RobotEye

Technology Primer

March 1, 2012

Contents

1 Core Concepts

1.1 Background

Systems used to point and/or scan sensors most commonly use pan-tilt or gimbals arrangements. Both gimbals and pan-tilts involve attaching a sensor/s to a platform and then moving the platform about two or three axes in order to move the direction of view of the sensor.

When there is a need to have dynamic control of the view of a sensor such as in;

- Stabilising the view of a sensor mounted to a mobile platform
- Target tracking/ multiple target tracking
- Fast environment mapping
- Rapid acquisition of information from disparate locations
- Stabilising while simultaneously doing any of the other tasks above
- And many more

the limitations of the pan-tilt and gimbals technologies soon become apparent in terms of the dynamic control over the view of a sensor.

The core reason for the low motion bandwidth of gimbals and pan-tilt systems is the relatively large amount of mass that needs to be moved in order to move the view of a sensor.

This mass includes;

- The sensor itself
- The motor that drives the second axis and in the case of 3 axis systems the motors that drive the second and third axes
- The supporting structure for both the sensor and second axis motor

Having to move all of these components in order to move the view of a sensor significantly affects the responsiveness that can be achieved with gimbals and pan-tilt systems.

In particular it limits

- The rate at which the system and therefore the view of the sensor can be accelerated/decelerated
- The ultimate slew rate that can be achieved
- The pointing accuracy that is possible at higher slew rates

These constraints mean that systems utilising pan-tilt or gimbals arrangements to point their sensing payloads are limited to modest levels of performance due to the speed with which they can dynamically orient their sensing systems, thus often forming the critical limit to system performance.

This same problem of having to move the sensor, motor and associated support in order to move the view of system sensing elements is the origin of a number of other deficiencies of the pan-tilt and gimbals technologies;

- The mass of sensing, drive and support elements suspended on the axes of the gimbals or pan-tilt devices result in large forces and moments through these axes and back through the drive train under shock and vibration, shortening serviceable life.
- Since the sensor is mounted in the gimbals or pan-tilt device and must be moved to reorient the sensor's direction of view either;
    - Cables must be provided to carry power and signals to both the sensor and the 2nd axis motor. This results in a restriction in the range of continuous tracking that is possible due to the finite length of the cables and a potential decrease in reliability due to cable flexure.

  or

    - Slip rings must be provided similarly to carry power and signals to the sensor and 2nd axis motor, adding expense and reducing reliability particularly where high data rate sensors are used.
- The sensing elements are necessarily exposed to damage through impact or ingress. Housings and seals provided to ameliorate this themselves add to the mass required to be moved to reorient the sensor's view.
- Weight and space restrictions constrain sensor choice.

Many attempts have been made to mitigate the motion bandwidth deficiencies of the pan-tilt and gimbals technologies usually these have been focussed on weight minimisation and/or increasing the power density of the motors. However, while this approach may result in modest improvements in capability the fundamental deficiency of these technologies remains limiting any gains that can be made.

1.2 The RobotEye

The RobotEye technology takes a very different approach by addressing the fundamental problem with the pan-tilt and gimbals technologies, the fact that the sensor/s, the second axis motor and their supporting structure must be moved to reorient the view of the sensor/s.

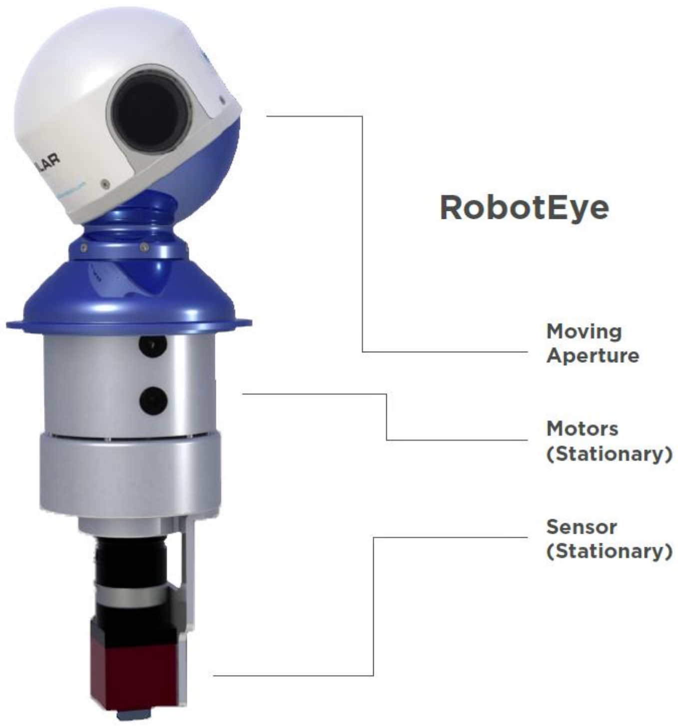
The solution offered by the RobotEye technology allows the sensor to remain completely stationary and the motors for both the azimuth and elevation axes to also remain completely stationary. Since the sensor and motors are now stationary during reorientation of the sensor's view, the moving supporting structure for the sensor and motor's is also entirely eliminated.

The RobotEye technology allows a sensor and/or source to remain stationary while its direction of view is reoriented by directing the optical flow in the case of a sensor such as a camera through the aperture to the sensor and in the case of a source such as a laser from the source through the aperture. In the case of LIDAR or a sensor/source combination the optical flow is directed both through the aperture to the sensor and from the source through the aperture.

As discussed above gimbals and pan-tilt devices require that at least the second axis motor is moved when reorienting the view of the sensor. The RobotEye technology achieves the high performance reorientation of the sensor's direction of view in both azimuth and elevation while both motors remain completely stationary through its unique transmission system.

The result is a system where the moving mass required to reorient the direction of view of a sensor is drastically reduced. This reduction delivers motion bandwidth improvements exceeding an order of magnitude over most gimbals and pan-tilt systems.

The remaining sections of this document address in more detail many of the advantages and features delivered by the RobotEye technology including an explanation of the scope of the technology, several case studies and an outline of the current and upcoming product suite.



2 RobotEye Motion Performance

The high motion bandwidth capabilities of the RobotEye technology are made possible by the low mass that must be moved in order to reorient a sensor's direction of view. As discussed above this results from two primary factors, firstly the sensor itself is able to remain stationary while its direction of view is moved and secondly, motors for both the azimuth and elevation axes remain stationary while the direction of view of the sensor is moved. It is important to note that this second factor allows the motion bandwidth advantages of the RobotEye to be maintained even as the size of the head is scaled to accommodate larger apertures, the reasons for this are covered in Section 4.2.

In the sections below the motion performance capabilities of existing examples of the RobotEye technology are detailed. The precise motion performance capabilities of different RobotEye implementations will vary depending on the details of their construction however, the two primary factors from the previous paragraph hold for all RobotEye implementations ensuring a significant performance gap between the RobotEye and the alternative technologies.

2.1 Aperture Motion Capabilities

The aperture motion bandwidth of the RobotEye is determined by both the acceleration and maximum slew rate of which it is capable. Current RobotEye implementations are capable of aperture accelerations up to 100,000°/s^2 and maximum aperture slew rates of 10,000°/s.

In order to demonstrate the motion bandwidth of the RobotEye the plots in this section show performance information collected during a test in which the RobotEye aperture was driven rapidly to sixty randomly selected points with its field. Figure 2-1 shows the RobotEye under test visiting these points in less than six seconds with a dwell time at each point of 20ms. Figure 2-2 shows the same trajectories presented in Figure 2-1 plotted in aperture space where the circles represent the random target points and the path the aperture takes between the points is shown in blue.

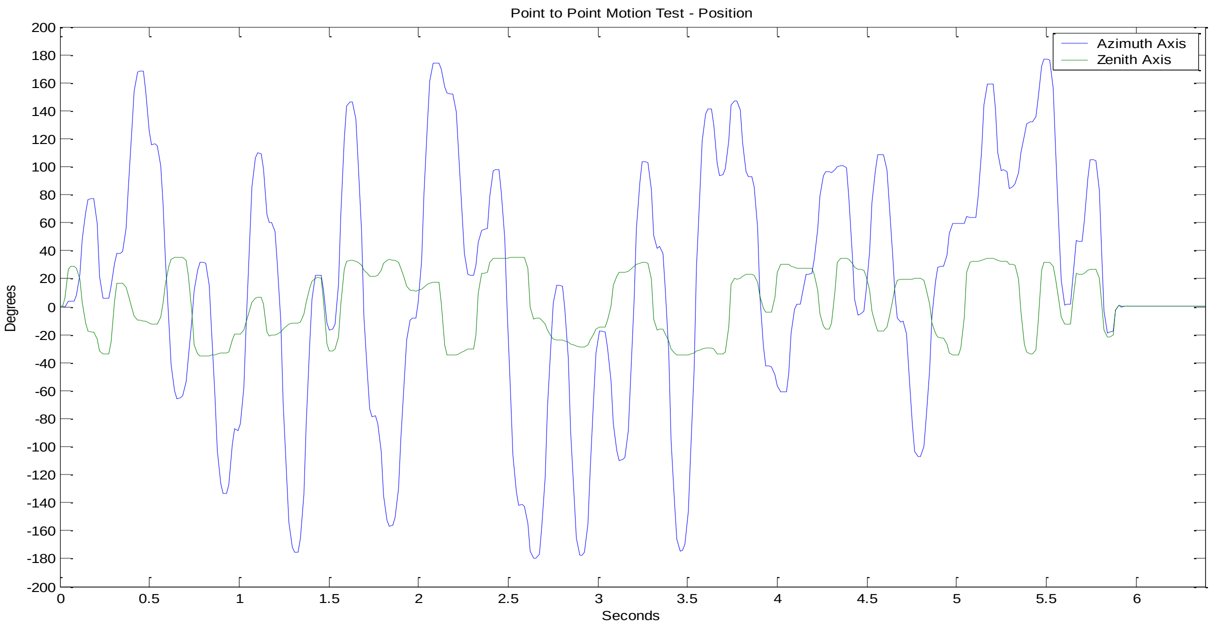


Figure 2-1 - Azimuth and Elevation Axis Trajectories during Moves to Sixty Randomly Selected Points within Six Seconds

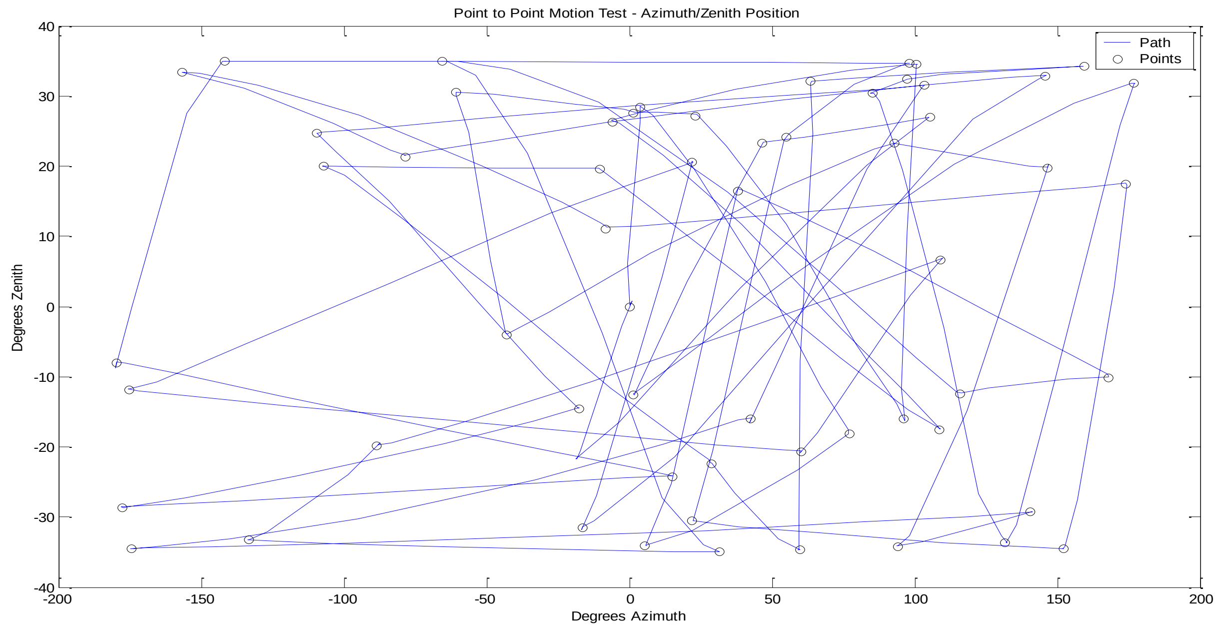


Figure 2-3 - The Aperture Moves from Figure 1 Plotted in Aperture (Azimuth, Elevation) Space

The maximum slew rate is primarily of interest in scanning applications as even when accelerating at 100,000°/s^2 it still takes a little over a 360° rotation to reach 10,000°/s. However, as can be seen from Figure 2-3 below the system under test achieves aperture slew rates during the series of random moves within the RobotEye's field of several thousand degrees per second which exceeds the capabilities of alternative technologies by a very significant margin.

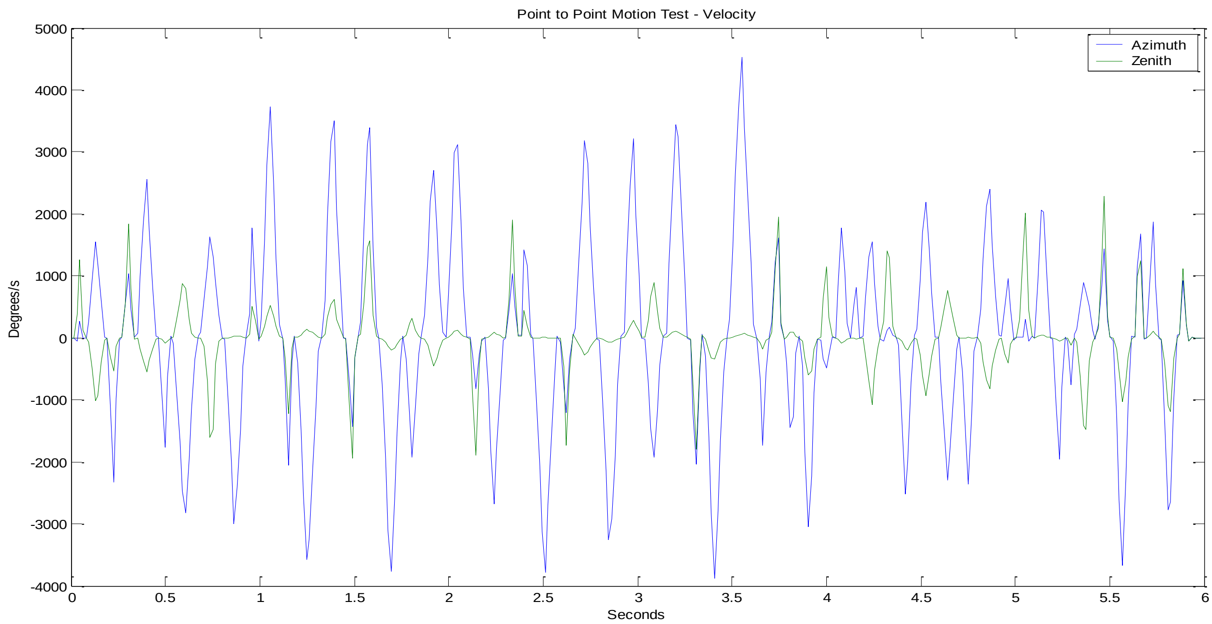


Figure 2-2 - Azimuth and Elevation Components of the Aperture Velocity

For all use cases apart from sustained 'full field' scanning the aperture acceleration capabilities are critical. For applications involving stabilisation, tracking, mapping, targeting and many more the ability to change direction quickly is of prime importance. Figure 2-4 shows the azimuth and elevation aperture acceleration components during the series of moves in the test, it can be seen from the plot that during the test aperture accelerations regularly exceed 60,000°/s^2. In practice this acceleration capability delivers responsiveness unattainable from the alternatives, making possible stabilised vision from highly unstable platforms such as a fast moving ground vehicle over rough terrain and small surface craft, lag free telepresence, multiple target tracking and more.

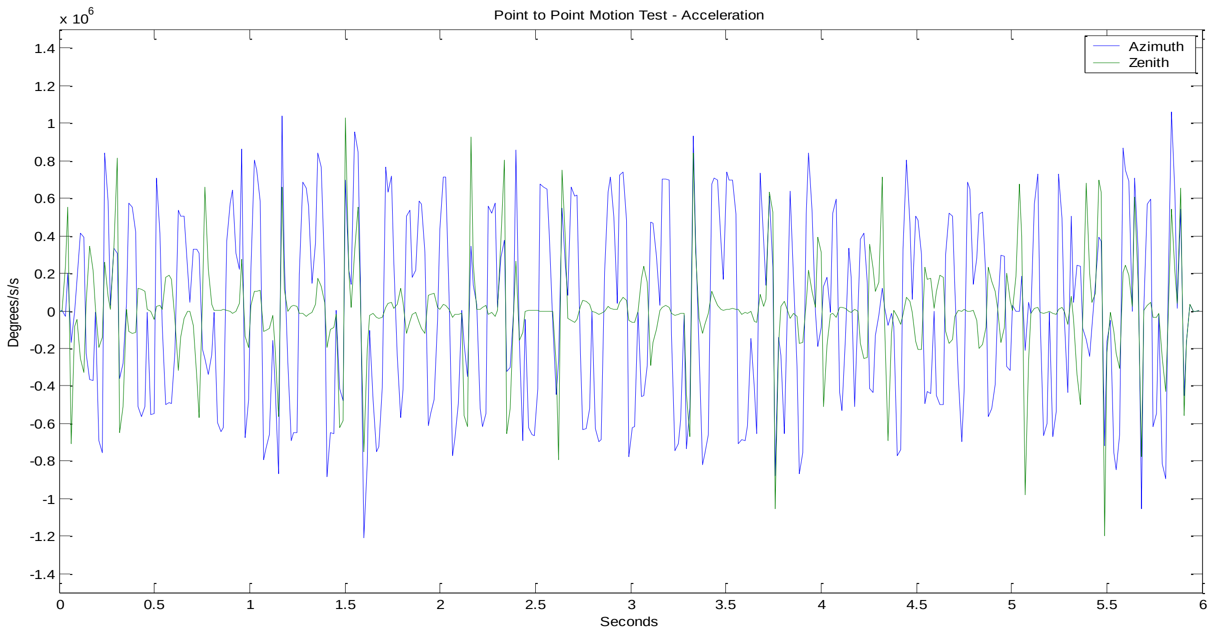


Figure 2-4 - Azimuth and Elevation Components of the Aperture Acceleration

2.2 Accuracy

The RobotEye is able to maintain excellent accuracy while simultaneously achieving the extremely high motion performance outlined in the previous section. The two factors contributing to this capability are the low mass required to be moved in order to reorient the sensor's direction of view which has already been discussed extensively in this document and the zero backlash construction and form of the RobotEye. The transmission path from the direct drive azimuth and elevation drive motors to the RobotEye aperture includes no elements which permit any backlash during operation ensuring that the RobotEye's control level accuracy is reflected directly at the aperture.

Figure 2-6 shows at test where the RobotEye aperture was rotated 360° in azimuth while simultaneously traversing from -35° to +35° in elevation for three cycles with 100ms dwell time between each move. The plot shows transition time for these moves from stable position to stable position is less that 200ms and that the aperture position at the dwell locations is highly repeatable. Figure 2-5 shows a plot of azimuth against elevation for the same test which further demonstrates the highly accurate and repeatable positioning of the RobotEye aperture under extreme speed and acceleration, the portion of the line inside the loop represents the transition to and from zero degrees in azimuth and elevation at the start and end of the test.

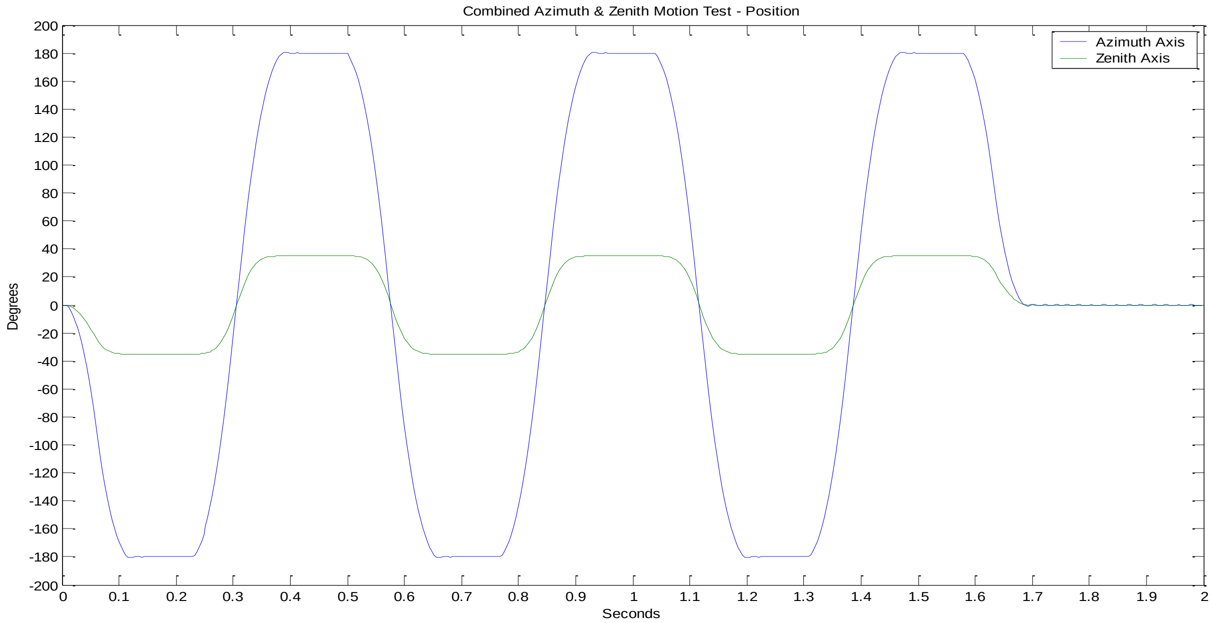


Figure 2-6 - Aperture Trajectory in Azimuth and Elevation Components under High Speed and Acceleration Test

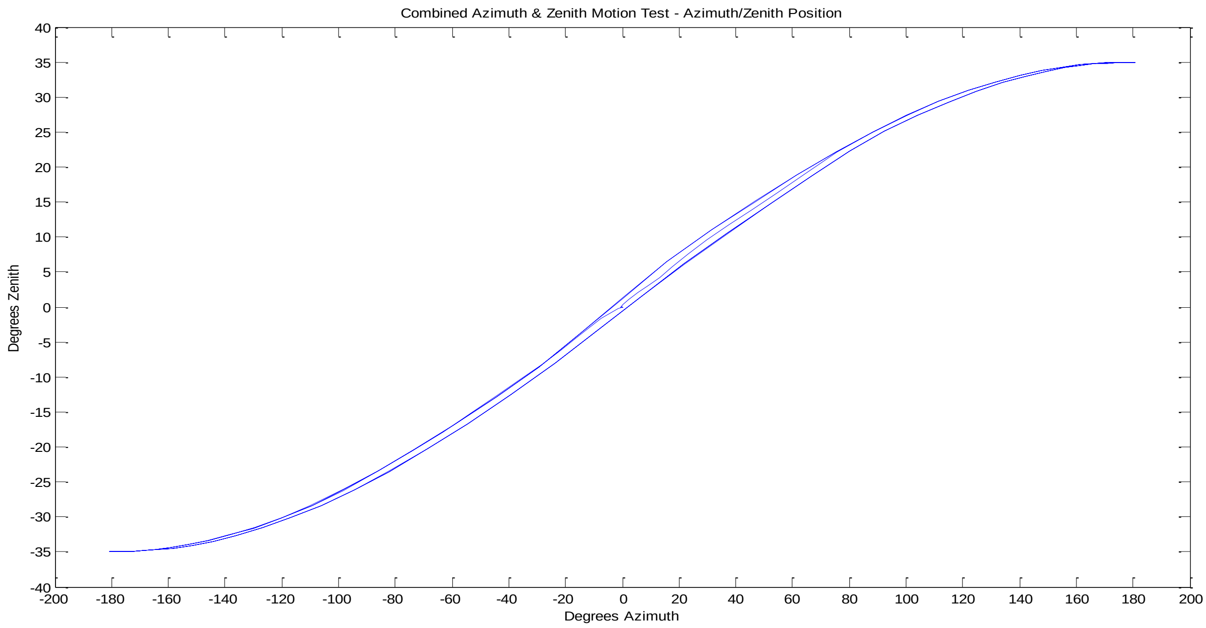


Figure 2-5 - Aperture Trajectory under High Speed and Acceleration Test

2.3 Axis Resolution

Axis angular resolutions can be tailored for any particular RobotEye implementation. Existing RobotEye systems have an azimuth resolution of 0.01°; due to the nature of the operation of RobotEye systems the elevation resolution is sinusoidal with an average elevation resolution of 0.004°. As can be seen from Figure 2-7 below the elevation resolution ranges from a minimum of less than 0.006° to greater than 0.002° at elevation angles exceeding ±28°.

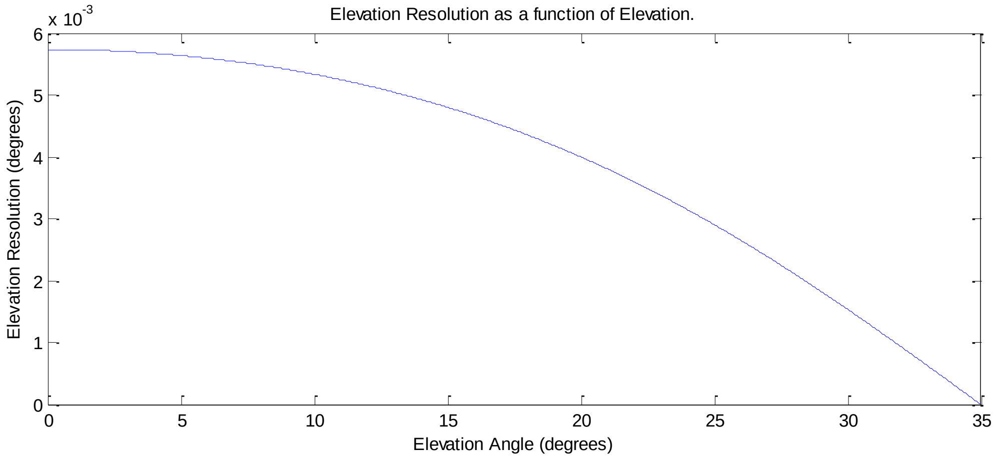


Figure 2-7 - Elevation Angular Resolution as a Function of Elevation

3 RobotEye Technology Features

3.1 Robustness and Survivability

RobotEye systems exhibit high levels of robustness to the effects of harsh environments as a consequence of their structure and design. This includes high immunity to shock and vibration, simplified environmental sealing and protected location of critical components.

The structure of RobotEye systems means that the sensing, control and drive elements of the system are able to be placed below protective housings such as in Figure 3-1, protecting them from impacts and environmental effects. This is particularly important when high value sensing elements are involved. In RobotEye systems only the optical head is exposed, if the optical head is damaged the rest of the system is left intact. The RobotEye optical head can then be replaced at relatively low cost and time out of service.

Systems which have relatively large masses suspended on rotating axes can transmit damaging forces and moments back through the transmission chain under shock and vibration resulting in premature failure. The RobotEye's high immunity to shock and vibration results from there being no system components that move in relation to each other which can transmit significant forces or moments through the system under shock and vibration.

As the sensor, control and drive elements of RobotEye systems remain stationary and reside within a similarly stationary housing such as depicted in Figure 3-1 the environmental sealing of moving interfaces in RobotEye systems involves just two areas, the rotating azimuth and elevation interfaces. Because of the exposed nature of many of the components of alternative technologies, separate sealing of sensor enclosures, motor housings, cable pass throughs and rotating shafts is often required. Standard RobotEye optical heads have an IP65 rating. This can be increased if required by upgrading to the sealing elements, however often the most effective means is to simply put the optical head in a dome.

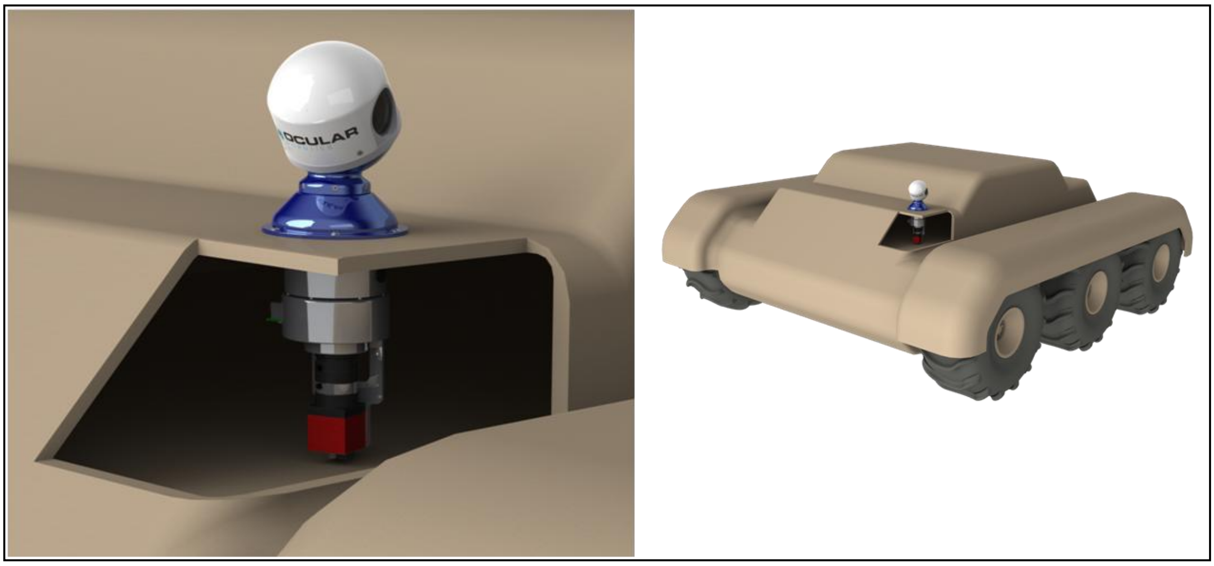


Figure 3-1- RobotEye Vehicle Mounting Showing Cut Away View

3.2 Reliability

RobotEye systems employ direct drive motors to drive their azimuth and elevation axes which eliminates the need for any mechanical reduction transmission. This is made possible through the low mass required to be moved to reorient the direction of view of a sensor and the fact that both motors remain stationary during any move, both features which have already been discussed in relation to other aspects of the RobotEye technology. The elimination of reduction transmissions from the axis drives results in a significant improvement in reliability as these elements are a common point of premature failure in alternative systems.

The requirement that the sensor and the motor for at least the second axis be moved when reorienting the sensor's direction of view in alternative systems means that power and data signals for the sensor/s and power and feedback signals for the motor need to traverse moving joints. This is achieved either by cables or slip rings, both methods potentially impact on reliability. Cables limit the continuous motion capabilities of the system by virtue of the finite length of the cables and close attention needs to be paid to cable flexure issues. Slip rings particularly when used for data signals from high bandwidth sensors are both expensive and impact on reliability. By Contrast RobotEye systems completely eliminate these issues by removing any need to pass electrical signals through a moving connection.

3.3 Flexibility

The flexibility with which a particular implementation of the RobotEye technology can be configured is addressed in Section 4 Technology Scope. This section will address two aspects of flexibility in the use of RobotEye systems, those of unconstrained sensor selection and flexibility in motion behaviour.

Because the sensor in a RobotEye system is stationary and located at the optical output port of the system sensor selection is completely unconstrained by size, weight or the nature of the signals to and from the sensor. This allows sensors that best suit an application to be used with the system rather than having to compromise on a sensor that it fits the size, weight and signal transmission requirements of a particular pan-tilt or gimbals system.

Figure 3-2 - RobotEye Technology Allows Unconstrained Sensor Selection

One aspect of having a fixed sensor with a rotating signal aperture is that for array sensors such as cameras the output image rotates around its centre as the aperture moves about the azimuth axis. For systems where the output images are an input into a machine vision system this has no impact however, where a human needs to view the vision output, frames need to be de-rotated prior to displaying which is a straight forward operation to perform.

The motion bandwidth of RobotEye systems allows great freedom in how a sensor pointing system is used. A single system can execute many different behaviours and instantly change between behaviour modes as required thus providing system redundancy or the potential to reduce the sensor count. From detailed high resolution mapping of an environment to tracking high speed targets to high performance stabilisation to persistent surveillance and more a single RobotEye system can cover many behaviours that might otherwise require a suite of sensor pointing systems to perform.

4 Technology Scope

4.1 Signal Bandwidth

The RobotEye system is capable of pointing sensors with a wide range of signal frequencies from the UV through the visible and infrared to mm wave. This wide signal bandwidth allows the RobotEye to point a wide range of sensors but also importantly it accommodates the pointing of wide-band sensors, simultaneously redirecting a wide range of optical-band frequencies for use in applications such as scanning spectrometer applications. RobotEye systems are adapted for a required signal band by installing appropriate optical elements in the signal path of the RobotEye. Applications using different signal bands may require varying aperture sizes, the scope for variation of the RobotEye aperture is discussed in section 4.2.

4.2 Scaling

The purpose in scaling a RobotEye system is to attain a system aperture most appropriate for the application and sensor/s being used. The RobotEye technology is able to be both scaled up and down from the existing implementations with the practical range of aperture sizes estimated to range between 5 and 200 millimetres. Because neither of the motors in a RobotEye system are moved when reorienting the view of the sensor/s the high motion performance characteristics of the RobotEye are able to be maintained as the technology is scaled up.

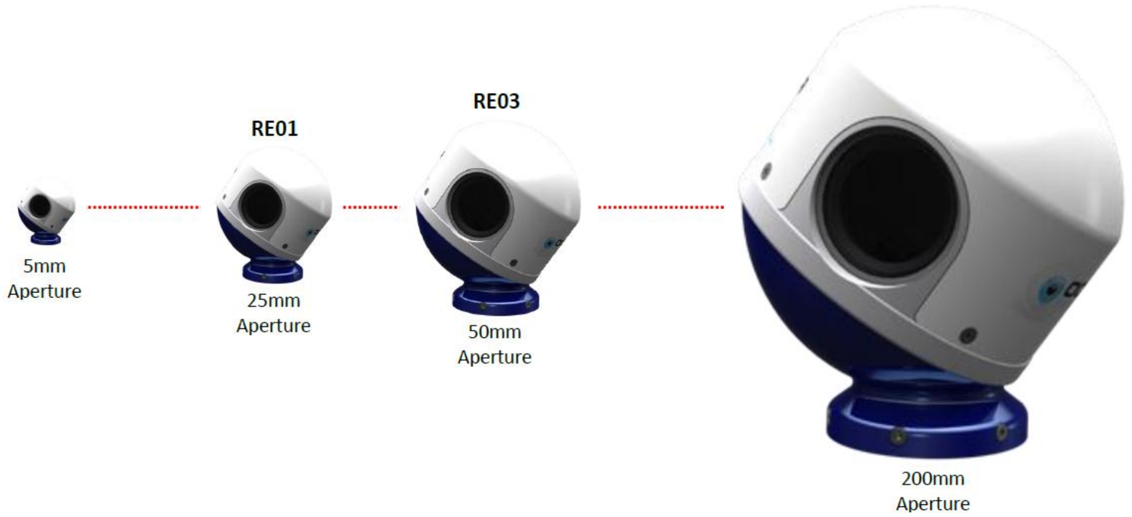


Figure 4-1 - RobotEye Technology Scaling Range

In simple terms this is achieved by increasing the power output of the motors to accommodate the increased moving mass, for pan-tilt and gimbals systems this same process is not possible because you have to move the larger motor that is added to the second axis. In more detail the reasons that scaling the RobotEye is far less power-intensive than any other architecture are;

- For pan-tilt and gimbals type systems, the drive for the second axis must be fixed to the moving components of the first axis, so the first axis motor has to move not only the sensor and frame mass, but the mass of the second motor as well.

- In order to improve the performance of the pointing system, the typical approach requires an increase in the size and power of the motors. The first axis motor then has to be up-rated even further to account for the increase in mass of the second motor. This leads to a quadratic growth in the power of the first motor as the performance of the system is increased.
- In the RobotEye system, both motors always remain stationary. This means that the motors scale linearly with any desired increase in aperture size or performance rather than quadratically.

4.3 Optical Customisation

Section 4.1 addressed optical customisation in terms of the bandwidth of the system optics. However, another significant factor in appropriate design for optical systems such as visible and infra-red cameras is field-of-view for others it is signal divergence and so on. In RobotEye systems any optical components to achieve a required optical behaviour may be included in the optical path.

Ocular Robotics' REV25 Vision product is an example of such a customisation where the use of a 1/3" imaging sensor delivers an approximately 20° diagonal field of view. The company is currently working to produce a number of standard field of view options for its imaging systems.

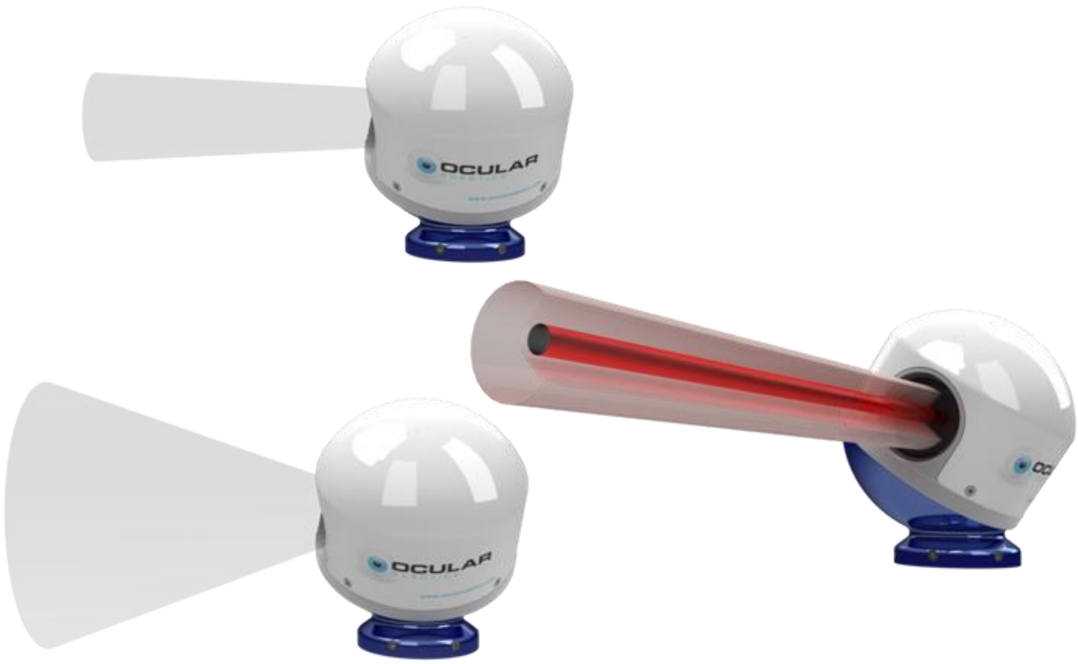


Figure 4-2 – RobotEye Optical Configuration Flexibility

4.4 Construction

The existing implementations of the RobotEye technology are manufactured using mainly aluminium and various engineering plastics. However, the core RobotEye technology is able to be produced in a variety of materials, to suit weight, environmental and other requirements such as low weight for airborne applications, enhanced anti corrosive properties for highly corrosive environments and resistance to degradation in high radiation environments. The flexibility in materials which can be used to meet application requirements adds further to the adaptability of the RobotEye technology described in earlier sections in the areas of signal bandwidth, aperture size and optical configuration.

4.5 Environmental

Standard RobotEye systems have an ingress protection rating of IP65, for applications that require enhanced ingress protection it is possible to upgrade sealing elements at a small cost to performance and an increase in scheduled maintenance.

In many cases a requirement for increased ingress protection is best accommodated by the addition of a dome over the RobotEye optical head. The size of RobotEye optical heads are in almost all cases considerably smaller than the envelope an equivalent pan-tilt or gimbals system meaning that a relatively small dome is required to increase the ingress protection of a RobotEye system into the submersible region.

4.6 Sensor Multiplexing

A significant challenge in modern perception is the problem of multi-modal sensing. Combining information about a single target from multiple sensors significantly improves the ability of most systems to track and evaluate the target in question. With the RobotEye system, multimodal sensing can be approached through three primary methods or a combination of them.

4.6.1 Multiple Eyes

The simplest approach is to mount multiple RobotEye's each pointing one of the required sensors. This has the advantage that the different RobotEye's can be pointed independently allowing the use of each sensor to be optimised rather than all sensors being tied to the one platform and being forced to look in the same direction and follow the same trajectory. For instance the way you may want to utilise a laser rangefinder is often completely different from the way you want to use a camera. The control capabilities of RobotEye systems are such that when you need to have two or more sensors pointing in the same direction their trajectories can be accurately controlled simulating a single RobotEye.

While implementing multiple separate systems on the face of it may seem to multiply the cost of a sensing payload, the cost of multi sensor payloads is often such that multiple smaller single sensor RobotEye systems can be very cost competitive.

One drawback with this approach is when mounting multiple independent sensors there is potential for them to occlude each other when pointing in certain directions; this can often be ameliorated or eliminated by careful arrangement of the sensors with respect to their intended field of regard.

4.6.2 Parallel Signals

A second approach is to use a parallel signal path where all sensors are grouped together pointing in the same direction along the RobotEye signal path. This is much the same approach as multi sensor gimbals, only as with all RobotEye systems the group of sensors do not need to move in order to point their direction of view. This approach requires a RobotEye aperture and signal path large enough to accommodate the optical flow of all the sensors in the group and the common optical components to be sufficiently broadband that they efficiently pass the signals of all the sensors in the group.

4.6.3 Split Signal Path

The third approach that can be used is a split signal path, using optical elements to efficiently split the signal off into bands relevant for each sensor. This approach enables the use of a smaller aperture than the parallel signal approach but it is the most complex method to implement. It also requires that it is possible to design an optical arrangement that can split the optical flow into the signal bands of each of the sensors involved.

4.7 Design for Market

There are a number of markets including defence, robotics, security and automation to which RobotEye based sensor pointing and scanning offers significant benefits. These markets however have very different requirements in terms of physical and performance attributes, volumes and price point. Both the core RobotEye technology and the peripheral components which go to make up a RobotEye system are capable of being engineered to meet the requirements of all of these markets enabling the RobotEye based systems to address the wide range of applications in different sectors and industries.

5 Application Case Studies

The motion bandwidth capabilities of RobotEye technology provide benefits in a wide range of applications. In some applications, the high velocity limits are advantageous. In others, the high acceleration capabilities of the eye provide previously unavailable response times and control bandwidths. Regardless of the application, the case studies herein all represent a significant improvement over the implementation of these applications using alternative technologies in the four key fields of performance, robustness, reliability and flexibility.

The majority of the case studies examined in this section have been implemented in basic demonstrations by Ocular Robotics. Videos of these demonstrations can be found on the on our website (www.ocularrobotics.com/demonstrations) or alternatively on our YouTube channel (www.youtube.com/ocular11).

5.1 Telepresence

One of the greatest challenges in the field of telepresence is that of visual feedback from a remotely operated vehicle (ROV). Vision is a core component of human perception, and a number of technologies seek to enable realistic telepresence of vision. Traditionally, these approaches have utilised fixed monitors with pan-tilt or gimballed cameras and joystick control of the orientation of these cameras.

This approach has two major disadvantages due to the slow slew rates of traditional sensor pointing systems. Firstly, the amount of time taken to scan the area around the ROV is inversely proportional to the speed of the scanning system. This leads to a large time delay for an operator to build situational awareness when they enter a new environment.

Secondly, the natural approach to telepresence would imply that a combination head mounted display (HMD) and head tracker will provide the most realistic telepresence environment. By interacting in a natural mode, the training burden for ROV systems can be reduced, and the operator's instincts can be leveraged to improve performance. The disadvantage of HMD is that latencies of any greater than 10 milliseconds between the motion of the operator's head and the projected motion in the HMD will induce severe motion sickness in the operator.

Both of these problems are overcome by the Robot Eye's high dynamic capabilities. The response time enables any operator to rapidly build up a picture of the working environment of the ROV. HMD and Head tracker applications are also now a usable option, since RobotEye response is rapid enough to eliminate the nausea problem. The ability to use such a natural interface also significantly reduces the training time of the operator on such a telepresence system.

5.2 Tracking

The tracking of rapidly moving targets has always been a challenging task for sensor pointing systems. Typically there needs to be a trade off made between three key parameters; Acceleration, Accuracy and Zoom. Low-zoom camera-based systems do not require high accuracy pointing, nor do they require high accelerations, however they do not produce detailed images of the target. High-zoom systems require accurate pointing and high accelerations to ensure that the target remains within the field of view of the sensor whilst manoeuvring.

The RobotEye system can deliver accuracy appropriate to tracking targets at long ranges using high-zoom cameras. The 0.02 degree accuracy equates to a lateral separation of approximately 1m between distinct points at 3 km range. This accuracy can be used to reliably track targets at extremely long ranges.

For short-range high-speed targets, the speed and acceleration of the eye enables the eye to follow objects moving at extremely high velocities at short ranges. Figure 5-1 shows an example of tracking a simulated target moving at Mach 5 performing a flyby 50m from the eye. The peak acceleration and velocity required to consistently track such a target can be seen to be well within the capabilities of the RobotEye.

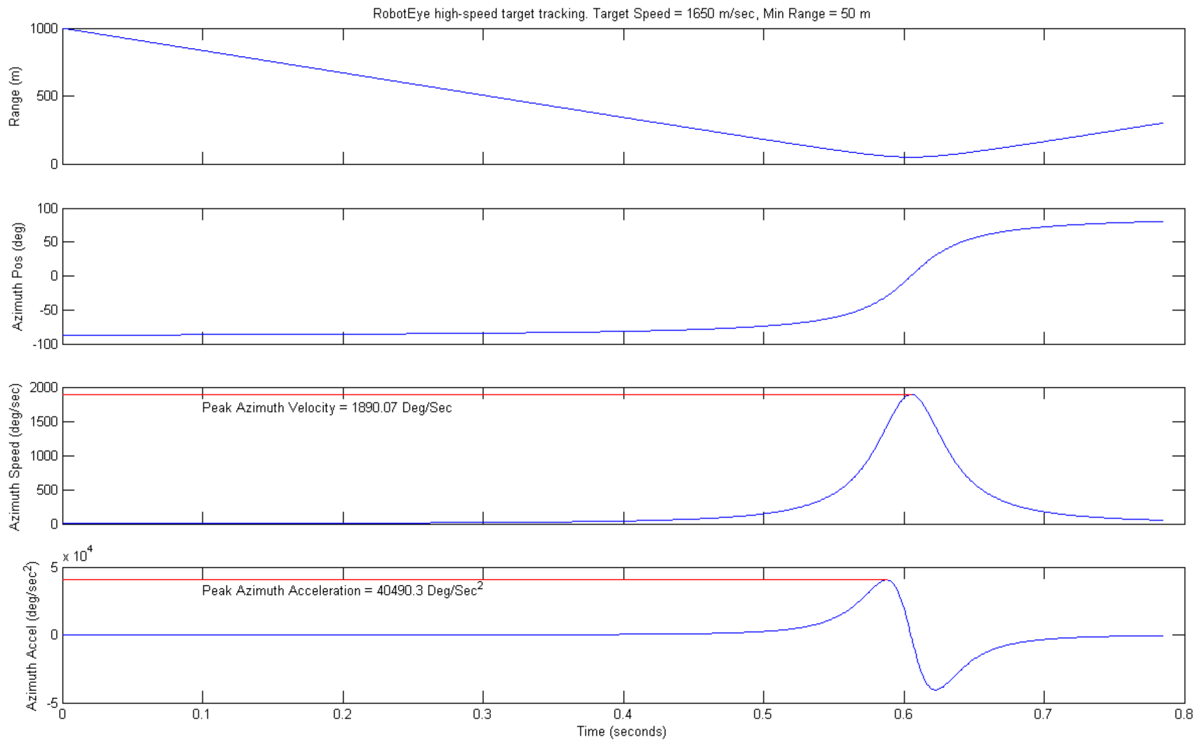


Figure 5-1 – High Speed Target Tracking Simulation

Such tracking behaviours are well outside the capability of comparable systems, indeed there is still a significant amount of headroom between the required peak acceleration and the acceleration capabilities of the eye. This gives the capability to maintain the track even of high-speed manoeuvring targets at short ranges.

5.3 Stabilisation

The field of image stabilisation has always been a challenging one for actively controlled sensors. Whilst static sensors can be quite easily stabilised by mounting them within a high-inertia passive gimbals system, actively pointed sensors require a set of gimbals sufficiently large that the reaction forces from motion will not cause the gimbals to rotate, however this limits their responsiveness during active pointing phases.

The alternative approach is that of active stabilisation. Utilising this approach enables the mass of the system to be reduced by removing the high-inertia gimbals. This comes at a cost however, as the limiting factor in the stabilisation becomes the acceleration and angular rates of the sensor pointing system.

By combining the extremely high aperture acceleration and velocities of the RobotEye with an inertial measurement unit (IMU) such as the Intersense NavChip shown below, the aperture can be actively controlled to counter-act the motion of the platform. Since the RobotEye is capable of the velocities required for this stabilisation on all but the most extreme of platforms, the determining factor in the performance with this system is no longer the performance of the sensor pointing system but the quality of the IMU solution. These parameters are under the control of the end user, enabling the RobotEye to be paired with an extremely high performance IMU should accurate and drift-free stabilisation be required.

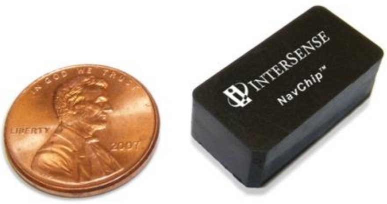


Figure 5-2 - InterSense NavChip IMU

The RobotEye also has sufficient headroom in the acceleration and velocity limits that even whilst on a highly unstable platform, the eye can accelerate sufficiently to track rapidly moving targets whilst continuing to stabilise. This is not possible with traditional approaches as existing actively stabilised platforms are already pushed to their performance limits whilst performing stabilisation on unstable platforms. A demonstration video of this application can be found here Stabilisation Demo.

5.4 Disparate Point Targeting

There are many applications for perception systems where multiple targets within an area need to be observed. Potential applications are the tracking of multiple objects within a region, the surveillance of regions of interest with rapid transitions or pointing an emissive optical device at multiple targets in rapid succession.

The main obstacle to performing these tasks effectively with current technology is the time penalty imposed in moving the sensor from one target to the next. If the sensor cannot be pointed quickly, the ratio of usable time to dead-time becomes prohibitive. The only alternative is to mount an independent sensor and pointing device for each target.

With the RobotEye, the ratio of on-target to dead-time can be significantly increased, to the point where it becomes feasible to point the sensor at an extremely large number of targets within the field of view. For example, in a 15x15 rectangular grid pattern shown in the following video RobotEye Grid Demo, a RobotEye can point to 225 distinct targets within a limited region of interest in under 5 seconds.

This capability extends beyond tracking. As shown in the video, the RobotEye can redirect emissive optical devices such as the laser pointer used in the demonstration. This capability could potentially be used to direct a target designator, or to aim technologies such as a dazzling laser for less-than-lethal applications. The primary benefit of the RobotEye in such applications is the minimal time spent re-directing between targets, meaning that large numbers of targets can be engaged with the device spending close to 100% of the time actively emitting.

5.5 Image Mapping

An alternative application of the performance advantages applicable to the section above is to rapidly acquire a large number of images in a fixed pattern. These images can then be stitched together to form a high-resolution panorama. This application is extremely useful for management and planning scenarios, where a single vehicle with a single sensor can rapidly acquire an extremely detailed picture of its surroundings. This image can then be used in teleconference planning scenarios, giving each participant an image of equivalent quality to being present with the vehicle while using high-zoom binoculars.

Such systems have not achieved significant market penetration to date, due largely robustness and accuracy limitations. One example of a currently available system is the Kolor Panogear, designed for scanning Digital SLR cameras to generate gigapixel panoramas. The Kolor Panogear system has a maximum scan rate of only 7.2 degrees/second, and accuracy of 0.25 degrees. These performance limits have a significant impact when there may be dynamic elements within the scene. The slower the movement of the camera, the longer it takes to acquire the scene and the larger the discrepancies between images.

In contrast, the high speeds of the RobotEye enable panoramas to be acquired much more rapidly, before there has been a significant change in the environment being scanned. These images can be stitched together to produce an extremely high-resolution image from a relatively low resolution camera. The example shown below was taken using a 900x900 pixel camera, stitching 96 separate images together to produce a final image of 11342x4872 pixels. The upper inset clearly shows the image quality attainable in the final product, extracting imagery of the people walking along the grass and identifying the person on the left as wearing a bright red jacket, jeans, and carrying a backpack.

This demonstration is simply a proof-of-concept, by pairing the RobotEye with a high-resolution high-zoom camera, images of tens or even hundreds of gigapixels can be acquired rapidly and simply. A demonstration of this capability can be seen in this video [Image Mapping Demo].

5.6 3D LIDAR Scanning

Since the RobotEye is capable of pointing both emissive and receptive devices, it is possible to combine it with a 1-dimensional laser range finding device and produce a highly controllable 3D laser scanner.

Typical high-end 3D laser scanners such as the Velodyne HDL-64E rely on a fixed scan pattern to generate 3D information. The Velodyne utilises 64 separate laser transmitter-reciever pairs, each scanned in a constant-elevation plane. Although it is capable of providing significant amounts of data, the scan pattern is fixed relative to the frame, and the angular resolution in elevation is relatively poor, since the lasers are spaced at 0.4°, the azimuth resolution is also limited to 0.09°.

In contrast to this, the RobotEye enables the scan pattern and resolution to be tailored to the application ensuring that the attention of the scanner is focussed on the region of interest. In the video available at 3D LIDAR Demo, the RobotEye is used to generate both a coarse scan of the entire room, and high-resolution scans of specific regions of interest. As an actively controlled scanner, the RobotEye is also capable of extreme resolution. Although the repeatability and control accuracy of the RobotEye is 0.02° to 0.05°, the reporting accuracy is 0.01°. As such, the projection of the ranges taken into 3D space is performed at a resolution significantly higher than the controller limitations allow for control of the eye. This is a unique ability of the RobotEye system, as there is no other 3D LIDAR on the market capable of this combination of accuracy, controllability and speed.

This example is also an application in which the flexibility of the RobotEye system is a significant advantage. Depending on the requirements for maximum and minimum range, range resolution and sample rate, the 1D laser paired with the RobotEye can be changed to provide performance appropriate to the application. This is in direct contrast to all other LIDAR systems, where there are a limited number of models available, and it is often necessary to trade-off accuracy and range against resolution and response time.