SpectroScan3D

MEMS Scanning LiDAR (MSL201)

User Manual

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1. GENERAL INFORMATION

This document provides information and instructional materials to enable users to operate the SpectroScan3D successfully. In particular, it provides information to set up and connect the SpectroScan3D components as well as to operate the SpectroScan3D.

1.1 DISCLAIMER

The information in this document is current as of the publication date. The manufacturer reserves the right to make changes to this document and products associated with it at any time without notice.

1.2 CONTACT US

For product information, operating assistance, literature request, product repairs, product warranty, and all customer service inquiries, please contact us:

Spectrolab Inc.

12500 Gladstone Ave.

Sylmar, CA 91342, USA

Illumination and Sensor Products

Customer Service: (800) 936-4888

www.spectrolab.com/sensors

2. SAFETY INFORMATION

- This product complies with the US Federal Laser Compliance Guide 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007.
- This product is classified as a Class 1 Laser Product, per the requirements of the IEC 60825-1, 2nd Edition, *Optical Radiation Safety and Laser Equipment*.

CAUTION: this product poses the following hazards that can cause serious personal injury:

HAZARDOUS VOLTAGE INSIDE

- Risk of electric shock. Do not remove the cover
- Do not operate with lid open
- Disconnect power cables before servicing

INVISIBLE LASER RADIATION

- Avoid eye or skin exposure to direct or scattered radiation
- Do not stare directly into beam.
- Keep a safe distance away from the laser transmitter port

NOTE:

This product has a safety laser interlock feature. For eye safety, if a failure in the scan pattern has been detected, the laser output is immediately extinguished and will not become operational again until a valid scan pattern has been detected.

3. INTRODUCTION

3.1 SPECIFICATIONS

Product Performance	
Type of application	Indoor/Outdoor
LiDAR technology	Point scanning LiDAR
Field of view	40° (horizontal) x 20° (vertical)
Operating range	0.5 m … 20 m (with 80% reflectivity surfaces)
Scanning frequency (frame rate)	4.8 Hz
Line scan time	1.5 ms
Image resolution	256 (horizontal) x 128 (vertical) pixels
Angular resolution	0.156 deg.
Ranging resolution per pixel	45 cm (multiple return per pixel spacing)
Pixel range resolution	6.25 mm (reported range increments)
Sample spacing	0.1 m
Sampling range	50.3 m (503 samples at 0.1 m per sample)
Dynamic range	4000:1 (12-bit equivalent)
Laser divergence	0.23 deg.
Data Interface	
Data protocol	Ethernet 100BaseT UDP
Data bandwidth	5 Mbit/s (128k bytes/frame at 5 frames/sec)
Pixels per frame	32766 (range and amplitude)
Pixel information	4 bytes per pixel (range and amplitude, 2 bytes each)
Pixel clock	201.6 KHz
Mechanical	
Dimensions (W x H x D)	4 in x 3.5 in x 5 in
Weight	5 lbs approx.
Housing material/finish	Aluminum/black anodized
Power cables (included)	24V DC power supply, 6 ft long, un-terminated (pigtail) wires
	AC power supply adapter.
Ethernet cable (included)	RJ45, Cat.5e, 2 m long (6.5 ft approx.)
Electrical	
Electrical connection	Circular plug-in connectors (Power and Ethernet)
Operating input voltage	24 VDC nominal, 18-28 VDC (min-max)
Power consumption (typ)	25 W
Supply current with laser off (typ)	0.55 A
Supply current with laser on (typ)	1 A
Optical	
Laser properties	λ =1550 nm, 2µJ at f = 200 kHz for 2.5ns pulse width
Laser power	400mW, 2A pump current (nominal)
Safety	
Laser safety compliance	Class 1, as specified by IEC 60825-1
Laser Safety Interlock	< 20 ms
Environmental	
Operating temperature	20 ^{o}C to 25 ^{o}C

3.2 PARTS LIST

Please inspect the following contents are included:

Item	Description	Part No.	Source	Quantity
1.	SpectroScan3D	070001	Spectrolab	1
2.	DC Power Cable	070015	Spectrolab	1
3.	AC Power Cable	070107	Spectrolab	1
4.	Ethernet Cable	17-101294	Conec	1
5.	Product CD	-	Spectrolab	1
6.	Data Package	-	Spectrolab	1

The SpectroScan3D CD contains the User Manual. The Data Package contains a hard copy of the SpectroScan3D Declaration of Conformity as well as the SpectroScan3D Test and Calibration Report.

3.3 QUICK START GUIDE (WINDOWS 64-BIT)

The SpectroScan3D Viewer software included in the product CD has been compiled to work on and tested on a Microsoft Windows 7, 64-bit Operating System. If using Linux or Apple Mac OS X, you can obtain the source code and recompile it on your specific machine from the Spectrolab Open Source repository at: https://github.com/SpectrolabInc/spectrolab.

To begin imaging for the first time using the included software, perform the steps below in order:

1. Make your computer's IP address 192.168.0.121, subnet 255.255.255.0. Disable all firewall and antivirus software on the computer.
2. From the SpectroScan3D Product CD, locate the file **spectroscan3D.exe**. This executable file will extract the SpectroScan3D viewer files. Create a new folder named **Spectroscan3D**, and extract the files to this new folder.
3. Connect the AC power cable to the SpectroScan3D power connector. Connect the Ethernet cable from the computer to the SpectroScan3D Ethernet connector.
4. Run the **spectrolab_viewer.exe** by right clicking on the file and selecting **Run as administrator**.
5. On the **Spectrolab Viewer**, click on the **SpectroScan3D** pull down menu and select **Connect**, and wait a few seconds. Live frames should then be displayed on the viewer window.
6. To view frames that have been previously captured, click **File** > **Movie** > **Load** and open the folder "demo_frames" and select the first file named "Frame0000".

3.4 SYSTEM OVERVIEW

Figure 1 below shows the block diagram of the LiDAR System. The LiDAR transmits a short optical pulse as a means to determine range to a target area and a two-axis mirror to establish the angular direction. Each pixel is illuminated one-at-a-time until the entire field of view has been scanned to create the full image. The scan then jumps back to the beginning and the process is repeated to produce another frame.

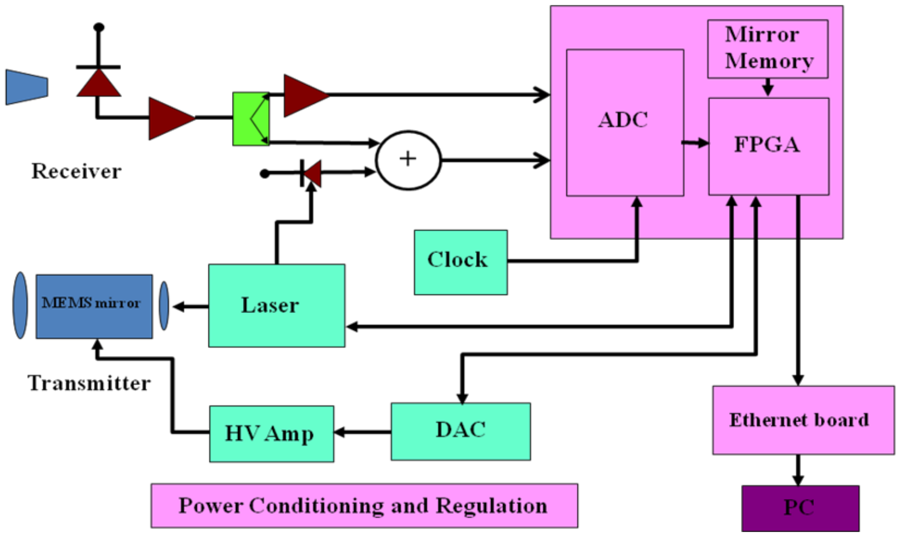


Figure 1 LiDAR Block Diagram

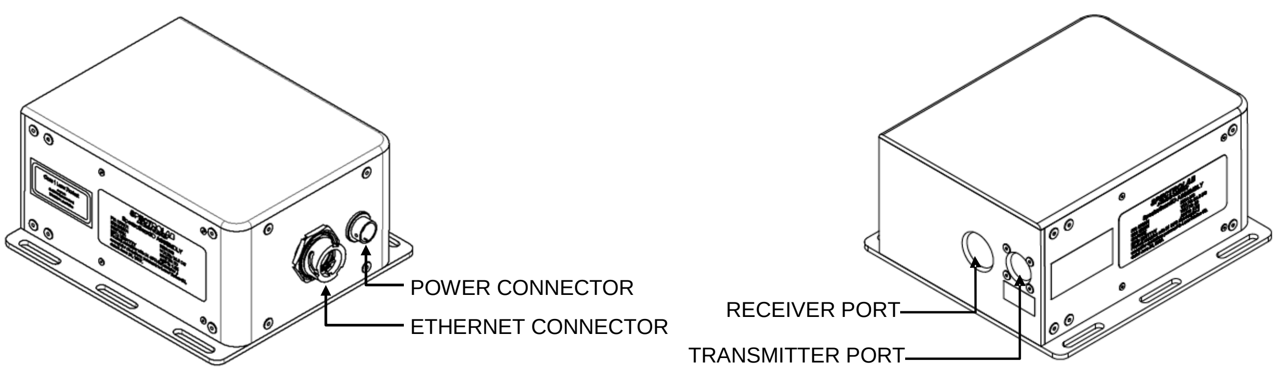


Figure 2 SpectroScan3D Front and Rear Views

A sample image capture is shown in Figure 3. This figure shows a range false-color image on the left, amplitude image (black and white) on the upper right, and pixel range readout information window on the lower right.

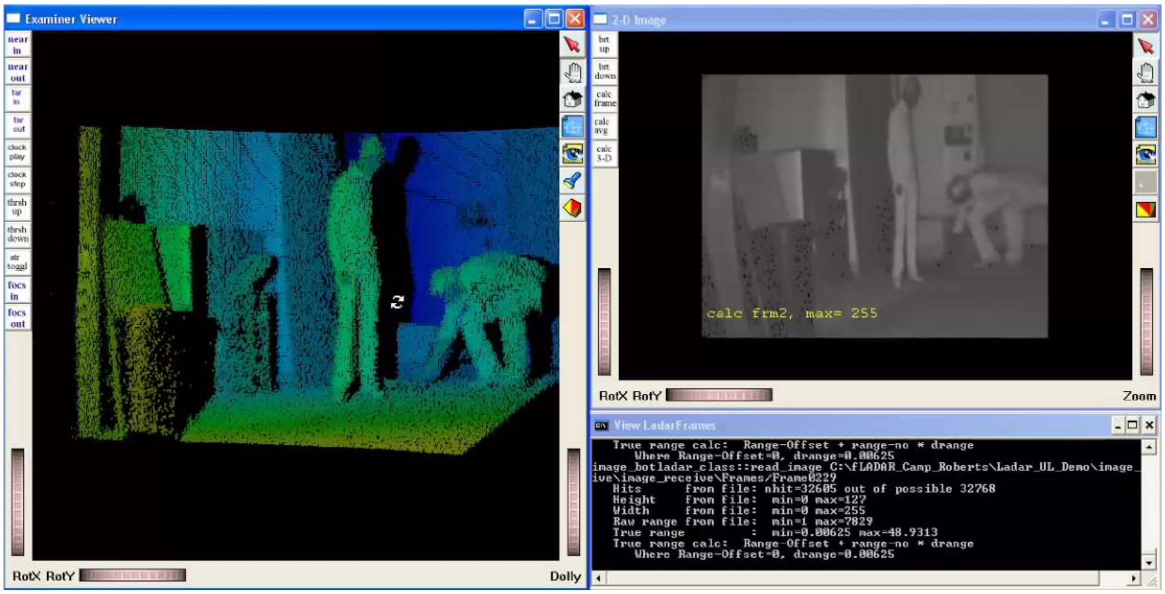


Figure 3 Sample Image - range false-color (left), amplitude (upper right), pixel range window (lower right).

3.5 POWER CONNECTOR

The External System Power Cable (Part No. 070015) is a 6 feet cable with flying wires, which allows you to interface the SpectroScan3D with your system. The camera's input power is 24V-DC nominal.

External System Power Cable (Part No. 070015)				
Pin	**Signal Name**	**Color**	**Description**	**Comments**
1	Power	Red	Input Power (+)	24V, 1A Power Supply
2	Ground	Black	Input Power (-)	Ground
3	Interlock	White	Interlock Signal	Remote power control line: ILK Grounded = System Enabled ILK Floating = System Disabled
4	Chassis	Green	Housing Chassis Ground	Earth Ground

Figure 4 Power Connector Pinout Table

3.6 ETHERNET CONNECTOR

The Ethernet Cable (Part No. 17-101294 by Conec) is a 2m (6.5 feet approx.) CAT5 cable used to interface the SpectroScan3D's Ethernet connector to the host computer's Ethernet port. The Ethernet port is a bidirectional Ethernet 100BaseT UDP straight or crossover cable. The Ethernet port is compatible with any standard Cat.5 or better cable.

4. ETHERNET INTERFACE

The Ethernet communication with the SpectroScan3D is bi-directional. From the SpectroScan3D's perspective, incoming Ethernet packets are either commands or queries. Outgoing Ethernet packets are either image data packets or responses to commands.

4.1 ETHERNET INTERFACE SETTINGS

The following list provides the SpectroScan3D's Ethernet interface settings:

Internet Protocol Version	IPv4.
Internet Protocol	UDP (User Datagram Protocol)
Source Port	27
Transmit Port	4950
Destination Port	4002 (for image frames)
Destination Port	4000 (for command replies)
Computer IP Address	192.168.0.121
SpectroScan3D MAC Address	00 0F CC 23 00 01
SpectroScan3D IP Address	192.168.0.27

The computer's ARP table must be setup to associate the LiDAR's MAC address to it's IP address. It can be set up on a Windows computer by typing the following command in a DOS prompt: arp -s 192.168.0.27 00-0F-CC-23-00-01 or by using the pseudo command on a Linux computer.

4.2 DATA FORMAT

Each pixel is tagged with two 16-bit words, range (first) and amplitude (second). Only the 13 LSB bits of the range word are used and only 10 bits of the amplitude word are used. The first two words of each frame are overwritten by a delimiter, FEDC BA98 (hex), placed so as to indicate the beginning of each frame. The next two words of each frame are overwritten with a frame count. Therefore, the first two pixels of the first line are non-image data. The LiDAR sends 1 line of image data (256 pixels * 2 words/pixel * 2 bytes/word = 1024 bytes) in each UDP packet (an "image line packet").

Frame Delimiter				Frame Count				Pixel #1 - Range		Pixel #1 - Intensity		…
Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8	Byte 8	Byte 9	Byte 10	Byte 11	… Byte 1024
0xDC	0xFE	0x98	0xBA	Count LSB	Count MSB	Count LSB	Count MSB	Range LSB	Range MSB	Intensity LSB	Intensity MSB	…

Figure 5 Ethernet Data Packet Example (Scan Line # 1)

One complete image frame consists of 256(H) x 128(V) pixels of amplitude and range data.

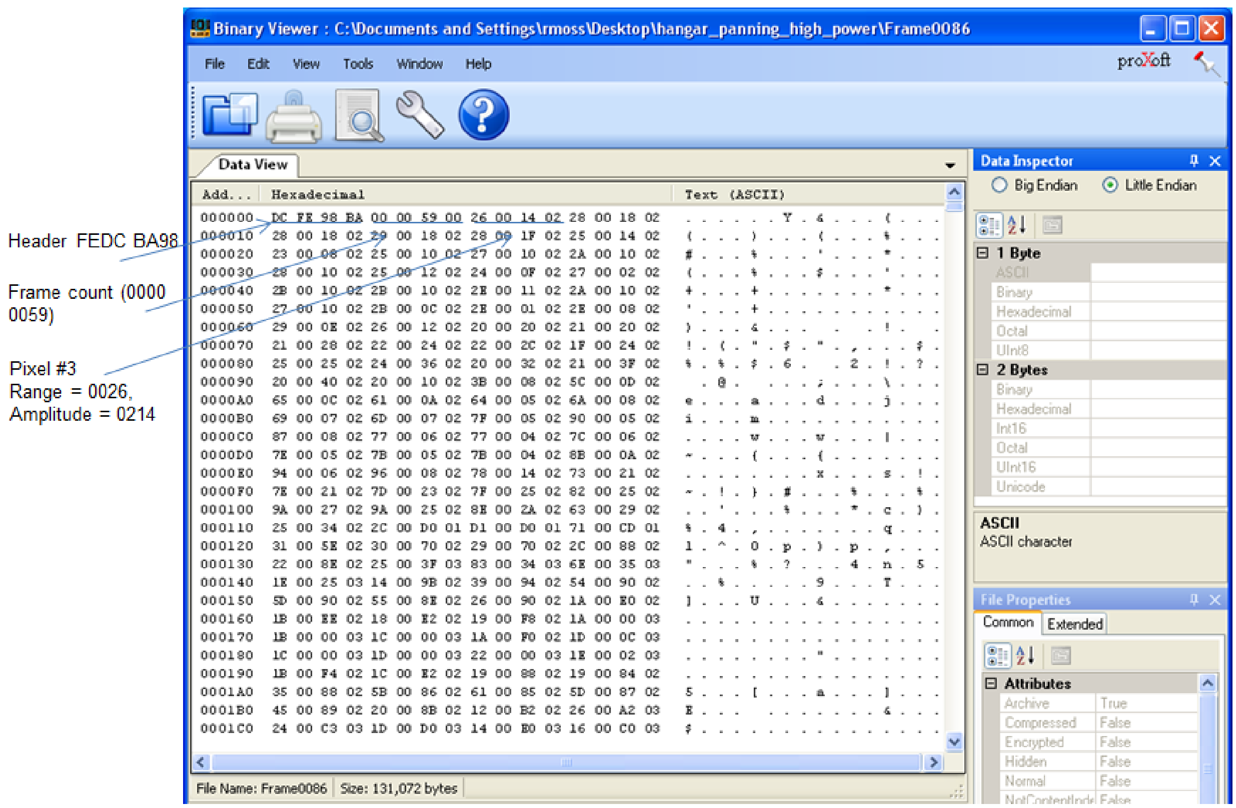
Image Frame Format						
horizontal line 1:	Start Frame Delimiter	Frame Count	Pixel 3: Image Data	Pixel 4: Image Data	…	Pixel 256: Image Data
horizontal line 2:	Pixel 1: Image Data	Pixel 2: Image Data	Pixel 3: Image Data	Pixel 4: Image Data	…	Pixel 256: Image Data
horizontal line 3:	Pixel 1: Image Data	Pixel 2: Image Data	Pixel 3: Image Data	Pixel 4: Image Data	…	Pixel 256: Image Data
…	…					
horizontal line 128	Pixel 1: Image Data	Pixel 2: Image Data	Pixel 3: Image Data	Pixel 4: Image Data	…	Pixel 256: Image Data

Start Frame Delimiter: (4 bytes, little-endian format) = 0xFEDC, 0xBA98. Send low byte first, then high byte.

Frame Count: (4 bytes, little-endian format). Send low byte first, then high byte.

Image Data: (4 bytes, little-endian format). [Range][Amplitude]. *Range* (2-bytes): Only bits 0…12 are used. *Amplitude* (2-bytes): Only bits 0…9 are used.

Once the full frame has been stored to disk the binary file should appear as shown in Figure 5 below.



6. Image frame sample capture

4.3 COMMAND/QUERY PACKETS

For each byte sent to the SpectroScan3D in a UDP packet ("command packet"), a byte is put in a buffer to be sent with the next "miscelaneous packet". These miscelaneous packets are separate from the image line packets and they arrive at a different port (see section 4.1 above). Because of the time critical nature of the system, it may not be possible to send a miscelaneous packet back for every command packet received. If the SpectroScan3D is busy sending an image line packet or a previous miscelaneous packet, all the new command replies are simply added to the miscelaneous packet buffer to be sent out as soon as possible with the next miscelaneous packet. This means that there may be multiple sets of command replies in the same miscelaneous packet. It is up to the client side software to remember what commands were sent, and to appropriately decode the miscelaneous packet. Image line packets have priority over miscelaneous packets. This means that if both a miscelaneous packet and an image line packet are waiting to be sent at the time another packet finishes sending, the image line packet is sent and the miscelaneous packet must wait.

4.4 INTERFACE COMMAND SET

Commands[1] (1 Byte)		
Name	**Value (hex)**	**Description**
System Reset	0x10	LiDAR processor reset command to power on state. Note: This command does not perform power down sequence.
Start Acquisition	0x11	Begins streaming data to the host over Ethernet.
Laser Power On	0x12	Turns on laser.
Laser Power Off	0x13	Turns off laser.
Laser ADI/TEC On	0x15	Turns ON laser Thermo-Electric-Cooler (TEC)
Laser ADI/TEC Off	0x16	Turns OFF laser Thermo-Electric-Cooler (TEC)
Laser Fire On	0x17	Enables laser.
Laser Fire Off	0x18	Disables laser.
Laser Low Power	0x19	Laser low power level. (22 mW)
Laser High Power	0x1A	Laser high power level. (375 mW)
Mirror Scan On	0x21	Starts scan mirror.
Mirror Scan Off	0x22	Stops scan mirror.
Laser Status Display	0x2D	Not implemented.
System Status Display	0x2E	Not implemented.
Interpolator On	0x31	Enable range sample interpolation.
Interpolator Off	0x39	Disable range sample interpolation.
Low Gain Channel On	0x32	Enable receiver low gain channel.
Low Gain Channel Off	0x3E	Disable receiver low gain channel.
ADC Calibrate	0x36	Perform ADC calibration. System must be on and in the initial reset condition. Recalibrate when system has been on long enough to reach full operating temperature.
High Gain Channel On	0x37	Enable receiver high gain channel.
High Gain Channel Off	0x38	Disable receiver high gain channel.
High Voltage On	0x3A	Enable scan mirror high voltage.
High Voltage Off	0x3B	Disable scan mirror high voltage.
Remove DC Offset	0x3F	Remove receiver DC offset. Must be performed after the initialization has been run through the Start Acquisition (0x11) step but before the laser has been turned on (0x12).

[1] Write commands are one byte if no value is to be sent. They are two bytes if a value (xx) is to be sent.

Writes[2] (2 Bytes)		
Name	**Value (hex)**	**Description**
Odd Sync Delay	0x23 XX	Set delay for odd scan lines. Can be used to correct odd/even line pixel displacement. Default value can be found on unit test datasheet.
Even Sync Delay	0x2F XX	Set delay for even scan lines. Can be used to correct odd/even line pixel displacement. Default value can be found on unit test datasheet.
Receiver Threshold	0x24 XX	Set threshold level for receiver signal to be counted as a return. Increasing this value will decrease sensitivity but lower the noise.
Scan Threshold	0x28 XX	Not implemented.
In FIFO Delay	0x2A XX	Sets delay between laser pulse and the 503 point input data window. Default value can be found on unit test datasheet.
Target Select	0x33 XX	Set to pick either the first, last, or best target to report ("00" => First, "01" => Best, "10" => Last)
Horizontal Voltage	0x3D XX	Sets scan mirror drive voltage amplitude in horizontal (x-axis). Full amplitude is default.
Vertical Voltage	0x3C XX	Sets scan mirror drive voltage amplitude in vertical (y- axis). Full amplitude is default.

Reads[3] (3 Bytes)		
Name	**Value (hex)**	**Description**
System ID Read	0x27 00 00	Reads FPGA firmware revision where NN is the revision number
System Status Read	0x26 00 00	System Status Bits, Active high: Bit 0, indicates all DCM clocks are locked. Bit 1, indicates ADC has been programmed. Bit 2, indicates Data Acquisition On command received. Bit 3, indicates H & V sync bits received. Bit 4, indicates ADC input overvoltage has occurred. Bit 5, clock synthesizer locked. Bits 6,7 not used
Laser Status Read	0x25 00 00	Not implemented.
In FIFO Delay Read	0x30 00 00	Reads back where the 503 point input data window begins relative to the laser electrical trigger.
Odd Sync Delay Read	0x40 00 00	Reads back current value for odd scan line sync delay. Can be used to correct odd/even line pixel displacement.
Even Sync Delay Read	0x41 00 00	Reads back current value for even scan line sync delay. Can be used to correct odd/even line pixel displacement.

Figure 7 Interface Command Set

[2] Write commands are one byte if no value is to be sent. They are two bytes if a value (xx) is to be sent.
[3] Read commands return one byte.

5. OPERATION

The SpectroScan3D is controlled via the Ethernet Port connection to a host computer.

On the host computer, verify the computer settings are as follows:

- IP Address: 192.168.0.121
- Internet firewalls and antivirus software: Disabled
- SpectroScan3D Viewer software communicates with low level ports. The functionality may be blocked by default. If there is no response from the query 0x27 00 00, close the program and re-run it by right clicking on the icon and selecting “Run as administrator” (Windows) or using the pseudo command on Linux.

If no response is seen from the SpectroScan3D, verify the connections and try again. If the camera continues to not respond, please contact Spectrolab Customer Service for technical support.

5.1 MANUALLY CONTROLLING THE LIDAR ACQUISITION

From the command prompt:

The interface commands listed above can be individually sent from the viewer’s command window.

Note: The order that the commands are sent is important.

To run the LiDAR follow the procedure below or follow the order when sending commands via host software.

Manually Beginning an Acquisition:

If it is desired to run the LiDAR by sending individual commands, send the following commands by selecting them from the command window and then clicking send, one at a time:

1. Reset 0x10
2. Read System ID 0x27 00 00
   (Note: verify firmware revision (e.g. 7B) is returned in 3rd byte)
3. MEMS HV On 0x3A
4. MEMS Scan On 0x21
5. Acquisition On 0x11
6. Remove Receiver Offset 0x3F
7. High Power (HP) Mode 0x1A
   (Note: Low Power (LP) Mode: default - no command)
8. Send Current Level 0x15
9. Enable TEC 0x17
10. Laser On 0x12

To End Acquisition:

11. Turn Pump Current to 0 0x18
12. Disable TEC 0x16
13. Laser Off 0x13
14. MEMS HV Off 0x3B
15. Reset 0x10

5.2 MANUAL CONTROL WITH STATUS CHECKING

Laser Status Byte is bit mapped:
Bit 0: Trigger Alarm
Bit 1: UCT Alarm
Bit 2: Laser On
Bit 3: LDC Alarm
Bit 4: Laser Power On
Bit 5: Interlock On
Bit 6: TBD
Bit 7: TBD

Turn-On Sequence with Status Checking:

1. Send: System ID Read (0x27 00 00)
   Returns: 0xXX (the current firmware revision tag)
   Action: Issue error message if return is 0x00. Halt.

2. Send: System Status Read (0x26)
   Returns:
      Bit (0) = '1' (Local DCM Locked)
      Bit (1) = '1' (ADC Enabled)
      Bit (5) = '1' (Synthesizer Locked)
   Action: Issue error message if any Bit = '0'. Halt.

3. Send: High Voltage On (0x3A)
   Returns: 0
   Action: None

4. Send: Mirror Scan On (0x21)
   Returns: 0
   Action: None

5. Send: Data Acquisition On (0x11)
   Returns: 0
   Action: None

6. Send: System Status Read (0x26 00 00)
   Returns: Bit (2) = '1' (Start Signal Received)
   Action: Repeat if needed. Issue error message if Bit (2) = '0'. Halt.

7. Send: Remove DC Offset (0x3F)
   Returns: 0
   Action: None

8. Send: Laser High Power (0x1A)
   Returns: 0
   Action: None

9. Send: ADI/TEC On (0x15)
   Returns: 0
   Action: None

10. Send: Laser Fire On (0x17)
    Returns: 0
    Action: None

11. Send: Laser Power On (0x12)
    Returns: 0
    Action: None

12. Send: System Status Read (0x26 00 00)
    Returns: Bit (3) = '1' (Sync Signals Received)
    Action: Repeat, if needed. Issue error message if Bit (3) = '0'. Halt.

Turn-Off Sequence with Status Checking:

1. Send: Laser Fire Off (0x18)
   Returns: 0
   Action: None

2. Send: Laser ADI/TEC Off (0x16)
   Returns: 0
   Action: None

3. Send: Mirror Scan Off (0x22)
   Returns: 0
   Action: None

4. Send: Laser Power Off (0x13)
   Returns: 0
   Action: None

5. Send: High Voltage Off (0x3B)
   Returns: 0
   Action: None

6. Send: System Reset (0x10)
   Returns: 0
   Action: None

6. RECONSTRUCTING THE IMAGE FROM THE DATA

6.1 PIXEL SCAN PATTERN

The scan begins in the bottom left of the scene as seen by someone behind the camera looking in the direction of an outgoing laser pulse. The MEMS Mirror causes the laser pulses to cross the scene from left to right horizontally for 256 pixels. These pixels are 1-256 of the image. Then the mirror moves the beam up one line vertically and scans the laser from right to left for pixels 257-512. In the scene, pixel 257 (first pixel of row 2) illuminates a spot that is directly above pixel 256 (last pixel of row 1) and pixel 512 (last pixel of row 2) is directly above pixel 1 (first pixel of row 1). Pixels are seperated in time by the pixel clock which is exactly 201.6 KHz.

Each data file size is 128k. That is 256 x 128 pixels x 4 bytes per pixel = 128k bytes per frame. After each frame, the mirror moves the laser spot back to pixel position 1 and repeats the scan patter for the next frame.

Pixel Scan Pattern				
32768	32767	32766	32765	…
513	514	515	…	768
512	…	259	258	257
1	2	3	…	256

The raw data from the LiDAR must be rearranged per the diagram above (flip alternating rows) to form an image frame.

Since the Ethernet protocol is UDP, it is possible that pixels or packets will be dropped. The client side software should have a strategy for maintaining a running pixel count and handling corrupted data.

6.2 SENSOR INTRINSIC VALUES

The following are default viewer settings that can be used to view SpectroScan3D data. The values that vary from unit to unit are measured at the factory and provided in a datasheet shipped with the unit.

Parameter	Units	Value	Description
Range Resolution	m	0.00625	Incremental value reported by the range word: $Range = \text{Range\_word} * \text{Range\_resolution}$
X-Angle Delta	deg/pixel	0.156	Angular separation between pixels in the horizontal (x-axis)
Y-Angle Delta	deg/pixel	0.172	Angular separation between pixels in the vertical (y-axis)
Field of View (Horizontal)	deg.	40	Full horizontal angle scanned
Field of View (Vertical)	deg.	22	Full vertical angle scanned
Range Offset	m	0	Offset value added to the range data to get accurate values

Figure 8 Sample sensor intrinsic values.

6.3 IMAGE DISPLAY AND CORRECTION

Image scan data is received in the format described in Section 4.2. To produce a viewable image, the raw data format must be corrected for the physical scan distortions described below. The correct spherical-to-xyz coordinate transform is also described.

6.3.1 Scan Angle Corrections

The laser scan pattern for one complete frame, shown below, has sinusoidal shape in the x-axis, and a modified sawtooth shape in the y-axis. The 32 pulses on each scan line's horizontal edge are ignored.

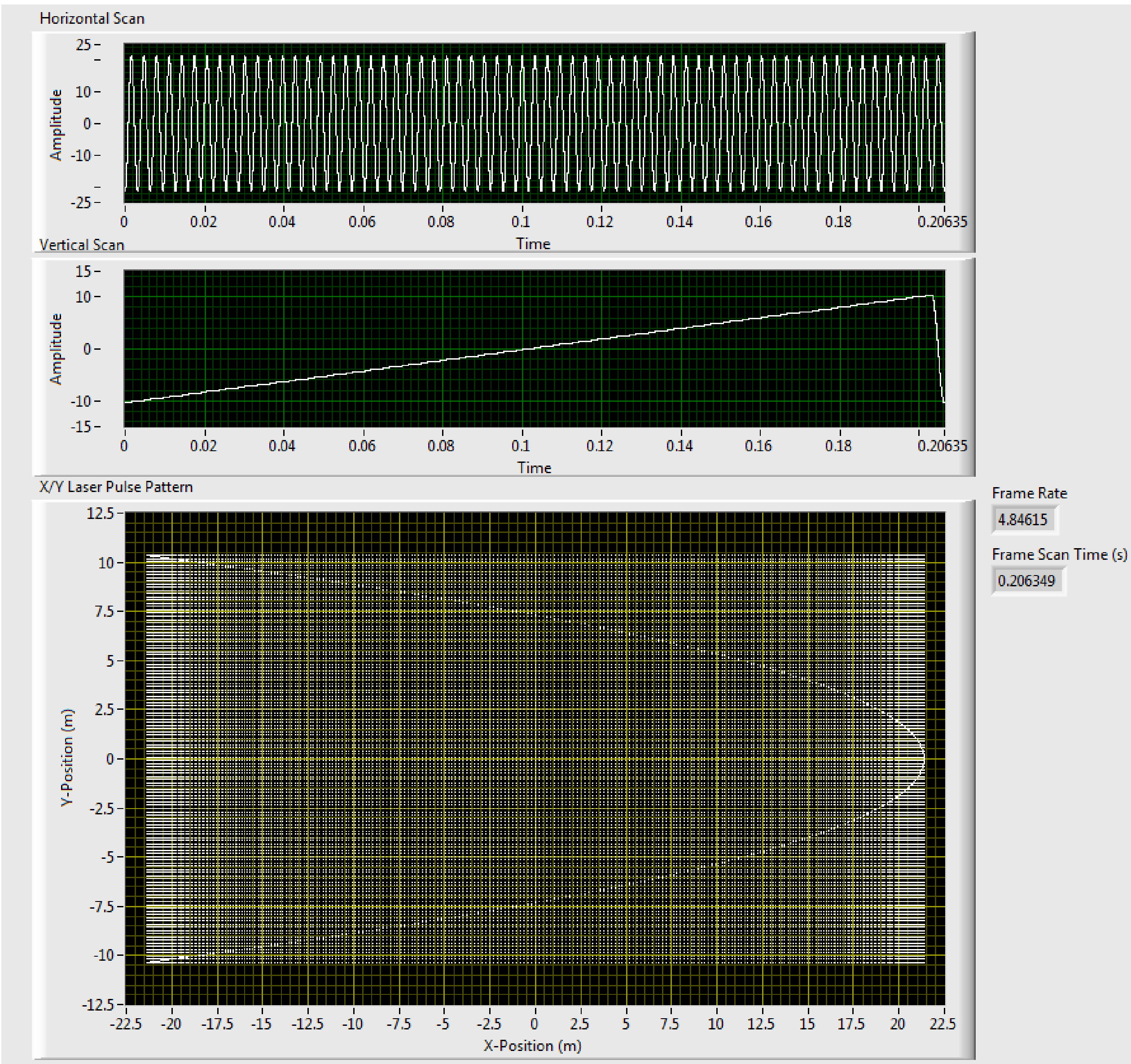


Figure 9 SpectroScan3D Horizontal (X), Vertical (Y) and XY Laser Scan Pattern for one full frame (including flyback).

Sinusoidal Scan Correction:

Since the scan pattern is not perfectly linear in the horizontal (x-axis), but sinusoidal, a correction must be applied to the x/y angles. The “overscan” (edge) laser pulses, 32 on each side for a total of 64 per line, are ignored and not reported to the host. The remaining pixel’s true x-angle is then calculated by:

$$x\_angle(i) = A\sin(\frac{\pi * i}{320})$$

Where:

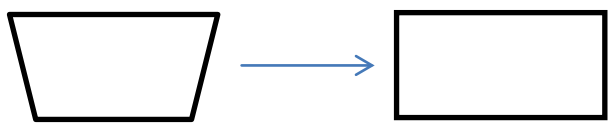
i is the current pixel’s column from -128 to +128.

A is the amplitude of the horizontal sinusoidal scan.

$x\_angle(i)$ is the x-axis angle of the i^{th} pixel away from the center of the scan.

Scan Foreshortening Correction:

The angle between the laser and the MEMS mirror normal axis is 15 degrees. Therefore, the scan pattern projection is not perfectly square but trapezoidal.



The correction factor applied to each pixel’s x angle is then:

$$x\_factor(i) = \cos\left(15 - \frac{y\_angle(i)}{4}\right)$$

Where:

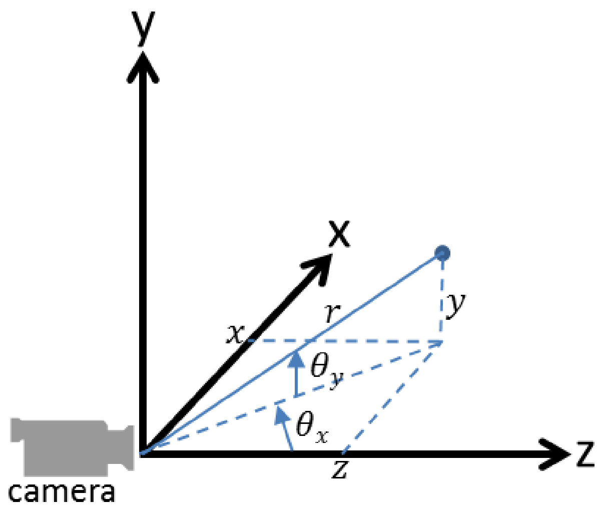
i is the index of the pixel in the x-axis, from -128 to +128.

$y\_angle(i)$ is the y-axis angle (in degrees) at x position i of the scan away from center. The $y\_angle(j)$ away from center is simply $j * dy$ where j is the current y-axis pixel row from -64 to +64 and dy is the delta angle between rows e.g. 22/128 degrees.

$x\_factor(i)$ is the scale factor that must be applied to the $x\_angle(i)$ above in order to compensate for the scan pattern foreshortening.

6.3.2 Spherical to Cartesian Coordinate Transformation

The SpectroScan3D outputs data in a (Range, Intensity) array format as described in previous sections 4.2 and 6.1. Some 3D viewers require the points to be in (x, y, z, Intensity) format. To get the points in this format a Spherical to Cartesian coordinate transformation must be applied. The correct transformation is shown in Figure 10 below.



$$x = r\cos(\theta_y)\sin(\theta_x)$$
$$y = r\sin(\theta_y)$$
$$z = r\cos(\theta_y)\cos(\theta_x)$$

Figure 10 Spherical to Cartesian coordinates illustration.

The algorithm implemented in C++ can be found in the source code in the repository:
https://github.com/SpectrolabInc/spectrolab

The file “spectroscan_3d_io.cpp” contains the transformation in the function pcl::rangeImageToCloud().

7. COMPLIANCE TO STANDARDS AND REGULATIONS

SpectroScan3D conforms to the following industry standards and regulations:

SAFETY OF LASER PRODUCTS	
U.S. FDA 21 CFR 1040.10 and 1040.11	US Federal Laser Compliance Guide.
IEC 60825-1:2007	Optical Radiation Safety and Laser Equipment
ISO/IEC/EN 17050-1	Declaration of Conformity
QUALITY ASSURANCE	
ISO 9001: 2000 and AS9100	Quality Management System
ENVIRONMENTAL	
ISO 14001	Environmental Management Systems

7.1 COMPLIANCE LABELS

This product is classified as a Class 1 Laser Product, and it has the following label, per the requirements of the IEC 60825-1, 2nd Edition:

Figure 11 Class 1 laser product label

This product complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007. This is noted in the product label, as shown below.

Figure 12 Manufacturer's product label (sample)