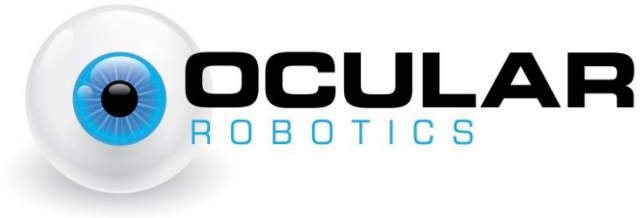

Robot Eye UDP Communications Specification V3.1

UDP Packet descriptions for communicating with an Ocular Robotics Robot Eye

Ocular Robotics

14 February 2017

Revision Table

Date	Notes
11/11/2015	• Version 3.0 initial public release
14/2/2017	• Updated RRBE command with new parameter/value pairs

Contents

Basic Specification:

Interface to the Robot Eye is through UDP datagrams. The Robot Eye will only ever speak when spoken to, with the exception of specific, defined 'broadcast' packets. It will respond either to the source port and IP from which the packet originated, or in a broadcast packet depending upon the instruction. At present, an IANA port allocation request is pending for the designated port number 4365, and this is the only port on which the eye will respond to commands. The eye will only respond to unicast UDP packets with a limited number of exceptions documented on the specific opcodes.

All communication with the Robot Eye begin with a 6-character ASCII human-readable opcode. The first two characters of a transaction define the type of transaction sent to the RE05 as follows (where <XXXX> indicates a 4-character ASCII opcode and <YYYY> indicates a 4-character data type identifier):

- RE<XXXX>: Robot Eye <XXXX> – Command from a host to a Robot Eye
- EA<XXXX>: Eye Acknowledge <XXXX> - Acknowledgement of the receipt/completion of command <XXXX>
- ER<XXXX>: Eye Response <XXXX> - Response to a one-off request for information
- EE<XXXX>: Eye Error <XXXX> - Response to an erroneous command, followed by a single-byte binary error code.
- EB<YYYY>: Eye Broadcast <YYYY> - Unsolicited broadcast of data of specified type.

EB, EE and ER transactions **shall** be followed by one or more arguments in a binary format. RE transactions **may** have one or more arguments passed in a binary format. EA transactions are **never** followed by arguments.

Eye Model Limitations

Not all commands are supported by all Ocular Robotics products. Unless otherwise documented, commands are supported by all robot eye products. Unexpected behaviours may occur if unsupported commands are executed on an Ocular Robotics product. The following is a brief list of single-model commands within this document:

REV25 (and variants) ONLY	RE08 ONLY
TRAA – Track Aperture Angles	RRBE – Run Range-Bearing-Elevation
	SRBE – Stop Range-Bearing-Elevation

REXXX-ST ONLY	
SRUN – Start Stabilising	
SSTP – Stop Stabilising	
SSTG – Stabilised Set Target	
SGTG – Stabilised Get Target	
SGRL – Stabilised Get Roll	
SSSP – Stabilised Set Speed	

Common Arguments:

NOTE: All arguments are written as [NAME-SIZE] where size is the size of the argument in bytes, all integer arguments are big-endian

Standard Angle Representation

All angles sent to and received from the RobotEye use a single standard representation. This is a 32-bit 0.32 fixed point notation, representing the angle as a fraction of a full revolution. Appropriate conversion factors and some useful identities are shown below.

Conversion Factors

	From			
To	**-----**	**Degrees**	**Radians**	**0.32 Fixed Point**
Degrees		$\theta_{DEG} = \theta_{DEG}$	$\theta_{DEG} = \theta_{RAD} \times \frac{180}{\pi}$	$\theta_{DEG} = \theta_{0.32} \times \frac{360}{2^{32}}$
Radians		$\theta_{RAD} = \theta_{DEG} \times \frac{\pi}{180}$	$\theta_{RAD} = \theta_{RAD}$	$\theta_{DEG} = \theta_{0.32} \times \frac{2\pi}{2^{32}}$
0.32 Fixed Point		$\theta_{0.32} = \theta_{DEG} \times \frac{2^{32}}{360}$	$\theta_{0.32} = \theta_{DEG} \times \frac{2^{32}}{2\pi}$	$\theta_{0.32} = \theta_{0.32}$

Note that all 0.32 representation results should be truncated to 32-bits, discarding any higher bits.

Useful Identities

In the 0.32 representation, the following identities hold:

- 0° == 360° == 720° == -360°
- +180° == -180°

The essence of these identities is that an integer overflow in the representation represents a single complete revolution, which can be concisely expressed as follows:

$$\theta_{0.32} == (\theta \pm n \times 360°)_{0.32} \qquad for\ any\ integer\ n$$

It should be noted that the choice of signed or unsigned representation of the 0.32 angle for the conversion back to degrees or radians will determine whether the resultant angle is in the range 0-360° or ±180°

Standard Speed Representation

Any commands to the RobotEye requiring a speed argument use a 32-bit 16.16 unsigned fixed point notation. Appropriate conversion factors are shown below:

	From			
To	**-----**	**Degrees/Second**	**Radians/Second**	**16.16 Fixed Point**
Degrees/Second		$\dot{\theta}_{DEG} = \dot{\theta}_{DEG}$	$\dot{\theta}_{DEG} = \dot{\theta}_{RAD} \times \frac{180}{\pi}$	$\dot{\theta}_{DEG} = \dot{\theta}_{16.16} \times \frac{360}{2^{16}}$
Radians/Second		$\dot{\theta}_{RAD} = \dot{\theta}_{DEG} \times \frac{\pi}{180}$	$\dot{\theta}_{RAD} = \dot{\theta}_{RAD}$	$\dot{\theta}_{DEG} = \dot{\theta}_{16.16} \times \frac{2\pi}{2^{16}}$
16.16 Fixed Point		$\dot{\theta}_{16.16} = \dot{\theta}_{DEG} \times \frac{2^{16}}{360}$	$\dot{\theta}_{16.16} = \dot{\theta}_{DEG} \times \frac{2^{16}}{2\pi}$	$\dot{\theta}_{0.32} = \dot{\theta}_{0.32}$

Error Codes:

Error codes are represented as a single 8-bit unsigned integer transmitted following an EA<XXXX> transaction, shown here in hexadecimal representation:

0x00 No Error.

0x01 Invalid Argument Length

A command was sent with the incorrect number of associated arguments. Test is performed on the number of bytes in the UDP packet in addition to the opcode, so typically indicates a poorly constructed UDP datagram.

0x02 Argument Out Of Range

One or more arguments passed in has exceeded the valid range for that argument

0x03 Error Not Ready

The eye is not in an appropriate state for the desired command.

0x04 Error Not Homed

The command requires the eye to have been homed since startup and this has not taken place.

0x05 Error Invalid Argument

The command specified an invalid argument such as an invalid axis.

0x06 Error Unknown Command

The command is not a recognised Robot Eye opcode.

0x07 Error Unsupported Command

The command transmitted is not compatible with this Robot Eye product.

0x08 Error Scan too Sparse

The requested scan pattern has too few lines per scan. See eye model documentation for details on the scan density limitations of each eye model.

0x09 Error Busy

The eye is currently executing another command which prevents the requested command from executing.

0x0A Error Bad Flash Page

The requested user flash page is not available for the requested operation.

0x0B Error Bad Flash Key

The requested user flash page operation could not be performed, as the incorrect key has been written for the requested page and operation.

0x0C Error Stabilisation Running

The requested command is not available while stabilisation is active.

0xFF Other Error

General Command Set:

CQRE – Seek Robot Eyes

Command: **RECQRE**

Response: **ERCQRE**[Serial-N]
[Serial]: Robot-eye serial number, an ASCII encoded character string of variable length.

Notes: *This eye will respond to this command when received in a broadcast packet.* This command is intended for use as a broadcast packet for eye discovery. All eyes on the network will respond with their associated serial number and IP address.

SIPC – Set IP Configuration

Command: **RESIPC**[Serial-N][IP-4]
[Serial]: Robot-eye serial number, specifying the eye who's IP is to be set.
[IP]: Desired new Robot Eye IP address, sent as 4 8-bit integers.

Response: **EASIPC**

Notes: *This eye will respond to this command when received in a broadcast packet.* This command enables the IP address of an eye to be specified. The serial number argument allows this packet to be sent as a broadcast without affecting more than the specified eye. Only the eye with the matching serial number will respond to this instruction, and the response will be transmitted from the old IP address immediately before transitioning to the new address.

Basic Motion Control Set:

HOME – Home Robot Eye

Command: **REHOME**
Response: **EAHOME**
Errors: **EEHOME**{0x01}
Notes: This command will cause the eye to execute its homing routine. Typically performed at start-up, this routine enables the eye to identify the index locations and correctly localise its pointing direction. This command will cause the eye to point in the direction (0,0); the acknowledgement will be transmitted when the homing is complete.
If stabilisation is currently running, this command will stop stabilisation.

STOP – Stop Robot Eye

Command: **RESTOP**
Response: **EASTOP**
Errors: **EESTOP**{0x01}
Notes: This command will cause the eye to stop any currently executing scan or non-blocking motion (TRAA).
If stabilisation is currently running, this command will stop stabilisation.

SEAC – Set Acceleration Limit

Command: **RESEAC**[Accel-4]
[Accel]: Desired acceleration limit in revoultions/second^2. This parameter uses the same 16.16 fixed point notation as the speed parameter and the same conversions described on page 5.
Response: **EASEAC**
Errors: **EESEAC**{0x01, 0x02}
Notes: This command will set the acceleration limit to be used for any future motion commands.

GEAA – Get Aperture Angles

Command: **REGEAA**
Response: **ERGEAA**[Az-4][El-4]
[Az]: Current Eye Azimuth
[El]: Current Eye Elevation
Errors: **EEGEAA**{0x01}
Notes: Due to network and communications latency, this method is not recommended for high-frequency position measurements.

SEAA – Set Aperture Angles

Command: **RESEAA**[Az-4][El-4][Spd-4]
[Az]: Desired Eye Azimuth
[El]: Desired Eye Elevation
[Spd]: Movement speed limit

Response: **EASEAA**
This acknowledgement packet will be sent when the eye has completed its move and settled at the commanded position.

Errors: **EESEAA**{0x01, 0x02, 0x03, 0x0C}

Notes: The eye will respond to other commands which interrupt an SEAA move-in-progress, and if another move command is given, no acknowledgement for the previously executing move will be sent.
The movement speed limit is an upper limit only. The peak attainable velocity is determined by the acceleration limits applied. Any value above this peak attainable velocity will guarantee a triangular velocity profile over the move, with the time taken and peak velocity determined by the acceleration limit.
This command disabled while stabilisation is active in REV25-ST systems. Attempted execution will result in error code 0x0C.

TRAA – Track Aperture Angles – REV25 ONLY

Command: **RETRAA**[Az-4][El-4][Spd-4]
[Az]: Desired Eye Azimuth
[El]: Desired Eye Elevation
[Spd]: Movement speed limit

Response: **EATRAA**
This acknowledgement packet will be sent immediately if the arguments are well-posed for the command. There is no acknowledgement when the eye has reached the desired position.

Errors: **EETRAA**{0x01, 0x02, 0x03, 0x0C}

Notes: This command is designed for small, high-frequency commanded position updates, such as those required to make small adjustments for target tracking or stabilisation applications. *It should not be used for large moves*, and has a longer settling time than an equivalent SEAA command.
The movement speed limit is an upper limit only. The peak attainable velocity is determined by the acceleration limits applied. Any value above this peak attainable velocity will guarantee a triangular velocity profile over the move, with the time taken and peak velocity determined by the acceleration limit.
This command disabled while stabilisation is active in REV25-ST systems. Attempted execution will result in error code 0x0C.

Scan Pattern Commands:

SFFS – Set Full Field Scan

Command: **RESFFS** [Speed-4][NLines-4]
[Speed]: Scan Azimuth rate
[NLines]: Number of lines within scan pattern. This is represented in a 32-bit 16.16 fixed point representation. Non-integer scan line counts will result in an interleaved scan. Target NLines can be converted to 16.16 format by multiplying by 2^{16}

Response: **EASFFS**
Errors: **EESFFS**{0x01, 0x02, 0x08, 0x0C}
Notes: This command will cause the eye to begin executing a full-field scan. Any existing scan pattern will be stopped. The scan will start from minimum elevation and will transition from the current location to that elevation over 3 rotations of the head in azimuth. Note that if the eye has not been homed, results may not be as expected.
This command disabled while stabilisation is active in REV25-ST systems. Attempted execution will result in error code 0x0C.

SBES – Set Bounded Elevation Scan

Command: **RESBES** [Speed-4][ElMin-4][ElMax-4][NLines-4]
[Speed]: Scan Azimuth rate in degrees/second.
[ElMin]: Lower Elevation Limit
[ElMax]: Upper Elevation Limit
[NLines]: Number of lines within scan pattern. This is represented in a 32-bit 16.16 fixed point representation. Non-integer scan line counts will result in an interleaved scan. Target NLines can be converted to 16.16 format by multiplying by 2^{16}

Response: **EASBES**
Errors: **EESBES**{0x01, 0x02, 0x05, 0x08, 0x0C}
Notes: This command will cause the eye to begin executing a bounded elevation scan. Any existing scan pattern will be stopped. The scan will start from minimum elevation and will transition from the current location to that elevation over 3 rotations of the head in azimuth. Note that if the eye has not been homed, results may not be as expected.
This command disabled while stabilisation is active in REV25-ST systems. Attempted execution will result in error code 0x0C.

SRES – Set Region Scan

Command: **RESRES** [AzMin-4][AzMax-4][ElMin-4][ElMax-4][Speed-4][NLines-4]

[AzMin]: Lower Azimuth Limit

[AzMax]: Upper Azimuth Limit

[ElMin]: Lower Elevation Limit

[ElMax]: Upper Elevation Limit

[Speed]: Scan Azimuth rate limit in degrees/second.

[NLines]: Number of lines within scan pattern. This is represented in a 32-bit 16.16 fixed point representation. Non-integer components of the NLines argument will presently be discarded, but may be implemented in future firmware revisions. Target NLines can be converted to 16.16 format by multiplying by 2^{16}

Response: **EASRES**

Errors: **EESRES**{0x01, 0x02, 0x05, 0x08, 0x0C}

Notes: This command will cause the eye to begin executing a region scan at the specified resolution within the specified bounds. The region scan shall take the shortest path between the upper and lower azimuth limits, giving a maximum azimuth width of 180 degrees. Any existing scan pattern will be stopped. The scan will start from minimum azimuth elevation and will transition from the current location to that location immediately respecting acceleration limits. Note that there may be some overshoot if the head is currently scanning at high speed due to acceleration limitations.

The azimuth rate limit is only an upper bound. For many scan patterns, the peak acceleration will be the limiting factor with respect to the line rate. For more detail on the relationships between acceleration limits and line rates, see the ACRA 2012 paper “A Novel Approach to 3D Laser Scanning”, available from the ocular robotics website.

This command disabled while stabilisation is active in REV25-ST systems. Attempted execution will result in error code 0x0C.

Laser Management Commands:

RRBE – Run Range-Bearing-Elevation Sensor – RE08 ONLY

Command: **RERRBE**{[Param1-1][Value1-4][Param2-1][Value2-4]…[ParamN-1][ValueN-4]}
This command takes a set of Parameter+Value pairs as arguments. Any parameters not included will be left to device defaults. The number of parameter-value pairs can be 0 if all parameters are desired to be default.

Parameter		*Valid Value Range*	*Description*
PORT	0x00	0 : 65535	Target UDP port for data streaming. (Default 4366)
MODE	0x01	0 : 2	0x00 - High Penetration
			0x01 - Fast Mode
			0x02 - High Speed Mode (Default)
MULTIPLE PULSE BEHAVIOUR	0x02	0 : 4	0x00 - All Targets (Default)
			0x01 - First Target Only
			0x02 - Last Target Only
			0x03 - Highest Amplitude Target Only
			0x04 - Highest Reflectance Target Only

Response: **ERRRBE**
Errors: **EERRBE**{0x01, 0x02, 0x04, 0x05, 0xFF}
Notes: This command will begin the laser fusion process. The laser will be sampled at the specified frequency, packets of multiple laser returns will be constructed, and these shall be transmitted as broadcast packets at the port number specified in the argument. For details on the broadcast packet, see the documentation for EBRBEP (Eye Broadcast Range Bearing Elevation Points).
If the Robot Eye is presently streaming data, the Robot Eye will return an error code of 0x09 indicating that it is busy. If the new client wishes to disconnect the currently streaming client, then this can be accomplished by sending the SRBE opcode to stop the running fusion process before restarting the streaming with RRBE.

SRBE – Stop Range-Bearing-Elevation Sensor – RE08 ONLY

Command: **RSRBE**
Response: **EASTLS**
Notes: This command will halt the RE08 laser data streaming. Any buffered laser data will be discarded when this command is received. This command will stop ANY running streaming, and could potentially cause the disconnection of another connected client.

Stabilisation Opcodes – REXXX-ST ONLY:

SRUN – Run Stabilisation

Command: **RESRUN**
Response: **EASRUN**
Errors: **EESRUN**{0x04, 0x07}
Notes: This command will activate stabilisation on the target REV25-ST. The aperture pointing direction in the world-frame when this command is received is taken as the current stabilised target. To make incremental movements, the SRUN command should be followed by a SGTG command to extract the current pointing position of the eye in the stabilised world co-ordinate frame. This will also enable checking of the state of stabilisation, as until the stabilisation startup has completed, the SGTG command will return error code 0x03 = UDP_ERROR_NOT_READY.

SSTP – Stop Stabilisation

Command: **RESSTP**
Response: **EASSTP**
Errors: **EESTOP**{0x07}
Notes: This command will stop any running stabilisation.

SSTG – Stabilised Set Target

Command: **RESSTG**[Yaw-4][Pitch-4][Roll-4]
- [Yaw-4]: The world-frame yaw between the target location and world-frame north.
- [Pitch-4]: The world-frame pitch between the target location and the horizon.
- [Roll-4]: The world-frame roll of the target about the target vector.

Response: **EASSTG**
Errors: **EESSTG**{0x01, 0x02, 0x03, 0x04, 0x07}
Notes: When working in stabilised mode, all commands are managed in the world reference frame. The angles transmitted with an SSTG command represent the required co-ordinate frame transformation which, when applied to the world-frame, will result in a reference frame with the X-axis directed at the target, the Y-axis pointing to the right in the image, and the Z-axis pointing down.

SGTG – Stabilised Get Target

Command: **RESGTG**
Response: **ERSGTG**[Yaw-2][Pitch-2][Roll-2]
- [Yaw-4]: The world-frame yaw between the target location and world-frame north.
- [Pitch-4]: The world-frame pitch between the target location and the horizon.
- [Roll-4]: The world-frame roll of the target about the target vector.

Errors: **EESGTG**{0x03, 0x07}
Notes: See SSTG for explanation of the stabilisation reference frame.
Be aware that when working in the Euler angle space, the problem of 'gimbal lock' can become present for commanded pitch angles close to ±90°. Near these pitch angles, the values returned by SGTG may become unreliable, however accurate and reliable pointing commands may still be issued using the SSTG command.

SGRL – Stabilised Get Roll

Command: **RESGRL**

Response: **ERSGRL**[ImageRoll-4]

[ImageRoll-4]: The roll angle required to be applied to an image taken at the instant the request was made in order for that image to align with the reference frame as defined in the SSTG command.

Errors: **EESGRL**{0x03, 0x07}

Notes: This command will extract the roll transform which, when applied to images from the camera attached to the REV25-ST, provides for the third axis of stabilisation. It is not necessarily required that the image be rotated according to this angle, if computer-vision based target tracking or other algorithms are being applied to the output images, then it will almost certainly be faster to deal with the image rotation after the target tracks have been extracted, rather than applying an affine transform to the entire image.

SSSP – Stabilised Set Speed

Command: **RESSSP**[Speed-4]

[Speed-2]: The maximum speed the eye is allowed to move at in degrees-per-second.

Response: **EASSSP**

Errors: **EASSSP**{0x01, 0x02, 0x03, 0x04, 0x07}

Notes: This command will set the motion speed limit used for the stabilisation. In most situations this parameter will not need to be changed from its default.

Eye Broadcast Packets

EBRBEP – Eye Broadcast Range Bearing Elevation Packet – RE08 Only

Header: **EBRBEP**

Payload: {[tStamp-4] [Az-4] [El-4] [Range-4] [Amplitude-2] [Reflectance-2] [PSD-2]} *repeated to end of packet.*

[tStamp]: The time at which the point was taken.
Measured in 100's of nano-seconds since powerup. Will overflow approximately every 429.5 seconds.

[Az]: The azimuth at which the range sample was taken.

[El]: The elevation at which the range sample was taken.

[Range]: The range in millimeters as an unsigned 32-bit integer.

[Amplitude]: The amplitude of the return as a 16-bit signed integer in units of 0.01 dB

[Reflectance]: The reflectance of the return as a 16-bit signed integer in units of 0.01 dB

[PSD]: The deviation in shape of the received pulse as compared to the transmitted pulse. 0 indicates no deviation, values below 15 can typically be considered as 'good' for most applications.

For more detail on the meaning of the Amplitude, Reflectance and Pulse Shape Deviation parameters, please see the RE08 User's Manual.