# Wide Area 3D Seafloor Reconstruction and its Application to Sea Fauna Density Mapping

Adrian Bodenmann and Blair Thornton
Institute of Industrial Science
The University of Tokyo
Tokyo, Japan
Email: {adrian, blair}@iis.u-tokyo.ac.jp

Ryota Nakajima and Hiroyuki Yamamoto
Institute of Biogeosciences
JAMSTEC
Yokosuka, Japan
Email: {nakajimar, kyama}@jamstec.go.jp

Tamaki Ura
Center for Socio-Robotic Synthesis
Kyushu Institute of Technology
Kita-Kyushu, Japan
Email: ura@lsse.kyutech.ac.jp

***Abstract*—3D visual mapping of the seafloor has found applications ranging from environment monitoring and survey of marine minerals to underwater archeology and inspection of modern man-made structures. However, the attenuation of light is significantly more pronounced in water than in air or in space, and so in order to obtain underwater images in colour, it is typically necessary to be within 2 to 3 m of the seafloor. In addition to the high risk of collision when operating underwater vehicles at such low altitudes, the limited area of the seafloor covered in each image means large area surveys require a huge investment of time. In this research, we aim to increase the efficiency of mapping large areas of the seafloor by developing an underwater imaging system that can take colour images at ranges of up to 12 m, so that each image can cover a larger area, together with the necessary algorithms to automatically process the data it obtains. The system was deployed to map artificial hydrothermal vents in Iheya North Knoll using the ROV Hyper-Dolphin in October 2012. In this paper, we describe the methods used to process the data it obtains and present wide area 3D reconstructions of habitats surrounding artificial hydrothermal vents. Habitats of *Shinkaia crosnieri* squat lobsters, which are abundant in the hydrothermally active areas, are identified in the maps and their population density calculated.**

## I. Introduction

Visual mapping of the seafloor is a versatile tool for underwater research with applications including benthic habitat mapping, survey of mineral resources, and inspection of man-made structures. In particular, the 3D imaging techniques developed in recent years can generate dimensionally accurate digital reconstructions of the seafloor [1]–[4]. The addition of colour information enhances the representation of the seafloor compared to conventional bathymetric mapping techniques, and allows for automatic algorithm-based classification and statistical analysis of features of interest. However, the attenuation of light is significantly more pronounced in water than in air or in space, and so in order to obtain underwater images in colour, it is typically necessary to be within 2 to 3 m of the seafloor. At such a low altitude, the area covered by every image is relatively small and it takes long time to map large areas of the seafloor. In this research we aim to increase the efficiency of mapping by developing an underwater imaging system that can take colour images at ranges of up to 12 m, so that each image covers a larger area, together with the necessary algorithms to automatically process the data it obtains. The system was deployed to map artificial hydrothermal vents in Iheya in October 2012.

The Iheya-North field is a kilometre scale active hydrothermal field [5], that was drilled extensively during the IODP 331 'Deep Hot Biosphere' expedition during September and October 2010 [6], [7]. During the NT12-27, the long range "SeaXerocks 2" mapping system developed in this work was mounted on the remotely operated vehicle (ROV) Hyper-Dolphin to obtain images of the seafloor between the three artificial hydrothermal vents and the North Big Chimney (NBC) mound in the Iheya-North field. 3D colour reconstructions of the seafloor have been generated based on an improved version of the mapping algorithm described in [3]. Furthermore, large communities of *Shinkaia crosnieri* in the hydrothermally active area around the chimneys, which can be used as an indicator of hydrothermal activity, were mapped. They were identified in the maps and their distribution density calculated.

## II. Setup and Data Processing

In our previous work, the authors developed a simple mapping system, which extends laser profiling to generate high resolution 3D colour reconstructions of the seafloor [3]. Here, we further extend the method, illustrated in Fig. 1, to obtain high quality images from altitudes of up to 12 m over the seafloor. The imaging system consists of a high sensitivity

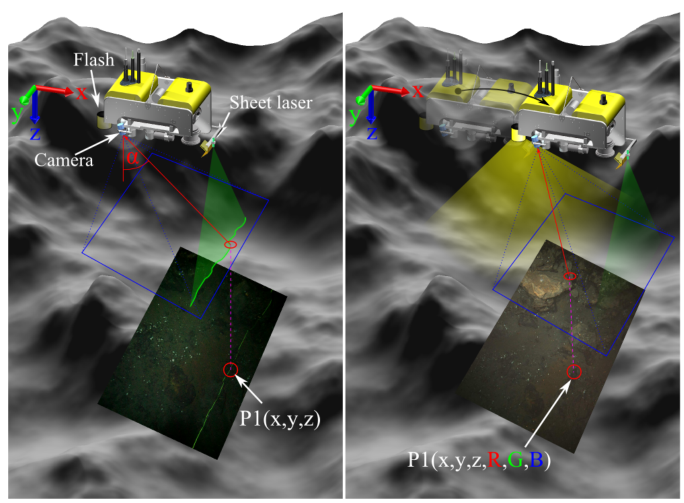


Fig. 1. Illustration of the mapping method. As the vehicle moves forwards, the laser projection scans the bathymetry of the seafloor. This is combined with colour information retrieved by taking flashed images every 6 s to generate 3D colour reconstructions of the seafloor.

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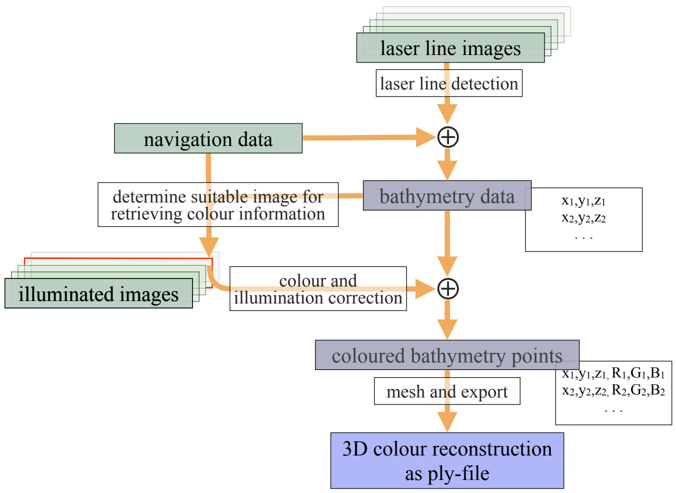


Fig. 2. Flowchart showing the basic steps of the data processing algorithm.

camera, a sheet laser and four synchronised flashes. The sheet laser projects a line perpendicular to the direction of motion of the vehicle onto the seafloor, which reveals the shape of the seafloor when seen from the camera, mounted with a certain offset from the line laser. During deployments, the vehicle scans the seafloor and acquires laser line images at a rate of 5 frames per second, from which the bathymetry map is calculated. Flash photos are taken every 6 s, which are used to calculate the real colour texture map of the bathymetry. At the same time navigation data is recorded from a Doppler velocity log and a depth sensor.

The image and navigation data is transformed in post-processing into coloured 3D reconstructions by an algorithm whose basic steps are illustrated in Fig. 2. The laser line projection is extracted in a set of images corrected for distortion, and by using trigonometric functions and navigation data, the bathymetry map of the scanned area is computed. For every bathymetry point, a flashed photo showing the same spot on the seafloor is determined and its colour is assigned to the bathymetry point. When doing so, the colour is corrected for differences in illumination and the attenuation of light in water based on the exact distance that the light travelled from the flash to the seafloor to the camera. Finally the so obtained coloured 3D points are meshed and written to a file, which can be displayed with standard 3D viewers. This technique allows to obtain highly resolved and dimensionally accurate 3D maps in actual colours from images taken at altitudes of up to 12 m above the seafloor, as it is robust to a certain amount of blurring.

## III. Results

The system was deployed at the Iheya-North field during the NT12-27 cruise of the R/V Natsushima using the ROV Hyper-Dolphin. During the dive, mapping operations were performed for 1 hour along a 920 m trajectory going over the three artificial hydrothermal vents and the NBC mound. A total of 13532 images were obtained from an average altitude of 7.7 m, resulting in a seafloor data acquisition rate of 8144 $m^2$/h with an average pixel resolution of 6.4 mm. This represents

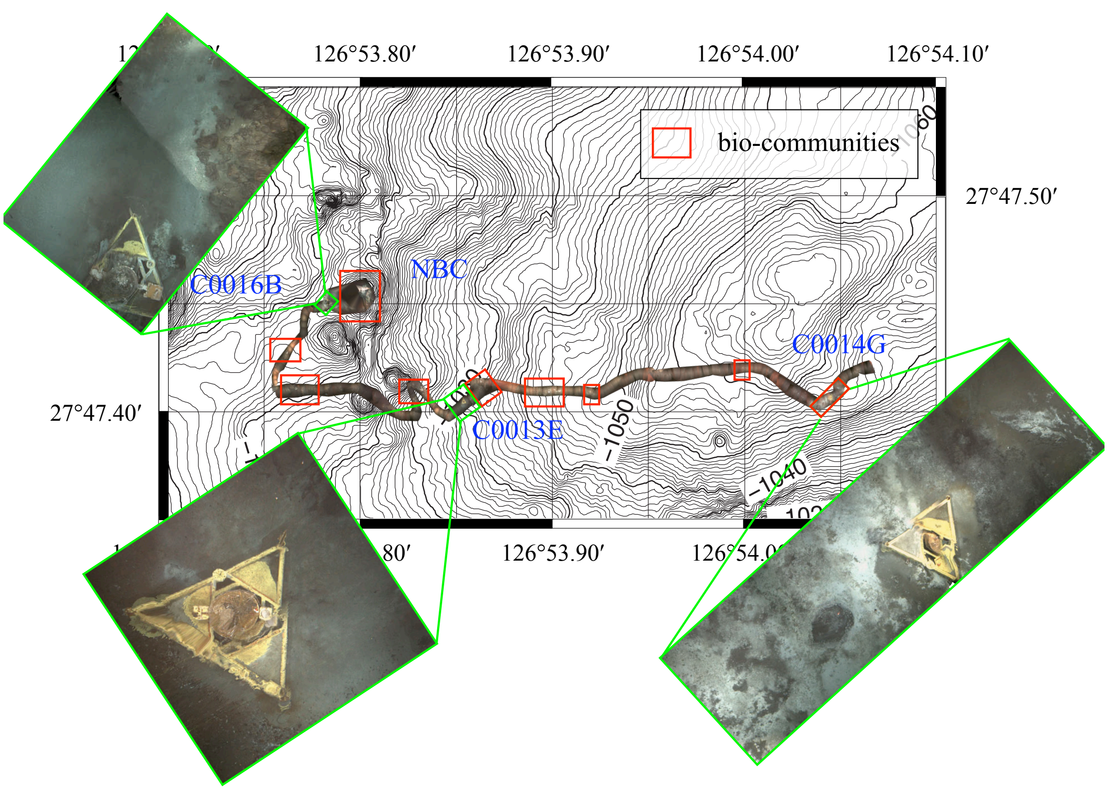


Fig. 3. 3D map generated from data collected in 1 hour overlaid on the depth map of dive site. While all the data was recorded in high resolution, 3 areas of interest, which are the man-made hydrothermal chimneys, are shown enlarged.

TABLE I. MAPPING OPERATION AT IHEYA-NORTH FIELD

| Duration (h) | No. images | Scanned area ($m^2$) | Av. pixel res. (mm) |
|---|---|---|---|
| 1.0 | 13532 | 8144 | 6.4 |

a significant improvement in data acquisition rate compared to conventional colour imaging of the seafloor. The mapping operations are summarised in Table I and the top-view of the 3D map generated from this data overlaid on a bathymetrymap is shown in Fig. 3, with enlargements of the three artificial hydrothermal chimneys.

Fig. 4 shows the C0014G artificial hydrothermal vent and its surrounding. The reconstruction was generated from a single pass over the man-made chimney from an altitude of about 10 m and it covers an area of 37.5 m by 15.5 m. This was mapped in 2 min 40 s. The white hydrothermally altered region, extends west of the vent for a distance of 24 m, and is heavily populated by *S. crosnieri* squat lobsters [8], visible in large numbers in enlargement A. The depression seen 4.7 m west of the artificial vent enlarged in detail view B is an abandoned drill hole made during the IODP 331 expedition and large numbers of *S. crosnieri* are also seen inside of it.

The *S. crosnieri* were identified in a top view of the 3D reconstruction by biologists and marked so that the data could be processed by an algorithm. From this data the population density maps for the area around the natural and the three man-made hydrothermal vents were generated. Fig. 5 shows the 3D map of chimney C0014G with the *S. crosnieri* population density overlaid. The total number of *S. crosnieri* found in the area was 3140 and the highest concentration was 420 individuals per $m^2$. The maps shows that the highest populations are not necessarily found very close to the vent but rather in the surrounding areas. The histogram of the number of *S. crosnieri* in relation to the distance from the mouth of the chimney shown in Fig. 6 shows that the majority of *S. crosnieri* is found at a distance of 6 to 14 m from the chimney. This suggests that there may be hydrothermal fluids seeping up through the ground, which are better capable of supporting sea life than the strong flow gushing out of an artificial vent. There is a particular high concentration of *S. crosnieri* in and around the abandoned borehole (feature B in Fig. 4) west of the artificial chimney, which leads to the assumption that there are cracks and fissures in the underground rock from the drilling operations through which hydrothermal fluids seep and so support sealife.

Fig. 7 shows the top view of the artificial chimney C0016B with its surroundings and Fig. 9 shows the population density maps of *S. crosnieri*. There are significantly less *S. crosnieri* than around chimney C0014G and they are mainly found close to the base of the artificial chimney. This suggests that there is much less hydrothermal fluid seeping through the seafloor. The histogram shown in Fig. 9 also shows that the peak density is much closer to the chimney.

Fig. 10 shows the top view of a transect going over the NBC mound and Fig. 11 shows the population density map of *S. crosnieri* in this area. A total number of 5025 *S. crosnieri* were identified in the coloured 3D reconstruction at a maximum density of 175 individuals per $m^2$. The actual total population is likely to be even higher, because some parts of

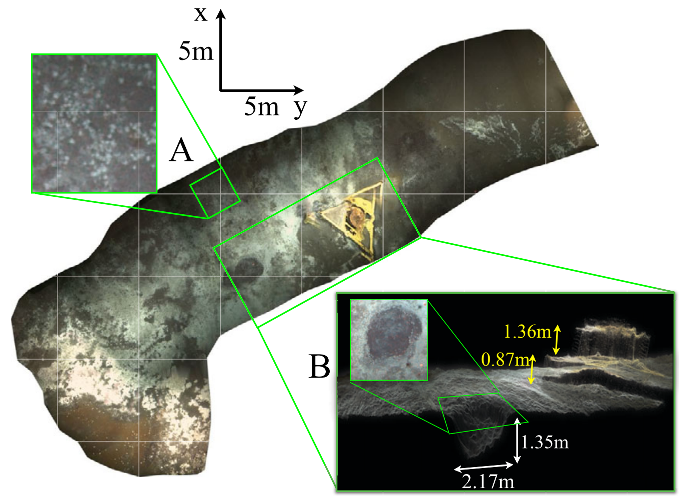


Fig. 4. 3D reconstruction of the area around the C0014G artificial hydrothermal vent measured using a single swath. The white grid lines are spaced at 5 m. Detail view A shows a colony of *Shinkaia crosnieri*. Detail view B shows an open drill hole, which is also populated by a large number of *Shinkaia crosnieri*.

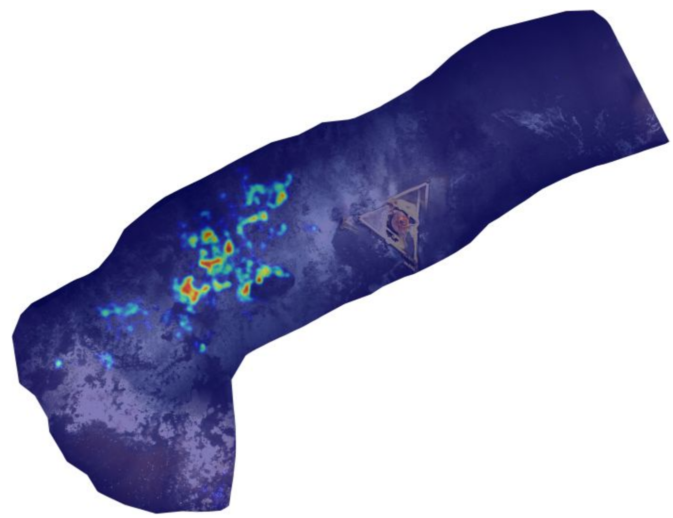

Fig. 5. Top view of the 3D reconstruction of the area around the C0014G artificial hydrothermal vent with the density map of *Shinkaia crosnieri* overlaid. Blue stands for no population and dark red for 420 individuals / $m^2$.

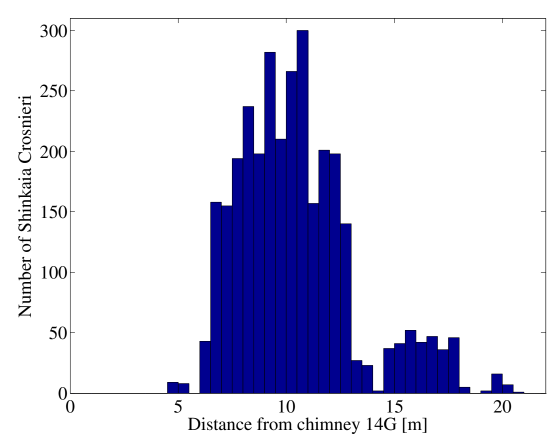


Fig. 6. Histogram of *Shinkaia crosnieri* population density versus radial distance from chimney mouth of chimney C0014G.

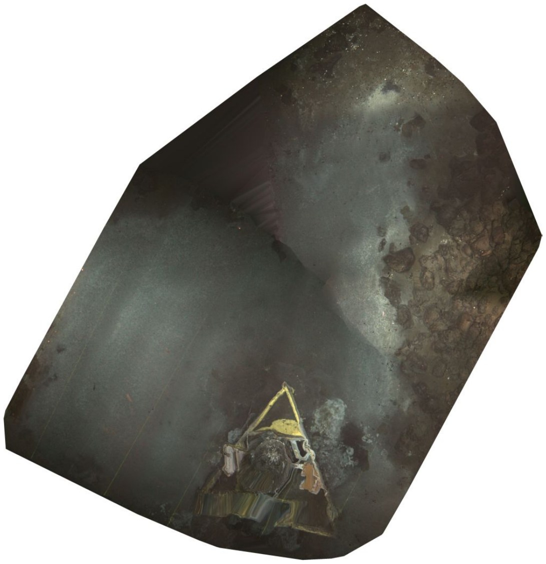

Fig. 7. Top view of a $19 \times 19.8\,\mathrm{m}$ 3D colour reconstruction of the C0016B artificial hydrothermal vent.

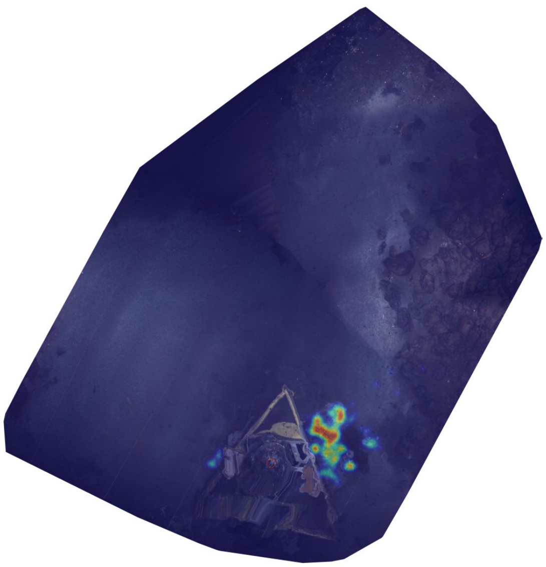

Fig. 8. Top view of the 3D reconstruction of the area around the C0016B artificial hydrothermal vent with the density map of *Shinkaia crosnieri* overlaid. Blue stands for no population and dark red for 190 individuals / $\mathrm{m}^2$.

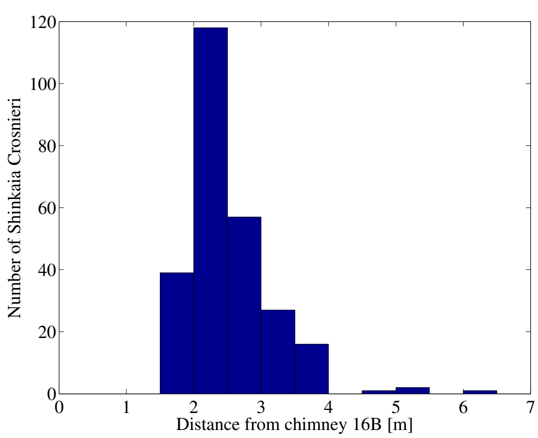


Fig. 9. Histogram of *Shinkaia crosnieri* population density versus radial distance from chimney mouth of chimney C0016B.

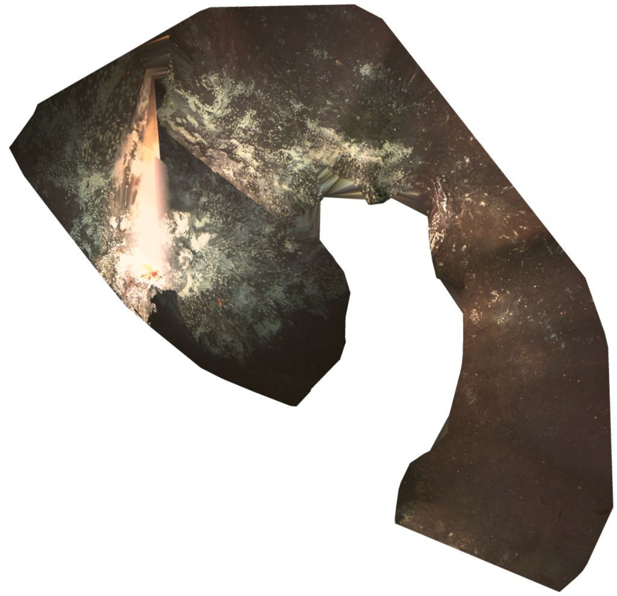

Fig. 10. Top view of 3D colour reconstruction of the NBC mound vent.

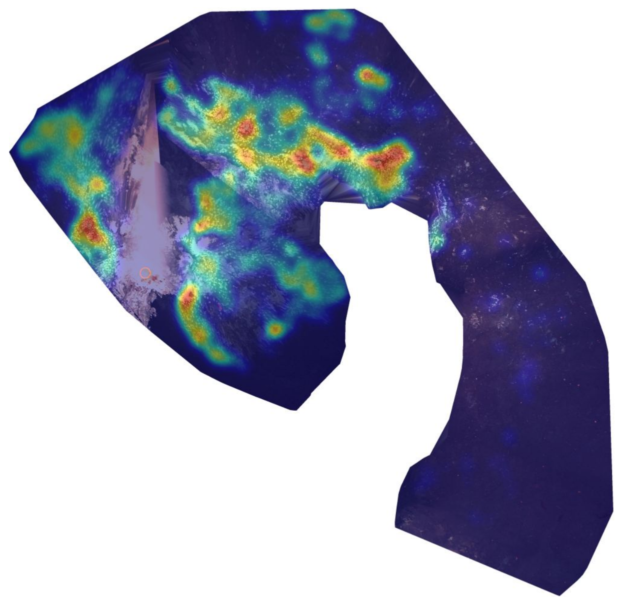

Fig. 11. Top view of the 3D reconstruction of the area around the NBC natural hydrothermal chimney with the density map of *Shinkaia crosnieri* overlaid. Blue stands for no population and dark red for 175 individuals / $\mathrm{m}^2$.

the 3D reconstruction are not clearly visible due to saturation in some of the photos, in particular around the peak and the reconstruction only covers part of the chimney. Due to time limitations only a single transect could be scanned with the mapping setup. However, thanks to the long range mapping capability a relatively large total area of $228.3\,\mathrm{m}^2$ projected could be reconstructed from the single track.

Around the artificial chimney C0013E, shown in the enlargement at the bottom left of Fig. 3, no *S. crosnieri* are found. This vent is clogged and no hydrothermal fluids rise to the surface. Table II summarises the numerical data of the *S. crosnieri* population around the three man-made and the one natural hydrothermal vent.

TABLE II. NUMBER AND DENSITY OF SHINKAIA CROSNIERI (S.C.) IDENTIFIED IN THE IHEYA-NORTH FIELD DRILLING SITE

| Chimney | Total nb. of counted S.c. | Highest density [S.c./m$^2$] |
|---|---|---|
| C0013E | 0 | 0 |
| C0014G | 3140 | 420 |
| C0016B | 261 | 190 |
| NBC | 5025 | 175 |

## IV. DISCUSSION

A long range 3D imaging system has been demonstrated that can generate 3D colour reconstructions of the seafloor from altitudes of up to 12 m. It has been demonstrated that the system is capable of mapping at a rate of $8144\,\mathrm{m^2h^{-1}}$ with an average pixel resolution of 6.4 mm. The system has proved itself as a powerful tool to study the marine environment on regional scales and entire colonies could be mapped in a short time. It is hoped that future deployments of the system combined with standardised data processing techniques will enable the scientific community to perform quantitative, statistical analysis of visible changes in the marine environment on regional scales and over long periods of time, and through such studies gauge the potential impact of human activity on deep sea marine ecosystems.

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