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APPLICATION OF REVERSE ENGINEERING TECHNOLOGY IN PART DESIGN FOR SHIPBUILDING INDUSTRY

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ABSTRACT

In the shipbuilding industry, it is difficult to create CAD models of existing or prototype parts, especially with many freeform surfaces. The paper presents the creation of the CAD 3D model of a shipbuilding component with the application of the reverse engineering technology. Based on the data obtained from the digitization process, the component is reconstructed in point cloud processing programs and the CAD model is created. Finally, the accuracy of the digital model is estimated.

Keywords: reverse engineering, laser scanning, freeform surface, measurement techniques

INTRODUCTION

Minimising the time needed for preparing a new project, with the resulting reduction of production costs, is of special importance in both implementing new innovative watercraft structures and retrofitting the existing ones. Reverse engineering (RE) is one of the methods used to support these activities, in particular for controlling the quality of elements used in shipbuilding, redesigning prototype structures, retrofitting existing constructions, etc. The main measurement methods used for shape data acquisition in the marine industry are: conventional manual measuring instruments, mechanical devices, scanning lasers, and photogrammeters [10].

Reverse engineering, in combination with laser scanning technologies and post-processing, is extremely useful in redesigning, testing, and updating the structure of watercraft components. Measuring and modelling of such a component with the aid of conventional measurement methods is very difficult, as it refers, as a rule, to a product with geometrically complex freeform shapes. In this case, the use of scanned data in the form of clouds of points allows the seagoing watercraft designer to create a precise CAD 3D model, which can then be used for assessing the quality of manufacturing, as well as for

CAE system-based redesigning, engineering and simulation tests, etc. This way, the laser scanning technology supports the ship control process and provides a method of data acquisition which may turn out profitable for the shipbuilding industry due to its time and cost saving nature. According to the ASE report on the National Shipbuilding Research Programme (NSRP), 3D laser scanning during ship data acquisition and postprocessing can decrease the cost by 37% and time by 39%, compared to traditional methods making use of traditional/manual measuring instruments [13].

The reverse engineering technology is also used for supporting engineering calculations [23, 25], and to obtain more accurate results in highly precise machining [26]. Its use also makes it possible to increase the accuracy of geodetic and astronomical measurements performed using radio telescopes [24] and to investigate and assess the architectonic heritage [22].

The following chapters of the article present: the literature review on the use of reverse engineering, especially in the shipbuilding industry, and the methodology of CAD 3D model creation with the use of the reverse engineering technology for a given ship component. Then, based on the data obtained from the digitisation process, the component is reconstructed in computer programmes for point cloud processing and the CAD model is created. The final stage of the analysis is the accuracy assessment of the digitised model.

LITERATURE REVIEW

The use of modern CAD/CAM systems and special measuring instruments for creating CAD 3D models of existing objects plays a key role in reverse engineering [19, 20], especially in the case of large-size elements [1] in the shipbuilding industry [14, 16] and aeronautics [7]. This is of special importance for a model of the part created in the absence of digital data related with the reconstructed object or when the part is to be retrofitted. The problem which consisted in applying reverse engineering techniques to retrofit the existing watercraft, or in the absence of basic technical data, such as construction plans, the data on the hull and machines installed on the deck, and/or working drawings of components, was studied by Tasseti at al. [17].

As far as object reconstruction is concerned, its requirements depend on the planned application, i.e. whether it is part replication, reconstruction, measurement, and/or modification related with change of the structure of the analysed model. Part modification can be easily performed following the approach presented in [19], which assumes reconstructing the design concept from the already existing objects. The obtained 3D models are based on geometric features (feature-based) and comprise the geometry description which provides opportunities for easy introduction of constructional changes to new innovative applications. A similar approach proposed in [4, 5] is additionally combined with virtual machining, which makes it possible to recognise technological features (feature recognition). In [11], the authors propose the reverse engineering-based approach to support regeneration of worn out parts. The CAD/CAM system generates tool paths for a device which will execute the virtual repair process, for instance for a robot welding a joint to fill the damaged area of the regenerated part with a given volume of welding material. Then, this part is machined on a five-axis CNC milling machine to a required dimension.

The use of modern measurement techniques in combination with additive techniques makes it possible to produce a wide variety of parts needed, for instance, to repair damaged devices on ships or offshore steel structures [6, 18], or in the automotive industry [15]. A structurally advanced group of products with complex geometry and higher-quality surface requirements are high-pressure stage blades in gas turbines used in ship propulsion systems or in Tesla turbines. The geometry of these blades is very complex, with additional elements such as holes and passages intended to deliver the cooling medium under the blade surface. The blades are tested both experimentally on real prototype objects, and with the aid of numerical methods [8].

Manufacturing of hull elements is one of key processes in shipbuilding. However, this process is still performed at low degree of automation. From 30% to 70% of typical ship hulls comprise parts with freeform surfaces shaped by experienced workers. The hull part measurement system is a component of the production automation system which allows the production assistance programme to generate proper data for part shaping [9]. In [14], large hull parts were scanned, after which the measured data were compared with the required geometry to check whether the required shape was achieved and to select heating line parameters for possible shape correction in further operations. The experiments were performed on real ship hull parts, and the obtained results demonstrated a possibility for automating the production process on the shipyard's heating line.

The complex object modelling methodology which utilizes photogrammetric and laser methods to generate a high-density cloud of points was presented by Menna and Troisi [12]. The structures analysed by them were small screw propellers, and the obtained results demonstrated the applicability of a hybrid approach which integrates the two considered technologies. The use of digital photogrammetric techniques for modelling 3D objects is essential in designing marine screw propellers and complex hull geometries [3].

In [16], using a 12-metre long yacht as an example, a methodology was presented for determining the symmetry plane of an object based on the cloud of points obtained from laser scanning or other measurement techniques. Precise finding of the vertical symmetry plane of the examined yacht provided opportunities for correct assessment of its future behaviour during the navigation. A possibility to increase the accuracy of measurements of prototype ship models built in decreased scale was presented in [2], where fast and compact terrestrial laser scanners (TLS) were used for this purpose. In that case the measurement accuracy was of special importance, as all measurement errors would be multiplied on the full-scale object.

OBJECT OF EXAMINATION AND MEASUREMENT METHODS

The object of examination was the housing of the main propulsion propeller shaft for a newly designed vessel. The initial product was a prototype element made using a conventional lamination technology with additional machining of selected structural elements. It had overall dimensions φ290 × 425 mm and numerous freeform surfaces which ensured correct functioning of the entire unit during yacht navigation in marine conditions (Fig. 1).

Fig. 1. View of prototype product

The measurements were performed using a 7-axis articulated measuring arm SMART Arm 7 2.5 produced by Nikon Smart Solutions, with the measuring range of 2,5 m, volumetric accuracy of ± 0,043 mm, and point repeatability of 0,030 mm (uncertainty within the entire operating range of the arm, values given for 2 sigma). The arm was made of light and durable materials: carbon fibre, aluminium, and titanium.

The measuring arm was equipped with a MMDx Nikon Metrology laser scanner, with laser beam width of 100 mm. The maximum number of really scanned points per second was 80 000. The Model Maker laser head was equipped with the Enhanced Scanning Performance (ESP3) technology, which adapted the laser power to the type of surface of the scanned object, for instance its structure and quality of finishing, among other features. Basic parameters of the laser head are given in Table 1.

Tab. 1. Parameters of MMDx 100 laser head

Accuracy (1σ)	10 μm
Stripe width (Y)	100 mm
Measuring range (Z)	100 mm
Stand-off	100 mm
Min. point resolution	65 μm
Max. data rate	150 Hz
Laser power	Class 2, 660 nm

The data generated by the 3D laser scanner were analysed using the Geomagic software, mainly Design X and Wrap [21]. After analysing and processing, the obtained clouds of points and triangle meshes made a basis for generating a parametric CAD model of the real prototype object. Then, using the processed scan of the element as a basis, a CAD 3D model was created in the Autodesk Inventor software. The final verification of this model was performed using the Geomagic Control X software.

RESULTS OF TESTS

The process of object surface digitisation was performed with the laser beam of 100 mm in width, as shown in Fig. 2a. The raw data obtained in the above way have the form of a cloud of points shown in Fig. 2b. Then, the point-defined object was converted to a so-called polygon model by imposing a surface of triangles onto the cloud of points (Fig. 3a).

Noteworthy are the defects which appear during model surface mapping (Fig. 3b). They result from two main causes: collection of insufficient number of data points in some object surface areas, and surface and/or geometry imperfections of the real prototype object resulting from insufficient precision of its manufacturing.

a)

b)

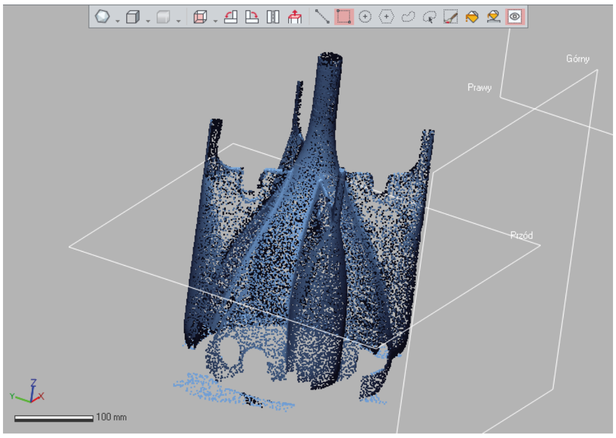


Fig. 2. Product surface digitisation with the aid of measuring arm SMART Arm 7 equipped with laser head MMDx 100 (a) and cloud of points obtained from the measurement (b)

a) b)

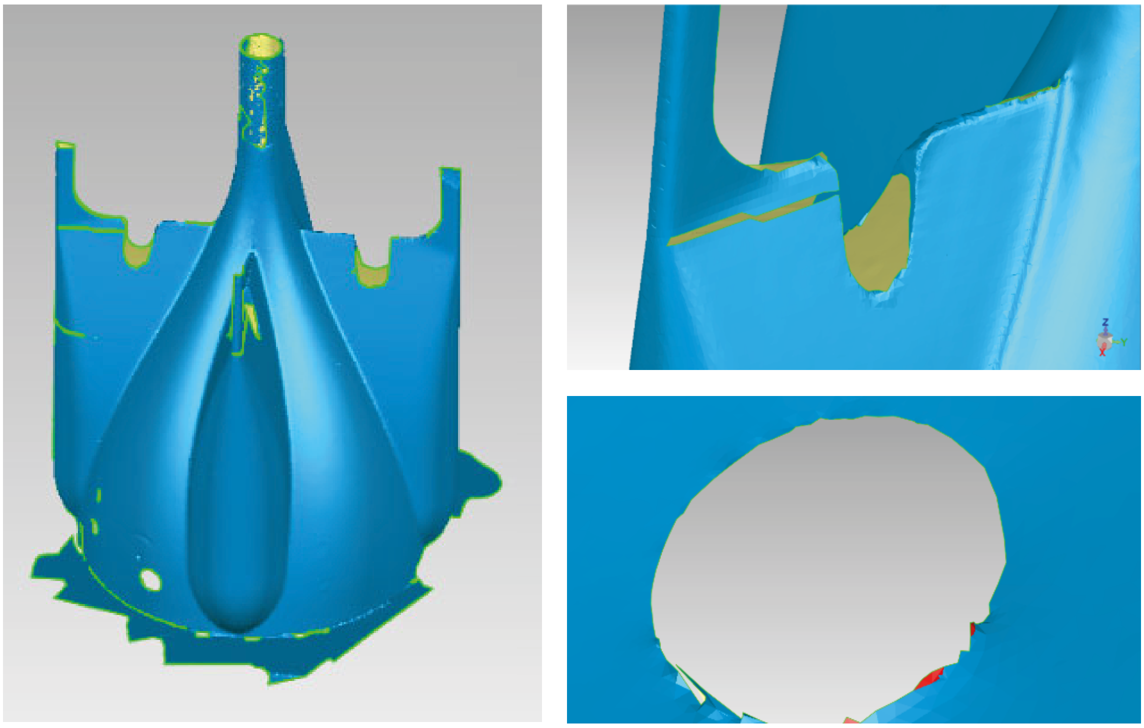


Fig. 3. Polygon model of the object (a), examples of surface defects (b)

In was therefore necessary to reconstruct the model mesh by filling small holes, smoothing and cleaning the mesh, removing model discontinuities and double walls, etc. This task was performed using mathematical algorithms directly implemented in Geomagic software. Moreover, some free-standing triangles which represented noise in the mesh (red areas) were removed (Fig. 3b).

Larger defects which came into existence as a result of the digitisation process and had the form of holes and surface discontinuities were removed using various programming functions, (Fig. 4). For instance, the function "bridge" was applied to increase the accuracy of adaptation of the filling to the surrounding mesh by dividing each discontinuous element into smaller parts. All this made it possible to reconstruct more precisely the areas in which the data from scanning were incomplete or missing.

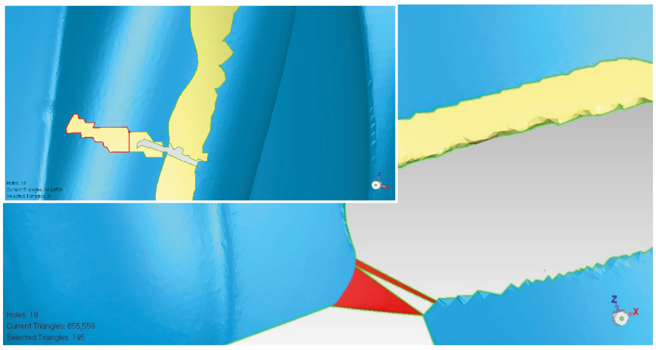


Fig. 4. Object imperfections identified after digitisation as surface discontinuities in the CAD model

The final refinement of the model was performed using the pre-installed functions "Relaxpolygons" which made it possible to smooth the model locally and improve the mesh. This was done by setting three main parameters: smoothing level, force, and required curvature, in selected areas of the model. The final view of the digitised model of the examined part is shown in Fig. 5a, and the corresponding *.stl view prepared in Inventor software in Fig. 5b.

a) b)

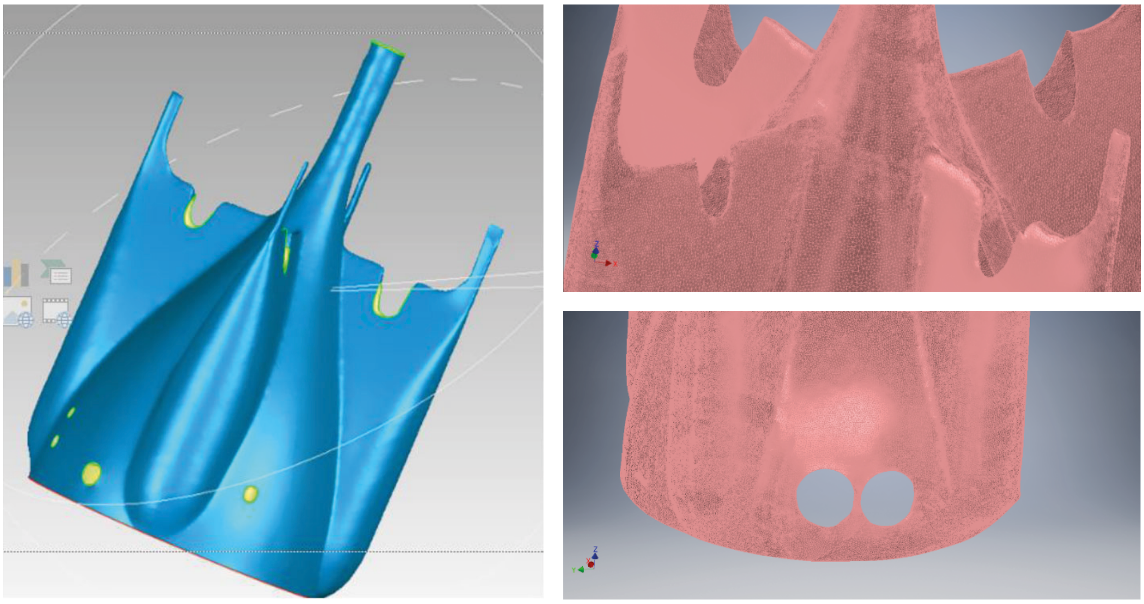


Fig. 5. View of object model after correcting measures (a), and *.stl model prepared in Autodesk Inventor software (b)

The obtained triangle mesh was used in the redesign process, which was performed under the assumptions of preserving the initial prototype geometry, especially the freeform surfaces, and meeting the symmetry condition by the product to be designed. Hybrid modelling functions were used for this purpose, such as the functions of rotation about axis, extrusion, and linking of solids, for instance. The accuracy of the created model was assumed at the level of about +/- 1,5 mm. Fig. 6a shows the final CAD 3D model (yellow) along with the applied *.stl mesh, while Fig. 6b presents selected views of the model.

The accuracy of the created CAD 3D model of the examined part was assessed using Geomagic Control X, an advanced software package used for controlling the quality of products based on point clouds recorded by scanning devices. In the examined case, the scanned 3D object was compared with the created CAD 3D model and the resulting deviations were analysed.

The CAD 3D model control was done after importing the following files:

- Reference data – the symmetrical CAD 3D model of the product, created in Autodesk Inventor software based on the modified *.stl file prepared in Geomagic software.
- Control data – the *.stl file being the input data for editing the point cloud in Geomagic software.

a) b)

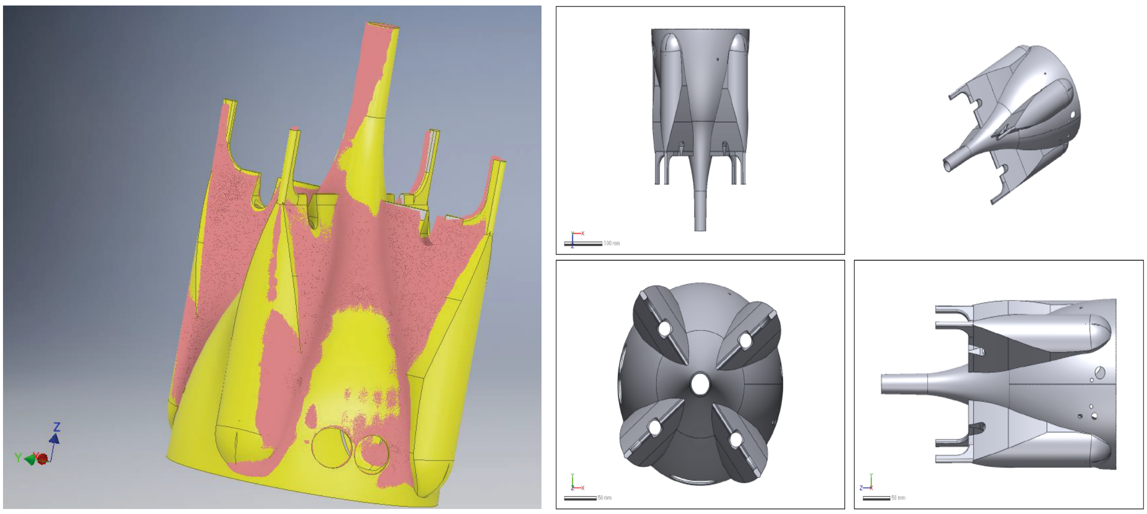


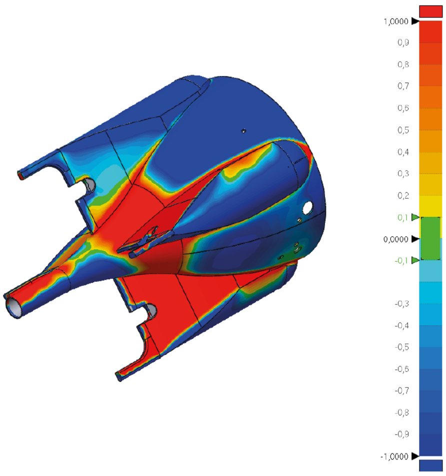
Fig. 6. CAD 3D model of the object after redesigning and *.stl mesh (a), selected views (b)

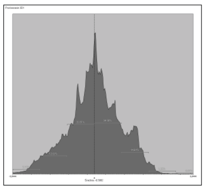
Based on the measurement report, the maximum deviation of the measured data from the CAD model was 7,66 mm (Fig. 7a). The average deviation over the entire model was

0,59 mm, with standard deviation SD= 1,75 mm. Large maximum deviation values are not acceptable taking into consideration the function of the product. The observed errors mainly result from the applied production technology which did not ensure preservation of the basic structural condition, i.e. geometrical symmetry of the product. This deficiency is clearly visible in the view of the propeller shaft guide sleeve (Fig. 7b).

- Due to faults and discontinuities of the object, the process of point cloud processing after digitisation is crucial for the entire task and requires special software.
- The accuracy of a CAD 3D model obtained in the redesign process can be assessed by comparing with data from measurements. In the analysed case, the average deviation over the entire model was 0,59 mm, with standard deviation SD= 1,75 mm.

a)





Min.	-7,6742
Max.	7,6627
Śred.	-0,5882
RMS	1,8482
Odch. Stand.	1,7521
Zm.	3,0698
+Średnia	1,2248
-Śred.	-1,5643
W Tol.(%)	4,4705
Poza Tol.(%)	95,5295
Powyżej Tol.(%)	32,9302
Zgodnie Z Tol.(%)	62,5993

b)

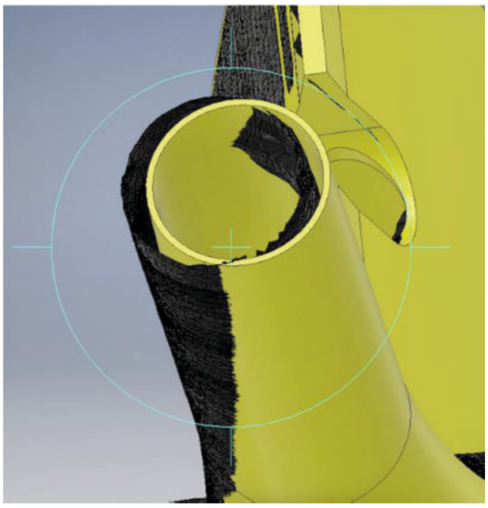


Fig. 7. Measuring report (a) and view of guide sleeve (b)

CONCLUSIONS

In traditional approach to the design process, creating a product is always preceded by the description of its structure, which makes it possible to assess its geometrical features, dimensional relations and their tolerances. Engineering drawings are usually used for this purpose. However, at present, the construction description has more and more frequently the form of a virtual CAD 3D model, obtained as a result of digital mapping of real objects (reverse engineering). This is of special importance in designing for the shipbuilding industry, where the geometry of a new target product is based on its initial prototypes and corresponding free surfaces. In this situation, the processes of digitisation and processing of clouds of points obtained from scanning, with further creation of CAD 3D models, become essential. The article analysed all steps of the CAD 3D model creation procedure, and the results of this analysis allowed formulating the following conclusions:

- Digitisation performed with the aid of an articulated measuring arm equipped with laser head provides an opportunity for wide-range measurements with volumetric accuracy of ± 0,043 mm and point repeatability of 0,030 mm.
- The maximal deviation reached nearly 7,66 mm, which was associated with the lack of symmetry of the prototype product caused by the applied production technology. Therefore, it is advisable to apply an alternative production process to ensure that the product will meet constructional requirements.

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