DOI: 10.23784/HN113-07

Reconstruction and visualisation of historic underwater objects at the example of *S.S. Terra Nova*

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This article deals with the reconstruction and visualisation of the former expedition ship *S.S. Terra Nova*. A data set consisting of historic photographs and a construction plan of the *S.S. Terra Nova* is used for the reconstruction. Bathymetry data recorded during a research cruise in 2017 show the wreck of the vessel. The vessel is reconstructed in its original state by employing different modelling approaches. Besides CAD-modelling also the Structure-from-Motion technique is used. By digitising the information of the construction plan the CAD-model is created. The historical photographs are combined in the Structure-from-Motion process and enable the processing of a point cloud of the vessel. An overlay of the resulting models and the bathymetry data is an important part of this article. This overlay is carried out in terms of the identification of the wreck and to examine the usability of the models. Subsequently the models as well as the wreck are visualised in different ways. A categorisation of the visualisations for different user groups is part of the discussion at the end of this article.

bathymetry | reconstruction | visualisation | wreck | Terra Nova | Structure-from-Motion | CAD modelling

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1 Introduction

The *S.S. Terra Nova* was a steam assisted three-mast barque launched in 1884 in Dundee/Scotland and was built as whaler and sealer for arctic waters. Her most famous journey as an expedition ship was an Antarctic Expedition in 1910 under the lead of Robert Falcon Scott which ended in a race to the South Pole as a Norwegian crew under the lead of Roald Amundsen started an expedition at the same time with the same goal. Even though the race ended in a tragedy for the British team, the *S.S. Terra Nova* was saved and used afterwards.

The vessel then was mainly operated in her original function as whaler and sealer. In World War II the vessel was reconstructed for supplying military bases in Greenland. On the 12th September 1943 the *S.S. Terra Nova* was damaged by ice north-west of Kap Farvel/Greenland. To prevent a possible drift with the tidal currents into the Atlantic Ocean it was necessary to sink the vessel (Traver 2006).

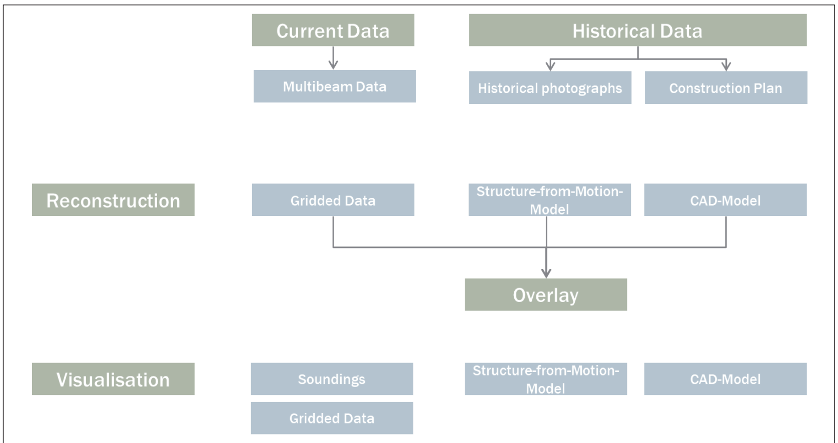

Fig. 1: Workflow and data used for the reconstruction and visualisation of *S.S. Terra Nova*

The wreck of *S.S Terra Nova* was rediscovered in 2012 by scientists on board of the *RV Falkor* from the Schmidt Ocean Institute (California, USA) during a multibeam survey (Schmidt Ocean Institute 2012).

During the research cruise MSM66 in 2017 the wreck was once again surveyed. Thereby, the following questions came into focus: Which options exist to create a 3D-model of the vessel *S.S. Terra Nova* in its original state? Which processes are in this case suitable for 3D-modelling?

Main issue of the modelling process is that only historical data show the vessel in its original state. Current data like the survey data only show the wreck. During the project methods to combine the current and historical data were developed. Furthermore, different reconstruction and visualisation methods are implemented for different user groups.

In this investigation a data set consisting of historic photographs and a historic construction plan of the *S.S. Terra Nova* were used for the reconstruction as shown in Fig. 1. Bathymetry data recorded during a research cruise in 2017 show the wreck of the vessel. An overlay of the models derived from historical data and the bathymetry data concludes the reconstruction part of this thesis. Following the different models and the bathymetry data showing the wreck will be visualised in different ways for different user groups. An overview of the data used for the reconstruction and visualisation is given in Fig. 1.

2 Multibeam data acquisition and postprocessing

On the 25th August 2017 the wreck of the *S.S. Terra Nova* was surveyed from the scientific crew during the expedition MSM66 on board of the German research vessel *Maria S. Merian*. Chief scientist was Dr. Boris Dorschel. The aim of the cruise was the reconstruction of the Laurentide Ice Sheet drainage into the northwest Baffin Bay and the palaeoceanography of the west Baffin Bay (Dorschel 2017a). For the wreck survey as part of the expedition MSM66 the two Kongsberg multibeam echo sounders EM712 and EM122 were used.

During the data collection, several loops with different opening angles were sailed. The aim of the survey was first to locate the wreck and thus to get as detailed information as possible. A map with the tracks sailed is shown in Fig. 2.

This map contains both the tracks sailed during the survey using the EM712 as well as the tracks with the EM122. For the further investigation only EM712 data was post-processed.

As result of the postprocessing, two different grids were created. One grid was used as overview of the area of investigation while a more detailed grid was used to export the coordinates of the grid cells for the overlay.

After data postprocessing, it was possible to characterise the wreck. The water depth around the wreck ranges from 158.6 m as a minimum to 168.3 m as a maximum. The mean water depth is 166.5 m. The dimensions of the wreck can roughly be determined and used for a first identification of the wreck and to check if the dimensions of the wreck are in the same range like the original vessel. The length of the wreck is around 58 m, the width was measured at the front, in the middle and the rear part of the wreck. The results differ between 14 m at the front of the wreck, 15 m in the middle part and 12 m at the rear. The bathymetry data of the wreck are shown in Fig. 3.

3 Reconstruction

The vessel was reconstructed in its original state by employing different modelling approaches. Besides CAD-modelling also the Structure-from-Motion technique is used.

The CAD model was created by digitising information of a construction plan. The construction plan used for the CAD model is illustrated in Michael Tarver's book »The S.S. Terra Nova« (Tarver 2006) and provided by The Natural History Museum, London.

The construction plan, showing a cross section and two deck views of the vessel, was imported in AutoCAD 2017 and scaled by the known length of the vessel. After digitising the cross section and the decks, the decks were spatially rotated to fit the decks into the cross section. The result is a raw-CAD model which is used to create a 3D model by employing different AutoCAD functions. An extract of the plan and the resulting 3D model are shown in Fig. 4.

Structure-from-Motion (SfM), as a technique to create 3D point clouds out of 2D images, seems another promising method to create a 3D model of the vessel (Pomaska 2016, p. 122 ff.). Therefore 65 images taken by a professional photographer

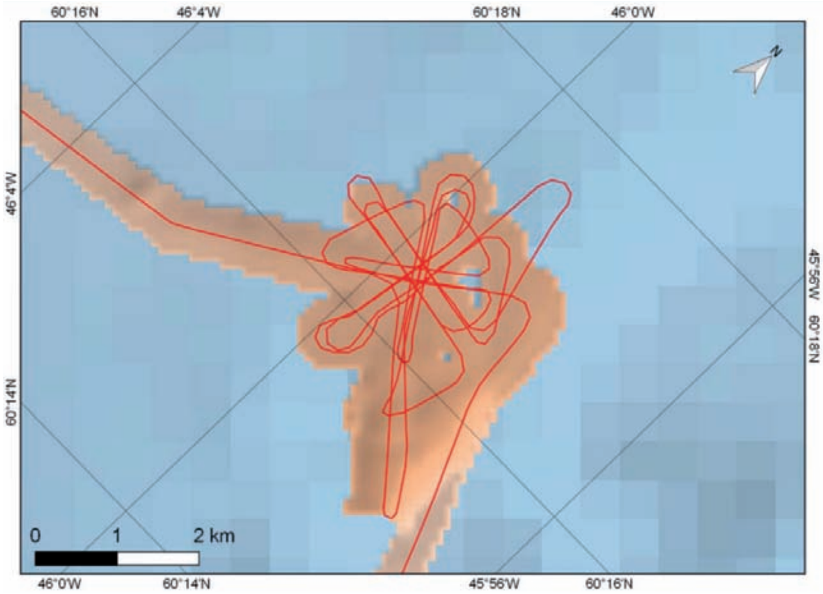

Fig. 2: Tracklines during the wreck survey

Source: Dorschel et al. 2017

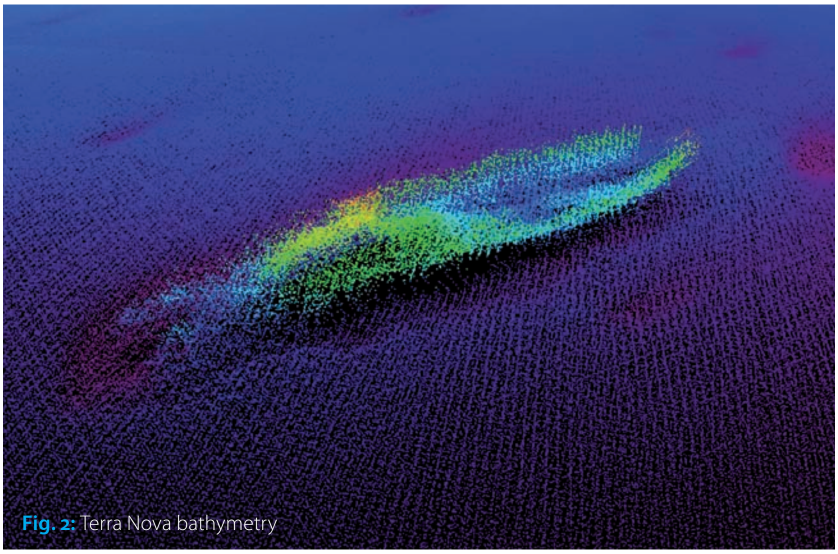

Fig. 2: Terra Nova bathymetry

Source: Dorschel 2017b

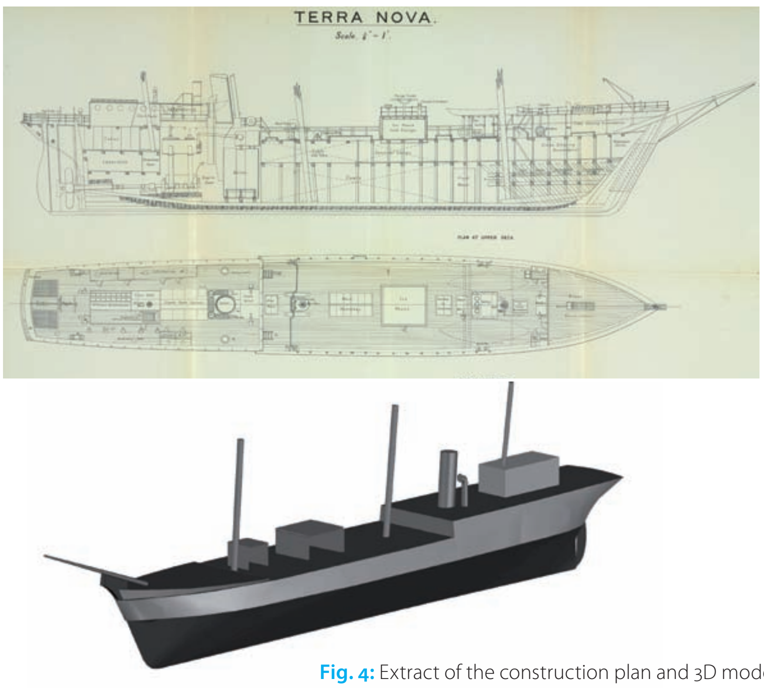

Fig. 4: Extract of the construction plan and 3D model

Source: Traver 2006 (construction plan); Täuber 2018 (3D model)

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during Robert F. Scott's Antarctic expedition were first classified into four groups, showing the vessel from the front and back side, from side with sails set and the fourth group shows *S.S. Terra Nova* from the side without any sails.

With regard to the further scientific task in this investigation, which are the overlay and the visualisation, the resulting point cloud has to fulfil the following requirements: the number of points should be as high as possible whereas, at the same time, the representation of the vessel should be as detailed as possible.

The best result is achieved from images showing *S.S. Terra Nova* from the side without any sails set. This image group consists of 15 images. For the SfM process using the software Agisoft Photoscan, additional seven markers are set. In this context, markers are manually defined points in each image. The resulting point cloud includes 242,007 points and is shown in Fig. 5.

Using Geomagic Wrap, first the point cloud is cleaned carefully. Since the point cloud consists of a very limited number of points these were kept in the point cloud rather than deleted. The point cloud only shows one half of the vessel, cut through the longitudinal axis.

4 Overlay correlation

For the overlay correlation, different test scenarios have been developed. Besides the bathymetry data, the CAD model and the point cloud resulting from the Structure-from-Motion process with the historical photographs are used. At first the CAD- and the Structure-from-Motion-model were overlaid with each other in order to compare the geometry and general fitting of both models. Fig. 6 shows the overlay of the Structure-from-Motion point cloud (green) and the CAD model (grey) and the distances measured between both. Distances are measured using different perspectives, like top and side view. Fig. 6 shows exemplary the measurement in the side view.

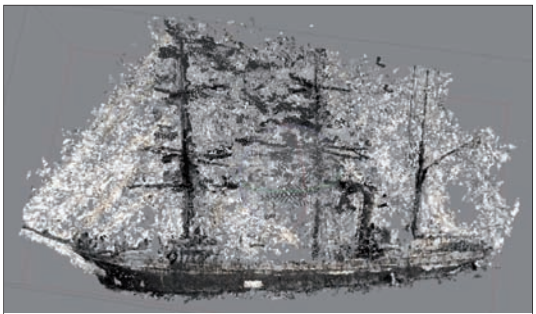

Fig. 5: Point cloud showing *S.S. Terra Nova*

Source: Täuber 2018

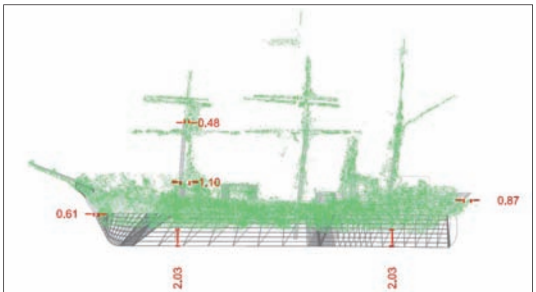

Fig. 6: Differences between CAD model and SfM model – side view

Source: Täuber 2018

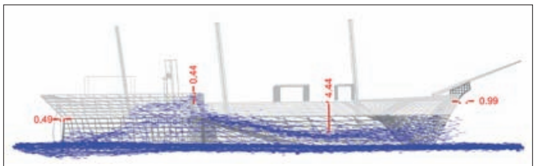

Fig. 7: Overlay of CAD model and gridded bathymetry data

Source: Täuber 2018

It is obvious that two of the three masts in the point cloud fit very well to the CAD model. For the mast at the bow, some deviations are apparent which have been determined by distance measurements at a lower point and the end of the mast. The distance between CAD model and the point cloud amounts to 1.1 m at the lower point of the bow mast and to 0.5 m at the point at the end of the same mast. For the other masts there is no need to measure distances due to the excellent fitting of both models. Furthermore, the draught of the vessel may be determined as the hull of the vessel is only part of the CAD model, but not part of the SfM point cloud. 2.0 m of the vessel are under the estimated water line. The length difference between both models amounts to 0.6 m at the bow and 0.9 m at the stern.

The overlay of the CAD- and the SfM models shows deviations within the metre range while the general shape of the vessel fits. The largest deviations can be seen in the top view and occur at the stern of the vessel which is expected due to very limited points in the Structure-from-Motion point cloud in this part of the vessel. Main structures of the vessel like the masts, funnel and bowsprit are prominent in both models and fit very well. The fact that these structures have different heights in both models is caused by missing height information in the construction plan for those features. In this case, the overlay of the models can lead to an addition of different information if the heights of the mast from the Structure-from-Motion point cloud are used to correct the masts heights in the CAD model.

In the next step the CAD model was overlaid with the gridded bathymetry data as shown in Fig. 7. Once again, distances were measured to evaluate the overlay. The distance between the stern of the vessel and the bathymetry point cloud amounts to 0.5 m. The highest point of the bathymetry point cloud and the corresponding part of the CAD model differ about 0.4 m. The distance of the lowest part of the point cloud and the upper deck of the CAD model amounts to 4.4 m. The difference between the bow of the CAD model and the bathymetry point cloud amounts to 1.0 m.

The elevation of the wreck in the area of the funnel is located at this part of the vessel where the former engine room is drawn in the construction plan. With regard to the construction of the engine which mostly consists of steel and other hardly degradable materials the position of the engine in the wreck seems to be reliable. The occurring deviations between the wreck and the CAD model are mainly caused by the condition of the wreck especially in the part of the bow of the vessel. A further unknown factor that leads to the differences between the model and the wreck is the sinking of the vessel into the seafloor while the model is fitted in a way that the keel line hits the seafloor.

5 Visualisation

Subsequently, the models as well as the wreck were visualised in different ways and categorised for different user groups. The main issue for the classification is the question if the visualisations will be used for scientific purposes or rather as presentation for laypersons. In the case of the *S.S. Terra Nova* it is conceivable that the user group with the more scientific background consists for example of archaeologists, especially underwater archaeologists. To the group of laypersons for example visitors of museums or other interested laypersons can be counted.

As first visualisation the SfM point cloud was meshed and then textured with images showing *S.S. Terra Nova* during the Antarctic expedition 1910. The whole process was carried out in Agisoft Photoscan. The result is shown in Fig. 8.

With regard to the initial dense point cloud which is the basis for the mesh, the texture represents the vessel in a very promising way. The textured model allows extracting more information of the model than the dense point cloud does. The texture consisting of several images works best at the hull of the vessel. Regarding the masts or interior superstructures, the texture is severely distorted and disproportioned. The visualisation of the point cloud resulting from the Structure-from-Motion process was categorised as suitable for scientific use.

The main issue why this visualisation is only restrictedly suitable for laypersons is because it shows *S.S. Terra Nova* incompletely. That includes the facts that it is only a half vessel as well as that the part of the vessel under the water line is not depicted within the point cloud. Furthermore, the texture is significantly distorted especially viewing the textured 3D models from a top view. Nevertheless, the textured models provide more details of the vessel than the not textured 3D model extracted from the SfM process.

To get an idea of the condition, shape and the position of the wreck at the seafloor, a visualisation of the wreck by means of the bathymetry data is useful. For the visualisation of the wreck, two interrelated visualisation scenarios were developed. The first scenario was the creation of a meshed model of the wreck (Fig. 9). Following, the resulting 3D model is used for a subsequent visualisation which shows the wreck in an underwater scene to answer the question what a diver would see if one dives to the wreck (Fig. 10).

Fig. 8: Textured model created with Agisoft PhotoScan

Source: Täuber 2018

The mesh of the soundings is classified into the scientist's category while the underwater scene is classified into the laypersons category. The mesh of the soundings shows the shape, size and condition of the wreck. Detailed structures are visible within this mesh.

6 Conclusion and outlook

This investigation deals with the reconstruction and visualisation of the former expedition ship *S.S. Terra Nova*. A data set consisting of historic photographs and a construction plan of the *S.S. Terra Nova* was used for the reconstruction. Bathymetry data show the wreck of the vessel.

Regarding the reconstruction, the methods CAD modelling and Structure-from-Motion are used. The reconstruction of the *S.S. Terra Nova* works with both methods. This investigation shows that it is possible to create a 3D model of an object that does not exist anymore. In this case conventional 3D modelling methods like laser scanning cannot be applied, since a direct relation to the object is mandatory. In contrast, especially Structure-from-

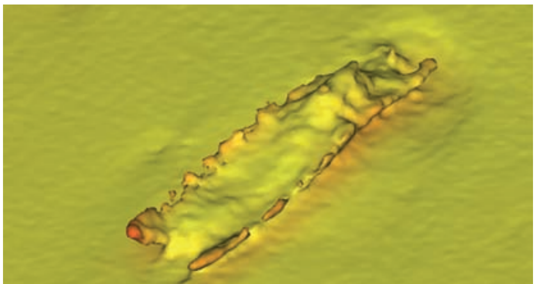

Fig. 9: Mesh of the bathymetry point cloud

Source: Täuber 2018

Fig. 10: Underwater scene

Source: Täuber 2018

Motion is a good alternative if a sufficient number of images showing the historical object is available. Furthermore, the images should have a sufficient resolution. This investigation shows that the meshing of a smaller number of images lead to a first result.

CAD modelling is a method that works very well if the input data, which is in this case a construction plan of the vessel, have a sufficient quality. That includes the details shown in the plan as well as the quality in terms of the readability.

Comparing the result of both the CAD and SfM method, there are obvious differences. As result of the modelling process the CAD model shows a complete vessel while the SfM point cloud only represents one half of the vessel. For the reconstruction of *S.S Terra Nova* both the Structure-from-Motion modelling as well as the CAD modelling are expedient. The transferability to other projects strongly depends on the data basis.

The combination of both reconstruction methods enables the creation of a more detailed model containing information of both the SfM point cloud and the CAD model. By overlaying the data provided by the CAD model with the SfM point cloud data, the additional information from the SfM model can be added to the CAD model. The result is a more detailed and accurate CAD model.

The visualisation of such a historical object is always done for a predefined user group and with a defined purpose. Depending on user group and purpose there are different visualisation methods. For laypersons details of the object are less important than a visually appealing appearance of the object. For the scientific usage details of the historical object are the main focus. With more detailed background information, a visualisation for scientific purposes can also be usable for interested laypersons as well.

There are further applications where the scenarios of reconstruction and visualisation of historical underwater objects shown in this project can be used. Reconstruction and visualisation of historic underwater objects is always required to understand the lost scenario of sunken vessels, submarines or other watercrafts.

One example is the vessel *S.Y. Aurora* that can be seen as sister vessel to the *S.S. Terra Nova*. *S.Y. Aurora* is regarded as lost, results of this project can be applied to this case. //