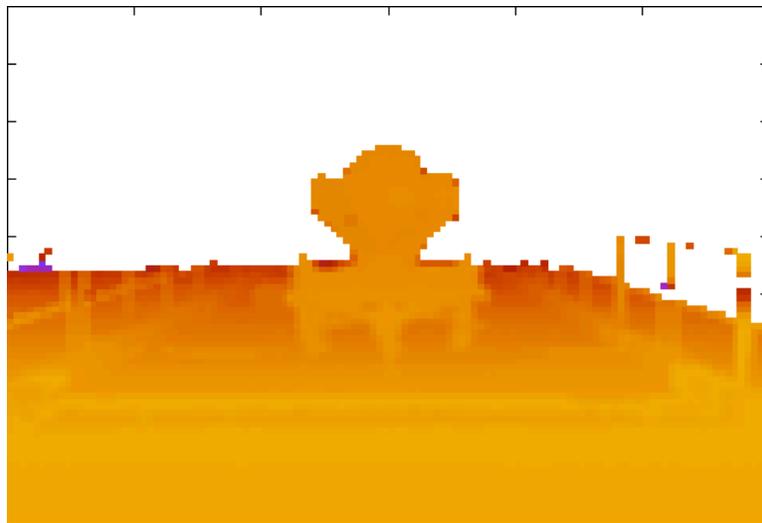


Figure 14. Non-XYZ Scan of Radar Antenna with Colored Range

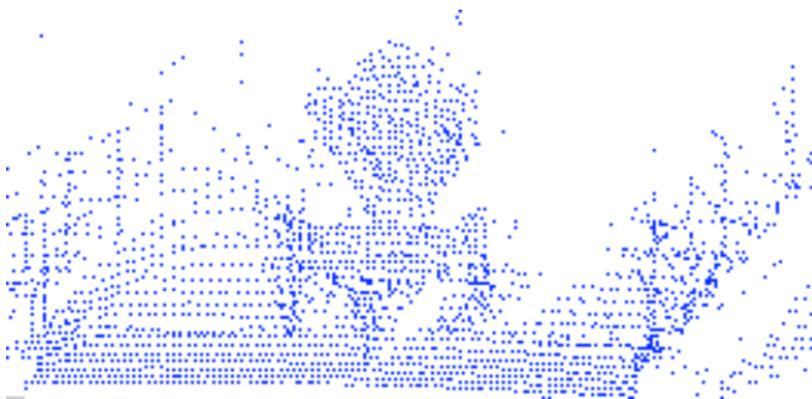


Figure 15. True XYZ Scan of Radar Antenna

VI. Conclusion

The APL-1 a good learning tool for someone who is new to laser radar. Being able to view the signals throughout the circuitry is very helpful for both learning about laser radar and debugging problems. For instance, in the middle of this semester the APL-1 stopped receiving any signals. By checking all of the outputs to see if they were working properly I was able to determine that the problem lied in either the APD or the transimpedance amplifier. The APD is what receives the returned laser light and outputs a current that is equal in proportion to the amount of photons received. This current goes through the transimpedance amplifier where it is converted into a voltage. At the output after the transimpedance amplifier no return pulse was being received. I could not determine whether it was the APD or the transimpedance amplifier because I could not view the received signal before it went through the transimpedance amplifier. After checking to make sure that the laser was working and checking that the transmitter and receiver lenses were aligned and focused the APL-1 was sent to H.N. Burns Engineering Corporation where the transimpedance amplifier was replaced.

While the APL-1 is a good learning tool, it is not as accurate as some laser rangefinders. In Appendix A I have all of the laboratory tests done with the APL-1. The sixth test was testing the time of flight. The TOF was usually off by several meters from the true distance. This is caused by a variety of things, one being that the pulsewidth of the laser is 20 nS. That means that the laser puts out a pulse that is approximately 6.5 meters wide. Because the pulse is so wide, where the pulse crosses the threshold can vary by several meters, causing the TOF error.

The National Instruments DAQCard 700 worked well as the DAQ in this LADAR setup. The analog to digital conversion time could have been faster, but it worked with its current speed. The biggest time consumer is using clock 2 to determine if a strobe pulse has occurred. A DAQ that has digital inputs that can detect pulses lower than 40 nS would be ideal for use with the LADAR.

The Sagebrush Model-20 works well as a pan and tilt gimbal. However, it simply takes too long to complete a scan of a large or high resolution area. The Model-20 would not be practical for use in a missile equipped with LADAR. The theoretical maximum speed of the Model-20 is 60 degrees per second. The Model-20 never actually achieves this speed because the stepper motor must start and stop slower to maintain accuracy. Because the steps taken in a high resolution scan are so small, the stepper motor never actually achieves maximum speed. For comparison the maximum speed of the scanner in THOR is over twenty times faster.

Given more time there are several improvements I would like to make to the LADAR software. For instance, the program I wrote to control the LADAR works, but the code could be cleaned up quite a bit. I would also like to change my command line program into a Windows program. I am not happy with the way the data is viewed during a scan. While it is a nice feature, Gnuplot does not display the axes equally and

the picture can be very distorted at times and hard to tell what it is. In order to view the image correctly I have to load it into MATLAB using another script and equalize the axes using the MATLAB graphing software. I would like to either find a way to equalize the axes in Gnuplot or display the live data using a different program. I would also like to make the live data display have colored range data. This would make the image easier to view and less rotating and tilting would be needed to determine what the image was. I would have also liked to make the data taken with this setup viewable in some of the LADAR department's software such as ALF Viewer and LADARVis.

Overall, I am happy with the results of my LADAR tests using the APL-1, the DAQCard 700, and the Sagebrush Model-20. I learned a lot about laser radar, programming, problem solving, and the engineering world in this summer co-op semester.

Appendix A: APL-1 Log Sheets

**H. N. Burns Engineering Corporation
Laser Product Compliance (21 CFR 1040.10)
Test Data**

General Information

Product Name Laser Radar
 Model No. APL-1 Serial No. 3
 New Repair
 Laser Type diode Laser Wavelength 904 nm
 Beam Divergence $\theta_L = 0.5 \text{ mrad}$
 $\theta_H = 34 \text{ mrad}$ Beam Diameter at Exit Aperture 20 mm x 42 mm
 Customer _____ Job No. _____

*Class I
R00*

Laser Beam Parameters

	Total Output	Thru 7 mm aperture 20 cm from source
1. Emission duration (s) <u>continuous</u>		
2. Repetition rate (pps)	<u>903</u>	
3. Peak power (W)	<u>492</u>	<u>1.24 (calculated)</u>
4. Pulse width (s)	<u>20×10^{-9}</u>	
5. Energy/pulse (J)	<u>9.85×10^{-8}</u>	<u>2.48×10^{-8} (calculated)</u>
6. Average power (W)	<u>89×10^{-6}</u>	<u>22.4×10^{-6}</u>
7. Scan rate (scans/s)	<u>-</u>	<u>-</u>
8. Effective rep rate (pps)	<u>-</u>	<u>-</u>

Test Equipment

	Model No.	Mfg. Serial No.	Calib. Due Date
Oscilloscope	_____	_____	_____
Frequency counter	_____	_____	_____
Peak power meter	_____	_____	_____
Average power meter	<u>Newport 1830-C</u>	<u>8582</u>	<u>8/13/00</u>

Tests Performed By R. A. Olson **Date** 8/6/99

Laboratory Task #1: Set Maximum Range

When experimentation with the APL-1 begins the maximum range should be set to 100 meters. In order to do this two switches on the range counter module need to be set.

- Make sure the power is off.
- Ground body to get rid of any static charge.
- Remove the legend plate
- Remove any screws holding the range counter module in place.
- Grasp the range counter module by the SMA connectors and pull it out of the chassis.
- Set both dip switches to the proper setting. (position one for 100 meters)
- Place range counter module back into chassis.
- Replace the screws holding the module in place.
- Put the legend plate back in place and screw on.

Equipment Used:

APL-1 Laser Rangefinder SN: 003

Results:

Switch #1 Setting: 1

Switch #2 Setting: 1

APL-1 Maximum Range Setting: 100 m

Notes:

APL-1 was previously set to 100 and is currently set to 100 meters of maximum range.

Tests Performed By: Adam Thole

Date: June 1, 2006

Laboratory Task #2: Check Power Supply

The power supplies, both external and internal, should be checked before use to make sure they are working properly.

- Make sure power switch is in the off position and the APL-1 is not plugged in.
- Make sure the transmitter and receiver lens caps are on.
- Unscrew and remove the power supply cover plate.
- Turn on DC power supply and set output to 12 volts.
- Using a voltmeter measure the output voltage to make sure it is close to 12 volts.
- Plug the power cord into the APL-1 and flip the power switch to the on position.
- Using a voltmeter record the transmitter and receiver high voltages.
- Check the 5V and 12V voltages.
- Flip the power switch to the off position.
- Replace the power supply cover plate and screws.

Equipment Used:

APL-1 Laser Rangefinder SN: 003
Fluke 26 III Multimeter
Tektronix PS280 DC Power Supply

Results:

Power Supply: 12.3 V
Transmitter Voltage: 105.6 V
Receiver Voltage: 210.4 V

+5V: 5.26 V
-5V: -4.98 V
+12V: 12.18 V
-12V: -12.60 V

Notes:

The internal voltages have no line regulation. For that reason, the input voltage should be a regulated source, which is why a DC power supply is being used instead of a wall adapter. A wall adapter was used early on, but caused the range voltage to be unstable.

Tests Performed By: Adam Thole

Date: June 1, 2006

Laboratory Task #3: Verify Specifications

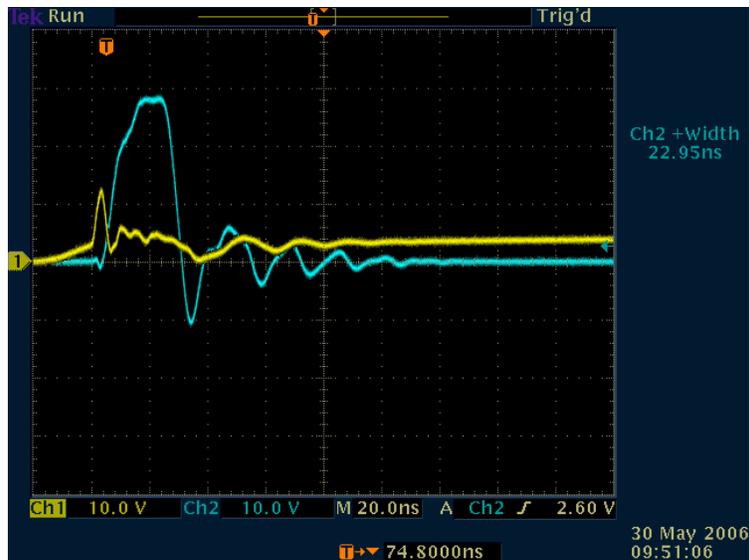
In this task the pulsewidth, internal clock pulse frequency, and peak laser power of the APL-1 will be verified.

- Connect channel one of the oscilloscope to laser trigger out.
- Connect channel two of oscilloscope to laser current out.
- Connect channel three of oscilloscope to the laser power meter.
- Flip the trigger switch to internal triggering.
- Plug in APL-1 and flip power switch to the on position.
- Look at the laser current output on the oscilloscope and record the pulsewidth.
- Look at the laser trigger output and record the clock pulse frequency.
- Place the power meter in front of the transmitter and record the peak laser power.
- Flip the APL-1 power switch to off.

Equipment Used:

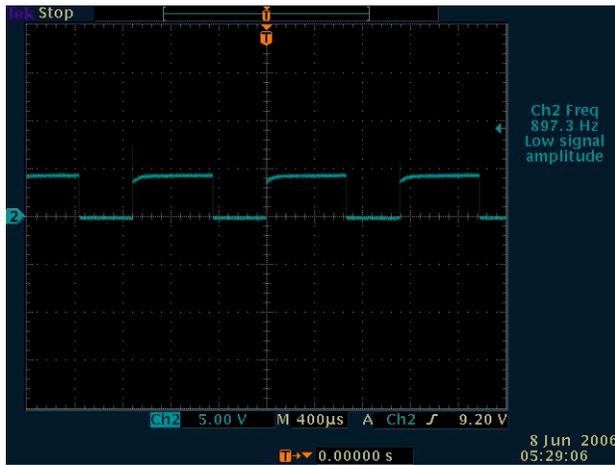
APL-1 Laser Rangefinder SN: 003
Textronix TDS 3034 Oscilloscope SN: B018486
CAL-1 Laser Power Meter SN: 10117

Results:

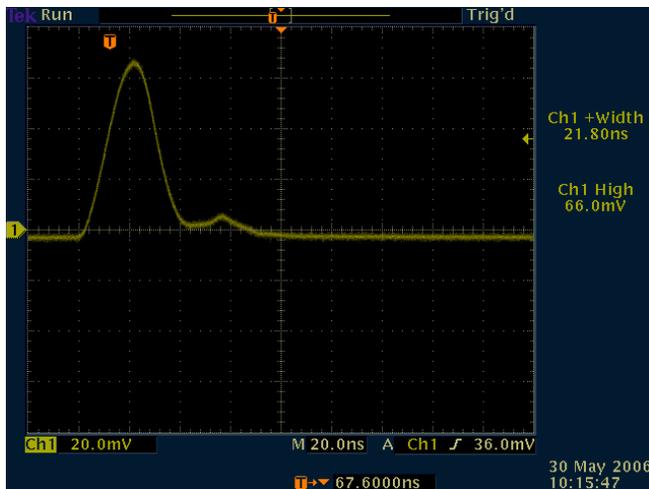


Pulsewidth: 22.95 nS (20nS, datasheet)
Pulsewidth (blue) and laser trigger (yellow)

Laboratory Task #3: Verify Specifications



Internal Clock Frequency: 897.3 Hz (800 Hz - 1 KHz , datasheet)



Peak Laser Power: 8.5 W (1.25 W, datasheet)

The CAL-1 used for this measurement outputs 129 watts per volt. Therefore, in the above capture the laser had a peak output of 8.5 W.

Notes:

The peak laser power computes to be higher than 1.25 Watts, coming in at 8.5 W. One possibility of why the measured peak power is so high is because the CAL-1 has not been calibrated in approximately seven years. It is still unclear at the time of this writing why the peak laser power is so high.

Tests Performed By: Adam Thole

Date: June 1, 2006

Laboratory Task #4: Alignment & Focusing

The transmitter, receiver and scope all need to be aligned and focused for easy targeting and best results.

- Setup a target in the general range the APL-1 will be used.
- Setup APL-1 on a tripod pointing towards the target.
- Flip the trigger switch to internal triggering.
- Flip the sound switch to on.
- Turn on the visible laser pointer.
- Remove transmitter and receiver lens covers.
- Plug in APL-1 and flip power switch to the on position.
- Using an IR viewer position the APL-1 so the laser beam can be seen on the target.
- Adjust the focus of the transmitter lens until the laser beam is as clear as possible.
- Adjust the focus of the receiver lens until the APL-1 is outputting a tone of approximately 1 KHz. When the APL-1 is pointed towards something out of range the 1Hz tone means that the APL-1 is receiving only one point of bad information for every 1000 points received (when the laser is being internally triggered with the 1 KHz clock pulse). The bad point could be due to internal or external noise.
- Adjust the visible laser pointer to line up with the 910 nm laser by adjusting the two screws.
- Adjust the scope until its view is centered on the laser beams.
- Point the APL-1 at a target that is well out of range and adjust the threshold potentiometer until a tone around 1 Hz is heard.
- Turn off visible laser pointer.
- Flip the APL-1 power switch to off.

Equipment Used:

APL-1 Laser Rangefinder SN: 003

Electrophysics Electroviewer Series 7215 IR Viewer SN: 35172

Results:

Notes:

The laser was easily focused using an IR viewer. The receiver was focused by adjusting for the best tone. The red laser was centered on the IR laser by adjusting the screws. The scope was already lined up with the lasers.

Tests Performed By: Adam Thole

Date: June 1, 2006

Laboratory Task #5: Range and Slope Adjustment

To get an accurate and linear range reading the offset and slope potentiometers need to be adjusted.

- Find two identical targets.
- Place one target at the maximum range of the APL-1.
- Place second target at ten percent of the maximum range of the APL-1.
- Setup the APL-1 on a tripod pointing towards the target at maximum range.
- Connect a multimeter up to the range output of the APL-1.
- Flip the APL-1 trigger switch to internal triggering.
- Adjust the slope potentiometer until the multimeter reads 10 volts.
- Point the APL-1 towards the target at ten percent of maximum.
- Adjust the offset potentiometer until the multimeter reads 1 volt.
- Point the APL-1 at the maximum range target again and repeat the adjusting steps until they are accurate.
- Flip the APL-1 power switch to off.

Equipment Used:

APL-1 Laser Rangefinder SN: 003
Fluke 26 III Multimeter SN: 77941050

Results:

The offset potentiometer of the APL-1 used for testing does not work. Adjustment of the offset potentiometer did not affect the range voltage at all. The slope potentiometer worked well and the range voltage was fairly accurate with adjustment of only the slope potentiometer.

Tests Performed By: Adam Thole

Date: June 7, 2006

Laboratory Task #6: Time of Flight

In this test the time between when a laser beam begins its path to when it is received will be observed. This is called the time of flight, or TOF. Using the TOF the distance a target is from the APL-1 can be determined. The TOF will be compared to the range voltage output and it will be determined which one is more accurate.

- Set up targets at known ranges.
- Hook up channel one of oscilloscope to the range output.
- Hook up channel two of oscilloscope to the strobe output.
- Flip the APL-1 trigger switch to internal triggering.
- Point APL-1 towards a target and turn on.
- Record the voltage value of the range output at the point where the strobe signal has a 40 ns pulse. This is the stable range output.
- Convert that range voltage (RV) into range and record.
- Hook up channel one of oscilloscope to the range gate signal of the APL-1.
- Using the oscilloscope record the TOF.
- Convert the TOF from nS to meters traveled and record
- Which is closer to the actual distance TOF or RV?
- Turn off oscilloscope and APL-1

Equipment Used:

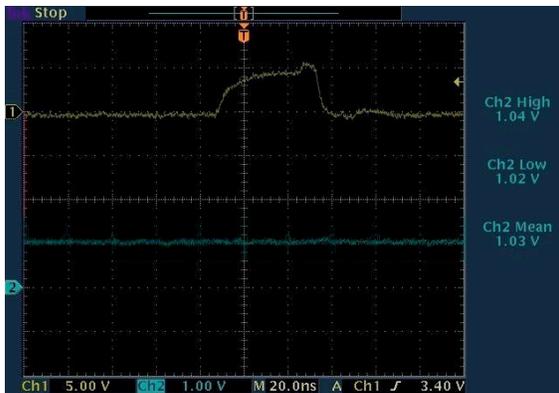
Textronix TDS 3034 Oscilloscope SN: B018486
APL-1 Laser Rangefinder SN: 003

Results:

Target 1:

Actual Distance: 10 m
Range Voltage: 1.03 V
Range (RV): 10.3 m

Time of Flight: 85.08 nS
Range (TOF): 12.75 m
Most Accurate: Range Voltage

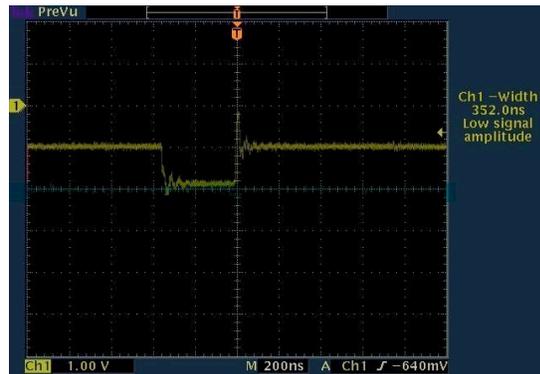
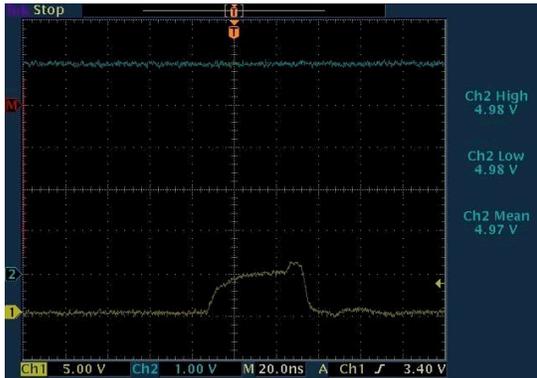


Laboratory Task #6: Time of Flight

Target 2:

Actual Distance: 50 m
Range Voltage: 4.98 V
Range (RV): 49.8 m

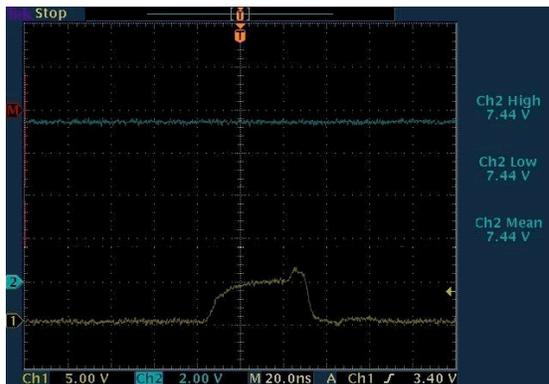
Time of Flight: 352.0 nS
Range (TOF): 52.76 m
Most Accurate: Range Voltage



Target 3:

Actual Distance: 75 m
Range Voltage: 7.44 V
Range (RV): 74.4 m

Time of Flight: 522.8 nS
Range (TOF): 78.37 m
Most Accurate: Range Voltage



Laboratory Task #6: Time of Flight

Target 4:

Actual Distance: 100 m

Range Voltage: 10 V

Range (RV): 100 m

Time of Flight: 699.0 nS

Range (TOF): 104.78 m

Most Accurate: Range Voltage



Notes:

Speed of light = 299,792,458 m/s or 0.29979 m/ns

In this test both the RV and TOF were very close to the actual distances. The RV was closer in all of the tests. The TOF was usually around three nanoseconds off. This could be due to rise and fall times of the signal on the scope or delay times of the circuitry. Some error is also due to the pulsewidth of the laser being so wide. The RV was more accurate than the TOF because any error in the TOF was compensated for with the potentiometer adjustment done in task 5.

Tests Performed By: Adam Thole

Date: June 7, 2006

Laboratory Task #7: Laser Trigger Delays

In the APL-1 the laser is triggered by the high transition of the trigger pulse. When that pulse is received the laser turns on and starts drawing current. When current is drawn a current sensor sends a start pulse to the range counter. In this test the delay between the trigger of the laser, the laser current draw and the start pulse being sent to the range counter will be viewed.

- Connect channel one of the oscilloscope to the range gate output of the APL-1. (use ECL adapter)
- Connect channel two of the oscilloscope to the laser trigger out on the APL-1.
- Connect channel three of the oscilloscope to the laser current output of the APL-1.
- Flip the APL-1 trigger switch to internal triggering.
- Turn on the APL-1 and the oscilloscope.
- Look at the outputs of channel one and channel two and observe the time between when the laser was triggered (rising edge of channel one) and when the laser draws current (turns on).
- Observe and record how much current the laser is using before the start pulse is sent. Laser current is displayed at one volt per watt. Start pulse is from ECL high to ECL low.
- Turn off oscilloscope and APL-1.

Equipment Used:

Textronix TDS 3034 Oscilloscope SN: B018486
APL-1 Laser Rangefinder SN: 003

Results:

Time between positive going trigger transition and laser current: 180 nS

Amount of power used by laser before start pulse is generated: 10 W

Time between laser drawing current and start pulse being generated: 10 nS

Notes:

Because the delays are constant, no real error is added because the adjustment potentiometers can be adjusted to compensate for the small error.

Tests Performed By: Adam Thole

Date: June 5, 2006

Laboratory Task #8: Using APL-1 With External Trigger

In this test the APL-1 will be used with an external trigger. The signal will be observed with the laser trigger out and the sound transducer. The maximum pulse repetition rate (PRR) will be determined.

- Setup function generator to output a 1KHz TTL level signal.
- Hook up function generator to the external trigger input on the APL-1.
- Flip the trigger selection switch on the APL-1 to external triggering.
- Flip the sound switch on the APL-1 to on.
- Hook up channel one of the oscilloscope to the laser trigger output of the APL-1.
- Turn on function generator, oscilloscope and APL-1.
- Does the output of the oscilloscope display a 1 KHz signal?
- Point the APL-1 towards a target in range. The APL-1 should be making a 1 KHz tone.
- Turn off APL-1, oscilloscope, and function generator.

Equipment Used:

Textronix TDS 3034 Oscilloscope SN: B018486

APL-1 Laser Rangefinder SN: 003

Agilent Model 33220A Function Generator SN: MY44007123

Results:

The APL-1 worked correctly with external triggering.

Notes:

The clock from the function generator is much cleaner and more accurate than the clock produced by the 555 timer. However, the 555 clock source works just as well. The only noticeable difference performance wise is that the 555 frequency is not right at 1 KHz.

Tests Performed By: Adam Thole

Date: June 5, 2006

Laboratory Task #9: Find Minimum Range:

In this test the minimum range of the APL-1 will be found. The APL-1 has a minimum range because of its bistatic setup.

- As described in task 1, set the maximum range of the APL-1 to 100 meters.
- Set up a target ten meters in front of the APL-1.
- Flip the APL-1 trigger switch to internal triggering.
- Flip the APL-1 sound switch to on.
- Turn the APL-1 power switch to on.
- As described in task 3, focus the receiver and transmitter on the target at 10 meters.
- Now that the APL-1 is outputting a 1 KHz tone, move the target forward until the tone stops.
- Record where the tone was last heard.
- As described in process 3, refocus the laser and receiver for the new target position. If the 1 KHz tone comes back, repeat the process until the tone does not come back.
- Record the minimum range of the APL-1.
- Flip APL-1 power switch to off.

Equipment Used:

APL-1 Laser Rangefinder SN: 003

Results:

Minimum Range: 4.2 m

Notes:

The minimum range test was done in the lab using a poster board.

Tests Performed By: Adam Thole

Date: June 6, 2006

Laboratory Task #10: Find Maximum Range

In this test the maximum range of the APL-1 will be determined. While the APL circuitry can read as far away at 10,000 meters, the maximum range is probably not that far.

- As described in task 1, set the maximum range of the APL-1 to 1,000 meters (position 2).
- Set up a target 100 meters in front of the APL-1.
- Flip the APL-1 trigger switch to internal triggering.
- Flip the APL-1 sound switch to on.
- Turn the APL-1 power switch to on.
- As described in task 3, focus the receiver and transmitter on the target at 100 meters.
- Now that the APL-1 is outputting a 1 KHz tone, move the target farther away until the tone stops. (Wear laser safety glasses.)
- Using the process described earlier, refocus the laser and receiver for the new target position. If the 1 KHz tone comes back, repeat the process until the tone does not come back. If the target gets past 1,000 meters use task 1 to change the maximum range to 10,000 meters (position 3).
- Record the maximum range of the APL-1.
- Flip the APL-1 power switch to off.

Equipment Used:

Textronix TDS 3034 Oscilloscope SN: B018486

Bushnell Yardage Pro 1000 Binoculars

APL-1 Laser Rangefinder SN: 003

Results:

Maximum Range: 144 m

Notes:

The maximum range test was done on the roof using rangefinder binoculars to verify the distance.

Tests Performed By: Adam Thole

Date: June 6, 2006

Appendix B: DAQCard 700 Log Sheets

DAQ Task #1: Analog & Digital Read Times

In this test the analog and digital read time will be measured. To do this a C++ program will be used that continuously reads an input over and over for a period of time (10 seconds). After the period of time is over, the amount of time will be divided by the number of reads to determine the amount of time required to perform a read.

- Start digital speed test program.
- Record the digital read speed time.
- Start analog speed test program.
- Record the analog read speed time.

Equipment Used:

Dell Inspiron 9100, 3.19 GHz Laptop Computer
National Instruments DAQCard 700

Results:

Digital Read Time: 7.965 uS

Analog Read Time: 108.663 uS

Notes:

The tests with the DAQ went well, however the digital input will not be suitable for use with the APL-1 strobe line which produces a 40 nanosecond pulse whenever a range is ready to be read. The digital read time is too long and cannot reliably detect a 40 nanosecond pulse. This was further verified by using a function generator to generate a 40 nanosecond pulse at 1KHz to see if the DAQ could pick them all up. It picked up very few.

The analog read time is even slower than the digital read time, but it will not cause a problem with the APL-1. The analog input is triggered to be read at a certain time where the current voltage is captured and converted to digital. The majority of the 109 uS is spent converting the captured signal from analog to digital. Since the APL-1 will only be operating at around 1 KHz, the 109 uS conversion leaves plenty of time to get the next reading.

Tests Performed By: Adam Thole

Date: July 5, 2006

DAQ Task #2: Clock Tests

In this test the clock on the DAQCard 700 will be tested. The amount of time it takes to read the clock count and the minimum pulse that can trigger the clock will be tested. Two different programs will be used to do this. The first program will continually read the clock count over a period of time, keeping track of the number of times it is read. After the period of time is over (10 seconds) the number of times read will be divided by the period of time to give the read time of the clock count. The second program will continually read the clock count and output a message every time it changes.

- Hook up the function generator to the CLK2 input of the DAQ.
- Have the function generator output a 1 KHz square wave.
- Run the clock read program and record the averaged amount of time it takes to read the clock count.
- Start the clock count output program.
- On the function generator, change the square wave to a pulse and continually lower the pulsewidth until the CLK2 count no longer increases by one each second.
- Record the minimum pulsewidth.

Equipment Used:

Dell Inspiron 9100, 3.19 GHz Laptop Computer

National Instruments DAQCard 700

Agilent Model 33220A Function Generator SN: MY44007123

Results:

Clock Count Read Time: 21.248 uS

Minimum Pulse Width: 20 nS *

Notes:

*The minimum pulse width detected by the clock on the DAQ card was 20 nS. However, 20 nS was also the minimum pulse tested on the DAQ card. The function generator has a minimum pulsewidth of 20 nS so no shorter pulses could be generated for testing.

The minimum pulsewidth of 20 nS is more than enough for the DAQ to detect the 40 nS strobe line.

Tests Performed By: Adam Thole

Date: July 5, 2006

DAQ Task #3: Analog Conversion Accuracy

In this test the accuracy of the analog input on the DAQ will be compared to the voltage reading on a high quality Fluke digital voltmeter.

- Using a variable power supply, adjust the voltage to somewhere between 0 and 10 volts.
- Measure and record the voltage with the voltmeter.
- Measure and record the voltage with the DAQCard 700.
- Repeat three times.

Equipment Used:

Dell Inspiron 9100, 3.19 GHz Laptop Computer
National Instruments DAQCard 700
Tektronix PS280 DC Power Supply

Results:

Reading 1

Voltmeter: 5.29 V

DAQ: 5.29 V

Reading 2

Voltmeter: 7.48 V

DAQ: 7.48 V

Reading 3

Voltmeter: 1.66 V

DAQ: 1.66 V

Notes:

The accuracy of this is within at least within 1/100th of a volt. Using the 100 meter setting on the APL-1 this would give a range accuracy of one centimeter, which is more than the accuracy of the APL-1 itself. The analog voltage accuracy of the DAQCard 700 is more than adequate for the range voltage conversion process.

Tests Performed By: Adam Thole

Date: July 5, 2006

Appendix C: Sagebrush Model-20 Log Sheets

Pan & Tilt Task #1: Basic Control With CPU

In this test the Model-20 will be controlled using the demo software included with the manual.

- Connect Model-20 to 24V DC power.
- Connect the serial port on the Model-20 to computer.
- Open demo software and select the appropriate COM port.
- Test & record travel range for elevation using digital level.
- Test & record travel range for azimuth.
- Disconnect power.

Equipment Used:

Sagebrush Model-20 SN: 245

SmartTool Smart Level

Dell Inspiron 9100, 3.19 GHz Laptop Computer

Results:

Elevation Range: +103 to -40 degrees (Datasheet: +95 to -35 degrees)

Azimuth Range: 360 degrees (Datasheet: 360 degrees)

Notes:

The demo software included with the sagebrush does not work. The COM port does not detect the Model-20. Instead a custom C program was used to interface with the Model-20. Using the C program, everything worked well. The range of elevation is even slightly more than the range given in the specifications.

Tests Performed By: Adam Thole

Date: June 28, 2006

Pan & Tilt Task #2: Model-20 Accuracy

In this test the Model-20 will be controlled using the demo software and the accuracy will be measured.

- Place a laser pointer on the Model-20.
- Turn on Model-20.
- Return Model-20 to home position.
- Center the laser on a stable target and mark precisely where the laser is shining.
- Move the Model-20 over long and short distances at slow and fast speeds, always returning to home.
- If the laser is not precisely on the home mark, record the difference.
- Turn off Model-20.

Equipment Used:

Sagebrush Model-20 SN: 245

Generic Laser Pointer

Dell Inspiron 9100, 3.19 GHz Laptop Computer

Results:

Long distance, fast speed: Centered

Long distance, slow speed: Centered

Short distance, fast speed: Centered

Short distance, slow speed: Centered

The Model-20 performed extremely accurately during the tests. While the tests were only performed at a distance of 10 meters, no variation from the home point was detected. Perhaps over a much larger distance a small error could be detected, as the datasheet lists a possible 0.1 degree error.

Tests Performed By: Adam Thole

Date: June 28, 2006

Pan & Tilt Task #3: Model-20 Speed

In this test the Model-20 maximum speed and scan times will be tested.

- Turn on Model-20.
- Tell the Model-20 go to -180 degrees azimuth.
- Start timer and tell Model-20 to go to 180 degrees azimuth.
- Stop timer when Model-20 reaches destination.
- Record the elapsed time.
- Record sample scan rates.
- Turn off Model-20.

Equipment Used:

Sagebrush Model-20 SN: 245

Dell Inspiron 9100, 3.19 GHz Laptop Computer

Results:

360° rotation: 7.485 S

Degrees/second: 48° (Datasheet: 60°)

Scan Rates:

Degrees of Tilt	Scan Time		Points/Second	
	10x10	25x25	10x10	25x25
1x1	6.250 S	29.297 S	16	21.3
2x2	7.781 S	39.047 S	12.9	16
5x5	13.984 S	48.797 S	7.2	12.8

Notes:

Everything in this test went well. A C++ program was used for controlling the Model-20 and for measuring the time. All times are accurate to within 1 millisecond. The degrees per second measured is less than that from the datasheet because the datasheet value states the absolute maximum, not the time it would take including the ramp to and from full speed. While taking the measurement over 360° did help this, it did not eliminate the ramping effect completely.

The scan rates were done with another C++ program that scanned it across an entire area, stopping at each point. The stop is as fast as the Model-20 allows, no other code is ran between start and stop. In the final version of this program, the scan rates will actually be slightly longer because the DAQ card will be factored into the program, adding up to another 1.25 milliseconds per point, with no averaging.

Tests Performed By: Adam Thole

Date: June 30, 2006