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Application of photogrammetry techniques for the visual assessment of vessels' cargo hold

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ABSTRACT: Visual inspection is an integral part of Condition and Class surveys, with the results comprising of the surveyors' opinion, documented by a sum of pictures indicating areas of interest. Although this way provides the most essential information, the communication of the results may be difficult, since isolated images cannot provide the context. Photogrammetry exploits pictorial data to provide 3D models, with a high level of accuracy and is not an uncommon method in the maritime environment. Use of such methods to support visual survey activities is examined in this work, providing the methodology for the data collection, which is structured in an algorithmic way, to enable realization by automated means (robots). The 3D model is provided, along with accuracy results.

1 INTRODUCTION

Vessel hulls are subjected to visual assessment for the detection of defects - usually signs of deterioration of the metallic structure, indicated by extensive rust, pitting, the presence of cracks or even welding seam failures. During visual hull surveys, the decision of identifying the failure and estimating the damage lies heavily on the surveyor's own experience. Ultrasound Thickness (UT) data is often collected to substantiate the observations and the collection of a sample of field images, may provide fragmented information from the real-life situation. Still this type of information is difficult to convey the 'sense/feeling' the surveyor uses to interpret his/her observations. The overall decision uses criteria of coating breakdown, extent of pitting as a percentage of the area, presence of patterns of defects on the structure and damage on sensitive areas – stiffeners' seams on the hull for example (IACS 2007). Although distinct data may provide localized information, it is not representative of the overall structural status, as it lacks the 'cumulative-effect', i.e. the data is not seen as a totality.

Recent efforts have focused on structuring a standardized format to facilitate the exchange of inspection data and allow for easier access to the raw information via 3D models (CAS 2012). Still, the information available to the user is generally in the form of 2D UT - tables and pictures or 3D models overlaid with an artificial color map. This type of electronic representation provides a better communication of the survey results, but lacks the real-sense the human surveyor obtains during the close-up survey.

Advances in Virtual Reality and its applications demonstrate the enhancement in the real-life feeling as the visual realism is increased. Insu Yu et al. 2012, have conducted experiments investigating the human sense (presence) in the virtual environment with more and less natural characteristics, showing higher 'presence' results in the enhanced virtual environment, while Lee et al. in (Lee et al. 2013) have examined the performance of humans in search tasks in an augmented reality and real-world scene showing minimum or indistinguishable results. In another work, Liu et al. in (Liu et al. 2009) identify the significance of texture in the visual realism and provide a method for the texture synthesis in the simulation of surgeries. Hence, the visual representation of data, positively affects the human-sense, while the use of additional information does not seem to have a negative role in the evaluation of visual information.

The enhancement of the visual realism on the representation of survey data can be increased by incorporating textured 3D models, thus encapsulating a large amount of visual information in a single 3D file. Photogrammetry has been used with increasing intensity to produce such representations for archaeological sites (De Reu et al. 2013), geological studies or civil engineering purposes (Nex & Remondino 2012) or even to perform navigation and control for docking in space applications (Blokhinov et al. 2012). The accuracy of photogrammetry can be a consideration when involved in survey activities, yet previous studies (Cuesta et al. 2012) have demonstrated that Coordinated Measuring Arms and photogrammetry have equivalent performance in the geometrical inspection of welded pins of medium-sized sheetmetal structures. In a similar comparison between photogrammetry and laser scanning methods (Skarlatos & Kyparissi 2012), have revealed that photogrammetry can have equivalent performance to laser scanning methods and can even be advantageous, given its low cost.

The potential to use photogrammetry in the marine industry has been investigated early on (Kenefick 1976) as a means of documenting shipboard conditions and expediting ship-check procedures for distributive systems such as piping, ventilation and structural components (Sparacino 1991). Although the advantages from the use of photogrammetry have been clear, the technological means available at the time, allowed only limited application of the technique (Mugnier 1997). Still, photogrammetry has been mainly used for the scheduling of activities by naval shipyards, primarily due to the cost needed to achieve the required accuracy (Ingram 1991) and is recognized as an efficient tool for the shipyard planning process with significant benefits in monetary terms (Komoroski 2005). The primary focus of the previous tasks has been the ship-checking prior to overhauling or maintenance activities. In a similar sense, but with a focus rather on the extraction of hull geometrical characteristics, as in (Koelman 2010), the shape - reverse engineering of ships is discussed for shape retrieval for damage repairs, post-building verification, etc. In (Menna et al. 2011) the methodology for 3D modeling of floating objects is extracted using a hybrid scheme of terrestrial and underwater image acquisition. The evaluation of structural defects has been approached in Chen et al. 2011, by producing a 3D model of distortions in plated structures via photogrammetry. In Rodriguez-Martin et al. 2015 a novel method of weld-inspection is given which uses the reconstruction of the welded-surface in a digital format via close-range photogrammetry in order to overcome the need for in-situ inspection.

Automated data acquisition for photogrammetry purposes has also been considered, by use of Unmanned Aerial or Underwater Vehicles (UAVs) in archaeology (Lo Brutto et al. 2012) and a civil application (Neitzel & Klonowski 2012). The facilitation of the data collection process for ship hull surveys has also been the subject of a previous research project (MINOAS 2012), where robotic means have been incorporated to support normal hull inspection activities.

The current work focuses on (a) the validation of the use of photogrammetry as a candidate for more efficient/comprehensive visual hull assessment and (b) the extraction of a specific methodology (collection and processing) that is tested on real life conditions. The process of hull assessment for visual survey purposes undertaken in this work, is different to the use of photogrammetry mentioned in the previous in: (a) the magnitude/volume of the model produced, (b) the goal of the process, which is to provide an accurate representation of the structure in order to visually identify defects, i.e. the model must contain both the information required for a close-up inspection and represent the overall status of the area (zoom out) – which involves the handling of a large amount of data, (c) the ability to produce acceptable results with low man-effort and low cost methodologies leading to automated procedures and (d) the use of non-intrusive methodologies (low number of Ground Control Points – GCPs – removed after the end of the photo-shooting campaign).

The validation and extraction processes relied on a trial and error method, hence enriching the initial specifications with a clear sequence of steps that is expected to be adoptable by robotic tools with high locomotion abilities. Increasing the level of automation in this process is an inherent characteristic of this work, in order to reach a more standardized procedure, with lower requirements in terms of means of access and at lower downtimes.

2 PHOTOGRAMMETRY AS A MEANS OF CONSTRUCTING A 3D MODEL

The generation of 3D models is multi-benefited when is held through photogrammetric procedures thanks to:

- Accuracy: combination of precision and reliability
- Cost-effectiveness: utilization of low cost cameras and open source software
- Fast-acquisition and portability in cases of accessibility limitations
- Flexibility: applicable techniques on objects of several scales, shapes and conditions

Photogrammetry follows disciplines of projective geometry and optics. Recent technological advances in digital cameras, computer processors, and computational techniques, make photogrammetry a portable and powerful documentation method, yielding dense and accurate 3D surface data with a limited number of photos, captured with standard digital photography equipment, in a relatively short period of time. Structure from Motion (SfM), as a related procedure to the general photogrammetry, finds the 3D structure of an object by analyzing the projected 2D motion field created by a sequential change of position of the camera sensor relative to the subject. SfM technique requires digital image sets that record this relative change in position between the camera viewpoint and the subject. This motion is identified by matching the pixels that reference locations on the object in one photograph with the pixels referencing the same location in other photographs. Photographic sequences, which are captured according to principles that maximize the information available from this change in viewpoint, yield optimum results.

The current project utilized the commercial software Photoscan by Agisoft (Agisoft 2011) for the production of the textured 3D model. Comparative studies between the most popular photogrammetry software suites have revealed that Photoscan provides high quality results with minimum user effort (Neitzel & Klonowski 2012), while the overall process can be automated, using the provided Python API (AgiSoft 2011), although a human in the loop is usually required.

3 3D RECONSTRUCTION OF A VESSEL HOLD – THE BULK CARRIER CASE STUDY

The selected case study focuses on a cargo hold of a 35,500 DWT bulk carrier, visited at the final stages of her built. This type of vessel was chosen firstly because the main characteristics of her structure are representative of merchant ships and secondly due to the fact that it provides suitable conditions for the operation of humans and robots. Investigation of robotic operation will be the subject of a next step of the current activity.

The application of photogrammetry in the large 3D environment of the bulk carrier hold has set special requirements for the image-collection campaign. Real-life difficulties considered during the design process were the presence of repetitive structures, obstructions in the view of the photo-shooting object from the presence of tools and temporary scaffolding and different lighting conditions. Additional problems stemming from the application of photogrammetry to the vessel hold are the presence of ‘hidden areas’ due to the structure of the side-frames and the difficulty to reach the object of the photo-shoot when accessibility means were not used.

3.1 *Data Acquisition*

For the project’s needs, a digital camera NIKON D3300 (24.2 MP, sensor size 23.5 x 15.6 mm) with an 18mm zoom lens fixed at 18mm, was used. This setup was chosen to allow accurate representation of distinct features for the photo shooting campaign’s special requirements: for an estimated worst case of distance-to-target approximately 10m, the level of detail captured in the image is 2mm (for the specific camera settings), according to Equation 1:

$$O = d / f \times px$$

where O is the object/detail size, d the distance-to-target, f the focal length and px the pixel size for the specific sensor.

Prior to the start of the photo-shooting campaign, a total of six rulers has been attached to predefined locations in order to provide scale and reference to the model. For the case of the specific case one ruler has been attached to each bulkhead (lower stool) and a pair of rulers to the hoppers at each side. The placement of the ruler is depicted in Figure 1.

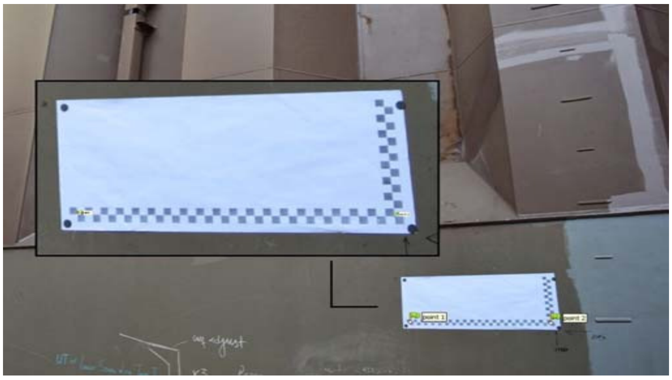

Figure 1. Close-up of the ruler attached to the bulkhead

The network of rulers has been used to set a local coordinate system in the area under survey, since usual georeferencing alternatives (GPS) are not available inside the vessel. The relative rulers’ locations have been measured and the local coordinate system has been set using global vessel information, i.e. the origin for the local system has been set at the intersection of the tank-top with the Center-Line at the position of the foremost bulkhead. Linking the local coordinate system with that referring to the vessel/global, allows immediate connection with the existing protocols like OpenHCM (CAS 2012). The position of the rulers is given in Figure 2.

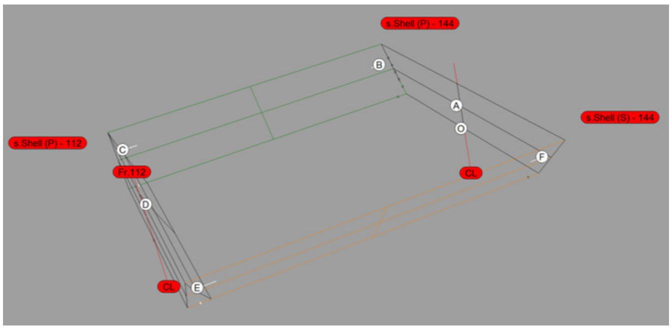

Figure 2. 3D representation of the rulers’ network; rulers’ positions are indicated by the white circles

Table 1. Location of Ground Control Points in the local coordinate system (values in mm)

Point	*x-Coord*	*y-Coord*	*z-Coord*
A	-349	0	1940
B	-13530	-870	2522
C	-13520	-25530	2510
D	-424	-25977	2700
E	13520	-25530	2510
F	13530	-870	2520
O	0	0	0

The data collection process is structured in an ‘algorithmic’ way, i.e. in a sequence of steps/ visitation routes that could be similarly realized in an automated way. The photo-shooting process obeys the basic guidelines of photogrammetry ((Kraus 1997), (AgiSoft 2011)), summarized as: *a)* the images are required to have overlapping (~80%), *b)* the shooting must be done from different locations and *c)* adequate coverage of the object is required to construct a suitable representation. The photo-shooting campaign is composed of three routes at the interior of the vessel hold. To eliminate hidden spots (especially in the vicinity of the side frames), two round trips are scheduled shooting the hold walls at an angle, as shown at the top of Figure 3. The distance to the walls and the intermediate distance travelled between two subsequent frames are determined by the requirement to retain the maximum possible overlap in the images. The final round trip is performed at a larger distance to the walls, shooting straightly at the target, mainly to provide information for the 'binding' of the previous images. Figure 3 provides a sketch for these guidelines.

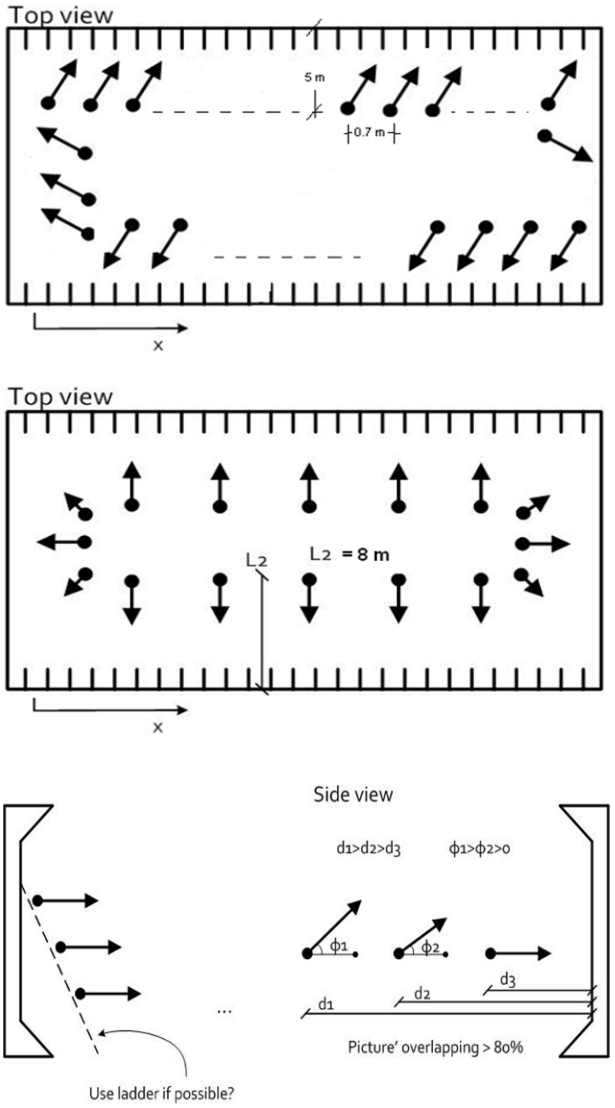

Figure 3. Photo-shooting guidelines for the vessel-hold use-case; location of camera is given with a black circle, side-shell frames marked with straight lines (top view)

Human operators have limited access to higher elevations of the hold. The collection of images from a ground-point – shooting at an angle as shown in the bottom image of Figure 3, provides valuable information for the objects that are higher, but images from different elevations are similarly required. For the purposes of the specific case-study a cherry-picker was used to collect a small dataset from higher positions. Figure 4 provides a small sample of the data collected.

Figure 4. Sample of the field images collected (top) from the location of the tank top and (bottom) deck

The photo-shooting campaign collected approximately 1000 high-resolution images making no interventions in the hold (the rulers used where temporarily attached during the shooting and removed upon completion).

3.2 *Data Processing*

The raw data collected during the image acquisition process, are used in the post-processing stage, analyzed into four sequential steps: (a) camera alignment, (b) point-cloud extraction, (c) construction of a polygon mesh and (d) texture extraction from by interpolation of raw-data.

The determination of the number of constraints has been one of the goals of this work (similar to the notions in Koelman 2010). The constraints used during the post-processing were *a)* the information provided by the attached rulers and *b)* minimal information provided by the hold structure itself (distinct features present have been used, for example hypsometric levels on the bulkhead). The camera alignment process identifies points in the images (invariant to changes of the viewpoint and lighting variations) in an approach similar to the SIFT algorithm. It then uses the bundle-adjustment algorithm, given the information of the constraints, to extract the camera locations and adjust the camera parameters. Along with the bundle-adjustment, a camera self-calibration was performed, resulting in the estimation of accurate camera parameters and the optimization of the block of images' final alignment. The minimal constraint to define the network datum was given by the aforementioned six rulers, as an explicit minimal control point configuration (Remondino & Fraser 2006). The set of parameters adjusted is summarized in Table 1.

Table 1. Camera parameters adjusted during the alignment phase

Camera parameters	Description
f_x	horizontal focal length, in pixels
f_y	vertical focal length, pixels
k_1, k_2, k_3, k_4 p_1, p_2	radial distortion coefficients, using Brown's distortion mode
c_x	X coordinate of the principal point
c_y	Y coordinate of the principal point

The camera locations in the vessel hold is shown in Figure 5 with blue rectangles - from a top-view. The dense cloud of camera locations is representative of the information used in the final project (approx. 800 images) and of the shooting routing followed/feasible, according to the previous guidelines. The extraction of the camera positions is information useful at the post-processing stage to allow for revisiting of the raw data when indicated by the user.

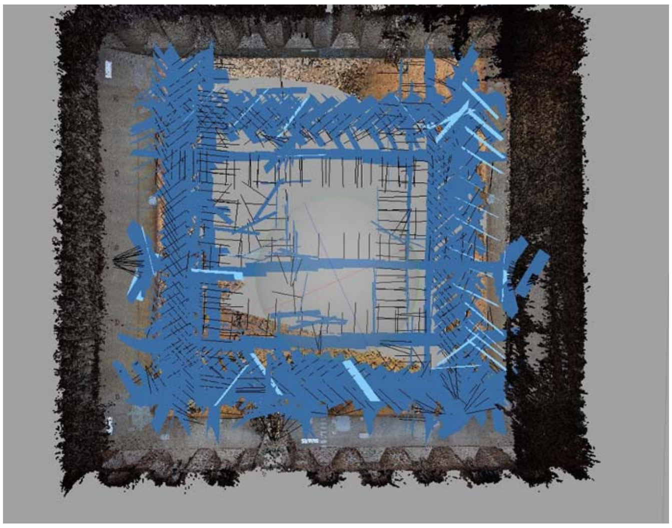

Figure 5. Camera positions after the alignment step (top-view of the hold)

Based on the estimated camera positions and pictures, a dense point cloud is built, edited and classified prior to the generation of the 3D mesh model. Figure 6 (top) shows a partial result of the dense point cloud generated. The extraction of the 3D surface is based on the quality of the point-cloud. Noise trimming is used prior to the application of interpolation methods, to provide a 'smooth mesh' which is the basis for the texture overlay. Figure 6 (bottom) shows the result of the surface built on the previous point cloud. Depending on the model scale and the level of detail description, defects and abnormalities on the original (real-life) structure may appear in the generated model either by the surface approximation (mesh shape) or by the texture information applied in the next step. The texture is formed by sampling the primary data (images) and interpolating on the surface, using blending or mosaicking approaches.

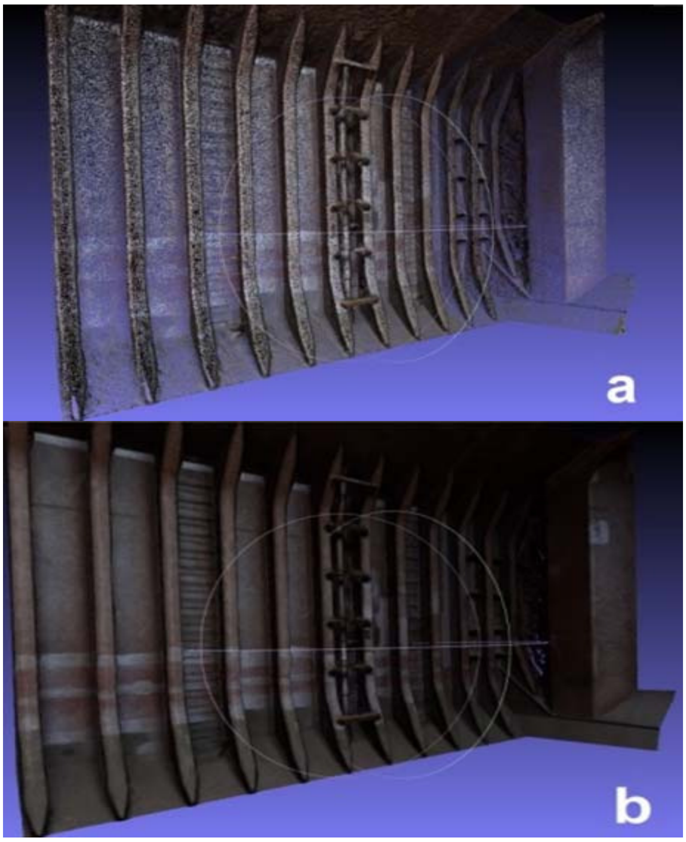

Figure 6. Partial point cloud of the 3D model (top) and textured model (bottom)

The 3D model constructed by these means includes a large amount of information from a large volume of the vessel structure (the dimensions for the hold of the current use-case are 30×25×15 m). The purpose of this attempt is to enable the fast visual inspection of the hold before going onboard, using representative data of the overall status. This should be feasible with tools for the 3D model like 3D rotations, translation/pan and zoom in-out. These tools have been provided, for the current project, by the open source software Meshlab (Meshlab 2014), visible in Figures 6-8. Although the requirement to encapsulate as much information as possible to a single file leads to easier navigation in terms of the user interface software, it was experimentally proven that it also leads to large size data files. Hence, in order to produce a 3D model that conforms to the current software and hardware limitations, the 3D model of the hold was cut in six interconnecting segments.

Figure 7 shows one half of the hold in the 3D model, in which, by a zooming operation, the user can reach the level of detail depicted in Figure 8.

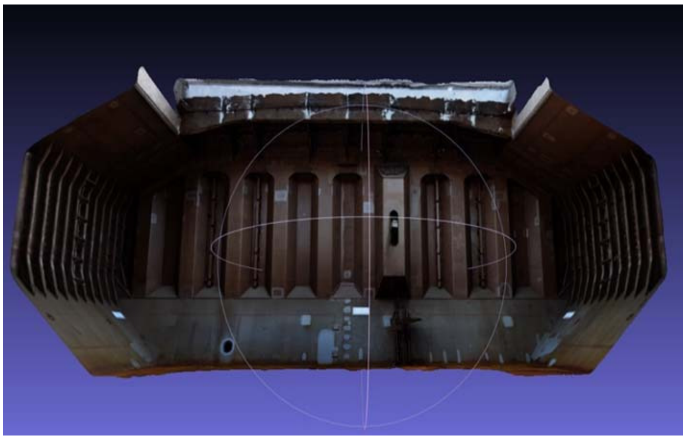

Figure 7. Part of the final 3D model

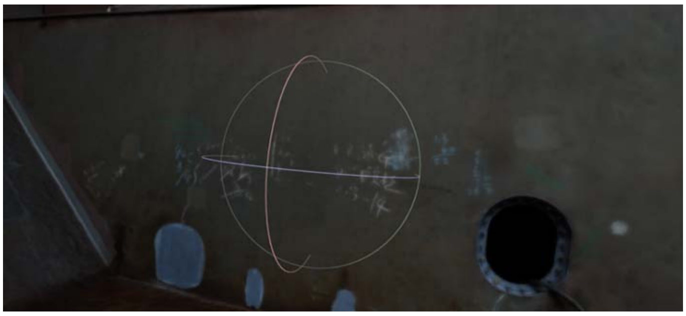

Figure 8. Detail - inscriptions on the bulkhead lower stool visible by zooming-in the 3D model

Visual inspection of vessels, attempts to identify defects in the coating, individual plates or their interconnection (seams). Typical minimum sizes of defects of this nature are in the range of 1-5 mm. The initial shooting campaign was set-up to reach a worst-case pixel size of 2 mm in the structure captured. Though this value of resolution may not enable the identification of minimum-size defects, it is considered to be adequate / sufficient for the first stage of the structure setup. A second round of photo-shooting is intended to complement the level of detail by providing close-up photos at locations of interest.

In the current case the final pixel size of the resulting 3D textured model was computed after a least square estimation of all images (combined images of various pixel sizes, due to various distances from the object) at 1.2 mm.

4 CONCLUSION

The current work has introduced an approach to visual inspection, based on photogrammetry, with the aim to reduce the time needed for in-situ survey and lead to more targeted surveys. The process for the data collection has been presented, which is structured in an algorithmic way – to be easily adopted by non-experts or robotic means. The results indicate that such an approach is feasible and can provide an adequate representation of the entire area.

This tool is intended to be used by exploiting either human collected data (similarly to the approach followed in the above) or by the introduction of robotic means, obeying the visitation routes described in Section *Data Collection*. The 3D model constructed through these means is intended to be used: *a)* to provide the information needed in order to schedule more targeted inspection schemes and *b)* serve as the underlying environment for the attachment (tagging) of real-life information, such UT thickness or defect detection results via image processing methods. This type of data representation could lead to a better and more immediate understanding of the topology of the information presented, leading to better substantiated survey results.

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