HDL™-64E

USER'S MANUAL

High Definition Lidar™ Sensor

Velodyne®

IMPORTANT SAFETY INSTRUCTIONS

CAUTION
### RISK OF ELECTRIC SHOCK
DO NOT OPEN

Caution

To reduce the risk of electric shock, do not remove cover (or back). No user-serviceable parts inside. Refer servicing to qualified service personnel.

The lightning flash with arrowhead symbol is intended to alert the user to the presence of uninsulated "dangerous voltage" within the product's enclosure that may be of sufficient magnitude to constitute a risk of electric shock to persons.

The exclamation point symbol is intended to alert the user to the presence of important operating and maintenance (servicing) instructions in the literature accompanying the product.

1. **Read Instructions —** All safety and operating instructions should be read before the product is operated.
2. **Retain Instructions —** The safety and operating instructions should be retained for future reference.
3. **Heed Warnings —** All warnings on the product and in the operating instructions should be adhered to.
4. **Follow Instructions —** All operating and use instructions should be followed.
5. **Heat —** The product should be situated away from heat sources such as radiators, heat registers, stoves, or other products that produce heat.
6. **Power Sources —** The product should be connected to a power supply only of the type described in the operating instructions or as marked on the product.
7. **Cleaning —** The product should be cleaned only as recommended by the manufacturer.
8. **Nonuse Periods —** The power connection to the product should be disconnected when left unused for a long period of time.
9. **Object and Liquid Entry —** Care should be taken so that objects do not fall and liquids are not spilled onto the enclosure.
10. **Damage Requiring Service —** The product should be serviced by qualified service personnel when:
    a. The product does not appear to operate normally or exhibits a marked change in performance.
    b. The product has been dropped or damaged.
11. **Servicing —** The user should not attempt to service the product beyond what is described in the operating instructions. All other servicing should be referred to qualified service personnel.
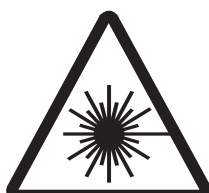
MAX Power: ___ mW
Wave Length: 905nm

Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated 7/2001

AVOID EXPOSURE-LASER RADIATION IS EMITTED FROM THESE APERTURES

Model No:

Serial No:

INVISIBLE LASER RADIATION DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 1M LASER PRODUCT

Mfg Date:

VELODYNE Acoustics, Inc.
MORGAN HILL, CA (USA)

Table of Contents

Introduction

Congratulations on your purchase of a Velodyne HDL-64E High Definition Lidar Sensor. This product represents a breakthrough in sensing technology by providing exponentially more information about the surrounding environment than previously possible.

This guide first covers installation and wiring, then addresses output packet construction and interpretation, and finally discusses the serial interface to the unit and software updates.

This manual is undergoing constant revision and improvement – check **www.velodyne.com/lidar** for updates.

Each shipment contains:
- HDL-64E sensor
- Wiring harness
- CD with user manual, calibration file (db.XML) and DSR viewer

Principles of Operation

The HDL-64E operates on a rather simple premise: instead of a single laser firing through a rotating mirror, 64 lasers are mounted on upper and lower blocks of 32 lasers each and the entire unit spins. This design allows for 64 separate lasers to each fire thousands of times per second, providing exponentially more data points per second and a much richer point cloud than conventional designs. The unit inherently delivers a 360-degree horizontal field of view (FOV) and a 26.8 degree vertical FOV.

Additionally, state-of-the-art signal processing and waveform analysis are employed to provide high accuracy, extended distance sensing and intensity data. The HDL-64E is rated to provide usable returns up to 120 meters.

Laser Emitters
(Groups of 16)

Laser Receivers
(Groups of 32)

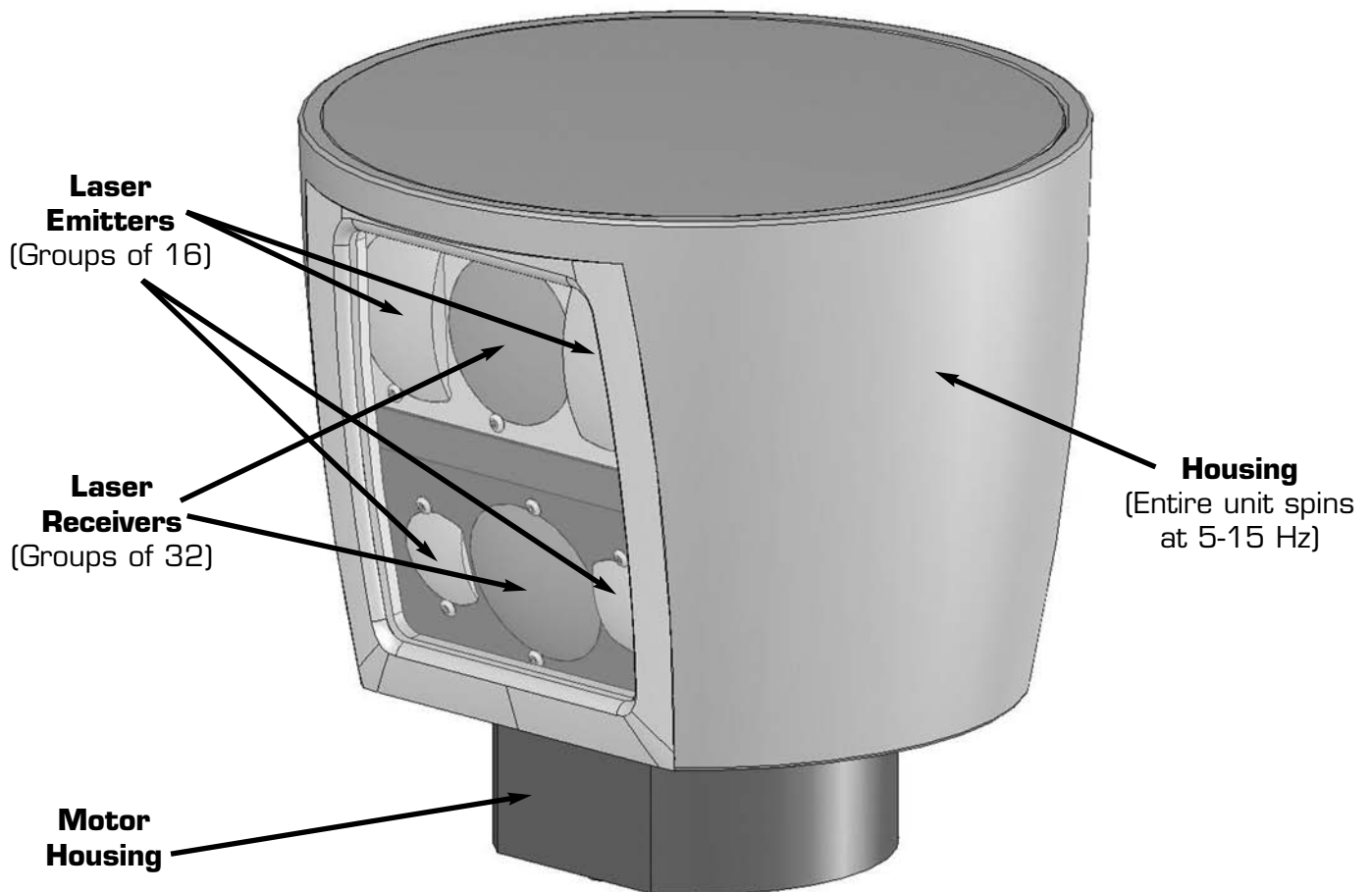**Housing**
(Entire unit spins at 5-15 Hz)

Motor Housing

Figure 1. HDL-64E design overview.

The HDL-64E employs a direct drive motor system — there are no belts or chains in the drive train.

Front/Back Mounting

The HDL-64E base provides two mounting options: side mount and top mount. See Figure 2 for front/back mounting options, Figure 3 for side/side mounting, and Figure 4 for top mounting instructions.

Four M8-1.25 x 12mm deep mounting points. (Four per side, for a total of 16.)
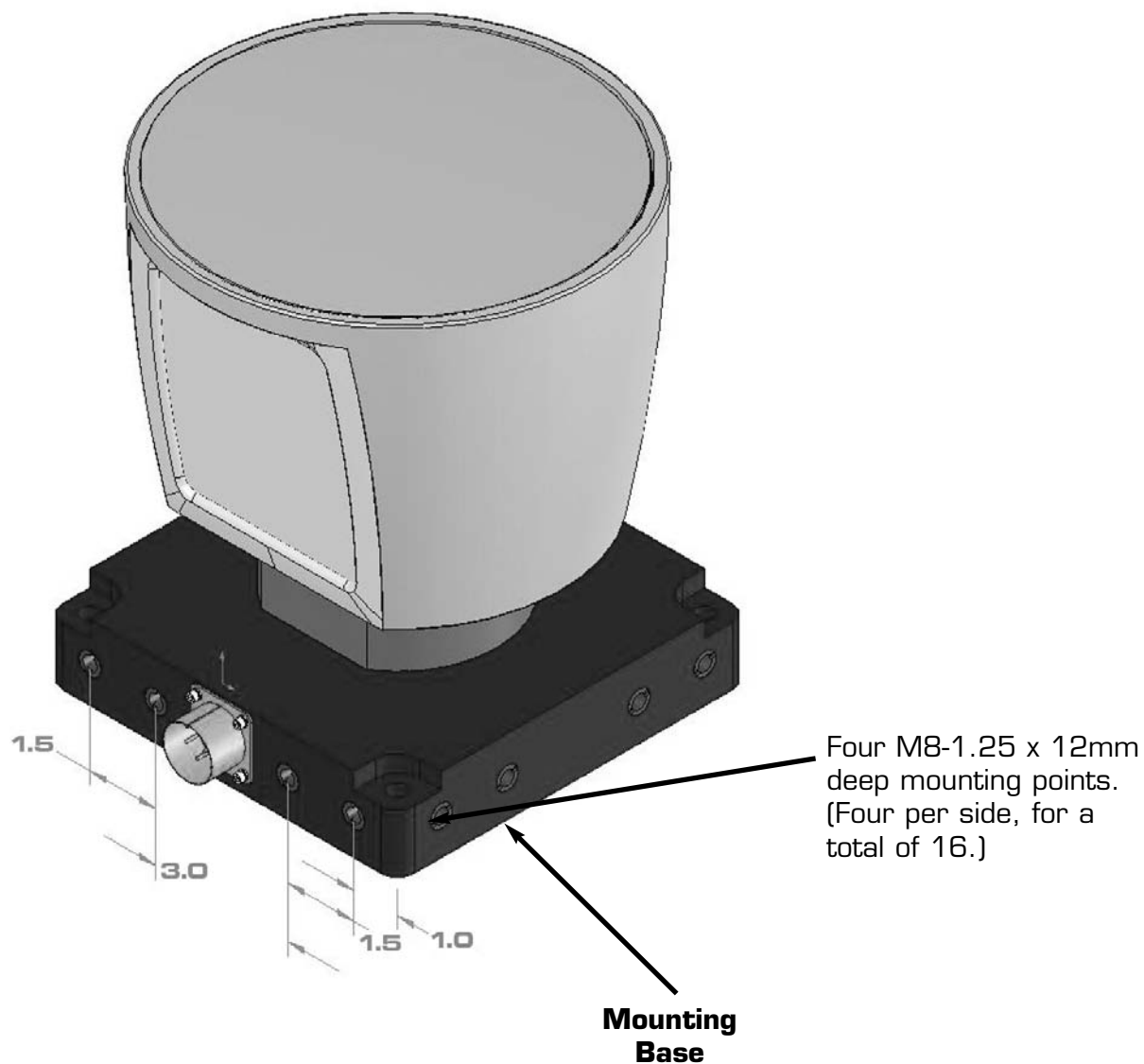
Mounting Base

Figure 2. Front and back HDL mounting illustration.

See Figure 2. This figure shows the HDL-64E's base plate screw locations with threaded inserts for standard M8 hardware.
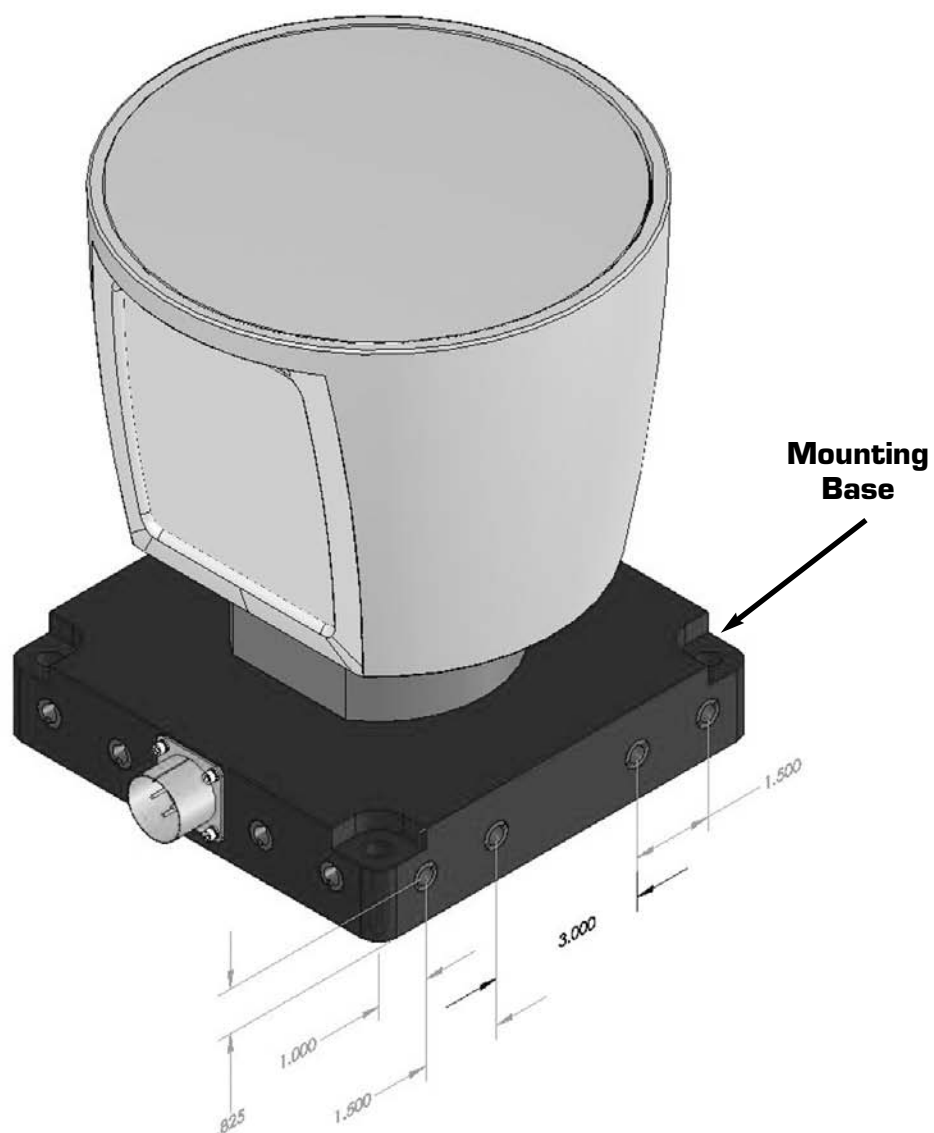
Mounting Base

Figure 3. Side/side HDL mounting illustration.

Top Mounting

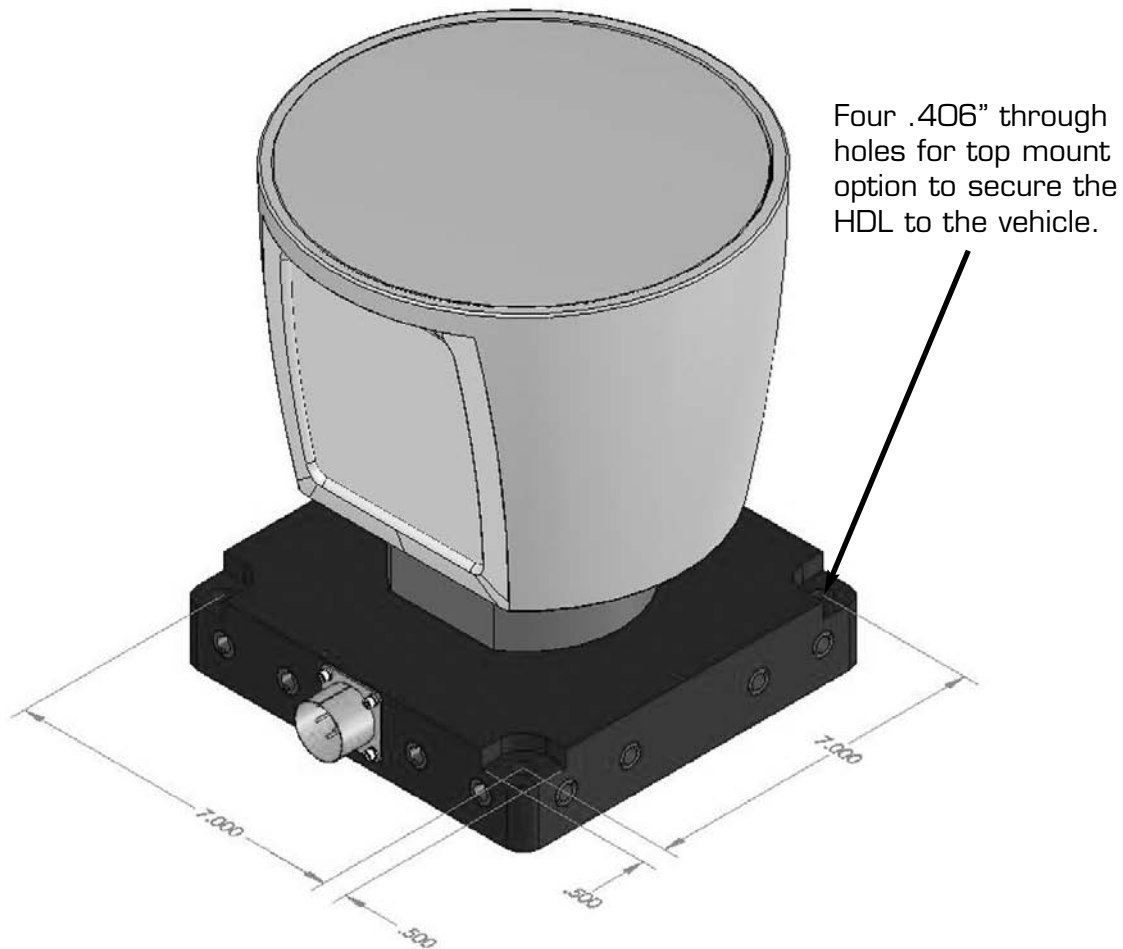Four .406" through holes for top mount option to secure the HDL to the vehicle.

Figure 4. HDL top mounting illustration.

Figure 4 shows the location of four .406" thru holes for top mounting.

For all mounting options, be sure the HDL-64E is mounted securely to withstand vibration and shock without risk of detachment. The unit need not be shock proofed — it is designed to withstand standard automotive G-forces.

The HDL-64E is weatherproofed to withstand wind, rain, and other adverse weather conditions. The spinning nature of the HDL-64E helps the unit shed excess water from the front window that could hamper performance.

Wiring

The HDL-64E comes with a pre-wired connector, wired with power, DB9 serial, and standard RJ-45 Ethernet connectors.The connector wires are approximately 25' in length.

Power. Connect the red and black wires to vehicle power. Be sure red is positive polarity. THE HDL-64E IS RATED ONLY FOR 12 VOLTS. Any voltage applied over 16 volts could damage the unit. Expect the unit to draw 4-6 amps during normal usage.

NOTE: The HDL-64E does not have a power switch. It spins whenever power is applied. The HDL-64E has a lockout circuit that prevents its lasers from firing at low RPMs.

Ethernet. This standard Ethernet connector is designed to connect to a standard PC. See the next section on usage for UDP packet formats.

Serial Interface. The connector also features an RS-232 DB9 serial connector. This connector allows for a firmware update to be applied to the HDL-64E (Velodyne may release firmware updates from time to time). It also accepts commands to change the RPM of the unit.

Cable Diagram. If you wish to wire your own connector, refer to Appendix A for a layout of the wiring pins.

USAGE

Data Packet Construction

The HDL-64E outputs UDP Ethernet packets. Each packet contains a data payload of 1206 bytes that consists of 12 blocks of 100-byte firing data followed by six bytes at the end of each packet that contains a spin counter and firmware version information. Each packet can be for either the upper or lower laser banks (called "laser blocks") - each bank contains 32 lasers. The packet format is as follows:

> **2 bytes of header info.** This header indicates whether the packet is for the upper block or the lower block. The upper block will have a header of 0xEEFF and the lower block will have a header of 0xDDFF.

> **2 bytes of rotational info.** This is an integer between 0 and 35999. Divide this number by 100 to get degrees from 0.

> **32 laser returns broken into 3 bytes each.** Each return contains two bytes of distance information in .2 centimeter increments, and one byte of intensity information (0 – 255, with 255 being the most intense return). A zero return indicates no return up to 65 meters.

> **Six status bytes that alternate between packets.** The end of the packet will show either:

> > - A reading showing the internal temperature of the unit. You will see a "DegC" ASCII string as the last four bytes of the packet. The two bytes before this string are the thermistor's reading in C in hex 8.8 format. This is in "big indian format" - i.e. the byte immediately preceding the DegC text is the whole degrees, and the byte preceding that is the fraction of a degree in 1/256 increments. So if you see c0 1a, the temperature of the thermistor is 26.75 degrees C.

> > - Or, the version number of the firmware in ASCII character format "Vn.n" where n.n is the version number, i.e. "1.5".

The HDL-64E data is presented as distances and intensities only. Velodyne includes a packet viewer called DSR, whose installer files are on the CD that came with the unit. DSR reads in the packets from the HDL-64E unit, performs the necessary calculations to plot the points presented in 3-D space, and plots the points on the viewer screen.

Note: The HDL-64E will output three upper block packets for every one lower block packet. This provides more resolution when identifying objects at greater distances.

The minimum return distance for the HDL-64E is approximately three feet. **Returns closer than this should be ignored.**

Correction Angles

Each HDL-64E laser is fixed with respect to vertical angle and offset to the rotational index data provided in each packet. For each data point issued by the HDL-64E, rotational and horizontal correction factors must be applied to determine the point's location in 3-D space referred to by the return. Each HDL-64E unit comes with its own unique .XML file, called db.XML, that was generated as a result of the calibration performed at Velodyne's factory. DSR uses this XML file to display points accurately. The .XML file also holds the key to interpreting the packet data for users that wish to create their own interpretation and plotting routines.

db.XML contains 64 instances of the following five values used to interpret the packet data:

rotCorrection: This parameter is the rotational correction angle for each laser, as viewed from the back of the unit. Positive factors rotate to the left, and negative values rotate to the right.

vertCorrection: This parameter is the vertical correction angle for each laser, as viewed from the back of the unit. Positive values have the laser pointing up, and negative values have the laser pointing down.

distCorrection: Each laser has its own unique distance due to minor variations in the parts used to construct the laser. This correction factor, in centimeters, accounts for this variance. This number should be directly added to the distance value read in the packet.

vertoffsetCorrection: This value represents the height of each laser as measured from the bottom of the base. It is a fixed value for all upper block lasers and a different fixed value for all lower block lasers.

horizOffsetCorrection: This value represents the horizontal offset of each laser as viewed from the back of the laser. It is a constant positive or negative value for all lasers.

Use the above values from the .XML file to calculate each point's position in 3-D space. Use the first 32 points for the upper block and the second 32 points for the lower block. The rotational info found in the header is used to determine the packets position with respect to the 360 degree horizontal field of view.

Note: There is a file on the CD called "HDL Source Example" that shows the calculations using the above correction factors.

Controlling the Spin Rate

The HDL-64E can spin at rates ranging from 300 RPM (5 Hz) to 900 RPM (15 Hz). The default is 600 RPM (10 Hz). Note that changing the spin rate does not change the data rate – the unit will send out the same number of packets (at a rate of one million data points per second) regardless of spin rate. The image resolution will increase or decrease depending on rotation speed. See Appendix B for angular resolution figures for various spin rates.

To control the HDL's spin rate, connect the serial cable to an available RS-232 COM port and issue a serial command of the format #HDLRPMnnn$ where nnn is an integer between 300 and 900. The characters are case sensitive and must be CAPS. The HDL-64E will adopt the new spin rate. Use the following serial parameters: Baud 9600, Parity: None, Data bits: 8, Stop bits: 1. The HDL-64E has no echo back feature, so no serial data will be returned from the HDL-64E.

Firmware Update

Velodyne may issue firmware updates from time to time. To apply the update, connect the DB9 RS-232 cable to a standard Windows-compatible PC's serial port. The HDL-64E must be powered up and spinning during the update.

Execute the file supplied by Velodyne – all the software and firmware is included to update the unit. Once the file is executed, the following screen will appear:
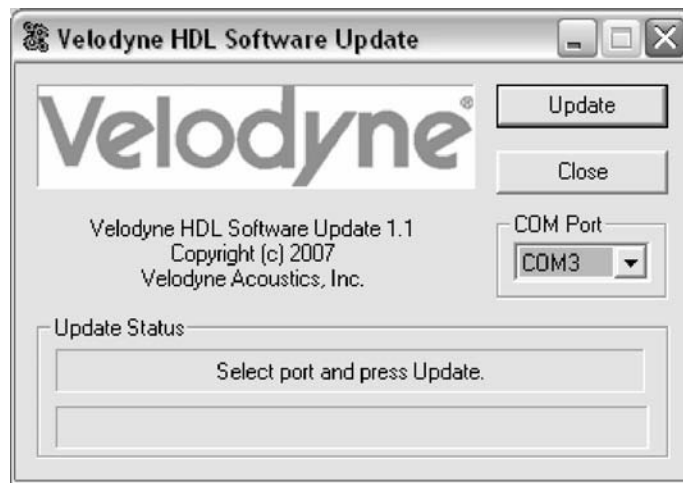
Figure 5. HDL software update screen capture.

Press update and the unit will update. If the update was successful, the unit will begin to spin down for a few seconds then power back up with the new firmware running. If the first update is not successful, it is recommended to try the update again several times before seeking assistance from Velodyne.

NOTE: The entire new firmware is uploaded and checksummed before being applied to the flash memory inside the HDL-64E. If the checksum is corrupted, no software update occurs. This protects the unit in the event of power or data loss during the firmware update.

Troubleshooting

Use this chart to troubleshoot common problems with the HDL-64E.

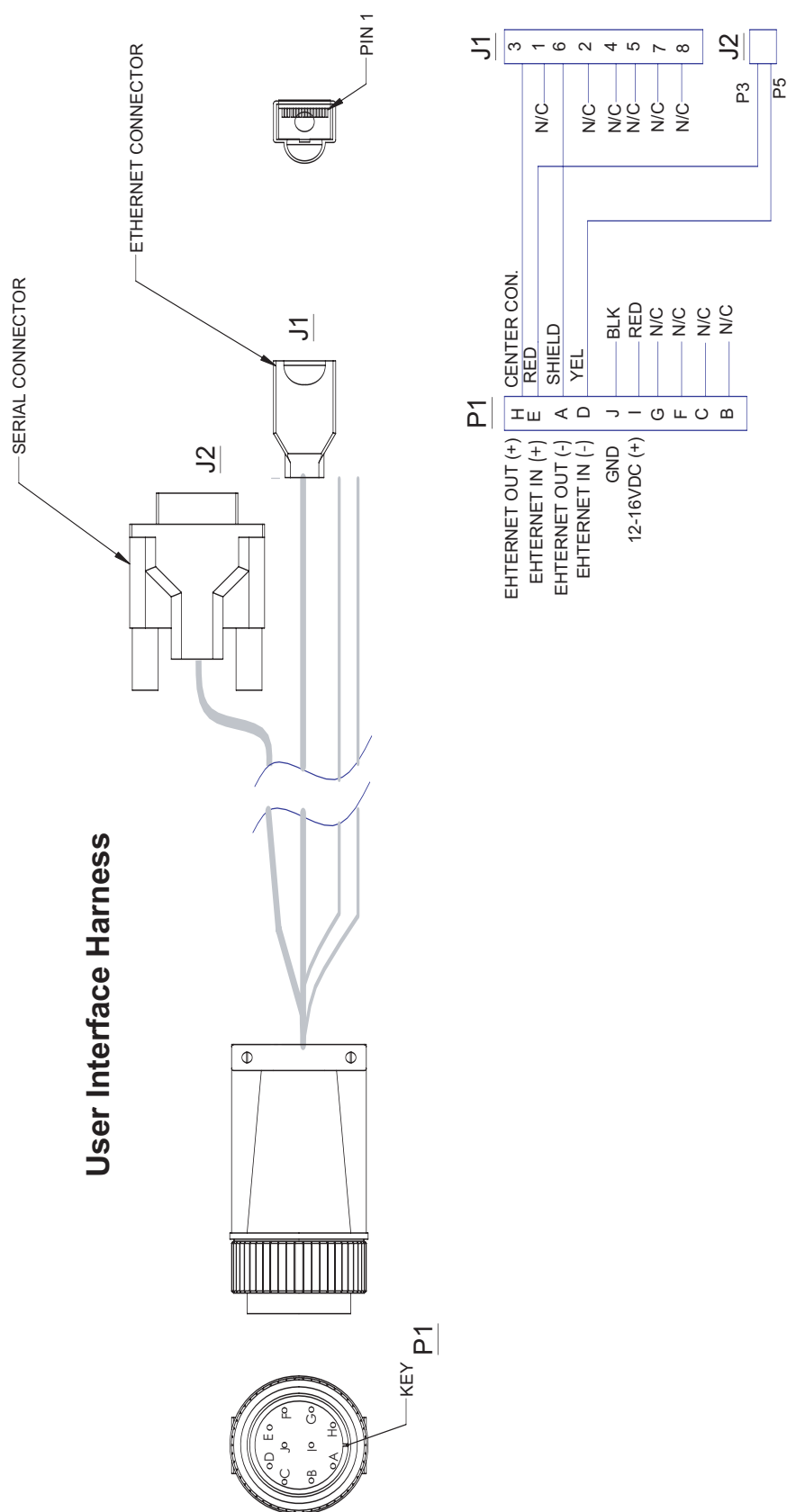| Problem	Resolution
Unit doesn't spin	Verify power connection and polarity. Verify proper voltage – should be 12 volts drawing about 3-4 amps. Remove bottom cover and check inline fuse. Replace if necessary.
Unit spins but no data	Verify Ethernet wiring. Verify packet output from another source (e.g. Ethereal/Wireshark).
No serial communication	Verify RS-232 cable connection. Unit must be active and spinning for RS-232 update. It may take several tries for the update to be effective.

Service and Maintenance

There are no user service or maintenance requirements or procedures for the Velodyne HDL-64E.

For service or maintenance, please contact Velodyne at (408) 465-2800, or log on to our website at www.velodyne.com/lidar.

Specifications

Sensor:	• 64 lasers/detectors • 360 degree field of view (azimuth) • 0.09 degree angular resolution (azimuth) • 26.8 degree vertical field of view (elevation) -+2° up to -24.8° down with 64 equally spaced angular subdivisions (approximately 0.4°) • <5 cm distance accuracy • 5-15 Hz rotation rate update (user selectable) • 50 meter range for pavement (~0.10 reflectivity) • 120 meter range for cars and foliage (~0.80 reflectivity) • >1M points per second • <0.05 milliseconds latency
Laser:	• Class lm - eye safe • 4 x 16 laser block assemblies • 905 nm wavelength • 10 nanosecond pulse • Adaptive power system for minimizing saturation and blinding
Mechanical:	• 12V input (16V max) @ 4 amps • <29 lbs. • 10" tall cylinder of 8" OD radius • 300 RPM - 900 RPM spin rate (user selectable)
Output:	• 100 MBPS UDP Ethernet packets

User Interface Harness

PIN 1

ETHERNET CONNECTOR

SERIAL CONNECTOR

J1

J2

KEY P1

J1		
3		
1	N/C	
6		
2	N/C	
4	N/C	
5	N/C	
7	N/C	
8	N/C	

J2

P3

P5

P1			
		CENTER CON.	
EHTERNET OUT (+)	H	RED	
EHTERNET IN (+)	E	SHIELD	
EHTERNET OUT (-)	A	YEL	
EHTERNET IN (-)	D		
	J	BLK	
GND	I	RED	
12-16VDC (+)	G	N/C	
	F	N/C	
	C	N/C	
	B	N/C	

APPENDIX B - ANGULAR RESOLUTION

Lower Block				
RPM	RPS	Points Per Revolution	Points Per Revolution Per Laser	Angular Resolution (degrees)
300	5	50000	1562.5	0.2304
600	10	25000	781.25	0.4608
900	15	16667	521	0.6912

Upper Block					
RPM	RPS	Points Per Revolution	Points Per Revolution Per Laser	Angular Resolution (degrees)	Post-Lower-Block Angular Resolution (degrees)**
300	5	200000	6250	0.0576	0.1152
600	10	100000	3125	0.1152	0.2304
900	15	66667	2083	0.1728	0.3456

Notes:

The HDL-64E generates 1 million points per second
- The lower block reports 250,000 points
- The upper block reports 750,000 points

There are three upper block packets then one lower block packet reported, then the pattern repeats.

** The first upper block measurement after the lower block measurement reports has half the angular resolution.

Digital Sensor Recorder (DSR)

DSR is a 3-dimensional point cloud visualization software program designed for use with the HDL-64E. It can be located on the CD provided with each HDL-64E sensor. Velodyne offers this software as an "out of the box" tool for the rendering and recording of point cloud data from the HDL-64E sensor.

DSR is intended as a reference platform from which the end user can author their own proprietary adaptation and visualization software packages.

Note: A code snippet is provided on the same CD to aid in understanding the methods at which DSR parses the data points generated by the HDL-64E sensor.

Installing DSR

Locate the DSR executable program on the provided CD. Double click on "DSR-1.1-2-install 3.exe" to begin the installation onto the host computer. Use of the default settings during the installation is highly recommended.

When the installation is complete, follow the "Utilizing the db.xml calibration data file in DSR" instructions in the next section to calibrate the DSR viewer to your new sensor.

Note: failure to use the calibration db.xml file supplied with your sensor will result in sub-optimal point cloud rendering in DSR.

Using DSR

DSR gives the user the ability to view point cloud data in real time or to create a recording of such data for future reference and playback. The recorded data will be stored in a standard pcap file format.

Note: These files can become quite large so the user should be mindful of recording duration when created.

Live Playback:

For live playback, first secure and power up the HDL-64E sensor so that it is spinning. Connect the RJ45 Ethernet connector to your host computer's network connection. You may wish to utilize auto DNS settings for your computers network configuration.

DSR desktop icon =

Open DSR from your desktop icon created during the installation. Pull down the "Options" menu and select the proper input device. Go to "Options" again and deselect the "Show Ground Plane" option. (Leave this feature off for the time being or until the ground plane has been properly adjusted).

You can now go to "Options/Properties" to change the individual settings for each LASER channel if so desired.

REFRESH button =

Provided that your computer is now receiving data packets, click on the Refresh button to start live viewing of a point cloud. The initial image is of a directly overhead perspective. See page 17 for mouse and key commands used to manipulate the 3D image within the viewer.

Note: The image can be manipulated in all directions and become disorienting. If you lose perspective, simply press F1 to return to the original view.

Recording Data:

RECORD button =

Once the input of streaming data has been confirmed through the live playback feature, click on the Record button and the program will request the name and location for the pcap file to be created. The recording will begin immediately once the file information has been entered. Click on the Record button again to discontinue the capture. One can string multiple recordings together on the same file by performing the Record function repeatedly. A new file name will not be requested until after the session has been aborted.

Note: An Ethernet capture utility such as Wireshark® can also be used as a pcap capture utility.

Playback of Recorded files:

Use the File → Open command to open a previously captured pcap file for playback. The DSR playback controls are similar to any DVD/VCR control features.

PLAY button =   ▷   *PAUSE button =*   ❚❚

Press the Play button to render the file. The Play button will alternate to Pause when in playback mode.

FORWARD button =   ▶▶   *REVERSE button =*   ◀◀

Use the Forward and Reverse buttons to change the direction of playback.

Note: The X, Y, Z and distance figures at the bottom of the image represent the distance of the x,y,z crosshairs with respect to the origin point indicated by the small white circle.

Note: In live display mode, click on the double arrow button to begin display. The concentric gray circles and grid lines represent 10 meter increments from the sensor, which is depicted on the screen by a white circle.

Utilizing the db.XML calibration data file in DSR

The db.XML file provided with your Velodyne HDL-64E contains all of the necessary data for the proper alignment of the point cloud information gathered by the HDL sensor for each laser. {vertical correction (deg), rotational correction (deg), distance correction (cm), vertical offset (cm), horizontal offset (cm), minimum and maximum intensity (0-255)}.

When implemented properly, the image viewable from the Digital Sensor Recorder (DSR) will be properly calibrated to provide an accurate visual representation of the environment in which the sensor is being applied.

This data should also be used in any other program using the data generated by the HDL-64E.

To integrate the db.XML file into the DSR program,
— follow these steps.

1. Provided that DSR has been installed on the host computer using the default settings, follow this path: c:\program files\Digital Sensor Recorder
2. Cut and paste the existing db.XML file to another location and rename as the default_db.XML
3. Copy and paste the db.XML file provided on the CD to the DSR program folder previously opened
4. Close out the windows and the program is ready to run
5. Open the DSR program
6. Click options\properties
7. Check that the new values are present and that they reflect the values in the example screen captures provided on the CD [Fig.6]
8. Your DSR viewer is now calibrated to your sensor

Properties

Scanner Properties

Distance LSB: 0.20 cm

Scanner Position (cm): X: 0.0 Y: 0.0 Z: 0.0

Scanner Angle (deg): Roll: 0.0 Pitch: 0.1 Yaw: 0.0

Laser Properties

ID	Enabled	Intensity On	Color	Vertical Corr. (deg)	Rotational Corr. (deg)	Distance Corr. (cm)	Vert. Offset Corr. (cm)	Horiz. Offset Corr. (cm)	Min Intensity	Max Intensity
29	☑	☐		2.020810	2.200000	36.000000	0.000000	4.000000	0	255
28	☑	☐		1.679890	0.500000	22.000000	0.000000	-4.000000	0	255
25	☑	☐		1.339140	-1.800000	38.000000	0.000000	4.000000	0	255
24	☑	☐		0.998555	-3.700000	23.000000	0.000000	-4.000000	0	255
3	☑	☐		0.658119	6.200000	43.000000	0.000000	4.000000	0	255
2	☑	☐		0.317822	4.000000	32.000000	0.000000	-4.000000	0	255
31	☑	☐		-0.022350	1.400000	40.000000	0.000000	4.000000	0	255
30	☑	☐		-0.362407	-0.400000	25.000000	0.000000	-4.000000	0	255
27	☑	☐		-0.702363	-2.800000	38.000000	0.000000	4.000000	0	255
26	☑	☐		-1.042230	-4.700000	28.000000	0.000000	-4.000000	0	255
21	☑	☐		-1.382020	6.700000	25.000000	0.000000	4.000000	0	255
20	☑	☐		-1.721740	4.700000	18.000000	0.000000	-4.000000	0	255
17	☑	☐		-2.061410	2.600000	34.000000	0.000000	4.000000	0	255
16	☑	☐		-2.401040	0.800000	29.000000	0.000000	-4.000000	0	255
13	☑	☐		-2.740630	-1.800000	28.000000	0.000000	4.000000	0	255
12	☑	☐		-3.080210	-3.300000	24.000000	0.000000	-4.000000	0	255
23	☑	☐		-3.300000	5.800000	30.000000	0.000000	4.000000	0	255
22	☑	☐		-3.759370	4.000000	17.000000	0.000000	-4.000000	0	255
19	☑	☐		-4.098960	1.500000	32.000000	0.000000	4.000000	0	255
18	☑	☐		-4.438590	-0.400000	22.000000	0.000000	-4.000000	0	255
15	☑	☐		-4.778260	-2.800000	32.000000	0.000000	4.000000	0	255
14	☑	☐		-5.117980	-4.600000	19.000000	0.000000	-4.000000	0	255
9	☑	☐		-5.457770	6.500000	37.000000	0.000000	4.000000	0	255
8	☑	☐		-5.797640	5.000000	20.000000	0.000000	-4.000000	0	255

Selected color:

Figure 6. Calibration values as seen in DSR/File/Properties

DSR Key Controls

Zoom:
Z = Zoom in
Shift, Z = Zoom out

Z axis rotation:
Y = Rotate CW
Shift, Y = Rotate CCW

X axis rotation:
P = Rotate CW
Shift, P = Rotate CCW

Y axis rotation:
R = Rotate CW
Shift, R = Rotate CCW

Z Shift:
F = Forward
B = Back

X Shift:
L = Left
H = Right

Y Shift:
U = Up
D = Down

Aux. Functions:
Ctrl, (Z,Y,P,R,F,B,L,H,U,D) Direction = Fine Movement

Alt, (Z,Y,P,R,F,B,L,H,U,D) Direction= Very Fine Movement

DSR Mouse Controls

Rotational:
Left Button/Move

Slide:
Right Button/Move

Zoom:
Scroll forward = Zoom In
Scroll backward = Zoom Out

Velodyne Acoustics, Inc.
345 Digital Drive
Morgan Hill, CA 95037

408.465.2800 voice
408.779.9227 fax
408.779.9208 service fax

www.velodyne.com
Service E-mail: service@velodyne.com
Product E-mail: help@velodyne.com
Technical E-mail: techhelp@velodyne.com
Sales E-mail: lidar@velodyne.com