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Automation of the finishing process of steel yacht hulls based on optical scanning

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Abstract

Purpose:

The manufacturing of large yacht hulls is a complex process in the shipbuilding industry. The traditional approach is based on the pre-fabrication of large steel panels that are welded together to form 3D superstructure assemblies. One of the most relevant aspects of a yacht is its visual impact. For this reason, a finishing phase is usually carried out in order to obtain a final target surface with smooth curvature. Current methodologies mainly rely on manual processes thus requiring a great amount of time and well-experienced workers.

Method:

This paper introduces an innovative methodology representing the basis for the automation of the finishing phase of large yacht hulls. The proposed approach is based on the measurement of the as-built hull surface through the integration of an active stereo vision system and a complex mechanical tracking system. A procedure to define the target surface has been developed by integrating information deriving from both the design and the as-built shapes.

Result:

The developed methodology has been tested on a broadside region of the hull of a 59 metres yacht assembled within a shipyard. A target surface, differing as little as possible from the design surface, has been modelled in order to obtain a uniform curvature shape. A finishing phase has then been carried out by applying a layer of filler and by milling the hull's surface.

Discussion & Conclusion:

Results obtained have demonstrated the feasibility of the proposed approach, speeding up the whole process and guaranteeing fair reflection line patterns on the manufactured surface.

1 Introduction

Commercial shipbuilding and ship repair is a strategic high-tech industry sector for Europe. It develops advanced technologies, provides essential means of transport for international trade and supplies modern navies with modern vessels. In the field of shipbuilding industry, the construction of large pleasure crafts (from 18 to 60 metres) has become, in recent years, a considerable resource. In Europe there exists a dense network of shipyards and other advanced technologies providers which have seen their productivity increasing more than fourfold over the last two decades. Highly-specialised European shipbuilding industry seems to be competitive and well equipped to face the future with confidence. However, recent large increases in global shipbuilding capacity, mainly in Asia, are likely to make the trading environment for European yards even more challenging in the near future [1]. Shipbuilders operate in, and depend on, high-tech market niches, and one of the key elements to strengthen world-wide competitiveness certainly relies on increasing research, development and innovation (RDI) investments. New yachts are sophisticated products and the most percentage of the RDI activity concentrates on designing and building prototypes tailor-made to the client's specific requirements. In this context, a significant part of the innovation activities is related to innovative design vessel concepts and optimization of the production process itself. The adoption of specific innovative solutions during the concept design phase or the manufacturing process can establish crucial advantages when competing with shipbuilders offering "*off the shelf*" solutions. The production of large steel yachts should be performed in the shortest time with the lowest costs. This process implies a significant industrial and technological effort for the shipyard. Although shipbuilding remains a comparatively labour intensive and highly skilled enterprise, the automation of some processes, in particular at early stages of production, could greatly reduce the number of man-hours required. Moreover, the removal of less efficient production capacity could be used to free resources for new investments.

The traditional approach to the shipbuilding process can be seen as divided into two parts: the prefabrication and assembly of the steel yacht external structure and the installation of the equipments and fittings into the craft. These two phases can be undertaken sequentially or, as far as possible, in parallel to improve efficiency.

In particular, the manufacturing of external hulls used for large steel yacht production is a complex process and can be summarized in four main steps: 1) welding of steel panels, 2) filler application, 3) milling and 4) final painting. One of the most relevant aspects for a pleasure craft is its visual impact. A large part of this impact can be attributed to the appearance of the external hull surface finishing. Nevertheless, at the end of the welding stage, the shape of the hull is far away from the designed solution, resulting with a poor surface quality characterized by raised welding joints, surface waviness and scratching defects. For this reason, a finishing phase is usually carried out by applying a layer of filler, and by milling the hull's surface in order to obtain a target surface with smooth curvature. Current methodologies mainly rely on manual processes thus requiring a great amount of time and well-experienced workers. The need of higher productivity and international competitiveness demands for innovative design and optimised manufacturing technologies, as computer aided design/computer aided manufacturing (CAD/CAM) and computer numerical controlled (CNC) machining systems [2].

This paper introduces an innovative methodology which represents the basis for the automation of both filler application and milling process for large yacht hulls. A procedure to define the target surface has been created by using the original CAD model surface and the existing as-built hull shape. The acquisition process of the hull shape has been developed by integrating a complex robotic system, a *full-field* 3D stereo vision system and an industrial laser station. The robotic system is composed of an anthropomorphic arm and two linear guides, vertical and horizontal, which allow the placement of the arm in different stations along the hull length. An optical scanner, based on structured lighting, is mounted on the arm as end-effector and is used to acquire single range maps. The acquired data are transmitted through a wireless connection and stored on an off-line computer. For each placement of the arm over the guides, the individual scans are aligned on the basis of an optical calibration procedure that accurately identifies the pose of the scanner with respect to the arm end-effector. The laser station is then used to align data measured in correspondence of different placements of the arm over the guides. The acquired data are used to obtain a target surface which is provided as input to a CAM system. Finally the CAM system guides the filling and milling tools mounted as end-effectors on the same robotic arm.

2 State of the art

The hull is the core body of water going vessels and is designed to be seaworthy, comfortable and efficient. The design of the hull shape is a complex process involving important decisions about shape, structure, materials and processes in order to optimise performances and reliability, minimising, at the same time, costs and weight. The hulls of the vast majority of large pleasure crafts are constructed from steel. The basic unit of hull's structure is a steel panel, obtained from a plate, to which steel bars are welded to give adequate stiffness. Panels can be flat or curved, in two or three dimensions, to provide shape curvature. These panels, cut to a predetermined shape prior the hull's manufacturing process, are then welded together to form three-dimensional steel assemblies [3]. The outfit equipment and fittings are then incorporated into the fabricated hulls as much as possible at this stage.

When producing mega-yachts, high quality for their surface finish is required. One of the most relevant elements for assessing the hull and its superstructure final coating relies on its visual appearance. Nevertheless, at the end of the welding stage, the assembled hull is far away from the expected surface finish. Moreover, the high shipbuilding tolerances as well as the welded joints cause substantial surface deviations from the designed shape. A finishing phase is then carried out by applying a layer of filler and by milling the hull's surface in order to obtain a uniform target surface with smooth curvature. A seawater-resistant lacquer coating is finally applied on the obtained surface.

Although some processes, especially at early stages of production, have been automated, shipbuilding still remains a relative highly skilled enterprise. In particular, one of the key bottlenecks in the whole process, greatly affecting the production cycle time, concerns with the filling and coating phases. These labour intensive processes, usually subcontracted to specialist companies, are largely manual and rely on the expertise of individual workers, resulting in surfaces that are generally different from the expected ones. When as-built data are not available, the geometry of the hull is usually measured by means of simple testing instrumentation (rulers). The filling phase is performed by empirical and manual fairing techniques through various laths and templates used as references (fig. 1). The hull surface is divided into different regions and the filling phase is performed one-by-one. Transition boundaries between adjacent regions represent critical areas and must be usually re-worked to assure curvature continuity. For this reason, the finishing phase covers a great percentage (at least 30%) of the whole mega-yachts production process (2÷3 years) and is subjected to a great material waste. Humidity and temperature variations can cause non homogeneous conditions in the filling coating. Moreover, geometrical asymmetries can lead to uneven distribution of mechanical stresses. Quality control approaches are rarely implemented by shipyards so that the real discrepancy between the designed CAD surface and the final hull shape is not fully evaluated. This situation, together with the demand of a greater productivity and competitiveness, is driving shipbuilders to improve the hull's production process with the introduction of new design and manufacturing technologies. The challenge is twofold: the reduction of both cost and time of the production cycle and the assessment of the quality of the final hull's shape and surface finishing.

Fig. 1 Filler application by handmade process.

In recent years, technical literature has documented the combined use of automatic non-contact reverse engineering methodologies and CAD/CAM systems in the shipbuilding and ship repair fields. Photogrammetric techniques can be used to measure the hull surface with the aim of defining dimensional and accuracy control systems. In [4] a close-range photogrammetric technique, using coded targets and scale bars, has been used in the measurement of decks in recreational crafts. The combination of CAD information with automated digital close-range photogrammetry has been used also in [5] to automatically analyse, through 3D edge detection techniques, the plate burning quality and its impact in the downstream stages of shipbuilding. These photogrammetric approaches use coded targets on the surface to be measured thus reducing the automation efficiency. The AMORES project [6] has been focused on developing ship repair and conversion processes through photogrammetric techniques and CAD/CAM technologies. Digital photogrammetry, based on the detection of textured points in digital images, has been used to automatically measure ship hulls and generate as-built models of the ship surfaces. This approach demonstrated to significantly reduce the measuring time. However, even if not depending on any marker point attached to the surface, results of full-scale tests have showed a certain dependence on the lighting conditions.

To improve the robustness of the measurement phase, active devices can be used. In [7], the use of coherent laser radar for the measurement of a composite ship hull is described. Dimensional measurements have then been obtained and compared to the CAD design model for conformance validation. In [8], a terrestrial laser scanner, based on the phase shifts measurement of constant waves with varying length projected by an infrared source and reflected back by the object, has been used. 3D models of the hull and the deck of a ship have been obtained in order to determine possible asymmetries and calculating the volume of the underbody. In [9] a 3D laser scanner has rather been used to measure the external surface of mega-yachts with the aim at defining the amount of filler to be applied before the coating phase. 3D laser scanner systems provide good results when the element to be modelled has a complex shape and a considerable size. However, when sub-millimetre accuracy is required, their use is not as effective and their cost substantially increases.

In this paper, a methodology for the automation of both filler application and milling process for large yacht hulls is presented. The proposed approach is based on the measurement of the as-built hull shape through the use of an active stereo vision system based on a structured light technique. Structured light systems are suitable for the reconstruction of objects having complex but small shape when *full-field*, non contact and accurate measurements are required. In order to extend the use of a similar approach to the measurement of large objects as mega-yacht hulls, a complex robotic system has been assembled.

3 Proposed approach

The aim of the filler application and milling process, within the hull shipbuilding process, is the creation of a final surface (target surface) having good aesthetics properties. The quality of visual appearance is ultimately dictated by the uniformity and smoothness of the surface that is observed.

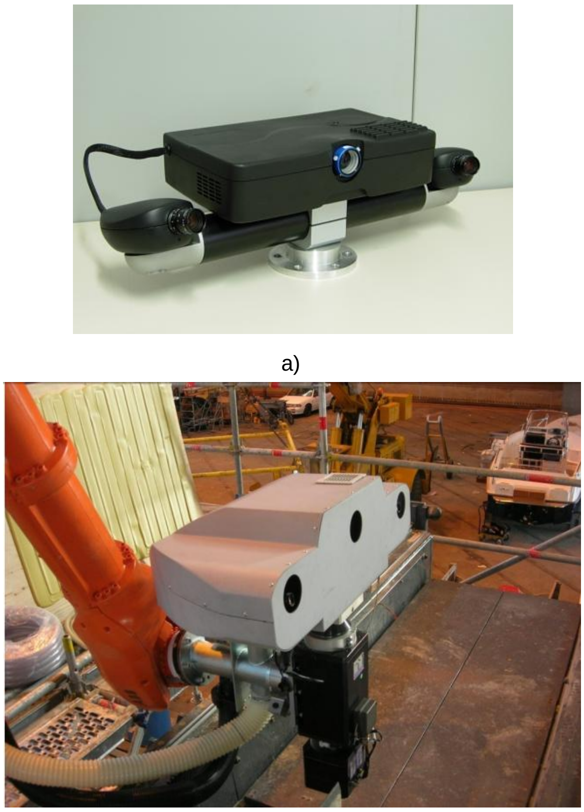
In this paper, two different methodologies, differing for both the amount of information used and user interaction required, have been developed to model the target surface. The starting point of the whole procedure relies on the accurate measurement of the as-built hull shape after the panels welding stage. The acquisition process has been developed by integrating a robotic system, a full-field 3D optical scanner and an industrial laser station. The purpose of the measurement process is the creation of a polygonal mesh representing the as-built hull surface. Commercial CAD software has been used to approximate the measured as-built shape with a NURBS surface having the required visual impact. A further methodology has then been developed in order to create a fully automatic surface modelling procedure by using the shape information contained in the design CAD model. The capabilities of the two methodologies have been exploited in the modelling of a region of the broadside of a yacht hull assembled within a shipyard. The presented approach represents the basis for the automation of both filler application and milling process.

3.1 Hardware architecture

The robotic system is composed of an anthropomorphic arm, and two linear guides, horizontal (12 metres long) and vertical (3 metres long), which allow the free placement of the arm in front of the hull surface. The whole system can be moved by an air bearing guide system that slides over the floor of the shipyard (fig. 2). The anthropomorphic arm is a commercial six-axis robotic arm *ABB IRB 6640 Foundry Plus* having position repeatability of 0.07 mm and path repeatability, at 1 m/s, of 0.7 mm. The arm effector can hold, in turn, the optical scanner, the nozzle and the milling tool as end-effectors. A dedicated software can read and memorize the coordinates of the end-effector (in the robot reference system) related to each operating position.

Fig. 2 Hardware architecture.

The optical scanner is based on a structured light approach, which uses binary patterns in order to capture three-dimensional shapes with high resolution [10]. The system configuration is composed of a standard DLP video projector (1024 × 768 pixels) to generate both vertical and horizontal black and white striped light patterns and two monochrome digital CCD cameras (1600 × 1200 pixels) to acquire images of the surface under structured lighting (fig. 3-a). The stereo vision system, composed of the pair of CCD sensors, is calibrated by evaluating the intrinsic and extrinsic parameters of the digital cameras [11], while the projector is un-calibrated and not directly involved in the measurement process. The scanner is capable of measuring about 800,000 points and has been configured for a working distance of 2000 mm, an acquisition field of 1200 mm × 900 mm (spatial resolution of 1.2 mm) and an overall accuracy of 0.07 mm. The optical devices are placed within a cover that guarantees a protection rating *IP54* against the intrusion of dust and splashing water (fig. 3-b). The cover, made in fibreglass, also contains an embedded PC, handling the scanning process, and an antenna for the data wireless transmission.


a)

b)

Fig. 3 a) Optical scanner configuration and b) its placement as arm end effector.

3.2 The 3D measurement process

The optical scanner is mounted on the arm as end-effector and is used to acquire single point clouds which are stored by wireless transmission. To create a complete 3D model of the hull, multiple partially overlapping point clouds, acquired at different sensor locations, have to be re-aligned with respect to a common reference system. Moreover, in order to use the acquired information in a reliable way for the filling and milling processes, the point clouds must be expressed in the Robot Reference System (RRS). Since the optical scanner provides data in the Camera Reference System (CRS), a calibration procedure is needed to refer the CRS to the RRS. In order to refer the point clouds into the RRS, the transformation describing the geometric relationship between the robot End-effector Reference System (ERS) and the CRS must be evaluated. In the present work, this information has been obtained through a photogrammetric calibration methodology using a reference target composed of a black and white squares pattern attached onto a planar glass surface. A certain number of points on the reference target are captured by the optical scanner from different viewing directions, without moving the target itself (through known displacements of the robot end-effector). Since the optical scanner is rigidly connected to the anthropomorphic arm, the CRS doesn’t change its position and orientation with respect to the ERS. The measured points can then be expressed in the ERS through roto-translation parameters describing the unknown geometry of the problem. An iterative process, by a least square method, can then be used to estimate the unknowns [12]. This approach allows the automatic point clouds alignment in the RRS without any use of external constraints, such as fiducial markers or similar.

However, the robotic system must be moved by an air bearing guide-way system to cover the whole hull’s length. The hull surface is thus divided into different blocks, corresponding to different placements of the robotic system, in order to be completely scanned (fig. 4). Single scan blocks, obtained with respect to the RRS, have then to be aligned with respect to a fixed World Reference System (WRS). In this paper, an industrial laser total station *Leica TDA 5005*, having a measurement range of 500 metres, has been used to track the RRS around the hull. Three targets *Corner Cube Reflectors* (CCR) composed of three perpendicular mirrors mounted on a spherical support (1.5” diameter), have been rigidly connected to the robotic system basis and tracked by the laser station with an angular accuracy of 0.5” and a distance accuracy of ± 0.2mm (for distances < 120 m). It is thus possible to align the various blocks containing the single point clouds. All the single scans are then merged together to form a unique point cloud representing the as-built hull surface. The overall complexity of such data set is reduced by removing outliers and performing proper sampling algorithms which eliminate redundant information, leaving more samples in regions of higher curvature [13]. The point representation lacks topological information. This has been recovered through a standard triangulation process that creates a triangular mesh representation. The mesh can be edited, if required, to handle possible imperfections such as holes occurring when missing data are present.

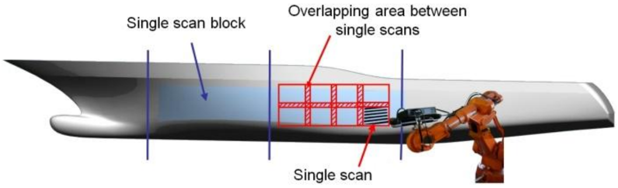


Fig. 4 Acquisition scheme of the ship hull.

3.3 Design of the target surface

The as-built measured surface (reference surface) represents the basis for the design of the final target surface. The target surface cannot be a simple offset of the reference one since it must represent a trade off between different requirements:

1) the distance should be within a narrow range (~ 2÷16 mm) in order to minimize the thickness of the layer of filler to be applied,
2) the curvature should be as uniform as possible allowing a good visual appearance,
3) the shape should differ as little as possible from the original CAD model surface (design surface).

Quality of visual appearance can be attributed to the uniformity and smoothness of the surface that is observed since it is a function of both long wavelength (orange peel effect) and short wavelength (micro-waviness) waviness [14]. In the shipbuilding field, there is a long tradition to judge the surface quality by inspecting reflection lines on the surface itself. However, at present time, a good surface yacht finishing is usually defined as whatever the customer is willing to accept or the yard is able to produce, within cost and time budgets of the project. Only in recent times, attempts to define ISO standards have been made [15]. These international standards are mainly focused on defining appropriate terms and definitions. Surface quality requirements are described in terms of cosmetic attributes as gloss, colour and fairness with the purpose of meeting customers' expectations. Neither geometric information on the shape to be accomplished nor measurement tools to analyse deviations from the expected surface are proposed.

In this paper, two different approaches for the definition of an appropriate target surface are described. The two approaches differ for the amount of information that is used and the user interaction that is required. Once the target surface has been created, it is uniformly sampled and deviations from the reference surface are evaluated in correspondence of the sampling points. These deviations are used by the filling process since the amount of required fairing material is proportional to the distance from the reference surface.

3.3.1 Target surface modelling by CAD software

The polygonal mesh of the measured data, expressed in the WRS, is used to create the target surface with the commercial package software UGS NX 6. The reference surface is approximated using a NURBS representation. The procedure can be detailed in the following steps:

1) a grid of points is determined by intersecting the mesh with uniformly spaced horizontal and vertical planes,
2) a grid of B-spline curves is created interpolating the extracted points in a least-squares sense,
3) the curves are then used to create a parametric surface composed of NURBS (Non-Uniform Rational B-Spline) surface patches (fig. 5),
4) control points are moved in order to modify the shape of the surface both preserving curvature smoothness (fig. 6-a) and minimizing the deviations from the reference surface. The inspection of reflection lines is a standard way to check the quality of free form surfaces [16]. For this reason, reflection patterns, simulated and mapped as texture by the CAD software, can be used to control the modelling process (fig. 6-b),
5) the target surface is finally created by offsetting the modelled surface. The extent of this operation is determined by the reference surface that must be completely embodied by the target surface.

3.3.2 Target surface modelling based on the design information

The above described methodology, even if effective, is subjected to a considerable amount of user interaction. Moreover, information regarding the original hull design shape is not fully exploited.

In this paper, a methodology to exploit the information contained in the original design surface has been developed. The basic idea relies on the use of the design shape, rather than the measured data, as a starting point for the definition of the target surface. The design surface is slightly deformed in order to obtain a final shape similar to the original one but sufficiently close to the reference surface. The whole process is composed of the following three transformations of the design surface:

1) rigid displacement,
2) deformation by minimizing an appropriate cost functional,
3) offset of the obtained surface.

Both the design and the reference surface have been discretized taking N node points equally spaced (~ 10 mm). The design surface is placed close to the reference surface through a rigid-body transformation. At first, a coarse alignment is performed using common reference points. Then an iterative process is carried out by slightly moving the design surface and minimizing the mismatch between the two point data sets. The process is formulated as an optimization problem whose objective function is given as follows:

$$\Phi = \sum_{i=1}^{N} \left| Y_i - \left(R \cdot X_i + T \right) \right|^2 \qquad (1)$$

where Y_i and X_i are the closest points on the reference and the design surface respectively and R and T represent the rotation matrix and the translation vector.

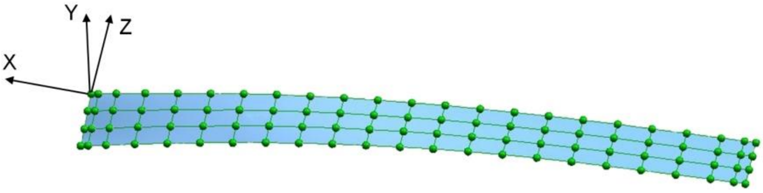
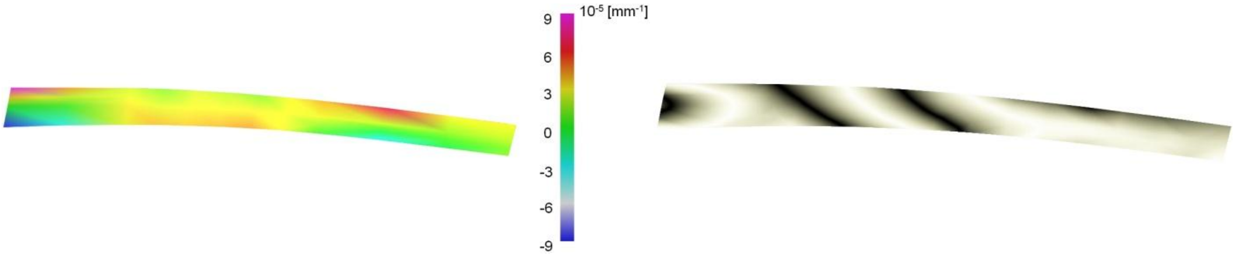


Fig. 5 NURBS surface patch with control points evidenced.



a)

b)

Fig. 6 a) Mean curvature map and b) reflection lines pattern of a surface patch modelled by the approach described in section 3.3.1.

The deformation stage has been mathematically formulated by defining an appropriate cost functional which represents a reasonable trade-off between design and reference shapes. The target, design and reference surfaces, z, ζ and Z, are represented as the graph of a function in a rectangular domain Ω:

$$z = f_t(x,y)\,,\ \zeta = f_d(x,y)\,,\ Z = f_r(x,y) \qquad (2)$$

The difference $u = z\text{-}\zeta$, which can be seen as the deformation of the design shape, is taken as the unknown function of the minimization problem. Displacements in x and y directions are not considered. The cost functional is expressed as a linear combination (with weights α, β) of two quadratic functionals: one based on the distance, h, between f_t and f_r and the other based on the difference between the mean curvatures (c and γ) of f_t and f_d :

$$F = \int_{\Omega} \left[\alpha h^2 + \beta \left(c - \gamma \right)^2 \right] dA \qquad (3)$$

where dA is the area element:

$$dA = \sqrt{1 + z_x^2 + z_y^2}\, dxdy \qquad (4)$$

The distance h, normal to the target surface f_t, can be expressed as:

$$h = \frac{\sqrt{1 + z_x^2 + z_y^2}}{1 + Z_x z_x + Z_y z_y} \left(Z - z \right) \qquad (5)$$

The mean curvatures of the target and design surfaces can be written as:

$$c = \frac{\left(1 + z_y^2\right) z_{xx} - 2 z_x z_y z_{xy} + \left(1 + z_x^2\right) z_{yy}}{2\left(1 + z_x^2 + z_y^2\right)^{3/2}} \qquad (6)$$

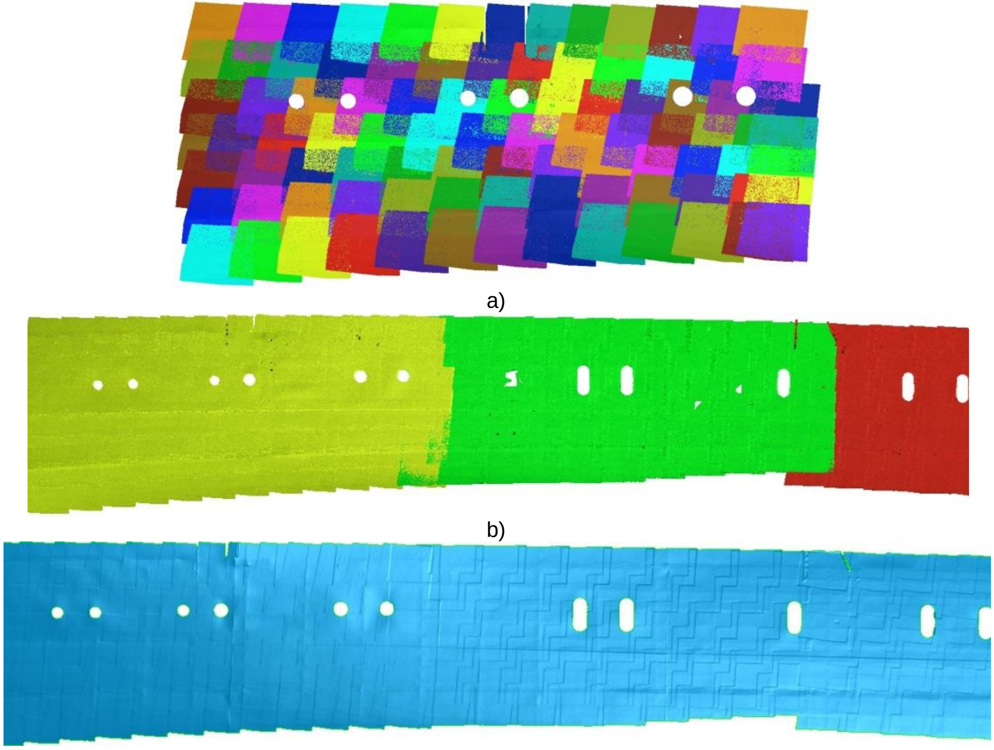
$$\gamma = \frac{\left(1 + \zeta_y^2\right) \zeta_{xx} - 2 \zeta_x \zeta_y \zeta_{xy} + \left(1 + \zeta_x^2\right) \zeta_{yy}}{2\left(1 + \zeta_x^2 + \zeta_y^2\right)^{3/2}} \qquad (7)$$

Since $Z\text{-}\zeta \ll 1/\gamma$, the cost functional has been linearized with respect to u. A finite difference method has been used to provide a numerical solution.

4 Results

The feasibility of the developed methodology has been finally tested on the hull of a 59 meters yacht assembled within a shipyard (fig. 2). Preliminary tests have been performed on the broadside of the hull. A wide region (25 × 5 metres) has been measured by aligning more than 200 single scans. The capability of adjusting the projector light intensity, in order to handle the varying illumination conditions existing in the shipyard, has guaranteed a significant robustness during the acquisition process. Fig. 7-a shows the scans relative to a single block (~ 100 different scans), while fig. 7-b reports the alignment of three different blocks performed by the laser station. A visual inspection of the measured data can assess the accuracy of the point cloud alignment phase even in absence of a proper metric tool. The overall distance between overlapping areas of different scans turned out to be of the same order of magnitude regardless of the multi-view registration method adopted (robotic system or total station). This has allowed the creation of a manifold representation of the measured surface (fig. 7-c).

A portion (20 × 1.5 metres, fig. 8) of the measured region has been modelled following the two methodologies described in section 3.3.


a)

b)

c)

Fig. 7 a) Aligned point clouds relative to a single scan block, b) three different scan blocks aligned by the laser total station, c) polygonal mesh (StL) of the measured data.

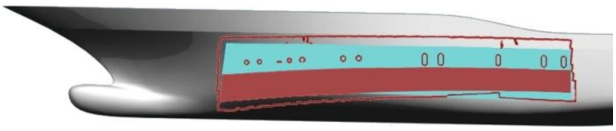
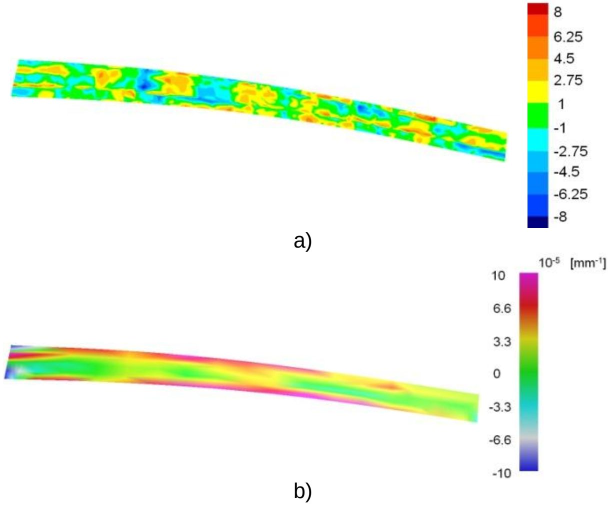


Fig. 8 Modelled region with respect to the whole reference surface.

Fig. 9-a reports the distance map between the modelled surface, as obtained by the approach described in section 3.3.1, and the reference surface while fig. 9-b shows the mean curvature map.



a)

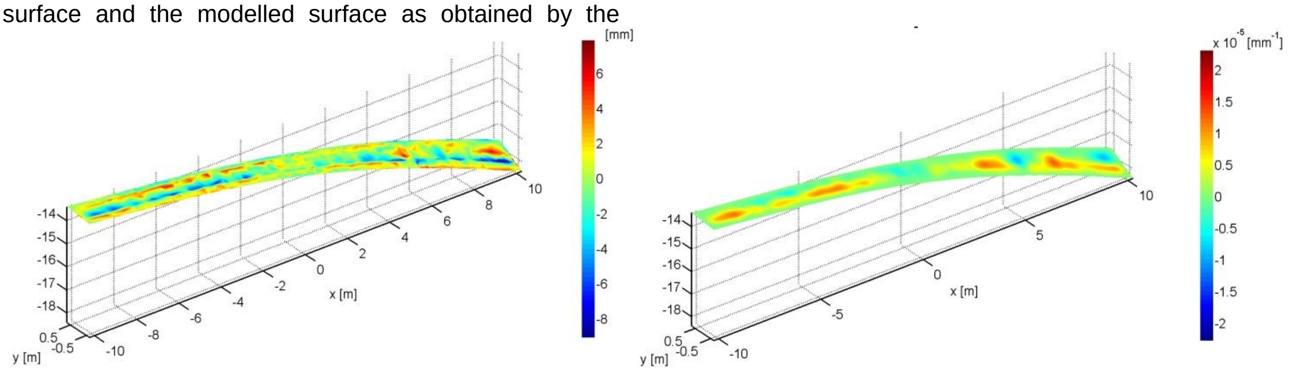
b)

Fig. 9 a) Distance map between the surface modelled by the approach described in section 3.3.1 and the reference surface and b) mean curvature values.

Fig. 10-a shows the distance *h* between the reference surface and the modelled surface as obtained by the approach described in section 3.3.2. The maximum positive distance value gives an indication about the offset to which the modelled surface must be subjected in order to create the final target surface. The overall distance range gives an estimate of the amount of material that would be used in the filling process. Fig. 10-b reports the mean curvature difference map (c-γ) between the modelled and the design surfaces. Fig. 11 shows the mean curvature values of the modelled surface (fig. 11-a) and the design surface (fig. 11-b).

Varying the ratio α/β from 0 to infinity, the target surface varies continuously from the design surface to the reference surface. Since the shape requirements have not been quantified, the ratio has been chosen so as to satisfy the distance range requirement (~ 2÷16 mm) while keeping the variation of the mean curvatures as little as possible. The surface obtained with $\alpha/\beta = 4 \cdot 10^{10}$ mm^4 demonstrated to be within the same distance range as the one obtained with CAD software modelling (fig. 9-a, fig. 10-a) clearly showing, at the same time, a better visual appearance (fig. 9-b, fig. 11-a). The low mean curvature variation (fig. 10-b) has thus guaranteed the compliance of the expected surface visual impact.

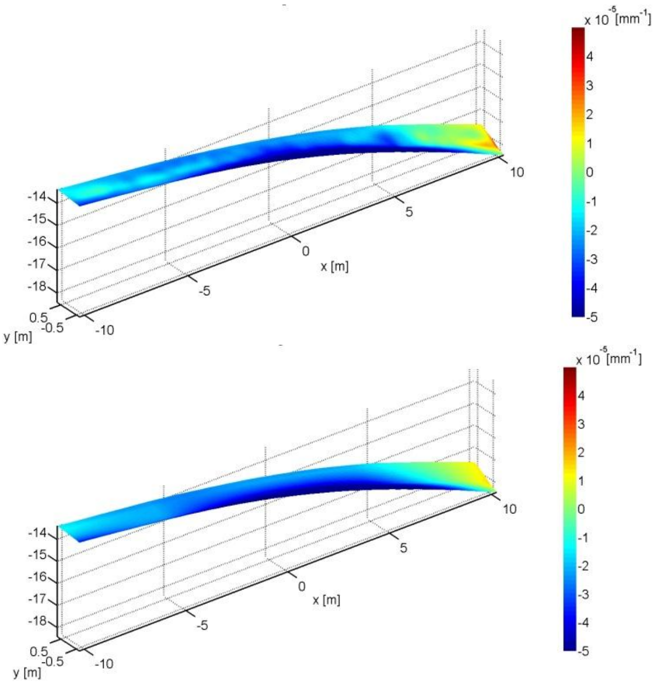
Information derived from the obtained target surface have been provided to the CAM system. The surface finishing process has been finally automated by supplying the anthropomorphic arm with filling and milling tools. Fig. 12 shows the final surface finish obtained after the application of a seawater-resistant lacquer coating.



a)

b)

Fig. 10 a) Distance between the surface modelled by the approach described in section 3.3.2 and the reference surface and b) mean curvature difference between the modelled and the design surfaces.



a)   (b)

Fig. 11 a) Mean curvature values of the surface modelled by the approach described in section 3.3.2 and b) of the design surface.

This is a standard empirical way to check the surface finishing quality of large yachts by the customer.

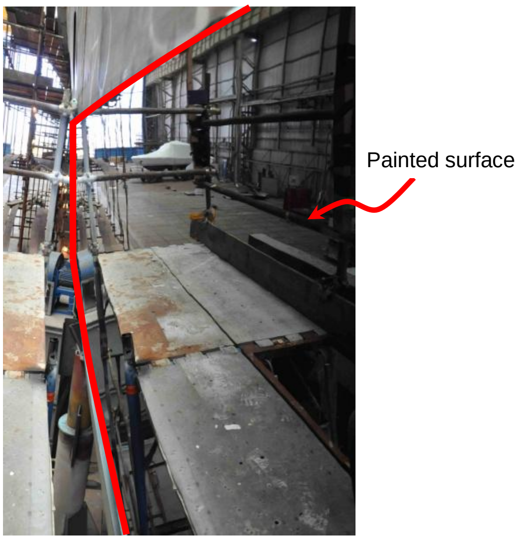


Fig. 12 Final surface after the painting process. The angle used to acquire the image enhances the reflection properties of the surface which mirrors the equipments contained within the shipyard.

5 Conclusion

In this paper, an innovative methodology for the automation of the surface finishing process for large yacht hulls has been presented. The procedure is based on the modelling of a target shape, having an appropriate visual appearance, by exploiting the information deriving from both the original CAD model and the existing as-built shape. The as-built surface has been acquired through the integration of an optical scanner and a complex robotic system. The robotic system, composed of an anthropomorphic arm and two linear guides, has been used to move the optical measurement device allowing an automatic multi-view data registration approach.

Preliminary results, obtained on the hull of a 59 metres yacht assembled within a shipyard, have shown the capabilities of the proposed methodology. The accuracy obtained in the alignment of multiple point clouds has allowed the creation of a proper reference surface to be used in the modelling process. Moreover, the use of the design shape information has enabled the preservation of curvature continuity in the target surface. Tests carried out on the broadside of a large yacht hull have led to remarkable results in terms of visual appearance of the finishing surface both reducing manufacturing time and filler material waste.

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