COMPLETED PROJECT CASE STUDY

GEOREFERENCED 3D PHOTOGRAMMETRY FOR MONITORING THE IMPACT OF AQUACULTURE ON HARD SEABEDS

PARTNERS

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BACKGROUND

Sustainable growth of the aquaculture sector requires stringent environmental monitoring to preserve protected species and habitats, particularly in sensitive marine environments. However, monitoring hard-substrate seabeds presents a challenge because of the limitations of traditional sampling techniques. To address this, advanced georeferenced 3D photogrammetry methods have been explored to enhance underwater surveying accuracy.

Photogrammetry creates 3D models from overlapping photographs taken from different angles, enabling detailed measurements of objects or environments. Specialised software processes these images, reconstructing the object or terrain in a digital 3D format. In underwater applications, photogrammetry is used with remotely operated vehicles (ROVs) or divers to capture images of the seabed, structures, or marine life for environmental monitoring, archaeology, or industrial inspections.

This case study was led by Tritonia Scientific, a leading underwater research and development company that led previous SAIC-funded research exploring 3D photogrammetry for monitoring hard seabeds. Collaborators include Mowi Scotland, Salmon Scotland, the Scottish Environment Protection Agency (SEPA), and NatureScot.

AIMS

The primary objective of this project was to develop and validate reliable, cost-effective techniques to improve underwater navigational accuracy and enable the semi-autonomous operation of ROVs.

By ensuring that ROVs could repeatedly follow predefined survey paths, the project aimed to generate high-resolution, georeferenced 3D models of the seabed.

Additionally, by integrating automated analysis of these models, the project aimed to ensure that data is accessible and transferable for regulators and aquaculture operators.

PROJECT OVERVIEW

The project was structured into five core work packages (WPs) focussing on technical and operational aspects.

WP1: SEMI-AUTONOMOUS ROV NAVIGATION

Work Package 1 dealt with achieving semi-autonomous control of the ROV surveys. The project leveraged advances made during previous feasibility studies to enhance the underwater navigational accuracy to levels needed to trial the semi-autonomous control of the Blue Robotics ROVs.

A key development was the integration of a Doppler Velocity Log (DVL), which calculates velocities and measurements with centimetres-per-second accuracy, with a WaterLinked UGPS Short Base Line (SBL) system and Kalman filtering. Combining velocity data with the ROV's heading enabled real-time position tracking and automated adjustments to the course, improving the precision of the ROV operations.

WP2: 3D PHOTOGRAMMETRY PROCESSING

This WP addressed challenges in 3D photogrammetry for underwater environments, focusing on the reliance on high-performance computing and proprietary software. Using a standardised set of underwater images, a comparative analysis of photogrammetry software platforms was conducted to evaluate performance, usability, and cost-effectiveness. Key performance metrics included image alignment, ground sampling distance (GSD), and reprojection error.

WP3: SURVEY SCALING AND RESOLUTION

This work package examined the impact of survey size and resolution on model accuracy.

While larger area models were assessed during the feasibility study to map broad-scale seabed or ecosystem conditions, this study focused on small-scale, high-resolution models, evaluating the effectiveness of different camera systems, scaling methodologies, sonar technologies and ROV-based photogrammetry for small-target features.

Using GoPro® HERO12 cameras, surveys were conducted at 0.5m and 1m altitudes, which indicated that lower altitudes improved resolution but required longer survey times because of the reduced field of view.

WP4: MACHINE LEARNING AND AUTOMATED ANALYSIS

The project advanced machine learning-based identification methods to enhance 3D model analysis of benthic marine environments. Machine Learning Auto Identification (MLAID), which uses a convolutional neural network (CNN), was originally developed by the team to classify coral types in tropical waters based on image segmentation and colour classification. This approach struggled in temperate waters because of more limited colour variation. Therefore, to improve performance, a pixel-wise semantic segmentation method was developed. Initial results showed improved classification accuracy but highlighted challenges such as overfitting and dataset limitations.

WP5: APPLICATION IN MARINE PEN FISH FARMS (MPFFS)

The feasibility of applying georeferenced 3D photogrammetry at MPFF sites was evaluated, focusing on the Barra Hellisay site for long-term monitoring. Surveys faced weather interference, acoustic disturbances, and positional drift in navigation systems, impacting photogrammetry quality.

However, advancements in Kalman-filtered navigation, GNSS compass integration, Multibeam Echo Sounder (MBES) bathymetric baselines, and a colour-balanced camera system improved survey accuracy. Despite these advancements, positional errors persisted in some transects caused by dead reckoning inaccuracies and unreliable UGPS data.

The project also integrated habitat data with photogrammetry using GIS.

RESULTS

Trials in Loch Craignish during WP1 validated the navigation system's accuracy, demonstrating path-following capabilities (Figure 1, below). Validation against acoustic positioning and photogrammetry software confirmed strong alignment between computed and observed positions.

Figure 1. Survey site within Loch Craignish where the semi-autonomous trials were conducted.

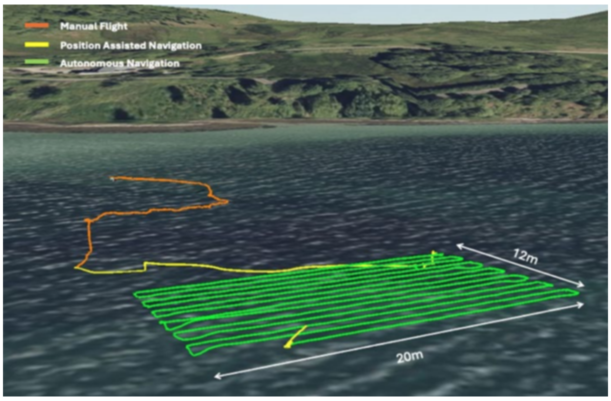

Figure 2. Illustration of the ROV's progress as it executed the pre-programmed mission in semi-autonomous mode. The positions shown in the images are the result of our early development efforts to integrate WaterLinked UGPS Short Base Line (SBL) with the DVL system. These data were fused using a Kalman filter within the ROV's operating system, enabling more precise positioning throughout the mission.

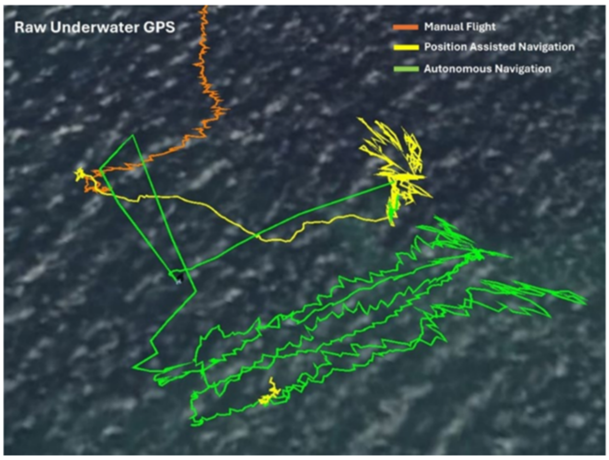

Figure 3. Underwater GPS tracking data for a semi-autonomous mission, highlighting the comparison between different modes of operation. The green path shows the autonomous mode, the yellow path represents position assisted navigation, and the orange path indicates manual control.

Pre-mission MBES surveys further enhanced mission planning, identifying optimal seabed areas for surveys, ensuring consistent imaging conditions and using identifiable seabed features as ground control points to enable precise georeferencing.

The evaluation results from WP2, presented in Table 1, demonstrate that AgiSoft Metashape performed best, achieving 98% image alignment and high model precision (GSD=0.281 mm/pix), though with a slightly higher reprojection error (2.37 pixels). Other software options, such as 3DF Zephyr and Bentley iTwin Capture, provided viable alternatives.

	Processing Time	Images Aligned	Avg GSD (mm/pix)	Reprojection Error (pix)
Metashape*	47m 6s	113/115 (98%)	0.281	2.37
3DF Zephyr	56m 46s	99/115 (86%)	0.311	1.59
RealityCapture	1h 4m	82/115 (71%)	0.331	1.91
Pix4Dmapper	57m 37s	85/115 (73%)	0.289	0.19
PIX4Dmatic	55m 24s	92/115 (80%)	0.345	0.21
Photomodeler	44m 32s	50/115 (43%)	0.421	2.12
iTwin Capture	51m 24s	107/115 (93%)	0.366	1.68

*Table 1. Comparison of photogrammetry software performance metrics. The table presents data on processing time, percentage of images successfully aligned, average Ground Sampling Distance (GSD), and reprojection error across various photogrammetry software platforms. *Metashape is the benchmark with which other platforms are compared.*

Software usability varied, with Metashape, PhotoModeler, and 3DF Zephyr offering intuitive interfaces, while others had more complicated user experiences. Additionally, cloud-based processing solutions using AWS were tested, and a Standard Operating Procedure (SOP) was developed for accessibility.

Analysis of image resolution in WP3 showed that the GoPro provided superior resolution to the DWE ExplorerHD, but required extensive preprocessing. The GoPro's larger frame provided high-quality, detailed images, but struggled with battery life. The DWE ExplorerHD's live-streaming capability improved efficiency, reducing the overall processing workload and shortening the project timescale. However, its image capture method offered limited image detail and georeferencing.

Integrating Side Scan Sonar (SSS) and MBES further refined seabed mapping and mission planning. SSS efficiently captured high-resolution images in shallow waters, allowing operators to assess potential ROV targets quickly. On the other hand, MBES provided detailed seabed terrain in deeper waters.

Cloud-to-Cloud (C2C) distance analysis performed during WP4 enabled the detection of seabed changes over time, providing insights into sediment deposition and biological activity. One of the most noticeable findings was the build-up of sediment along the base of the bedrock and a definite change in the sediment ripples, suggesting that either sediment deposition or erosion occurred.

WP5 applied the techniques from WP1-4 to MPFF sites, using Kalman-filtered navigation and MBES to accurately map complex seabed structures, establishing a foundation for long-term environmental monitoring.

By integrating real-time kinematic (RTK) and DVL technologies, ROVs achieved precise, repeatable survey patterns, generating high-quality georeferenced 3D models. Automated analysis of these models improved monitoring efficiency, making the technology accessible to regulators and producers. Demonstrations at operational marine fish farms confirmed the practicality of these methods, with potential applications in soft-substrate environments, reducing reliance on labour-intensive sampling techniques.

IMPACT

The project successfully demonstrated the feasibility of cost-effective, high-precision underwater navigation and 3D photogrammetry to monitor hard seabed environments.

By improving the accuracy and precision of underwater surveys, this project contributes to the sustainable growth of aquaculture while minimising environmental impacts. Standardised georeferenced photogrammetry techniques enhance regulatory oversight and inform effective marine management strategies.

The methodologies pioneered here not only address regulatory gaps for hard-substrate sites, but also lay the groundwork for their application in soft-substrate monitoring.

Continued research and development will further refine these techniques, ensuring their long-term viability in aquaculture and marine conservation.