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TWO REVERSE ENGINEERING METHODS FOR THE RECONSTRUCTION OF AN HIGH SPEED CRAFT SURFACE: A COMPARISON

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1. Introduction

In the present paper the authors determine and present an optimal method for the virtual reconstruction, through Reverse Engineering (RE) techniques, of the hull and spray rails of a high-speed craft (HSC). The inexact correspondence between the manufactured hull shape and designed lines may strongly affect the ship performance, as well as the control and the propulsion efficiency. Differences in spray rails and in the chine symmetry or in the water-jet inlet shape will result in loss of speed and in difficult steering. The work moves following four main phases:

1. 3D acquisition of the physical HSC,
2. Editing of point clouds,
3. Application of the customized algorithm for curve/surface fitting,
4. Comparison of the results with those deriving by using commercial software.

The topic concerns with the application of recent scanning techniques for geometry control of existing objects by a digital duplication process able to create the model to which it is possible to apply advanced analysis software tools. The RE process adopted here enables designing and developing a product by means of the digital model obtained from a dense point cloud which is acquired through 3D scanning instruments applied to a real object. The study was born from the naval designer needs to verify quality of the wood model used for experiments in test tank: the "water answer" of the designed hull is decisive to validate the hull design and plan successive modifications. In particular, the "Series 64" was analysed, hull of reference for ships belonging to High Speed Craft category: it is characterized by high slimness, with a width/length rate equal to 1/14. The use of RE techniques gives a valid instrument to designers for verifying correspondence between the "nominal geometry", subject to hydrodynamic studies, and the real hull made in carpentry, destined to the tests in the test tank.

2. R.E. Techniques and system set-up

By using 3D scanning system the acquisition of the entire hull surface was realized. The Minolta VIVID 700 laser scanner was employed, which is based on the optical triangulation principle. The relative position of the three elements (laser source, object and sensor of reception) allows to get coordinate information of many points belonging to the object surface [Sansoni 2000].

The scanning resolution depends on the distance between the object and the sensor. Therefore, a movement system of the scanner was installed by means of a linear guide, so that the instrument moved along a line, in parallel with the diametrical plan of the hull. In this way the introduction of an eventual difference of resolution due to the movement system along the entire hull was avoided.

The adopted scanner is characterized by a maximum resolution of 0.11 mm in ideal conditions – minimal distance (600 mm) from the object and maximum zoom factor (8) – till to a lowest resolution of 7.23 mm when the object stays at 2.5 m. To a better resolution corresponds a smaller dimension of the scanned area; therefore, an acquisition procedure was established by setting the minimal distance (600 mm) and the zoom factor to level 2, so that the entire hull was scanned with 40 single scans, divided in two parallel series of 20 scans.
Based on some intrinsic feature of the laser scanner, some tricks were also adopted to reduce noise and limit the scanning only to the hull area of interest: the background of the laboratory was covered with a black, no-reflecting panel of tissue (cotton). Finally, proper light conditions were guaranteed by using diffused white lights, loyal to the laser during its movement.

3. From point cloud acquisition to surface reconstruction

Due to the nature of the original hull surface some problems were occurred in the acquisition phase: black water lines, useful for the tests in test tank, generated disturbs in the laser passage, such as excessive brightness of the paint applied to the surface. A solution was found by slightly dulling the surface. Then, some markers (white circles) were attached in order to allow the correct registration of the several partial point clouds. The scanning system used, in fact, permits the acquisition of the 3D coordinates of the points along with their RGB color, so allowing to apply the color texture to data set, and this information may be used to guide the positioning phase (registration) of a couple of point clouds by choosing three corresponding markers on each one (see Figure 1). This procedure works better with object characterized by well defined geometrical features, such as mechanical elements.

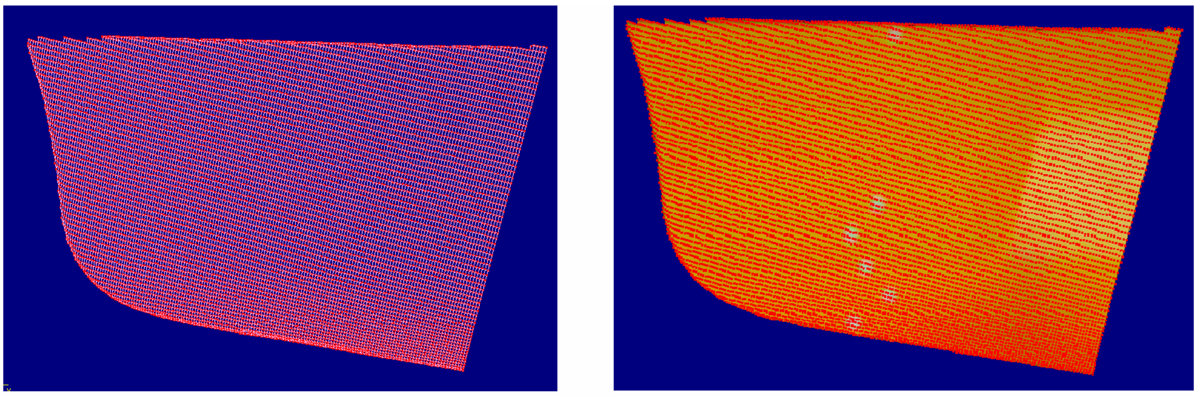

Figure 1. Portion of the acquired point cloud, without (left) and with (right) applied texture

Thus, the entire hull surface was acquired, moving the scanner along the linear guide so that each patch contained at least three markers of the previous portion; a total of 40 scans with about 25000 points each one was obtained.
The successive phases of editing (e.g. repairing eventual holes), merging and surfacing – typical of data post-processing – have produced the digital model of the analyzed hull, virtually exportable in any CAD environment. A specific commercial software for reverse engineering (Geomagic Studio by Raindrop Geomagic, Inc.) was used to process the acquired data.
The first phase of model reconstruction is, therefore, the registration of partial point clouds. Once loaded all the patches corresponding to the different portions of hull, the reconstruction of the entire hull was made by means of the three point registration algorithm applied to all the patches. The fine registration operation on the entire hull reconstruction presented a remarkable difficulty due to the similarity of curvature between adjacent surface portions. This geometry similarity is typical of naval shapes, which, just due to fairing geometric characteristics, have to present curvature as regular as possible. Then, adjacent portions of hull have very alike curvature, causing alignment ambiguity during the registration made by means of the commercial software algorithms.
The problem consisted in the likely sliding of a patch over the successive one along the axial direction. Even if it is accepted by the algorithm of the software with a tight tolerance, it would cause an

unacceptable error in the total registration, adding itself for each pair of adjacent patches, and, therefore, in the final result. To resolve it, the registration operation was limited to the parts of point clouds corresponding to the markers placed on the hull, cut out from the original clouds at a distance sufficient to guarantee the correct relative positioning. Therefore, just marked parts isolated from the clouds were affected by registration and, after, the loaded corresponding clouds matched perfectly with parts previously aligned. Figure 2 shows the final result of the registration phase related to one series of scans.

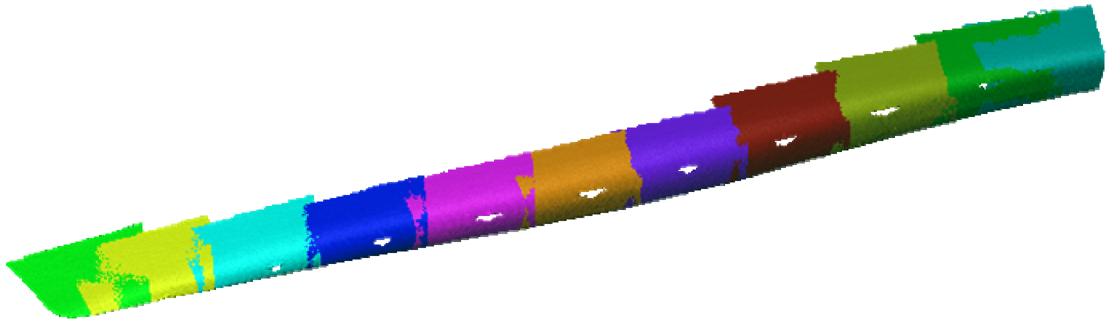

Figure 2. Relative position of different patches after registration phase

After assembling all patches the software generates a unique point cloud by merging data, allowing to choose the collapsing level of points. The result is a point cloud that can be transformed into a polygonal model (also called tasselled model), which represents a first rough surface. The software has many functions to process data: among the useful editing tools, the *fill holes* operation fills gaps in the model that may have been introduced during the scanning process.
Moreover, functions of data filtering allow to decimate the number of points following specific rules: uniform or curvature-based operation of sampling points and tools for reducing noise by eliminating too far points. Once prepared to become a surface, the polygonal model was submitted to auto-surfacing function available in Geomagic Studio 5: in this way the needed operations were optimized by an unique process (figure 3). Now it's possible to compare the hull surface reconstructed with the original point clouds through the 3D test tool.

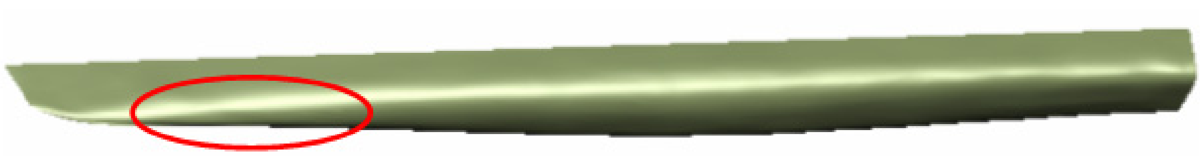

Figure 3. Rendered view of the complete surface reconstructed in Geomagic Studio 5

Later on in the present paper we will compare the above surface with the one resulting from the application of customised algorithm for surface fitting. The comparison is related to a portion of the hull, which is positioned in the first hull quarter on the bow side with respect to the hull middle section and it represents a zone with high curvature as pointed out in figure 3.

4. Curve and surface fitting by customised algorithms

To better analyse the shape deviations between the reconstructed models with two different approaches, all the geometries were converted in surface models by fitting surfaces to the tasselled geometry or directly to the point cloud. The surface reconstruction by a commercial software has been described above. In the following an alternative approach for surface reconstruction by using a home-made algorithm will be described.
In handling several point data there are two different types of curve/surface fitting: interpolation and approximation. Interpolation requires to find a curve/surface passing "through" the given points, while

approximation requires to find curve/surface passing "near" the given points and minimizing a prescribed error, e.g. the minimum distance between points and curve/surface.
The specific improved algorithm for fitting, already described in [Campana 2002], which permits to have a local and global control over the reconstructed NURBS curves/surfaces with an approximation method, was adopted. The inputs to the approximation problem are points, the error bound and the degree of the curve. The outputs will be a set of control points, the knot vector and weights. The parameterization of the given points Q_i and the number and distribution of the knots in the knot vector are two critical aspects. In the present paper a different approach based on a new kind of parametrization has been adopted which offer a better results especially for sparse points, as pointed out in [Hoschek 1993]. The parameterization described in [Foley 89], which takes into account the vector distance between points as long as the angle between those vectors (figure 4), has been implemented in the algorithm used in the fitting problem.
Given the knot vector, the more adopted parameterization strategies usually are: *equally spaced*, *chordal* and *centripetal*. The [Foley 89] criterion gives in general better result for very scattered points, which are those coming from points decimation made with commercial software.
In the following the adopted parameterization is described. Given n points $\mathbf{P_i}$, the variations of the associated parameter values t_i , i = 0(1) n, are:

$$\Delta t_i = d_i \left[1 + \frac{3\hat{\theta}_i d_{i-1}}{2(d_{i-1} + d_i)} + \frac{3\hat{\theta}_{i+1} d_{i+1}}{2(d_i + d_{i+1})} \right] \qquad (1)$$

where

$$d_i = M[\mathbf{P}](\mathbf{P}_i, \mathbf{P}_{i+1}) \text{ , } \hat{\theta}_i = \min(\theta_i, \frac{\pi}{2}) \qquad (2)$$

and θ_i is the angle between $\overline{\mathbf{P}_{i-1}\mathbf{P}_i}$ and $\overline{\mathbf{P}_i\mathbf{P}_{i+1}}$ (figure 4).

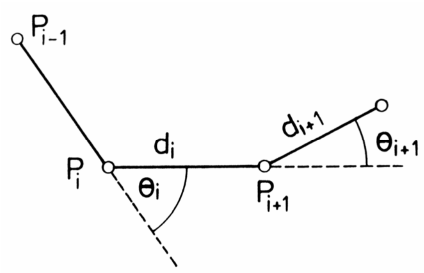

Figure 4. [Hoschek 1993] - New kind of parametrization used

A very important parameter in the fitting problem is the *smoothing factor (S)* specified by the user. Its value has to be fairly picked. If an high value for S is chosen, the curve/surface may lost its real characteristics. Instead, if a small factor is chosen the point cloud noise may render inaccurate the fitting. So, it is advisable to select an appropriate smoothing factor to obtain realistic results.
Before fitting surfaces, the scanned set of points was structured in a matrix-like form, and edited so to have the same number of points along both x and y direction following the hull shape. The obtained results were analyzed and visualized in Matlab (see figure 5), and then Geomagic Studio environment was use to make the comparison.

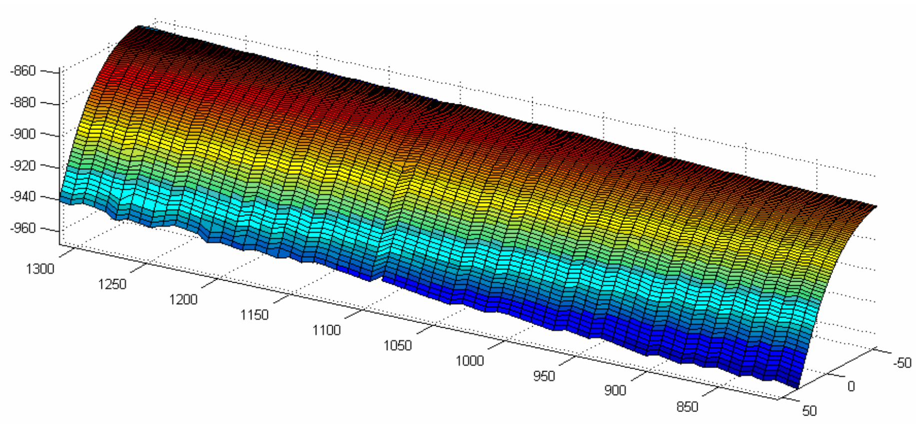

Figure 5. Reconstructed surface (visualized in Matlab environment) by means of the customised algorithms

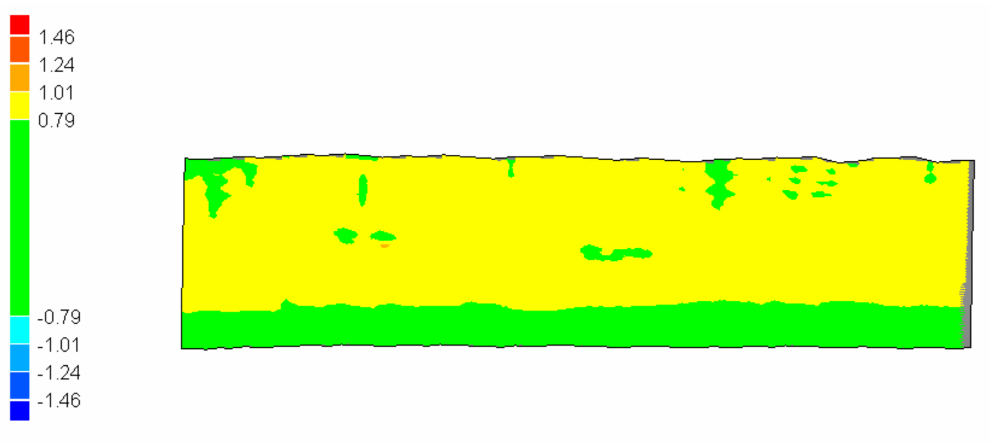

Figure 6. Results of the variation analysis obtained by means of the custom algorithms (visualized in Raindrop Geomagic environment)

5. Results

Several test to evaluate the goodness of the results obtained by means of fitting functions was made. Tests were made adopting different values for the parameters controlling the final shape of the surface. The maximum error found is near high curvatures of the surface, thus pointing out the elevated smoothing action of the adopted algorithm. The average error is about ± 1.2 mm. The results were analysed in Matlab and Raindrop Geomagic environment by means of some statistical tool to evaluate the gap between the original points cloud and the surface reconstructed. The new adopted parametrization has shown a better fitting of the surface in the zone with related higher curvature.

In particular, in the case shown in figure 6, the average error is 1.01 mm, whereas the maximum error is 1.46 mm. These results are going to be improved by means of other trials. More works are needed to make the algorithm more efficient in giving back the optimum result with just a few user control.

The deviation analysis between surface and points, made in Geomagic Studio, gave the following results shown in figure 7 in terms of color map: distance keeps in the range of ± 0.49 mm, whereas most part belongs to ± 0.063 mm range. The maximum error is 0.49 mm, whereas the average distance is 0.049 mm.

The results show that software used give a good surface reconstructed with a very small error compared with acquired points, representing original wood model. Therefore, it is indicated to verify quality of manufactured model in terms of distance between its surface reconstructed and nominal geometry.

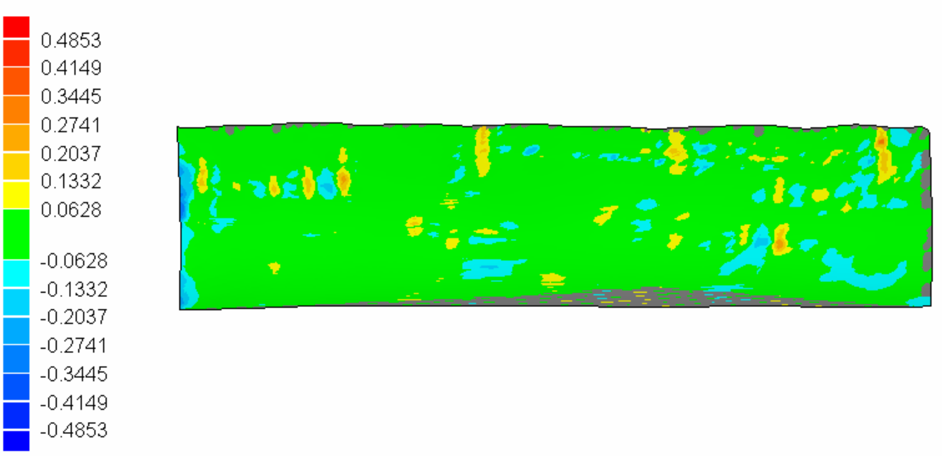

Figure 7. Analysis of the results obtained in Geomagic

6. Conclusions

Two different approaches for the reconstruction of the CAD model of an HSC were presented. The first is based on the use of a commercial software (Raindrop Geomagic), the second based on customised algorithms. The commercial software used allows to get very accurate results (average error 0.049 mm). So the analysis of the shape deviation can be really precise. At the same time, the customized algorithms show an acceptable average error. The new parametrization adopted in the algorithms allowed to get encouraging results for the next improvement of the codes. In particular, by means of the C++ language and some new tools we are going to realize a new custom reconstruction environment.

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