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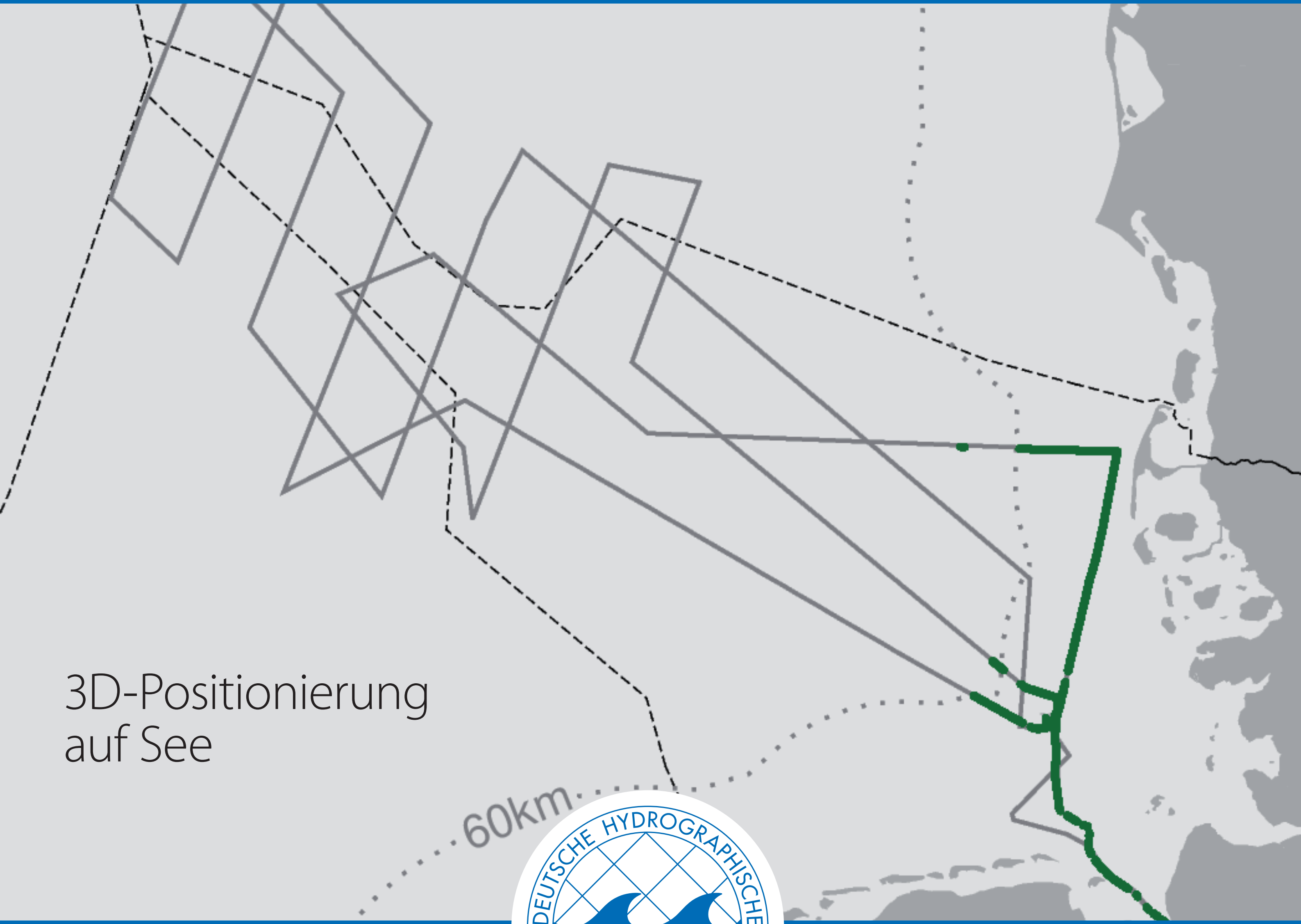

3D-Positionierung auf See

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Subsea positioning using camera systems

An article by MERLIJN VAN DEEN

Determining the position of structures (assets) on the seabed accurately and robustly is challenging. Typically used land-based techniques such as satellite-based positioning are not available subsea due to the attenuation of radio waves in water. Visual navigation is challenging due to the lack of natural light and limited visibility. Conventional subsea positioning therefore uses acoustic techniques such as long baseline (LBL) or ultra-short baseline (USBL) positioning, with an acoustic beacon mounted on the asset. The high pressure at depth means that this hardware is heavy, bulky and expensive. Furthermore, removing the beacon after the asset was installed adds risks and complexity to the asset positioning process. To reduce the risk in subsea asset installations, Fugro developed a touchless, camera-based approach to subsea positioning: QuickVision. By combining an accurate camera system with calibrated pattern targets, this unique approach enables quicker and safer operations in a difficult environment.

QuickVision | camera system | structure from motion – SfM | V-SLAM | intelligent camera
QuickVision | Kamerasystem | Structure-from-Motion – SfM | V-SLAM | intelligente Kamera

Die genaue und zuverlässige Bestimmung der Position von Strukturen (Anlagen) auf dem Meeresboden ist eine Herausforderung. Typische landgestützte Verfahren wie die satellitengestützte Ortung sind aufgrund der Dämpfung von Funkwellen unter Wasser nicht verfügbar. Die visuelle Navigation ist aufgrund des fehlenden natürlichen Lichts und der eingeschränkten Sicht schwierig. Für die herkömmliche Unter-Wasser-Ortung werden daher akustische Verfahren wie die Long-Baseline-Ortnug (LBL) oder Ultra-Short-Baseline-Ortung (USBL) eingesetzt, bei der eine akustische Bake am Objekt angebracht wird. Aufgrund des hohen Drucks in der Tiefe ist diese Hardware schwer, sperrig und teuer. Darüber hinaus birgt das Entfernen der Bake nach der Installation der Anlage zusätzliche Risiken und macht das Verfahren zur Positionierung der Anlage komplizierter. Um das Risiko bei der Installation von Unter-Wasser-Anlagen zu verringern, hat Fugro einen berührungslosen, kamerabasierten Ansatz zur Unter-Wasser-Positionierung entwickelt: QuickVision. Durch die Kombination eines präzisen Kamerasystems mit kalibrierten Zielmustern ermöglicht dieser einzigartige Ansatz einen schnelleren und sichereren Betrieb in einer schwierigen Umgebung.

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Introduction

The accurate positioning of subsea assets is a critical component of subsea installations. The conventional technique is to temporarily mount survey and ancillary equipment on the asset during the positioning phase of the work, such as long baseline (LBL) acoustic beacons, fibre optic gyros (FOGs) and associated cabling and battery packs. This equipment allows the real-time positioning of the assets via mature acoustic survey techniques. Nevertheless, the installation, configuration and maintenance of this type of equipment takes time and adds a degree of complexity. It also presents an operational health and safety risk due to the weight of the equipment and the use of battery packs in sealed housings.

To remove the necessity to temporarily mount, and subsequently remove, survey equipment on an asset to be positioned subsea, we developed and patented a touchless, camera-based approach to subsea positioning: Fugro QuickVision®. QuickVision consists of a small, calibrated machine-vision subsea camera which can be mobilised onto any remotely operated vehicle (ROV), and a software solution running on a surface vessel. This is often combined with a unique coded pattern which is attached to the asset. Combined, these components allow QuickVision to accurately determine the asset's position and orientation in real-time.

In this article, we will discuss the development of QuickVision and will highlight the advantages the system provides over contemporary systems and techniques through three use cases. Finally, we discuss the future of cameras in subsea survey operations.

Subsea camera systems

Conventional ROV cameras, built for piloting and inspection, generally do not have the attributes to be part of a camera-based survey system. For example, a zoom lens under pilot control limits the ability to accurately calibrate the lens, and high frame rates and short shutter times come at the cost of increased noise in images. Issues such as these limit what can be achieved with conventional camera systems from a survey perspective.

In 2015, we therefore started development on an in-house designed and fabricated subsea camera system (Fig. 1), to be used as the key component in a touchless, vision-based, subsea survey system. This camera system combines three attributes that are vital for accurate measurements:

First, a light-sensitive camera module which provides access to unprocessed and uncompressed images. By using a modern machine vision camera module, we gain access unprocessed and uncompressed (»raw«) imagery. To increase light-sensitivity, we chose a module with a physically large sensor and moderate spatial resolution. We are thus able to acquire quality imagery suitable for use in both the QuickVision toolset and for use in third party offline photogrammetry suites.

Second, the use of a fixed zoom (prime), fixed aperture and fixed focus lens. A fully manual lens, combined with a hemispherical porthole allows for an accurate in-water calibration procedure to be undertaken at the time of manufacture.

Finally, an accurate timestamping approach. The vast majority of subsea camera systems do not support accurate timestamping of imagery. By using a triggerable machine vision camera module and accurate triggering hardware, our camera system can timestamp images to sub-millisecond precision. We are then able to synchronise images with all other ROV sensor data, allowing us to perform measurements in even the most dynamic scenarios.

Starfix navigation software

The design and fabrication of a calibrated subsea camera system with the attributes to allow the camera to form part of a robust and accurate subsea survey technique is only part of the challenge. Whilst such a camera system acquires high-quality and accurately timestamped imagery, these images must be processed and combined with a great deal of ancillary data to allow subsea survey to be undertaken.

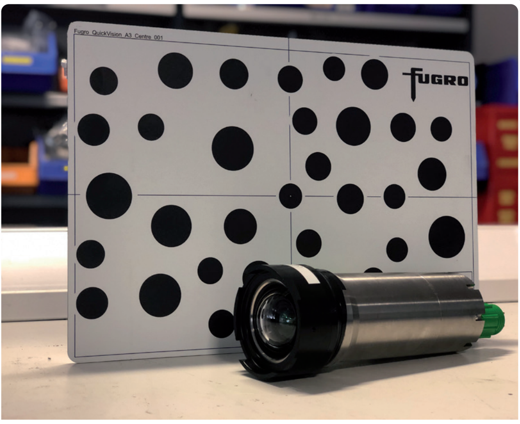
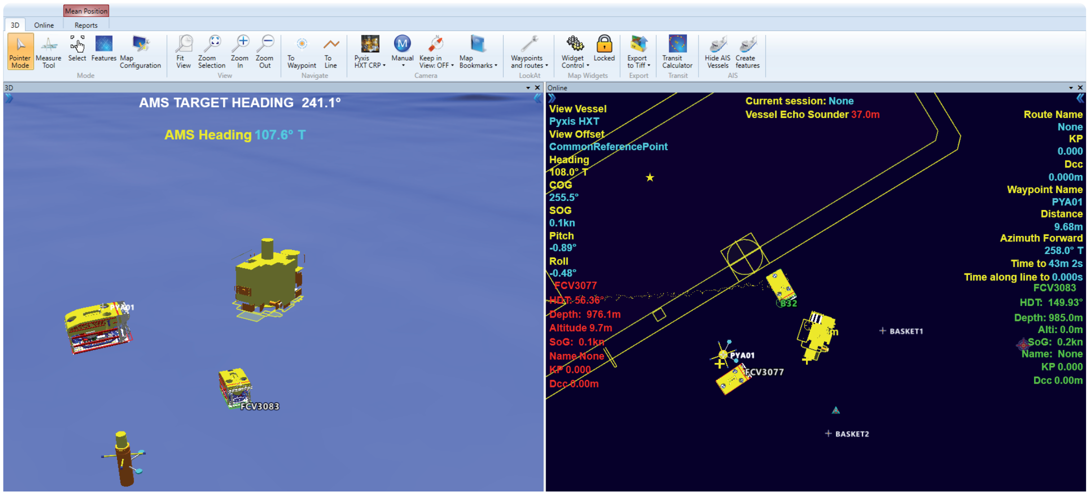


Fig. 1: QuickVision camera system and A3 pattern board

We extended Fugro's online navigation suite Starfix with a QuickVision module to allow imagery to be used as the basis for real-time surveying. This module combines the timestamped images with the lens calibration model, descriptions of the QuickVision patterns and how they are mounted on assets, and the position and orientation of the camera system on the ROV into a positioning result relative to the ROV. This relative result is then combined with the position and orientation of the ROV, which are computed based on the ROV's navigational systems such as LBL and FOG.

The results of the computation can be displayed in Starfix using a variety of methods, for example through numerical overlays, time-series plots, and two- or three-dimensional maps (Fig. 2).



AMS TARGET HEADING 241.1°

AMS Heading 107.6° T

View Vessel
Pyxis HXT
View Offset
CommonReferencePoint
Heading
108.0° T
COG
255.5°
SOG
0.1kn
Pitch
-0.89°
Roll
-0.48°
FCV3077
HDT: 56.36°
Depth: 976.1m
Altitude 9.7m
SoG: 0.1kn
Name None
KP 0.000
Dcc 0.00m

Current session: None
Vessel Echo Sounder 37.0m

Route Name
None
KP
0.000
Dcc
0.000m
Waypoint Name
PYA01
Distance
9.68m
Azimuth Forward
258.0° T
Time to 43m 2s
Time along line to 0.000s
FCV3083
HDT: 149.93°
Depth: 985.0m
Alti: 0.0m
SoG: 0.2kn
Name: None
KP 0.000
Dcc 0.00m

Fig. 2: Real-time numerical and graphical displays in Starfix. A 3D representation of two ROVs and the subsea structure (left). A 2D surveyor map with overlaid numerics used to precisely monitor the positioning of the asset (right)

Patterns

The most used tool within the QuickVision module is Fugro’s patented dot-based positioning system QuickVision Tracking. This tool uses calibrated pattern boards (Fig. 1) mounted onto the structure to be positioned. Each pattern has a unique layout of dots, which allows QuickVision Tracking to recognise each individual pattern and to distinguish different patterns from each other.

During preparations for subsea operations, the survey team will mount one or more dotted patterns onto the asset to be positioned. The patterns can be installed on any flat or cylindrical surface, and the size of the pattern boards can be optimised for each project. For example, we generally use smaller (A3 or A4) patterns for subsea installations, and larger (1 m × 1 m) patterns for monopile foundation installations.

The position and orientation of these patterns with respect to the structure is then determined using conventional dimensional control techniques such as total station and steel tape measurements. This can be done early in the project scope, even before the structure leaves the fabrication yard.

During the positioning phase, the solution tracks the patterns automatically and in real-time. The position and orientation of the asset is then computed using the dimensional control results and the ROV positioning information. This can be done in either a local or a geo-referenced coordinate system.

Example use cases

In this section, we will detail three projects where we used QuickVision rather than conventional survey techniques. First, we’ll discuss the use of the virtual inclinometer to take anchor chain inclination measurements for a floating production storage and offloading unit (FPSO). Second, we’ll discuss how patterns were used in the installation of a horizontal christmas tree (HXT) on top of a wellhead. Finally, we’ll show how patterns were used in the installation of torpedo pile anchors.

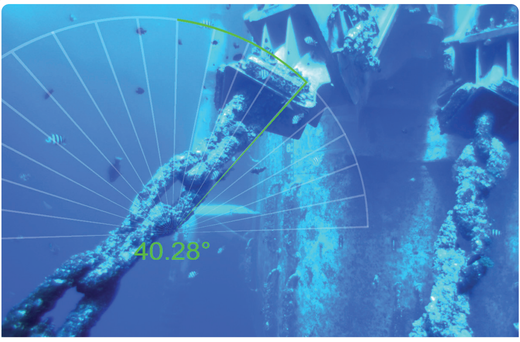


Fig. 3: Virtual inclinometer measuring the inclination of an anchor chain. This measurement is combined with a measurement taken at a perpendicular heading. Combined, these measurements allow us to derive the inclination of the anchor chain

Anchor chain inclination measurements

The first example is the measurement of inclination along an anchor chain. Many floating offshore structures, such as floating wind turbines and FPSOs, are (semi)permanently anchored to the seabed. As part of the installation of the structure, the anchor chains must be tensioned to the correct tension. During the lifetime of the structure, inspections are performed to verify that the mooring tension is still within specification. In both cases, the tension in the mooring chain is computed using a catenary model. One of the inputs to this model is the inclination angle of the chain at different points along the chain.

The conventional approach to measuring the inclination is to physically place a tilt sensor on a chain link. This requires cleaning the link from any marine growth, a time-consuming process. In addition, care must be taken while placing the sensor to allow for highly accurate measurements.

In contrast, the QuickVision camera system can be used to take this measurement without physical contact with the chain. Using the virtual inclinometer tool, we measure the chain angle (Fig. 3) from two perpendicular headings. These two measurements, combined with the synchronised heading data from the ROV, allow us to calculate both the inclination angle and inclination direction. To further improve accuracy and robustness, additional measurements can be taken at intermediary headings.

Orientation monitoring

The second example is the installation of a horizontal christmas tree (HXT) on top of a wellhead. An HXT forms the connection between an oil well and a jumper or flowline transporting the oil or gas. To be able to connect this jumper, the HXT must be placed with the correct orientation.

Conventionally, the heading of the HXT would be measured using expensive, bulky and battery-operated equipment such as a subsea gyro and an acoustic modem or visual display. A gyro allows for very accurate measurements, but removing the equipment from the HXT after the installation adds significant risk to the operation. In addition, if a sensor or battery malfunctions, replacing it offshore can be a time-consuming and costly operation.

For this project, we opted for patterns mounted onto the asset. As the pattern boards are inexpensive, we can easily place multiple pattern boards – in this case four – and can leave them in place after installation. The patterns were mounted and dimensionally controlled outside of the project critical path, further reducing project risk.

After the patterns were installed and dimensionally controlled, and the system was configured, the QuickVision system automatically detects the patterns when they come into view, and switches between patterns when required. For each detected pattern, the relative position and orientation with respect to the camera is computed. This information is then combined with the ROV navigation data to compute the HXT's heading (Fig. 4).

Torpedo pile anchors

The last example is the positioning of torpedo pile anchors. Torpedo piles are deep-water dynamically installed anchors. These piles, weighing up to 200 tonnes, are embedded into the seabed by free-fall. They are typically dropped from 30 to 100 metres above the seabed. Before they are dropped, they need to be accurately positioned above the target location.

As it is not feasible to mount equipment on the piles, the conventional method to position the piles is to physically touch them with the ROV. Despite this being an effective method, it does introduce unnecessary risk to the ROV.

As with the previous example, we chose to use sacrificial patterns to allow for a fully touchless solution. In this case, we used stickers rather than rigid pattern boards as this simplified the installation on the cylindrical surface of the pile. Once the patterns were detected, QuickVision could compute the pile position relative to the camera. Combined with the ROV's positioning system, Starfix could then compute the georeferenced position of the pile. Through this method, we were able to position all piles safely and well within tolerance.

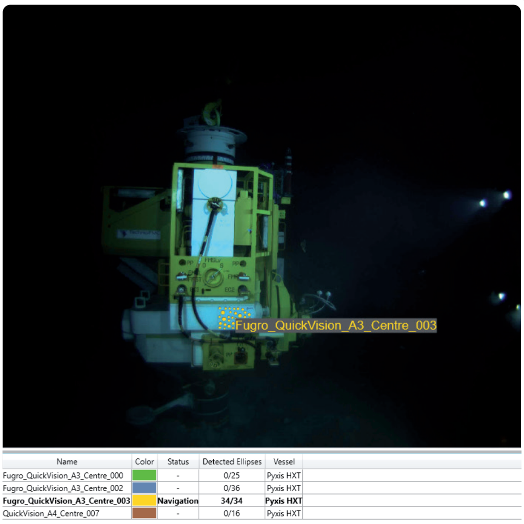
The future of subsea cameras

The original QuickVision solution was built around 2015. Over the last eight years, technology has progressed significantly: The increase in computing power on computers and graphics cards over the last decade have opened a wide array of opportunities for computer vision, and improvements in camera technology have led to larger and more light-sensitive camera modules.

In this section, we will discuss two areas where this progress can be seen in subsea camera-based survey: structure from motion, reconstructing 3D models from images, and intelligent cameras, which can process images subsea in real time.

Structure from motion

Structure from motion (SfM), also often called photogrammetry or visual simultaneous localisation and mapping (V-SLAM), is a computer vision methodology to build 3D point clouds based on image data. SfM algorithms detect key features in images, match these features between images, and uses this information to build a three-dimensional model of the environment. By providing the algorithm with external scale information (e.g., through a calibrated scale bar) or positioning information (e.g., through the ROV navigation system), it becomes possible to generate a correctly scaled and georeferenced point cloud.



Name	Color	Status	Detected Ellipses	Vessel
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Fugro_QuickVision_A3_Centre_002	🟦	-	0/36	Pyxis HXT
Fugro_QuickVision_A3_Centre_003	🟨	**Navigation**	**34/34**	**Pyxis HXT**
QuickVision_A4_Centre_007	🟫	-	0/16	Pyxis HXT

Fig. 4: Subsea view of the structure with a target detected by the QuickVision camera on the ROV

An advantage over conventional techniques such as multibeam sounding and laser scanners is a decreased dependence on accurate positioning throughout the process. Instead, the SfM system can provide positioning information by detecting earlier seen features (loop closure). As such, it becomes possible to run surveys with limited (e.g., just USBL) or no positioning information at all.

We've successfully used SfM for a variety of projects, ranging from subsea metrology projects to benthic surveys. Although often a full 3D model is not required for the immediate deliverables, having the model provides significant flexibility, such as the opportunity to take measurements that were not planned as part of the project scope.

Intelligent cameras

The increased computational capacity of low-power devices has made it possible to embed powerful computers in a subsea housing next to the camera. This allows for much simpler interfacing on an ROV, and also allows low-latency integration of image data into an ROV control system.

One example of this is our second generation QuickVision camera, which runs part of the computer vision algorithms in the camera housing. This simplified interfacing the camera significantly: for example, we no longer require a gigabit Ethernet channel to interface the camera system. An additional benefit is that the camera can run in »standalone« mode, without topside computer, which allows for operation from autonomous underwater vehicles (AUVs).

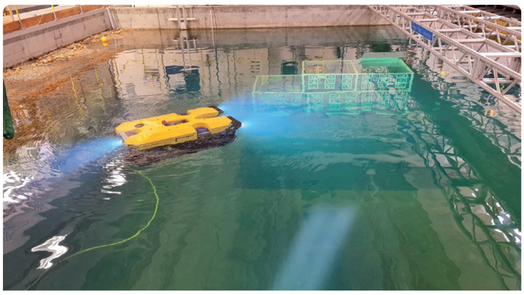

Fig. 5: Fugro Blue Volta electric ROV trial using the National Robotarium camera system

A second example is the real-time V-SLAM camera design by the UK's National Robotarium. Fugro has partnered with the institute around the common interest in autonomous ROVs. The National Robotarium has designed a camera system which is able to build a real-time three-dimensional picture of the environment. Through this digital twin of the environment, it becomes possible to autonomously navigate the ROV within that environment. We are currently in the process of integrating this camera system on our Blue Volta line of ROVs (Fig. 5), which are launched from our Blue Essence Uncrewed Surface Vessels (USVs) and are controlled from a remote operations centre (ROC).

Conclusion

The ability to determine the position of structures (assets) on the seabed accurately and robustly is challenging. In this article, we have shown that an integrated camera-based survey solution makes it possible to position assets without the need for mounting and removing bulky, heavy, and expensive equipment. Developing this solution required an integrated approach, combining a subsea camera system designed for survey applications with an integrated navigation solution and a patented pattern navigation system. The combination allows us to position subsea assets accurately and safely, accelerating project delivery, increasing health and safety performance. //