RobotEye RE05

3D Laser Scanning System
User Manual

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Copyright Notice and Disclaimer

Revision Table

Date	Notes
1/11/2012	Draft
10/05/2013	Initial Release
11/10/2013	Regulatory Information Update
13/10/2014	Ancillary Components Added – IP67 Information
27/11/2014	Region Scan Duration Addendum

Table of Contents

1 Introduction

IMPORTANT
READ CAREFULLY BEFORE USE
KEEP FOR FUTURE REFERENCE

The RE05 User Manual is provided as a guide to the connection, configuration and safe use of the Ocular Robotics RE05 3D laser scanner. For development of custom software applications for use with the RE05 system see the RE05 EyeLib Application Peripheral Interface (API) Reference Manual and UDP Packet Specification Manual. For further information, contact Ocular Robotics.

Chapter 2 Basics, describes the initial setup and basic use of the RE05 including information on cleaning, maintenance and safety. Chapter 3 General Description presents a system description in terms of the system's Mechanical and Electrical properties and its communication and power interfaces. Chapter 4 Performance and Measurement Accuracy outlines the impact of the various system settings on system performance and the accuracy of measurements made. Chapter 5 Scan Patterns describes the scanning features available to the RE05 laser scanner.

CAUTION - USE OF CONTROLS OR ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN SIGNIFICANT RISK OF INJURY. IT WILL ALSO VOID YOUR WARRANTY

2 Basics

IMPORTANT – Before connecting the power to this system or attempting to operate it in any way, read and follow all instructions regarding safe operation of this system contained in Section 2.5.

2.1 System Components

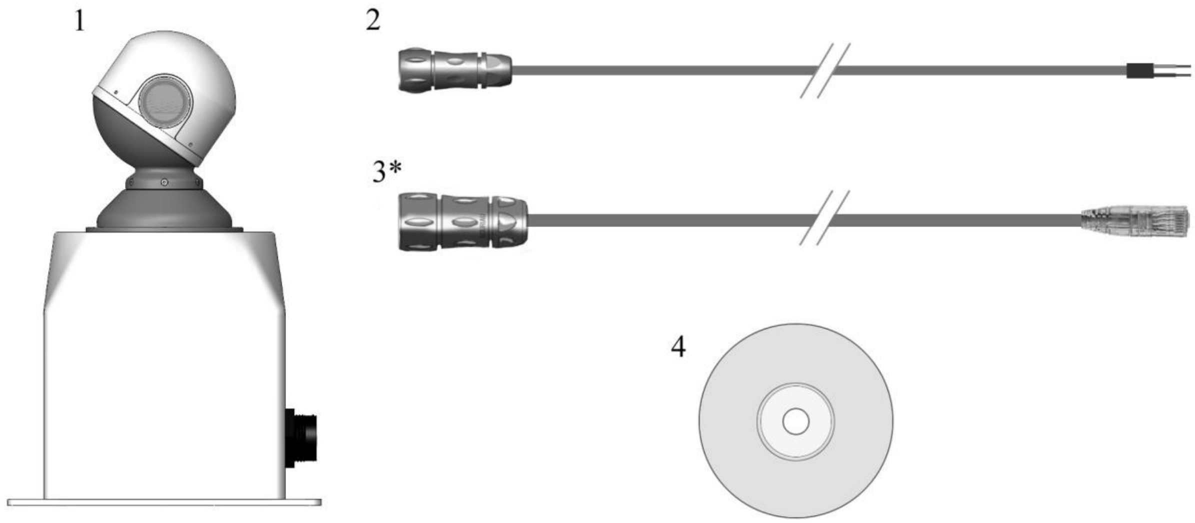


Figure 2.1 – RE05 Packing List

The RobotEye RE05 3D laser scanning system is supplied standard with the following components, each of which can be seen in Figure 2.1:

1. The RobotEye RE05 3D laser scanning system.
2. RE05 power cable.
3. Cat-5e Ethernet cable (*optional).
4. Installation & documentation disk.

2.2 What You Need

In order to operate the RE05 laser scanning system, you will need:

1. Power supply – A 24 volt DC 10 Amp power supply with a continuous current capacity of 10 Amps.
2. Ethernet cable – A standard Ethernet cable (Cat5e or Cat6) is needed for control and communication with the RE05 system.
3. A computer with a Windows or Linux operating system with an available 100 Megabit or Gigabit Ethernet port.

2.3 Handling and Transportation

Avoid handling the RobotEye using the scanning head. This may result in mechanical damage and misalignment of the sensor.

When transporting, make sure the RobotEye head will not be subject to large external loads and stresses.

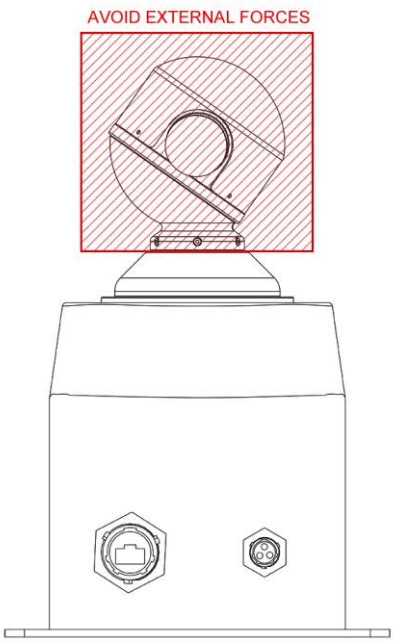


Figure 2.2 – RE05 Handling Zones

2.4 Initial Setup

NOTE – The robot eye head must be handled with extra care during transport and installation. External loads exerted on the head may result in damage.

Follow the steps below to set the RE05 system up for use on a computer with a Windows or Linux operating system. The system IP address shipped with your system should be noted on the supplied *Certificate*.

1. Connect one end of the Ethernet cable to the network port on the PC or switch. Connect the other end to the RE05 Ethernet port. Refer to Figure 2.3

2. Make sure the 24 volt power supply is switched OFF. Connect the supplied power cable to the 24 volt power supply. On the unterminated end of the cable you will find two wires one black and one with a red sheath on it. The black wire should be connected to the negative terminal on the power supply. The cable with the red sheath should be connected to the positive terminal on the power supply. The green and yellow cable should be connected to a ground reference.

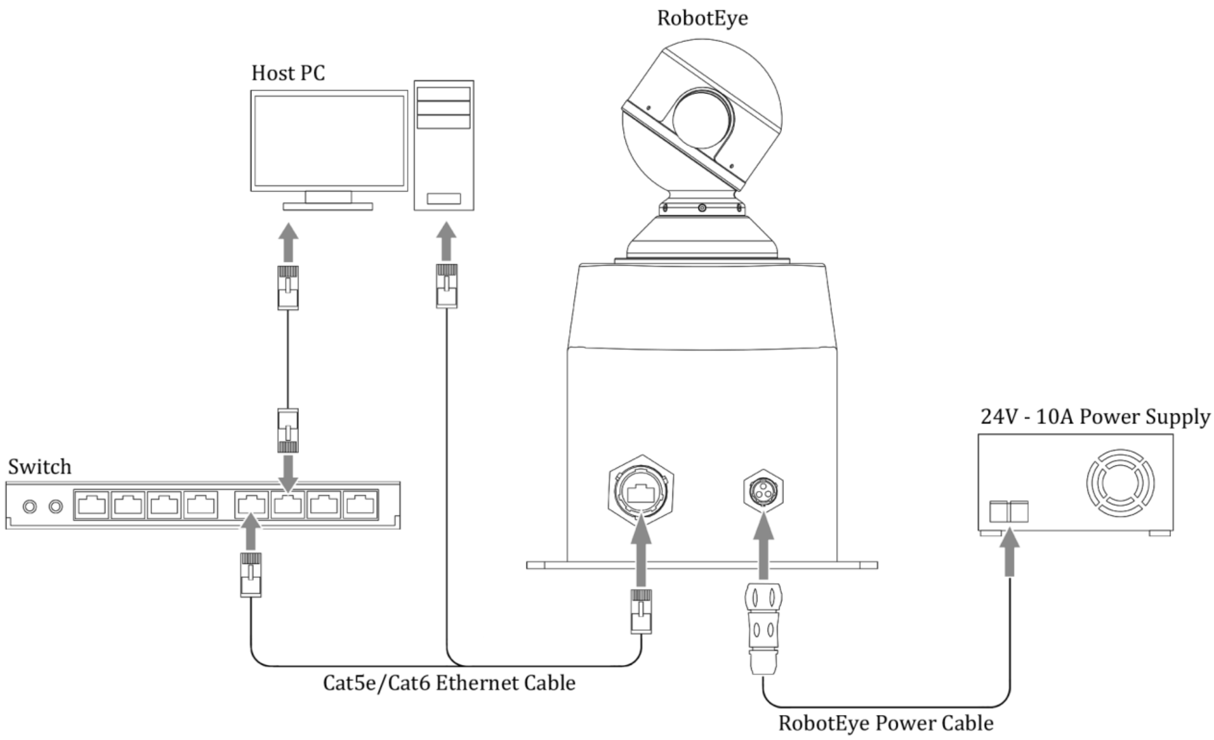


Figure 2.3 Wiring and connections for the RobotEye

NOTE - Make sure the power supply is not powered before connecting the cables.

3. Connect the power supply cable to the corresponding plug on the RE05 unit. Ensure the correct orientation by aligning the polarisation keys on the panel connector and the plug. If forced in the incorrect orientation, damage to the system is likely to result. Refer to Section 3.3 for further details.

2.5 Safety

The RobotEye RE05 3D Laser Scanning System is a Class 1 laser device which contains a laser which emits invisible radiation.

The device complies with Laser Class 1 based on IEC 60825-1:2007 and does not pose any significant risk to a naked human eye.

Protection Class 3. The device operates with a separated extra low voltage (SELV) of 24 Volts DC.

The device may only be operated as intended and in faultless condition. Safety and warning signs must not be removed.

The device is in accordance with Ingress Protection 65 (IP65). The device is protected against dust and jet water.

All instructions regarding safe operation of this system should be strictly followed.

- The user is responsible for the safe operation and maintenance of this system at all times.
- This laser device should not be aimed at the human eye or the beam modified using any optical instruments.
- Installers of laser sensors are responsible for ensuring their safe use in accordance with all applicable regulations in the state, country or territory of use.
- Tampering with any enclosure will void warranty coverage. Opening the device potentially exposes personnel to laser radiation that may cause eye injuries.
- The device's rotating head is not designed to accommodate for any alterations or additions. High speed projectiles may result.
- The device must be securely mounted during operation to prevent unstable motions or vibrations.
- Ensure that the Robot Eye head will not contact anything while operating in its full range of movement.
- **Do not try to hold or touch the Robot Eye head while operating.**
- **Do not attempt to disassemble the sensor.** Improper disassembly will destroy the optical alignment of the sensor and necessitate factory repairs.
- The manufacturer will not accept liability for any resulting damages caused by the non-observance of this manual or any unauthorised modification to the system.

2.5.1 Safety Features

Class 1 laser products are required to be fitted with specific safety features. These features are issued in the Laser Safety Standards ANSI Z136 and IEC 60825. The required features fitted to the RE05 System are listed below:

Laser Safety Warning Labels – The following laser safety warning labels are fitted to the RobotEye RE05 3D Laser Scanning System:

1. Laser Classification and Information Label (on face above ethernet connector)

Figure 2.4 Laser Classification label

2. RobotEye Model Label (fitted on enclosure below to RobotEye head)

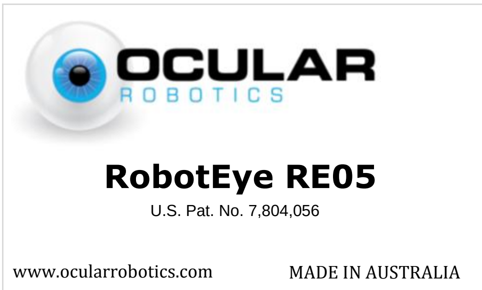


Figure 2.5 RobotEye Model Label

3. RobotEye Identification Label (fitted on face above power connector)

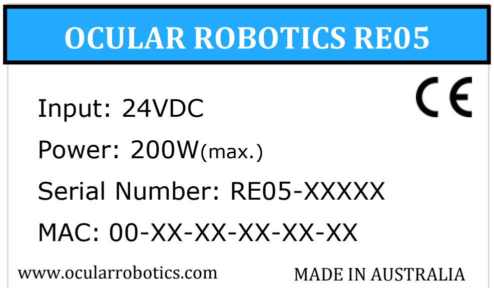


Figure 2.6 RobotEye Identification Label

2.6 Operation

Special precautions for when operating the device.

- The RE05 is NOT intended for use by children or inexperienced personnel.
- **DO NOT** attempt to touch or impede the Robot Eye head during operation.
- Avoid strands of fabric or long exposed hair from being in the vicinity of the Robot Eye head during operation. Significant injury and/or mechanical damage may result.
- The device must be protected from direct impact.

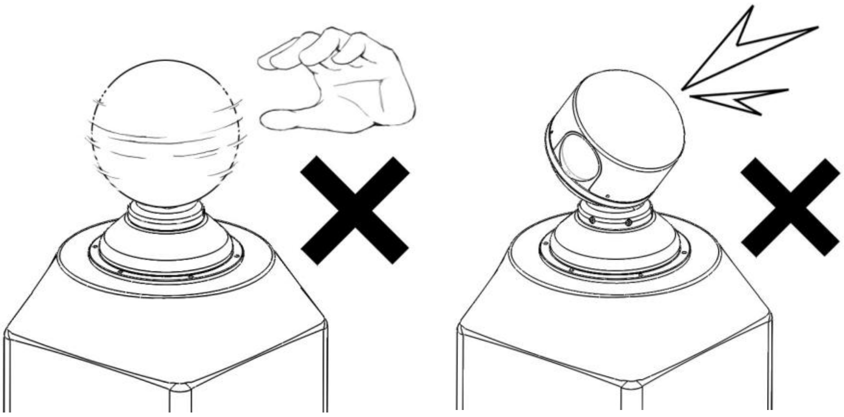


Figure 2.7 Do not touch RE Head while in operation. Avoid impacts.

General considerations for when operating the device.

- The RE05 should not be put into operation when the aperture is fogged or dirty. The aperture should not be touched with bare hands. Refer to Section 2.7 for cleaning the device.
- The device must be protected against overheating. Persistent overheating of the device will lead to reduced lifetime of the laser diode.
- Additional protection is recommended when operating the device under extreme or adverse environmental conditions. Rapid changes in temperature may lead to humidity entering the device.

IEC 61000 EMC Warning - This product may cause interference if used in residential areas. Such use must be avoided unless the user takes special measures to reduce electromagnetic emissions to prevent interference to the reception of radio and television broadcasts.

2.7 Cleaning and Maintenance

CAUTION – Power must be disconnected from the RE05 system before any cleaning or maintenance is carried out.

User performable cleaning and maintenance of the RobotEye RE05 3D Laser Scanning System is limited to cleaning of the exterior housing and the laser window. For ANY other maintenance or repair the unit should be returned to the factory. Opening of the system enclosure will void warranty. Use the following guidelines for cleaning of the system enclosure and laser window.

- It is **VERY** important not to abrade or scratch the laser window during cleaning or at any other time as it has the potential to significantly degrade system performance.
- Use a soft non-abrasive cloth or tissue to clean the window, make sure there are no foreign abrasive particles on the window before performing cleaning, as this may damage the window.
- **DO NOT** use solvents. If a cloth alone is not sufficient, a mixture of soap and water may be used.
- The rest of the RE05 unit housing can be cleaned with a soft damp cloth.

2.7.1 Replacing the Window

The aperture window can be replaced in the case of irreparable damage to the window surface.

1. Use the **Retaining Ring Driver** to unscrew the **Retaining Ring** from the aperture.
2. Carefully take out the damaged window.
3. Make sure the **O-ring** remains in position, re-seat if necessary.

NOTE – The O-ring is very flexible and is prone to dislodge itself after relieving the window from the aperture. Patience and care must be taken when re-seating the O-ring .

4. Carefully place the new replacement window into position. **DO NOT** allow dust or dirt to enter the RobotEye head.

NOTE – Any particulates such as dust or dirt entering the RobotEye head will significantly degrade performance. If particulates are deposited on the mirror, use puffs of air to lift the dirt off the mirror surface. DO NOT use canned/compressed air as it may result in hydrocarbon residue forming on the mirror. Damaging the mirror surface may necessitate factory repairs.

5. Screw the **Retaining Ring** into place using the **Retaining Ring Driver**.

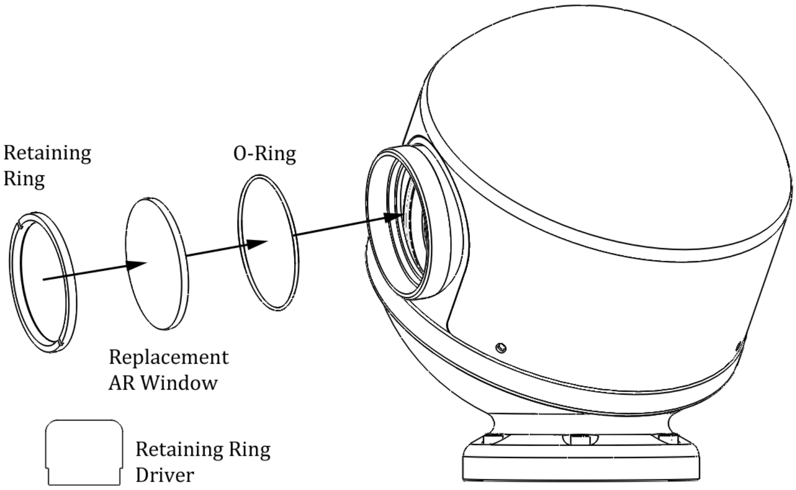


Figure 2.8 Replacing the Anti-Reflective Coated Window.

2.7.2 Replacement Parts

Replacement parts can be ordered directly through Ocular Robotics.

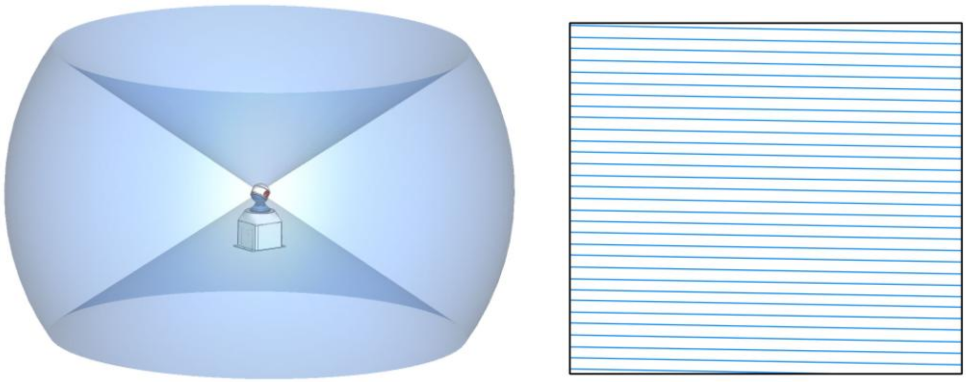
1) *RobotEye power cable.*
   a) The power cable comprises of a standard 3 core power cable rated for at least 10A.
   b) The power cable has an IP68/IP69K connector attached to interface with the mating receptacle on the enclosure.
2) *IP68/69K Data cable.*
   a) An optional IP68/69K cable can be purchased from Ocular Robotics
3) *5mmx20mm 16A Slow Blow Fuse.*
   a) The fuse is located in the Fuseholder located between the connectors.
4) *Anti-reflective Coated Laser Window.*

3 General Description

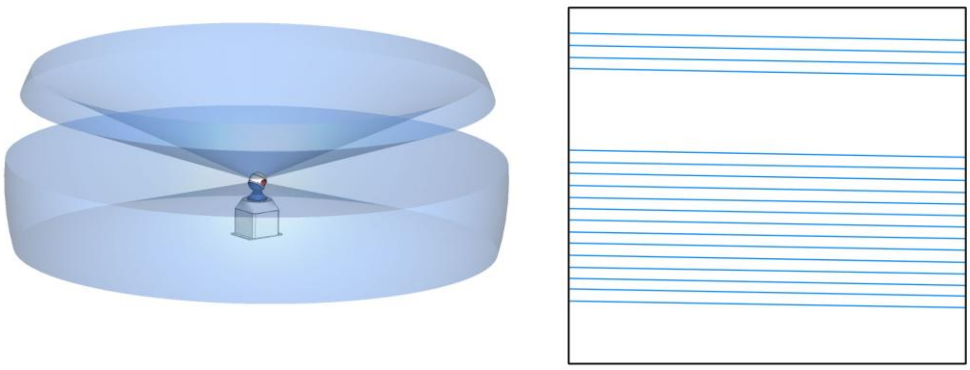
The RobotEye RE05 3D Laser Scanning System is a high performance long range laser scanning system, designed for rapid 3D cloud point imaging. The RE05 System with sample rates up to 30 kHz and high scan speeds is ideally suited to generating dense point clouds of the environment both indoors and outdoors, at ranges up to 30 meters.

The RE05's embedded RobotEye technology brings to laser scanning previously unavailable control over scanning behaviour. Three scanning schemes are currently standard with the RobotEye RE05 System. Each scan pattern is fully parameterised, so that the behaviour of the system is entirely user defined.

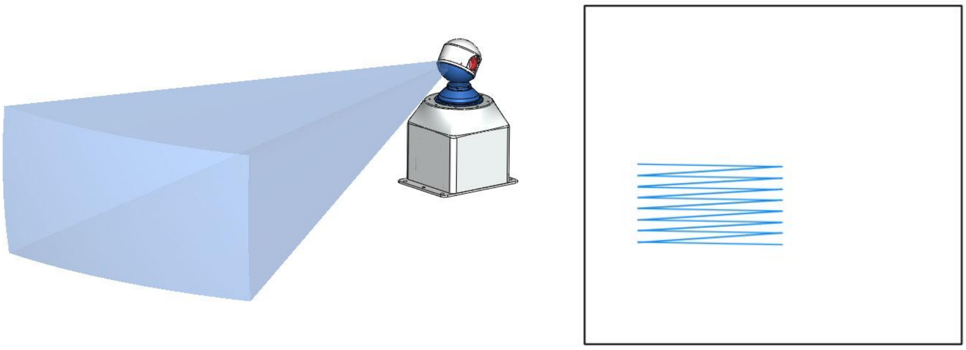
Full Field Scanning — When Full Field Scanning is used, the RobotEye scan parameters are the azimuth and elevation rates. Varying these parameters results in a wide variety of possible scan patterns, ranging from fast, coarse scans, to slower, more dense sampling patterns.



Bounded Elevation Scanning — In bounded elevation scanning mode, the operator is able to define a scan that covers a full 360° in azimuth but is restricted to a region of the elevation range of the RE05. Again the azimuth rate is configurable as is the line density of the scan. This mode enables the operator to concentrate the focus of the RE05 Scanner to a desired region and at the same time have complete control over the density of the samples taken in that region.



Region Scanning — The region scanning mode allows the operator to define a region within the RE05's azimuth and elevation range in which to concentrate the range scanning. The region scan mode gives the most control over the attention of the scanner with settings for azimuth rate and number of lines as in the bounded elevation scan as well as the extent of the scan region relative to its top left hand corner where it will scan repeatedly until a different scan is commanded.



The RE05 3D Laser Scanning System is also able to reconfigure or swap between any of these scanning modes immediately, making dynamic control of the scanner behaviour easy. Further details about the scanning behaviours are covered in Chapter 5.

3.2 Electrical

The RE05 System requires a 24 Volt DC power supply that has a continuous current capacity of 10 Amps. The output voltage of the 24 VDC power supply used with the RE05 System should not vary by more than ±15% from the nominal 24V under any circumstances otherwise damage to the RE05 System may result.

3.3 Power

Power is delivered to the RE05 with the supplied 5 metre power cable. The unterminated end of the power cable has three wires, one black, one with a red sheath on it and a green/yellow wire. The black wire should be connected to the negative terminal on the power supply. The cable with the red sheath should be connected to the positive terminal on the power supply and the green/yellow wire to a ground reference.

During connection of the power supply cable to the corresponding plug on the RE05 unit, ensure the correct orientation by aligning the polarisation keys on the panel connector and the plug. If forced in the incorrect orientation, damage to the system is likely to result.

A 16A rated fuse is housed in the fuseholder to prevent potential damage to internal electrical components from power surges.

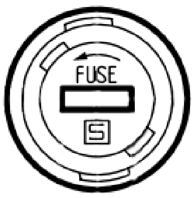


Figure 3.1 – Fuseholder on the RE05 Enclosure

3.4 Mechanical

The RE05 System has an environmental protection rating of IP65 and can operate in ambient temperatures of up to 40°C making it suitable for use in a wide range of industrial environments. The bounding dimensions and positions of mounting holes for the RE05 are shown in Figure 3.2.

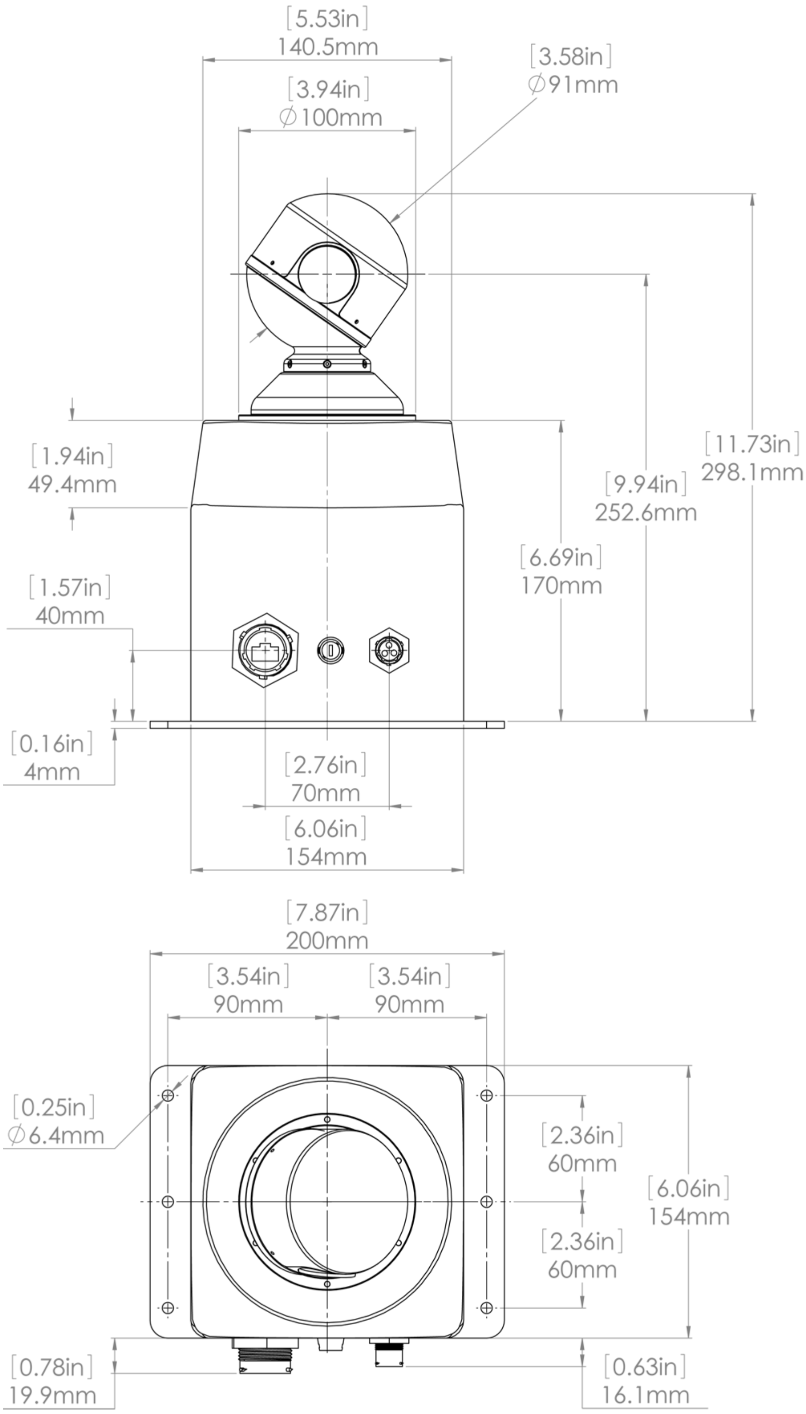


Figure 3.2 – RE05 Mechanical Dimensions (IP65 ver.)

3.5 Ethernet

The RE05 System interfaces with a computer via a standard Ethernet cable. The RE05 supports Gigabit connectivity however a 100 Megabit connection is sufficient for operation even at the highest data sampling rates.

It is recommended that the system be used on a private network to avoid large amounts of (unwanted) data potentially being sent to all computers on the network (see Figure 3.3). Multiple RE05 Systems can be connected on a single network. However this should be done using a switch to avoid data collisions on the network (see Figure 3.4).

The RE05 is configured to allow any number of clients to receive data when in broadcast mode. The RE05 will only accept commands from the Primary Client however. This is to ensure that multiple clients cannot simultaneously send conflicting commands to the sensor. The Primary Client is determined by the RE05 in a very simple manner, it is the client that first sends data to the RE05 after it is powered up. For a more detailed explanation of the network behaviour of the RE05 System see the RE05 UDP Communications Specification available for download from the Ocular Robotics website.

In most situations use of a Cat5e Ethernet cable will be sufficient for operation of the RE05 system, however it is recommended that a Cat6 cable be used over long distances to avoid packet loss due to the large volume of data.

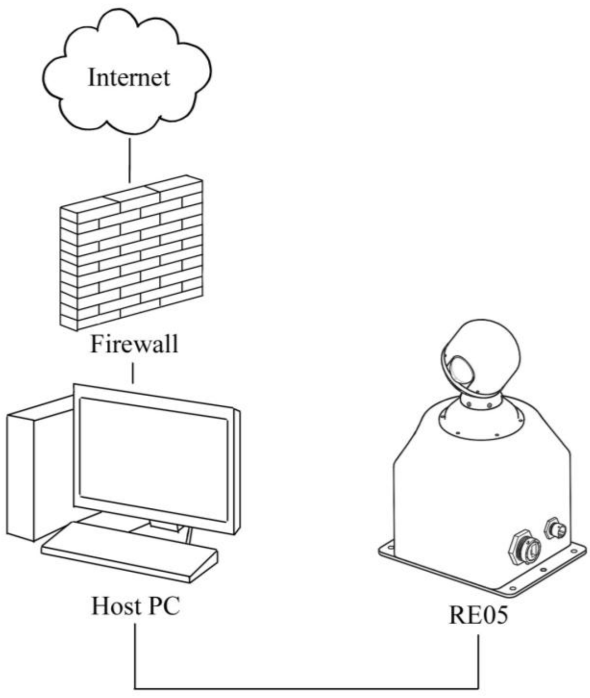


Figure 3.3 – Network Schematic for Single Host PC to Single RE05

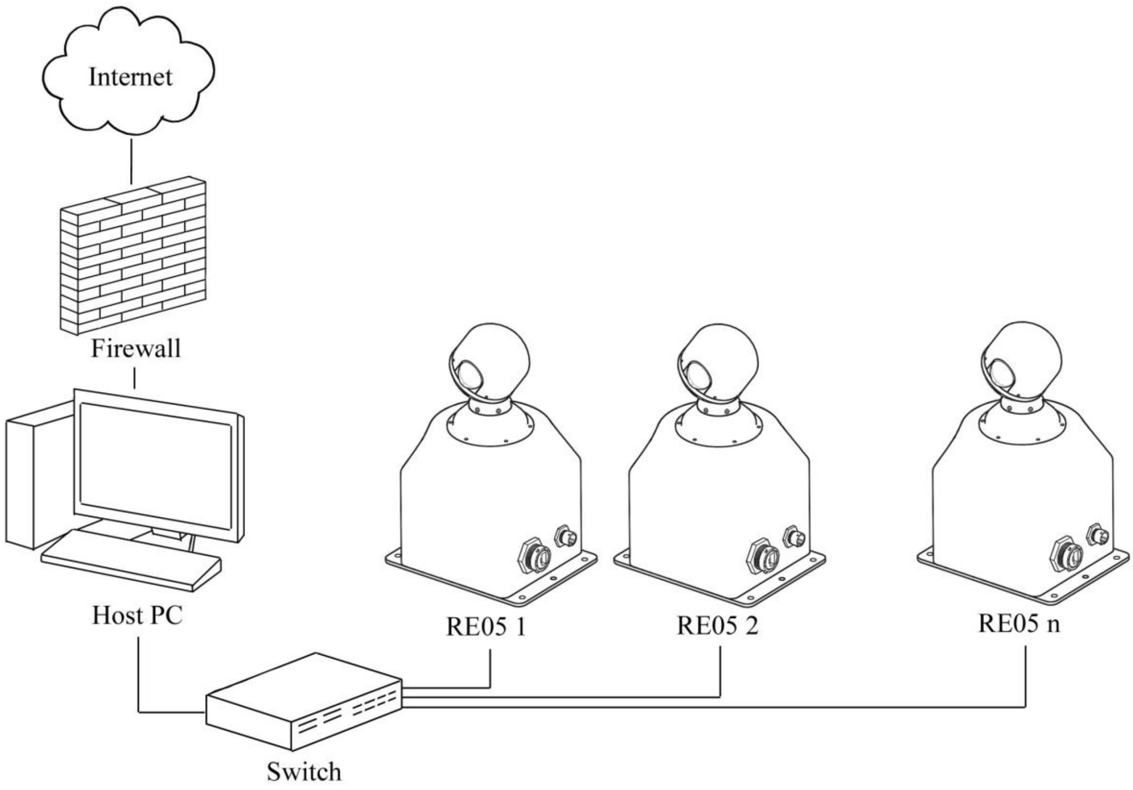


Figure 3.4 – Network Schematic for Single Host PC to Multiple RE05s

4 Measurement Accuracy

4.1 Angular

The RE05 laser scanner natively records each 3D data point in spherical coordinates of *range, azimuth, elevation* and additionally *intensity*. The accuracy of the two angular components of *azimuth* and *elevation* along with the *range* measurement determine the accuracy with which each data point can be placed in 3D space.

The angular resolution of the *azimuth* and *elevation* components are both 0.01° respectively. The angular accuracy is <0.05° for both *azimuth* and *elevation*. Due to the fact that the aperture position in *azimuth* and *elevation* for 3D data points is tracked separately from the aperture motion control, the accuracy of the reported *azimuth* and *elevation* aperture angles is independent of any path following errors of the aperture. This means that regardless of what type of scan mode or *azimuth* and *elevation* rates are set the angular accuracy of the positions of the points reported by the RE05 are unchanged.

4.2 Range

The laser range finding module accurately measures range to a wide variety of surfaces and materials. The rangefinder achieves measurement accuracy nominally of 50mm as configured for use with the RE05, however measurement accuracy for any particular scenario will be determined by factors such as sample averaging, nature of the surface being measured and ambient light levels.

The effect on range measurement accuracy due to the user settings of the RE05 comes from the *Sample Average*. A higher sampling average will results in less range dispersion in the measurements.

NOTE – The RE05 laser scanner has a minimum range of 500 mm from the aperture. Objects within 500 mm might be resolved based on the surface properties but performance is not guaranteed.

5 Scan Patterns

The RE05 currently supports three configurable scan patterns; the *Full Field Scan*, *Bounded Elevation Scan*, and *Region Scan*. These scan patterns are able to be altered, or switched between on-the-fly (usually within a couple of milliseconds of the command being sent) which is an unprecedented capability for a 3D laser scanner. Each scan pattern is fully parameterised, meaning that the parameters (or variables) that define the way the aperture moves can be altered by the user to create the arbitrary scanning behaviour demanded by a given application. Users are encouraged to explore the range of options available to them, so that an 'optimal' configuration can be found for the problem at hand.

The settings for each of these scan patterns will be examined in the following sections.

5.1 Sampling Rate

Two laser sampling rates are supported on the RE05.

The **default distance tracking mode** operates at a 1 to 10 kHz sampling frequency. The distance values are returned with corresponding intensity values. The output sampling frequency is determined by the *Sample Average* value (Parameter *Avg* in RNLS command – Refer to UDP Communications Spec).

The dispersion of the measured distances is defined by:

$$\sigma_{disp} = \frac{\sigma_0}{\sqrt{Avg}}$$

where $\sigma_0 \approx 5$cm.

Table 1 – Distance Measurement Dispersion

Freq [Hz]	Avg	Output Freq [Hz]	Dispersion [cm]
10000	1	10000	5
10000	10	1000	1.6
10000	100	100	0.5
10000	1000	10	0.2

The discrete **fast distance tracking mode** operates at a 30 kHz sampling frequency. The distance values are not sample averaged. i.e. *Sample Average* = 1. Intensity values are not returned for this sampling rate.

5.2 The Full Field Scan

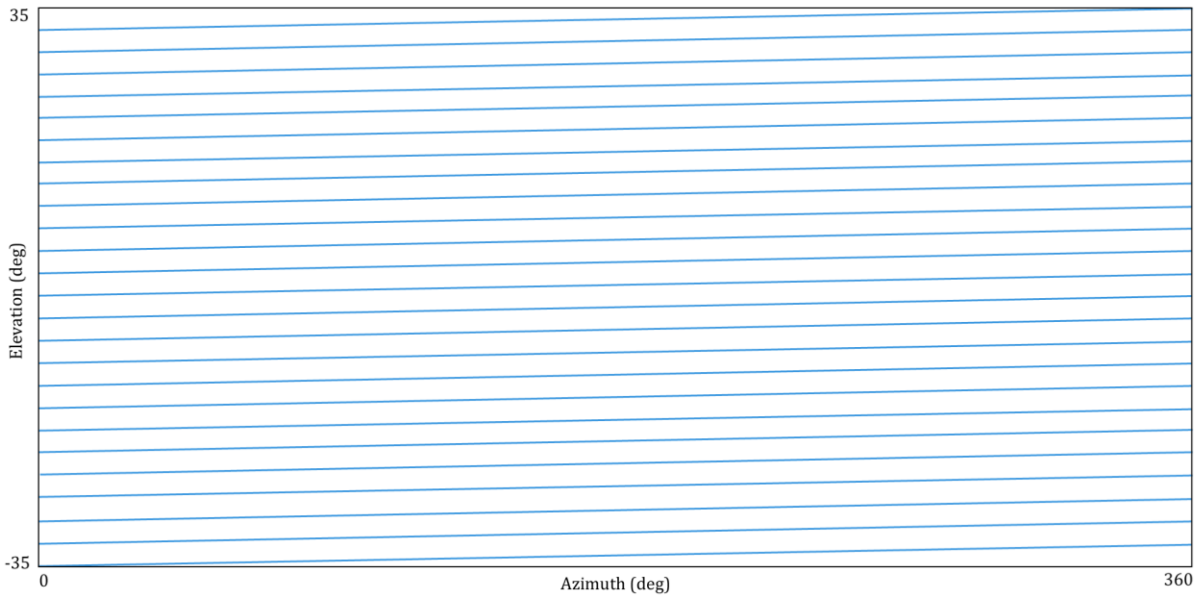


Figure 5.1 – The Full Field Scan Pattern

Parameter	Limit
Azimuth Rate	Maximum 5400 degrees/second (= 15 revolutions/second)
Number of Scan Lines	Based on Azimuth rate. Limited to one sweep of elevation range / second: $$nLines_{MIN} = \frac{azRate}{360}$$ e.g: • Minimum 1 lines/scan at 1 rev/second • Minimum 8 lines/scan at 8 revs/second • Minimum 15 lines/scan at 15 revs/second **NOTE:** All units in this equation are in degrees or degrees/second. **NOTE:** There is a special error code for attempted scans with an insufficiently dense scan pattern: 0x08 = ERROR_SCAN_TOO_SPARSE

This mode is completely parameterised by two variables: the *Azimuth Rate* and *Number of Scan Lines*, which are given in units of Hertz (Hz) and lines per maximum elevation range. An *Azimuth Rate* of 1Hz is therefore equivalent to one rotation per second in azimuth, or 360 degrees per second. A *Line Number* of 10 is defined as one sweep (360 degrees of azimuth) per 1/10th total elevation range (i.e. one line every 7 degrees of elevation over -35 to +35 degrees).

For a given *Azimuth Rate* and *Number of Scan Lines*, the RE05 laser aperture elevation rate is constant over the total elevation range.

Because of the configurable nature of the scan pattern, it is possible to obtain a 'coarse' scan, followed by a 'dense' scan if desired, simply by changing the *Azimuth Rate* and *Number of Lines* parameters on-the-fly at the desired moment.

5.3 The Bounded Elevation Scan

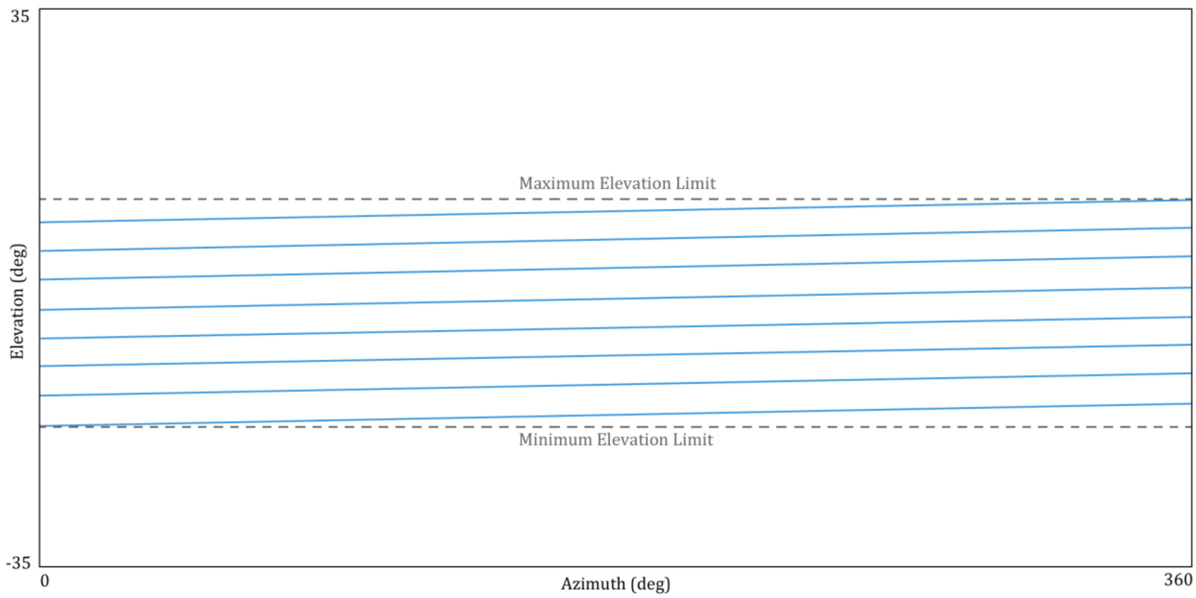


Figure 5.2 – The Bounded Elevation Scan Pattern

Parameter	**Limit**
Azimuth Rate	Maximum 5400 degrees/second (= 15 revolutions/second)
Elevation Scan Width	Minimum 2 Degrees $ElRange = ElMax - ElMin \geq 2°$
Number of Scan Lines	Based on Azimuth rate and elevation width, down to an absolute minimum of 3 lines per scan. Limited to equivalent of one full sweep of elevation range / second rounded up to the nearest integer. $nLines_{MIN} = ROUND\_UP\left(\frac{AzRate \times ElRange}{25200}\right)$ e.g: • Minimum 4 lines/scan for a 35° high scan at 8 revs/second • Minimum 8 lines/scan for a 35° high scan at 15 revs/second • Minimum 4 lines/scan for a 17.5° high scan at 15 revs/second **NOTE:** All units in this equation are in degrees or degrees/second. **NOTE:** There is a special error code for attempted scans with an insufficiently dense scan pattern: 0x08 = ERROR_SCAN_TOO_SPARSE

The *Bounded Elevation Scan* pattern is similar to the *Full Field Scan* with one important difference. The lower and upper extents in elevation in the aperture space can be configured, thus limiting the RE05 sensor's vertical field of view.

In this mode, the vertical extents of the scan in aperture space are defined by the parameters *Minimum Elevation* and *Maximum Elevation*. The *Number of Lines* defines the number of (mostly horizontal) scan lines within the elevation limits. See Figure 5.2 for an example of how these parameters affect the trajectory of the RE05 sensor.

5.4 The Region Scan

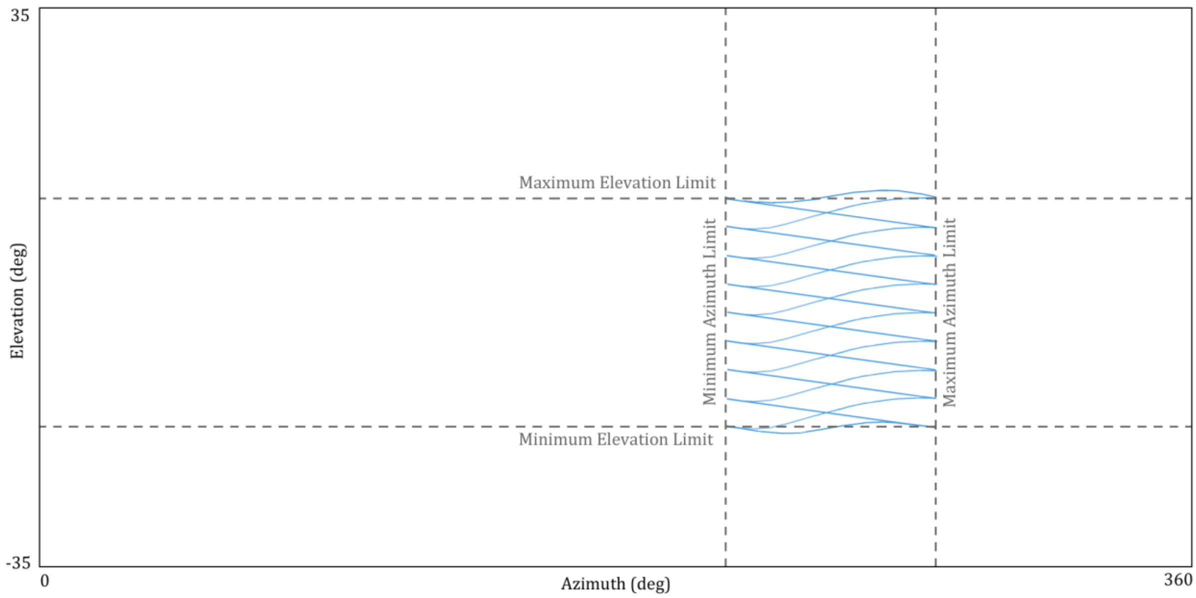


Figure 5.3 – The Region Scan Pattern for Number of Lines = 9

Parameter	Limit
Azimuth Rate	Maximum 5400 degrees/second (= 15 revolutions/second) **NOTE:** Azimuth rate in region scan is an upper limit only, for some scans a lower limit may be applied due to the acceleration limits of the eye. The internal velocity limit can be calculated as: $$AzRate_{MAX} = \sqrt{0.375 \times Accel \times AzWidth_{degrees}}$$ If the specified AzRate is lower than this limit, then the specified rate will be used. The acceleration limit [$°/s^2$] is set by the user. **NOTE:** Maximum acceleration is limited to 40,000$°/s^2$. This velocity limit is also used for the transition segment from the current eye location to the region scan starting location.
Elevation Scan Width	Minimum 2 Degrees $$ElRange = ElMax - ElMin \geq 2°$$
Azimuth Scan Width	Minimum 5 Degrees Maximum 180 Degrees **NOTE:** The region scan will take the shortest path between the specified Azimuth limits. Azimuth limits are specified in the range 0-360, so a scan from 340° to 20° will be a 40° wide scan.
Number of Scan Lines	Based on *Actual* azimuth rate, azimuth width and elevation width, down to an absolute minimum of 3 lines per scan. **Maximum 500 lines per scan.** Limited to equivalent of one full sweep of elevation range / second rounded up to the nearest integer. $$nLines_{MIN} = ROUND\_UP\left(\frac{ElRange \times AzRate \times 10^6}{420\left(\frac{AzRange \times 10^6}{6} + AzRate^2\right)}\right)$$

	NOTE: All units in this equation are in degrees or degrees/second. Be aware that the *actual* azimuth rate is used in this equation, so if the internal velocity limit as above is being applied, this is the velocity used to calculate the minimum line count. **NOTE:** There is a special error code for attempted scans with an insufficiently dense scan pattern: 0x08 = ERROR_SCAN_TOO_SPARSE

The *Region Scan* pattern is a parameterised scan pattern intended to allow a user to focus in on a subject in the environment and obtain dense 3D data from just that area, and no others. The scan pattern is similar to a standard 'raster' pattern used in many applications, such as television and computer graphics. The specific pattern used for the RE05 sensor can be seen in Figure 5.3, which shows the typical trajectory for specified bounds in the aperture space.

When viewed in aperture space, the raster pattern is scanned over a rectangular region which is defined by the *Minimum Azimuth, Maximum Azimuth, Minimum Elevation,* and *Maximum Elevation* parameters. The *Azimuth Rate* and *Number of Lines* define the speed of the scan, and the line resolution within the bounded region.

Note the *Region Scan* is limited to a 180° azimuth window. Hence it will always select the shortest arc segment out of the *Minimum Azimuth* and *Maximum Azimuth* parameters.

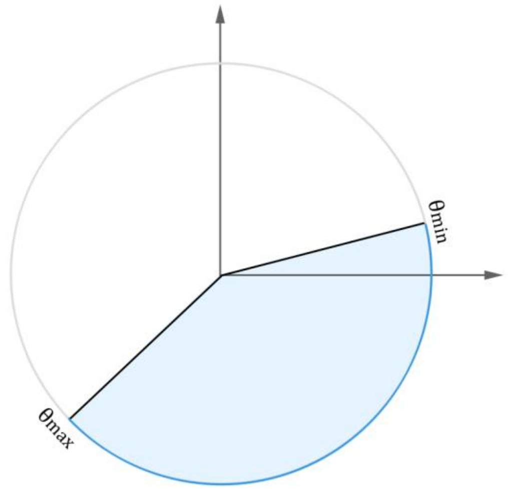
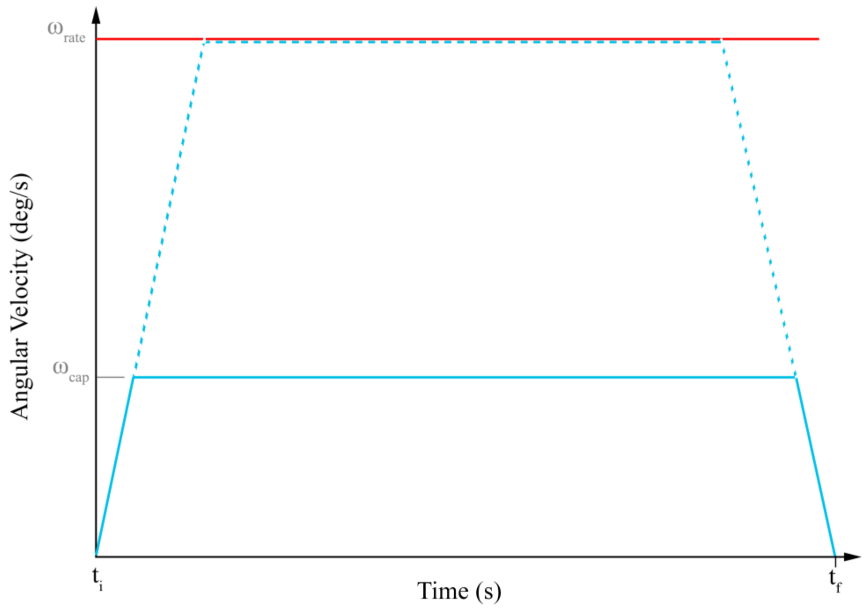


Figure 5.4 – Selected Azimuth Scan Arc for given Min/Max Azimuth Parameters

5.4.1 Region Scan Velocity Profile

The general velocity profile of the scanning head is illustrated below for *Bounded Elevation* and *Region Scan* modes.



As the *Region Scan* mode requires the scanning head to accelerate and decelerate at the specified Azimuth boundaries, using the *Bounded Elevation* mode may be faster in certain situations. Conversely, slow high resolution region scans may be more efficient when utilizing the *Region Scan* mode.

NOTE: A ***single frame*** consists of a scan that spans across an *Azimuth Width* and *Elevation Height* determined by the *min/max* limits of *Azimuth* and *Elevation* respectively, i.e. A single sweep starting at the bottom of the region to the top that contains *n* scan lines.

5.4.2 Bounded Elevation Duration

Scanning a region of the aperture space using ***Bounded Elevation*** for a single frame requires,

$$t_{BE} := \frac{n}{\omega_{rate}} \quad (1)$$

where ,

t_{BE} is the total time taken for the region scan in [sec]
n is the **Number of Scan Lines**
ω_{rate} is the *user specified* **Azimuth Rate** in [Hz]

As *Bounded Elevation* requires the scanning head to do full azimuth revolutions, the total scan time is the same irrespective of Azimuth Width/Boundary limits.

5.4.3 Region Scan Duration

Scanning a region of the equivalent aperture space using ***Region Scan*** for a single frame requires,

$$t_{RS} := \left(\frac{540\omega_{RS}}{a} + \frac{\Delta\theta_{AZ}}{360\omega_{RS}}\right) n \qquad (2)$$

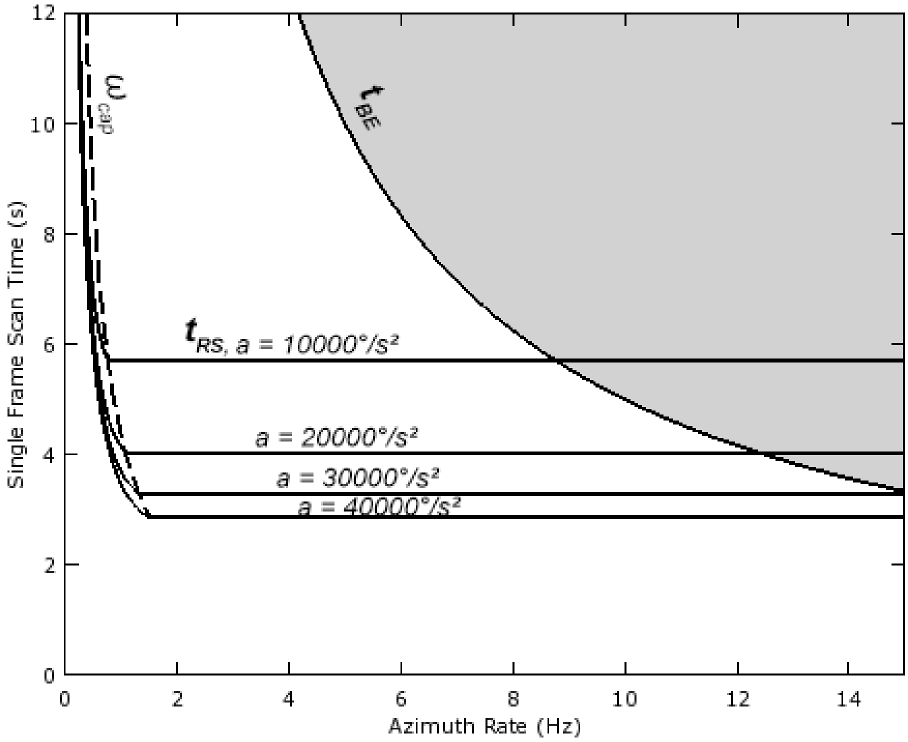
$$\begin{array}{ll} \omega_{RS} = \omega_{cap} & \text{if } \omega_{cap} < \omega_{rate} \\ \omega_{RS} = \omega_{rate} & \text{if } \omega_{cap} \geq \omega_{rate} \end{array} \qquad \text{where } \omega_{cap} := \frac{\sqrt{0.375a \times \Delta\theta_{AZ}}}{360}$$

where,

> t_{RS} is the total time taken for the region scan in [sec]
> a is the *user specified* **Acceleration Limit** [deg/sec^2]
> $\Delta\theta_{AZ}$ is the **Azimuth Width** in [deg]
> n is the **Number of Scan Lines**
> ω_{rate} is the *user specified* **Azimuth Rate** in [Hz]
> ω_{RS} is the *applied* **Azimuth Rate** in [Hz]

Therefore if $\boldsymbol{t_{RS}} > \boldsymbol{t_{BE}}$ then it is faster to use the Bounded Elevation scan mode to scan a region of interest.

For example, using the following parameters [n = 50 lines, $\Delta\theta_{AZ}$ = 20°, ω_{rate}= 15 Hz] we obtain the following scan durations for a single frame,



6 Specifications

Mechanical	
Maximum Azimuth Rate	15 Hz
Maximum Elevation Rate	3 Hz
Azimuth Axis Resolution	0.010°
Elevation Axis Resolution	0.010°
Azimuth Range	360° Continuous
Elevation Range	70° (±35°)
Weight (IP65/IP67)	2.8 kg/3.0kg

Electrical	
Communication (minimum 100 Megabit)	Ethernet
Supply Voltage	24 VDC
Power Consumption — Typical (average)	50 W

Software	
RobotEye C++ Development Library	Windows/Linux
RE05 Tools Application	Windows/Linux

Rangefinder	
Laser Class	1
Laser Wavelength	905 nm
Laser Divergence	3 mrad x 1 mrad
Range (Reflectorless) Range (Retro-reflector)	30 metres Up to 250 metres
Range Accuracy	±50 mm
Range Reproducibility	±20 mm
Maximum Sample Rate	30 kHz

Environmental	
Operating Temperature Range	-20°C - +50°C
IP Class Rating	65 & 67 models
(!) *Note: IP Rating valid only when both supplied power & optionally supplied Ethernet cable connectors are fitted.*	

APPENDIX A

Laser Rangefinder Module

Performance and Measurement Accuracy

The Laser distance measurement device is made for distance measurement onto static and moving objects with a precision down to the centimeter:

1. Measurement within 0.2 m - 30 m onto natural surfaces with reflectance > 10%.
2. Measurement onto reflectors (e.g. Scotchlite 3000x) at distances between 0.2 m and 250 m.

To achieve correct measurement results, avoid the following error sources:

3. Measurements against the sun or other intense light sources.
4. Measurements onto low reflective target surfaces in highly reflective environments.
5. Measurements onto highly reflective surfaces (mirror).
6. Measurements through glass, optical filter, Plexiglas or other transparent materials can lead to measurement errors.
7. Two or more RE05s may not be aligned in "frontal view" because the devices interact with each other.
8. Operation and storage of the device under conditions that do not conform with the specifications.

It is possible to increase the gain of the received input of the laser rangefinder module. This may allow measurements to be collected from targets with poor reflectivity. The gain levels are 0, 1, 2 and 3, where the default value is 0. These changes must only be made while the laser is stopped.

However, as the gain is increased, the noise that occurs within the 3D point cloud also increases. The performance of the laser rangefinder module then becomes unpredictable, especially in the presence of highly reflective targets. Due to this, it is strongly recommended the gain is left at the default setting of 0.

Measurement Properties	
Property	**Value**
Measurement Range[1] onto target Board (Scotchlite Cube 3000x) onto target with reflectance > 10%	 0.2 m – 250 m 0.2 m – 30 m
Measurement Accuracy	± 5 cm
Repeatability	± 2 cm
Measurement Resolution	1 mm
Maximum Sampling Rate Binary data output Decimal data output (ASCII)	 30 kHz 15 kHz

[1] Depends on the reflective properties of the target, ambient light influence, and atmospheric conditions.

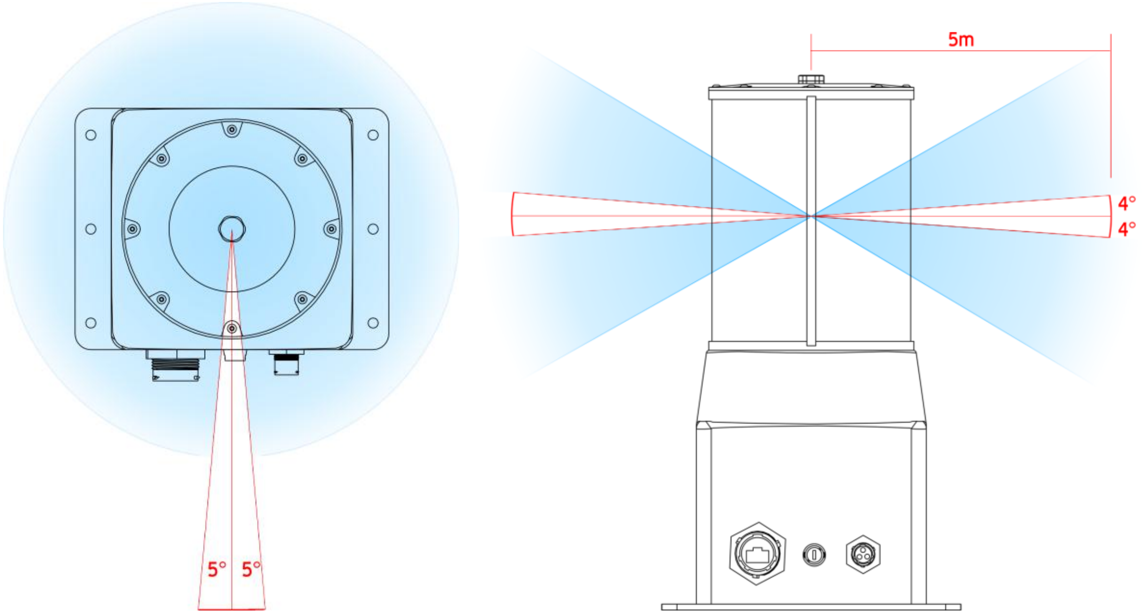
APPENDIX B

IP67 Dome Ranging

Dome Ranging Occlusion

Structural limitations on the IP67 dome result in laser range occlusion along the seam located towards the back of the device.

The angular occlusion in azimuth is approximately 5 - 10° either side of the seam.



An angular occlusion in elevation occurs around the horizon with approximately 4° occluded due to optical design limitations.

Occlusion is nominally limited to objects ranged within 5 metres. Objects beyond 5 metres are usually resolved as per normal operation.