# Comparison between image analysis techniques for boat shape measurements

Sofia Catalucci[1], Roberto Marsili[2], Michele Moretti[3], Gianluca Rossi[4]

[1] *University of Nottingham, University Park, NG72RD Nottingham, UK, sofia.catalucci@gmail.com*
[2] *University of Perugia, Via Goffredo Duranti 93, 06125 Perugia, IT, roberto.marsili@unipg.it*
[3] *University of Perugia, Via Goffredo Duranti 93, 06125 Perugia, IT, michele.moretti@unipg.it*
[4] *University of Perugia, Via Goffredo Duranti 93, 06125 Perugia, IT, gianluca.rossi@unipg.it*

*Abstract* – **The aim of this paper is to define performances and metrological characteristics of simple and economical photomodelling techniques for boat shape measurements, an innovative technique developed recently. Compared with the technique based on a Creaform ScanGo 50 structured light 3D scanner with metrological certification, the investigation wants to verify the potential of this recent technique and to be as reference for photomodelling performance metrological evaluation.**

## I. INTRODUCTION

Based on the same principles of photogrammetry, photomodelling permits the economical and fast reconstruction of three-dimensional models from the simple acquisition of photographic images. The results are 3D point clouds, sets of x,y,z coordinates that represent the first form of the object surveyed [1].

Since photomodelling is strictly related to photographs, it is possible to call 3D point clouds as *pixel clouds*, because each pixel of an image corresponds to a point of the cloud, thus preserving the chromatic characteristics of the object surveyed [2].

The design of the boats involves complex free-form geometric shapes, very difficult to measure, and model with traditional measurement methods. Photomodelling and scanning data allow creating precise 3D models that can be used by naval designers, architects and engineers to ensure the quality of interior and exterior construction, as well as for design, simulation and inspection purposes.

## II. TEST PERFORMED

Object of the survey is a Beneteau First 456/s boat, 1984, with 3 cabin all with toilets, engine Yanmar 55 cv, 14 m length (Fig.1).

The measurements has been performed on the driving seat area, by using photomodelling technique and the Creaform 3D scanner, on the same surface (Fig.2).
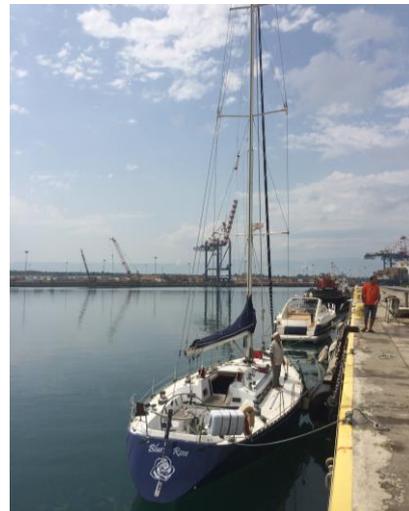


*Fig. 1. The Boat.*



*Fig. 2. Driving seat area.*

At first, the survey has been performed using the 3D scanning system (Fig.3); target stickers have been applied randomly to facilitate the capture process, due to the autosimilarity of the surface pattern.
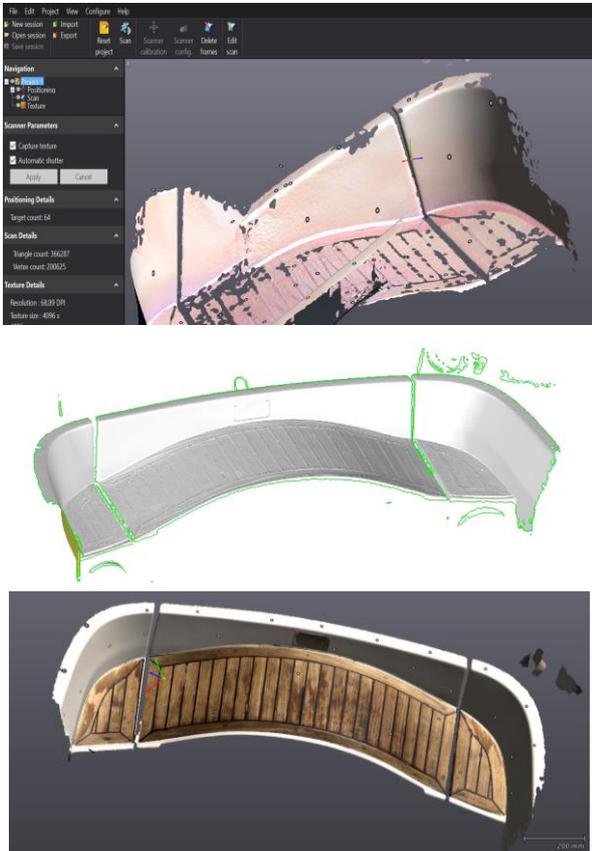


*Fig. 3. Boat surface scanning by Creaform ScanGo 50.*

The survey carried out by the photomodelling technique included a totality of 20 images, loaded in three different dedicated software: Agisoft Photoscan, Visual SfM and Autodesk Remake. Each instrument is different because of their time data processing, difficulty of use, accuracy and precision of results [3]. Furthermore, the applications proposed are both open-source and commercial software.

## III. DATA PROCESSING

The 3D data processing is the same for each software: the first operation is the manipulation of the 3D point cloud. The next step is the creation of three-dimensional model, called "triangulation": starting from the input data vertices, edges and faces are generated. The result obtained is a set of coordinates, which is converted into a polygonal surface [4, 5, 6]. With editing software as MeshLab and Geomagic Studio, it is possible to perform manual editing of data, merge, scale, align different surfaces, creating a three-dimensional surface with the aid of different algorithms [7, 8, 9] (Fig.4, Fig.5, Fig.6).
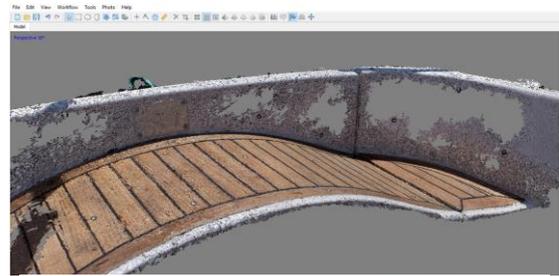


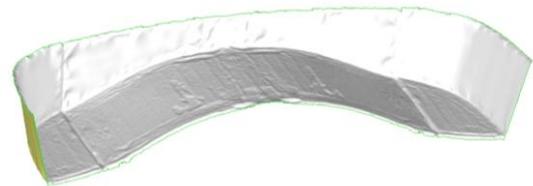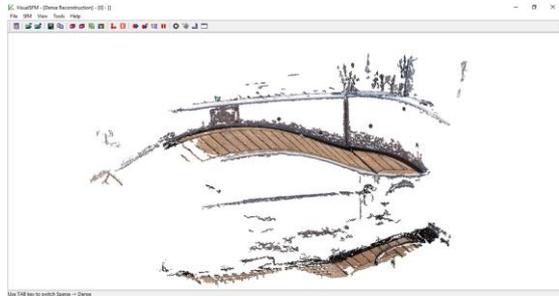*Fig. 4. Surface 3D model and point cloud by Agisoft Photoscan.*



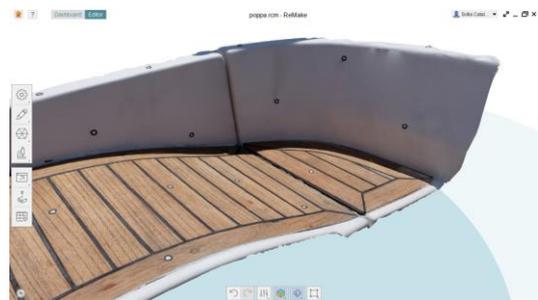*Fig. 5. Surface 3D model and point cloud by Visual SfM.*



*Fig. 6. Surface 3D model by Autodesk Remake.*

## IV. COMPARISON

After the alignment of the edited models, the research concerned the comparison between TEST 3D models, realized by the photomodelling software, and a REFERENCE model. It has been chosen as reference, the surface reconstructed by the scanning system [10, 11, 12]. Geomagic Qualify is the software used for the comparison, through algorithms, which provide variances and deviations between geometric entities in the space. The comparison involved the creation of 2D and 3D maps of the deviations, from which it was possible to derive a matrix in .CSV format of the spatial coordinates x,y,z of models points, test and reference ones and the values of the mutual distances for each pair of points.

After the manual and automatic alignment between the models, a spectrum of 15 intervals of values has been set: -10 and +10 mm deviation is the range of acceptability; the range between -1 and +1 mm is the optimum correspondences between the test and reference points.

As it is clear from the various elaborate graphs, the best result is the comparison with the TEST model of Agisoft Photoscan (Tab.1, Fig.7). The results obtained with Visual SfM are close to the previous ones (Tab.2, Fig.8). On the contrary, Autodesk Remake highlight the differences in terms of precision and accuracy of each software, especially the second one. Autodesk Remake is a simple software, which can be used by every kind of users, and it does not elaborate significant results (Tab.3, Fig.9). After the comparison, the next step is to upload the data into MATLAB, processing the data in histograms of frequency, absolute values of deviations and curves of the probability density (Fig.10).

*Table 1. Agisoft Photoscan.*

| Deviations distribution | Number of points |
|---|---|
| n>10 | 1536 |
| 8.5<n<10 | 1463 |
| 7<n<8.5 | 2605 |
| 5.5<n<7 | 5926 |
| 4<n<5.5 | 13862 |
| 2.5<n<4 | 25336 |
| 1<n<2.5 | 41193 |
| (-1)<n<1 | 59806 |
| (-2.5)<n<(-1) | 41812 |
| (-4)<n<(-2.5) | 20400 |
| (-5.5)<n<(-4) | 13607 |
| (-7)<n<(-5.5) | 10720 |
| (-8.5)<n<(-7) | 5914 |
| (-10)<n<(-8.5) | 2082 |
| n<(-10) | 3499 |

Max +/- : 54.381 / -63.689 mm
Average +/- : 2.652 / -3.080 mm
Mean value of the distance between TEST/REFERENCE models: -0.27303 mm
Standard Deviation: 3.9393 mm
Mean value of all differences +-devstd: (3.6663,-4.2124) mm
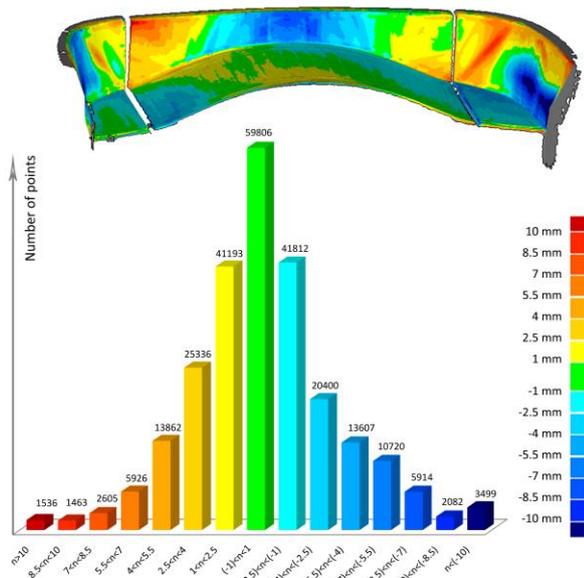Number of measured points: 249761



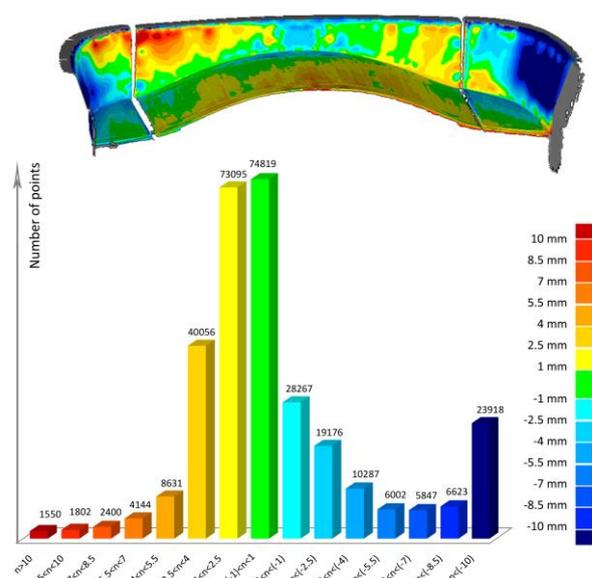*Fig. 7. Maps of deviation distribution (Agisoft Photoscan).*



*Fig. 8. Maps of deviation distribution (Visual SfM).*

*Table 2. Visual SfM.*

| Deviations distribution | Number of points |
|---|---|
| n>10 | 1550 |
| 8.5<n<10 | 1802 |
| 7<n<8.5 | 2400 |
| 5.5<n<7 | 4144 |
| 4<n<5.5 | 8631 |
| 2.5<n<4 | 40056 |
| 1<n<2.5 | 73095 |
| (-1)<n<1 | 74819 |
| (-2.5)<n<(-1) | 28267 |
| (-4)<n<(-2.5) | 19176 |
| (-5.5)<n<(-4) | 10287 |
| (-7)<n<(-5.5) | 6002 |
| (-8.5)<n<(-7) | 5847 |
| (-10)<n<(-8.5) | 6623 |
| n<(-10) | 23918 |

Max +/- : 51.380 / -22.958 mm
Average +/- : 2.271 / -4.750 mm
Mean value of the distance between TEST/REFERENCE
models: -0.81653 mm
Standard Deviation: 4.9616 mm
Mean value of all differences +-devstd:
(4.1451,-5.7781) mm
Number of measured points: 306617

*Table 3. Autodesk Remake*

| Deviations distribution | Number of points |
|---|---|
| n>10 | 10136 |
| 8.5<n<10 | 2956 |
| 7<n<8.5 | 2745 |
| 5.5<n<7 | 2526 |
| 4<n<5.5 | 3104 |
| 2.5<n<4 | 3367 |
| 1<n<2.5 | 3837 |
| (-1)<n<1 | 4168 |
| (-2.5)<n<(-1) | 3118 |
| (-4)<n<(-2.5) | 3924 |
| (-5.5)<n<(-4) | 4520 |
| (-7)<n<(-5.5) | 5298 |
| (-8.5)<n<(-7) | 5873 |
| (-10)<n<(-8.5) | 4188 |
| n<(-10) | 13311 |

Max +/- : 27.726 / -45.905 mm
Average +/- : 7.499 / -7.730 mm
Mean value of the distance between TEST/REFERENCE
models: -1.2971 mm
Standard Deviation: 8.772 mm
Mean value of all differences +-devstd:
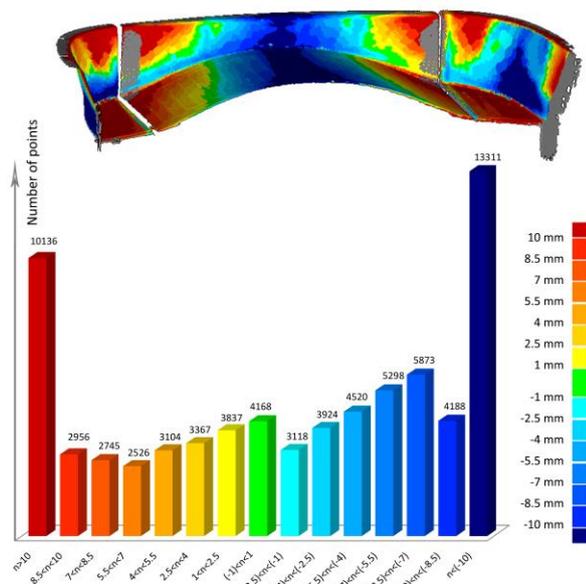(7.4748,-10.0691) mm
Number of measured points: 73071



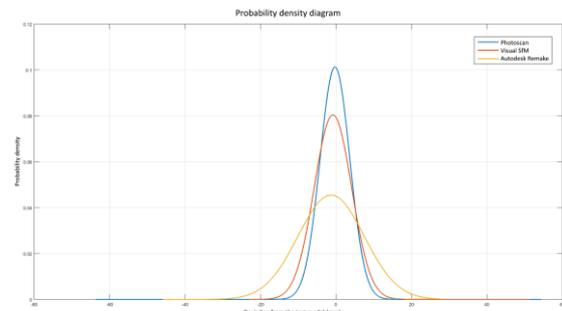*Fig. 9. Maps of deviation distribution (Autodesk Remake).*



*Fig. 10. Probability density diagram.*

*Table 4. Tot number of measured points.*

| | |
|---|---|
| Agisoft Photoscan | 249761 |
| Visual SfM | 306617 |
| Autodesk Remake | 73071 |

A "measure" is a range of values, acquired with the purpose of controlling a process, perform the calibration of an instrument or allow the physical understanding of a partially known phenomenon [13, 14, 15].
Binding to this assertion, to further support the

experimentation, the same obtained 3D models have been imported into the multi-paradigm numerical computing environment MATLAB. Through the elaboration of chromatic maps (Fig.12), which identify the volumetric error distribution and the distance between the closest point-to-surface of the meshes composing the models, it has been possible to compare the reference and tests three-dimensional surfaces through an algorithm. This algorithm is based on a modified function based on a well known ICP (Iterative Closest Point) approach, which minimize the distance between two dispersion of multidimensional points, i.e. the two point cloud to be registered and compared, respectly labeled as Reference Point Cloud (RPC) and Measured Point Cloud (MPC). The algorithm works through an iterative process, and it's goal is to minimize the value of a global goal function. In this case the global function as been developed as the global volumetric error (GVE), calculated as the sum of volumes of the single prismatic element, as shown in Fig.13.
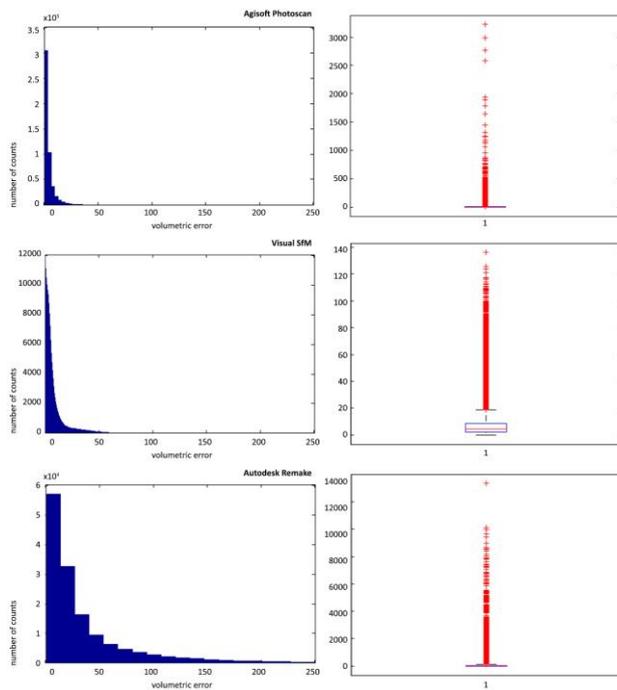


Fig. 11. Volumetric error distribution and Box Plot: Agisoft Photoscan, Visual SfM and Autodesk Remake.



Fig. 12. Chromatic maps: Agisoft Photoscan, Visual SfM and Autodesk Remake.

Table 5. Volumetric error distribution.

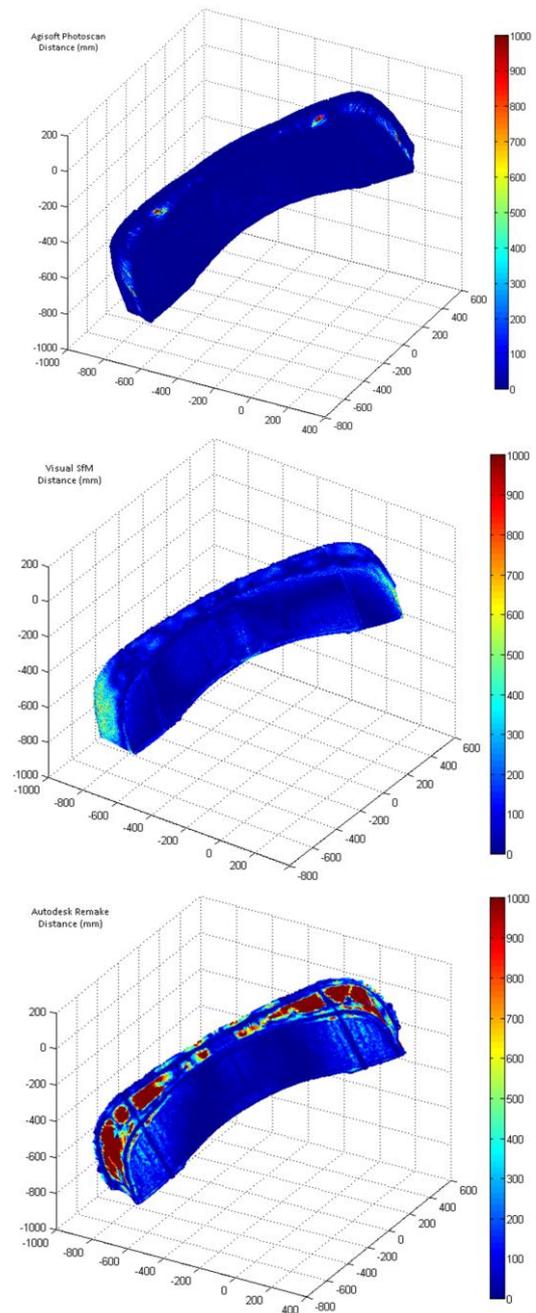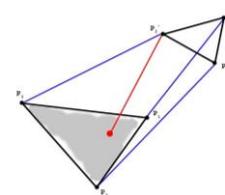| | |
|---|---|
| Agisoft Photoscan | Mean=5.6638 mm$^3$ STD=19.5801 |
| Visual SfM | Mean=7.8655 mm3 STD=10.4855 |
| Autodesk Remake | Mean=54.5649 mm3 STD=223.882 |



Fig. 13. Triangular mesh distance (mm): ICP function (Iterative Closest Point)

The approach in terms of volumes instead of the classic point-to-point distance gives an improved information: the value of GVE takes in account the size of the element of the triangulated meshes. Flat areas with large mesh size have a larger weight than areas characyerized by a small mesh size. This behaviour is characteristic of volumetric approach. For each comparison, the algorithm has elaborated box plot statistical diagrams and volumetric error distribution graphs (Fig.11).

It's possible to notice that the volumetric error distribution is quite similar to the behavior of point-to-point approach, due to the high regularity of mesh sizing of both reconstructed surfaces.

## V. CONCLUSIONS

Metrological characteristics of simple and economical photomodelling techniques for boat shape measurements has been investigated. The surfaces generated by the photomodelling techniques and generated by a structured light 3D scanner with metrological certification has been registrated in order to investigate the alignment error due to a poor geometry reconstruction. Geomagic commercial software has been used in order to register the point cloud measured and analyze the error distribution. A tailored software in MATLAB enviroment has been realized in order to modify the target of registration algorithms through the global volumetric error calculation. The photomodelling process performed by three softwares has been compared and results shows different performances, in terms of deviation distribution of distances and in terms of volumetric errors.

## VI. REFERENCES

[1] L.De Luca, "La fotomodellazione architettonica. Rilievo, modellazione, rappresentazione di edifici a partire da fotografie", Dario Flaccovio Editore, Palermo, 2011, pp.19-30.

[2] M.Filippucci, "Nuvole di pixel. La fotomodellazione con software liberi per il rilievo d'architettura", Disegnarecon, 2010, vol.3(6), pp.50-63.

[3] V.A.Girelli, "Tecniche digitali per il rilievo, la modellazione tridimensionale e la rappresentazione nel campo dei Beni Culturali", Tesi Dottorato di ricerca in Scienze Geodetiche e Topografiche, Alma Mater Studiorum Università di Bologna, ciclo XIX.

[4] R.Marsili, A.Garinei, "Thermoelastic Stress Analysis of the Contact Between a Flat Plate and a Cylinder", Measurement: Journal of the International Measurement Confederation, 2014, vol.52(1), pp.102-110. Available from: http://dx.doi.org/10.1016/j.measurement.2014.03.005

[5] R.Marsili, M.Moretti, G.L.Rossi, "Thermoelastic Modal Stress Analysis", IMAC XXVI Conference & Exposition on Structural Dynamic, Orlando, Florida USA, 4 – 7 February 2008; ISBN: 0912053984 ISBN 9781605600666

[6] R. Marsili, G. Brustenga, M. Moretti, J. Pirisinu, G.L. Rossi, "Measurement on rotating mechanical component by thermoelasticity", Journal Applied Mechanics and Materials, ISBN 0-87849-987-3 ISSN 1660-9336, Vols 3-4, August 2005, pp 337-342, pp 411– 416

[7] M.Kazhdan, M.Bolitho, H.Hoppe, "Poisson Surface Reconstruction", Eurographics Symp. on Geometry Processing, ed K Polthier and A Sheffer, 2006.

[8] F.B.J.Mittleman, H.R.C. Silva, G. Taubin, "The Ball-Pivoting Algorithm for Surface Reconstruction", IEEE Transactions on Visualization and Computer Graphics, 1999, vol.5(4).

[9] R. Marsili, A. Garinei, "Design of an optical measurement system for dynamic testing of electrospindles", in *Measurement*, 2013, vol.46, Issue 5 (Amsterdam: Elsevier), pp.1715-1721. DOI information: 10.1016/j.measurement.2013.01.006, ISSN: 0263-2241

[10] J.F.Brouckaert, R.Marsili, G.Rossi, "Development and experimental characterization of a new non contact sensor for blade tip timing", 10th International Conference on Vibration Measurements by Laser and Noncontact Techniques - AIVELA, Ancona, ITALY, JUN 27-29, 2012 Conference Proceedings Volume 1457 Pages: 61 - 68 DOI: 10.1063/1.4730543 Published: 2012 IDS Number: BBI34 ISSN: 0094-243X ISBN: 978-0-7354-1059-6

[11] E.Cardelli, A.Faba, R.Marsili, G.Rossi, R.Tomassini, "Magnetic nondestructive testing of rotor blade tips", Journal of Applied Physics 117, 17A705 (2015); doi: 10.1063/1.4907180

[12] R.Marsili, A.Garinei, "Development of a new capacitive matrix for a steering wheel's pressure distribution measurement", International Journal of Industrial Ergonomics Volume 44, Issue 1, January 2014, Pages 114-119 doi: 10.1016/j.ergon.2013.11.012

[13] G.Rossi, "Misure meccaniche e termiche. Basi teoriche e principali sensori e strumenti", Carocci, Roma, 2010.

[14] M.Becchetti, R.Flori, R.Marsili, M.Moretti, "Comparison between digital image correlation and thermoelasticity for strain field analysis", (2010) 9th International Conference on Vibration Measurements by Laser and Noncontact Techniques and Short Course; Ancona; Italy; 22 June 2010 - 25 June 2010 AIP Conference Proceedings, Volume 1253, pp. 233-240, doi=10.1063/1.3455462 ISSN: 0094243X ISBN: 978-073540802-9

[15] R.Marsili, G.L.Rossi, M.Becchetti, R.Flori, "Stress and strain measurements by image correlation and Thermoelasticity", Society for Experimental Mechanics - SEM Annual Conference and Exposition on Experimental and Applied Mechanics 2009, Volume 1, 2009, Pages 70-75; Albuquerque, NM; United States; 1 June 2009 through 4 June 2009; Code 78716; ISBN: 978-161567189-2; 978-161567189-2