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Research Article

MOBILE PHONE-BASED PHOTOGRAMMETRY FOR 3D MODELING OF SHIP HULLS

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ABSTRACT
Currently, maritime transportation constitutes the biggest part of world trade. For this reason, ships have a great importance and are effectively used throughout the world. Shipbuilding and ship repair industries frequently utilize engineering processes such as design, manufacture, repair, research and development, quality and control etc. In all the mentioned processes, digital data and CAD drawings of the ships are regularly used by engineers. While all these documents are usually included in the inventory of most ships, there are cases where these documents are lost or unavailable. Reverse engineering studies allow the reconstruction of digital data and CAD drawings of already existing ships. Ships are structures that are difficult to measure due to their sizes, complex geometries and curvature natures. For this reason, measurements are mostly made by advanced technological devices, not by human hands. Photogrammetry and terrestrial laser scanning are two of the most utilized methods contributing to ship surveys. In this study, a mobile phone-based photogrammetric survey method was utilized with the aim of obtaining the digital CAD data of a boat's hull. Data acquisition, post-processing, accuracy analysis, and results are presented in the study.

Keywords: *3D modeling, Photogrammetry, Hull modeling, Reverse engineering*

1. INTRODUCTION

Transport demand has risen sharply in recent decades, at or above the rate of gross domestic product (GDP) growth, and maritime trade has evolved as the most important type of cargo transportation. Maritime transport accounts for nearly 90% of global goods transported today, and it accounts for over 90% of the European Union's external trade and 43% of its domestic trade (Andreoni *et al*. 2008).

The shipping industry is an important part of international trade, as well as a significant factor for citizens and economies all over the world. The industry transports the majority of the world's goods, and thus serves as a cornerstone for global trade and the value generated by it (Holm and Kalinovs 2017).

Shipbuilding and ship repair industries frequently utilize engineering processes such as design, manufacture, repair, research and development, quality and control etc. In all the mentioned processes, digital data and CAD drawings of the ships are regularly used by engineers.

Since it usually refers to a product with geometrically complex freeform shapes, measuring and modeling such a component with traditional measurement methods is very difficult. The use of scanned data in the form of point clouds enables the designer of a seagoing watercraft to produce a detailed CAD 3D model, which can then be used for determining manufacturing quality, CAE system-based redesigning, engineering and simulation tests, and many more (Deja *et al*. 2019).

This digital model could not exist or be destroyed in many cases. As a result, implementing a reverse engineering technique which is capable of recreating a digital hull design is critical, and in some cases, the only wise choice (Athanasios 2021). Sometimes the literature provides no established design lanes for ship hull's variables, so engineers or researchers use reverse engineering techniques in order to obtain these variables, and then create 3D CAD model of ship surfaces (Winyall *et al*. 2012). When no product information exists (anymore) or when such information is considered inaccurate, re-engineering can be needed. Post-production shape validation, shape retrieval for damage repairs, safety evaluation (stability, strength) of ill-documented vessels, and interior refurbishment are examples of typical applications (Koelman 2010).

Traditional manual surveying instruments, mechanical machines, laser scanners, and photogrammeters are the key measurement techniques used in the marine industry for shape data acquisition (Koelman 2010).

Photogrammetry is an age-old technique that has been used in cartography and architecture since the second half of the nineteenth century (Yakar and Yılmaz 2008). Since it is based on the intersection of two or more optical rays, photogrammetry, like theodolites survey techniques, was destined to be used only by specialists with very costly instrumentation (Ackermann *et al*. 2008; Yakar 2009).

Photogrammetry has become an efficient, inexpensive, and simple to use technique as a result of the digital age and modern advances in informatics (both hardware and software) (Yakar *et al*. 2016). As compared to the traditional metric and semi-metric film cameras, digital cameras with high resolution frame sensors are becoming more popular and affordable (Yılmaz *et al*. 2000; Ackermann *et al*. 2008).

In the documentation process, photogrammetry is a stand-alone tool. This method relies on at least two images with overlapping data to ensure that the triangulation process is effective (Unal *et al*. 2004). The aim of digital close-range photogrammetry is to simplify and accelerate the data recording and processing (Yakar and Doğan 2018).

In a study, the researcher had developed reverse engineering algorithms for automated generation of ship hulls from hydrostatic curves and general ship data by using photogrammetry and laser scanning techniques (Athanasios 2020). Another study shows that photogrammetric survey methods make it possible to obtain 3D models of cultural heritages with the aim of documenting them digitally (Yakar and Doğan 2018). With application of photogrammetry-based systems, re-engineering processes such as ship hull shape modeling, hull shape measurements and corrections, damage analyzes and repairing can be carried out efficiently (Koelman 2010). In another study, a housing of the main propulsion propeller shaft for a newly designed vessel had been examined to create 3D CAD model and detect production defects (Deja *et al*. 2019). Another study demonstrates that hull form modeling and screw propeller modeling applications can be completely done by using low-cost and easy-to-apply photogrammetric methods (Ackermann et al. 2008). In addition, photogrammetry can also be utilized for creating 3D CAD datas of a trawler's hull and propeller. After obtaining the digital data, Martelli *et al*. (2015) used them to compare with the production data and to make efficiency evaluation. Another research showed that submarines also can be modeled in 3D by using photogrammetric and terrestrial laser scanning methods (Burdziakowski and Tysiac 2019). Another examination shows that prototypes of a fisherman boat and a catamaran hull vessel were measured by using photogrammetry and laser scanning methods with the aim of determining the accuracy of prototype ship models (Abbas *et al*. 2016). Documentation of maritime heritage is also an appropriate topic to utilize photogrammetric survey. In a study, the 3D modelling of a 3-m-long-scale model of a historic warship, the Indomito, is presented (Menna and Nocerino 2014). Hydrodynamic performance computations can also be made with photogrammetric modeling technique. Martelli *et al*. (2016) showed that overall efficiency assessment of a trawler propulsion system is completed with the aid of photogrammetric survey.

In this study, a mobile phone-based photogrammetric survey method was utilized with the aim of obtaining the digital CAD data of a boat's hull. In addition, lines plan of the boat was created. Finally, basic hydrodynamic calculations were made as a case study. Camera calibration, data acquisition, post-processing, accuracy analysis, and results are presented in the paper.

2. METHOD

2.1. Camera Calibration

A photograph is a central viewpoint that is often associated with a simple device known as a "pinhole camera". Three elements are necessary to fully define perspective in this geometric model: focal distance and the optical axis' intersection point coordinates with the image plane (interior orientation). Nonetheless, due to the nature of a lens that induces optical distortions, such a model is far from the real one (Ackermann *et al*. 2008).

In this study, Samsung Galaxy S10 mobile phone was used to capture images of the boat. The mobile phone has three rear cameras. The main camera of the phone has 12-megapixels with a 5.6x4.2 mm sensor size. Auto-focusing and focusing at infinity settings were applied. The minimum focusing distance of the camera is 0.10 m and the hyperfocal distance of the camera is 3.60 m. The lens of the camera has a focal length of 4.32 mm and (f/1.5) aperture. Focal length (35 mm eq.) is 27.7714 mm. In addition, the lens has a 66.3^o horizontal field of view and 52.2^o vertical field of view. Magnification factor was 1x for all photos taken.

Camera calibration process was made in Agisoft Metashape Professional software. The chessboard image of the software is utilized to calculate camera calibration parameters. 20 photos of the image were taken. Subsequently, the photos taken were transferred into the Agisoft software. In the final step, camera calibration parameters were calculated by the software automatically.

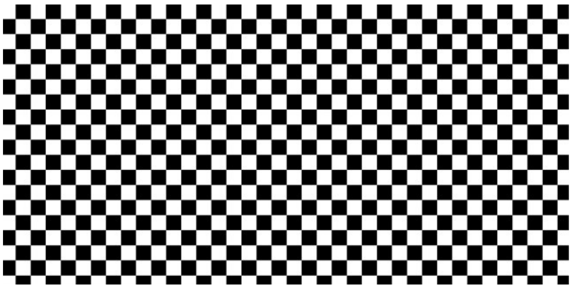

Fig. 1. Chessboard image of Agisoft Metashape Professional software

Table 1. Camera calibration parameters

Focal Length: 4.32 mm/Pixel size: 0.001554 x 0.001554 mm			
f:	2890.202	**cx:**	-43.351
k1:	0.307	**cy:**	11.783
k2:	-1.805	**p1:**	0.0007
k3:	4.087	**p2:**	0.0005
k4:	-3.124	**b1;b2:**	-0.253; -3.33

2.2. Data Acquisition

Fig. 2. Some captured images of the boat

The photogrammetric survey part of the study consists of two phases such as field work and the office work. During the field work, 185 images of the boat were captured by using the mobile phone. A constant focal length during the acquisition and a constant and lighting were utilized as much as possible. Blurry photos, flash light, optical stabilization, digital zoom, and fish-eye lenses were avoided with the aim of producing better results.

Furthermore, 8 measurements were taken on the boat for later verification. Three of these were used in dimensioning, while the rest were used in accuracy analysis. Red double-sided tapes were used to mark the boat.

2.3. Post-processing

After the completion of the field work, the office work phase was initiated. During the office phase of the study, 180 of the images were processed at Bentley's ContextCapture Software.

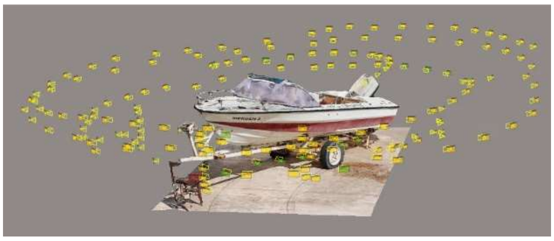

Fig. 3. Camera stations configuration of the boat

In order to use in dimensioning, six attachment points were marked on the model with the aim of defining three previously taken measurements. Six user tie points were marked on the boat to submit an accurate triangulation to the photos. Then, by taking precise measurements on the parts of the boat, predefined positioning and scale constrains were generated with six user tie points that marked before. Generic block type option was selected in order to help the triangulation process. Camera calibration parameters calculated before were imported into aerotriangulation process.

Fig. 4. User tie points and scale constrains – 1

Fig. 5. User tie points and scale constrains – 2

Fig. 6. User tie points and scale constrains – 3

The 3D point cloud data generation phase was started after the aerotriangulation process was completed. Colored point cloud was generated by selecting the options of 1 pixels point sampling, no-compression, and visible colors for color source. The acquired 3D point cloud data was imported into Agisoft Metashape Professional to remove redundant points and create an accurate 3D solid model of the boat.

Fig. 7. Point cloud data obtained by ContextCapture

During the mesh reconstructing process, source data was selected as dense cloud which was imported from ContextCapture. Arbitrary (3D) surface type was selected and high quality face count was applied. Interpolation was enabled and calculate vertex colors option was marked. 66 295 875 points for the boat were processed to obtain the 3D solid model.

Fig. 8. 3D solid model of the boat by ContextCapture

Fig. 9. 3D solid model of the boat by ContextCapture

After the 3D solid model of the boat constructed, accuracy assessment was also implemented. Firstly, a wavefront object (.obj) format of the 3D model was generated to utilize it in ANSYS Aqwa analysis after accuracy assessment step. In order to define the metric performance of the 3D model, 5 distances between selected detail points on the boat were compared with the distances acquired from Bentley's ContextCapture dimensions.

Fig. 10. Detail measurements for accuracy assessment

Before starting ANSYS Aqwa analysis, the 3D model produced was transferred to the Rhinoceros software. In Rhino, surface defects were removed and the surface was smoothed. After the surface treatments were completed, the lines plan for the boat was created by taking sections on the 3D model. As a result of this step, the waterlines, cross sections, buttocks and profile curve belonging to the boat were obtained.

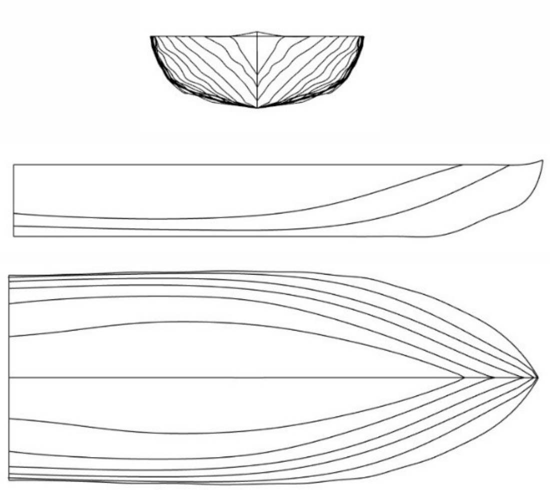

Fig. 11. Lines plan of the boat by Rhinoceros

In the last part of the study, simple hydrodynamic calculations of the boat were made. ANSYS Aqwa software was utilized for analysis. Firstly, the 3D model of the boat has been transferred to the software. Subsequently, boat draft, volume moments of inertia, center of gravity and weight of the boat were defined to the software. These basic hydrostatic values were calculated by using Rhinoceros, and then imported into ANSYS. The next step involved creating mesh and specifying analysis settings. After these were also completed, the analysis was started and the results were examined.

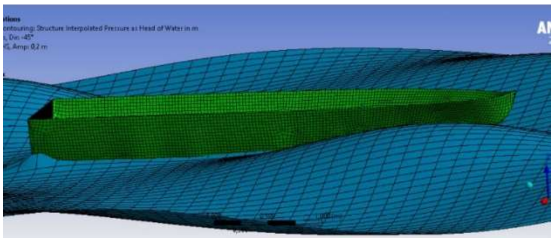

Fig. 12. Free surface and hull mesh image of simulation

3. RESULTS

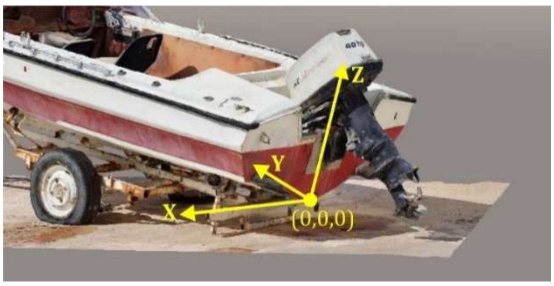

Fig. 13. Coordinate center of the 3D model

All results are presented according to the coordinate system specified in the ‘‘Fig. 13’’.

Considering the significance of design verification in the overall reverse engineering phase, few, if any, publications on part-to-CAD reverse engineering discuss modeling accuracy (Ingle 1994). After 3D model of the boat was obtained, the accuracy assessment was also applied. The result of the accuracy analysis was shown in the “Table 2”.

Table 2. Accuracy assessment of the 3D model [in cm]

Length	**Real**	**Model**	**V**	**VV**
1	6.80	6.90	0.10	0.010
2	20.28	19.63	0.65	0.423
3	22.75	22.63	0.12	0.014
4	35.65	36.01	0.36	0.130
5	85.80	86.17	0.37	0.137
			RMSE = 0.378 cm	

According to ‘‘Table 2’’, the 3D model of the boat has a root mean square error (RMSE) of 0.378 cm.

Table 3. Hydrostatic stiffness of the boat model

	Z	**RX**	**RY**
Heave (Z):	-46227.04 N/m	-127.45 N/°	1.02e-5 N/°
Roll (RX):	-7302.51 N.m/m	-753.53 N.m/°	-2.1e-5 N.m/°
Pitch (RY):	5.85e-4 N.m/m	-2.11e-5 N.m/°	-95.975 N.m/°

‘‘Table 3’’ shows the hydrostatic stiffness of the boat model. The values on the table indicates the boat’s resistance to doing the movements which are heaving, rolling and pitching. For instance, heave Z value was calculated as 46227.043 N/m, and it means that to force the boat into 1 meter heave motion, this amount of force is required. The similar situation is valid for the rotational motions above.

Table 4. Small angle stability parameters of the boat

BG	0.193 m	
GM_X/GM_Y	5.482 m	0.717 m
BM_X/BM_Y	5.675 m	0.911 m
M_X/M_Y	-733.403 N.m/°	-95.975 N.m/°

‘‘Table 4’’ indicates the small angle stability parameters of the boat model. BG was calculated as 0.193 m and it represents the distance between center of gravity (CoG) and center of buoyancy (CoB). GM_X and GM_Y are metacentric heights of the boat. BM_X and BM_Y represents the distance between center of buoyancy (CoB) and metacentre point. M_X and M_Y are the restoring moments of the boat at small angles.

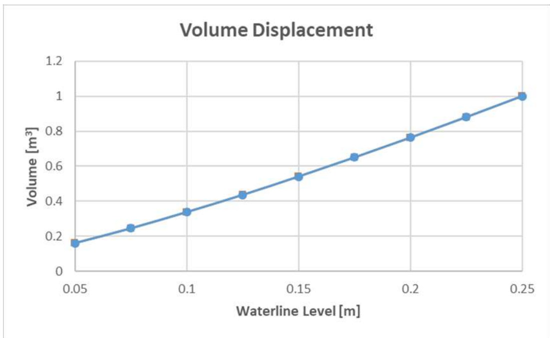

Fig. 14. Volume displacements at different water levels

‘‘Fig. 14’’ shows the displaced volume values in specified units. As the draft increases, the volume values increase as shown in the figure. This stems from the upwardly expanding geometry of the boat.

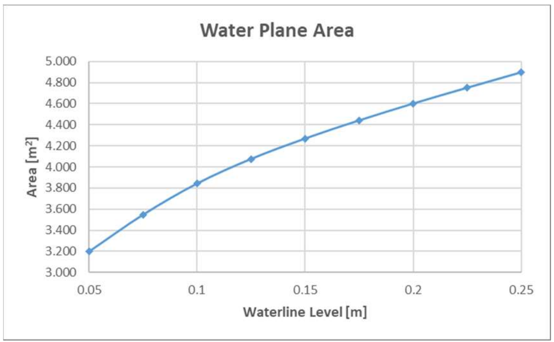

Fig. 15. Water plane areas at different water levels

‘‘Fig. 15’’ indicates the water plane areas of the boat at different waterline levels. As shown in the figure, the increase in waterline level leads to an increase in water plane areas. At small waterline levels the increase in area values is faster, while at the next values the increase is slower. This is again due to the geometry of the boat.

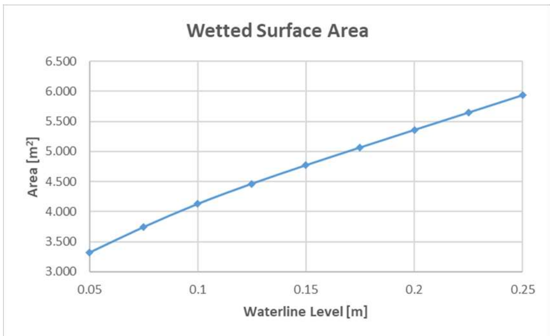

Fig. 16. Wetted surface areas at different water levels

‘‘Fig. 16’’ demonstrates the wetted surface area values of the boat at different water levels. As the waterline level increases, the wetted surface area also increases due to the fact that the boat will sink further into the water.

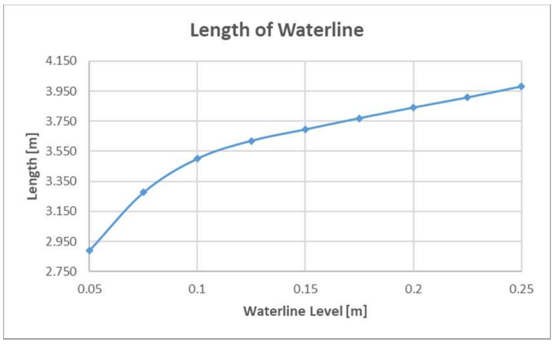

Fig. 17. Waterline lengths at different water levels

‘‘Fig. 17’’ displays the waterline lengths of the boat at different waterline levels. As shown in the figure, the increase in the waterline level gives rise to an increase in the waterline lengths.

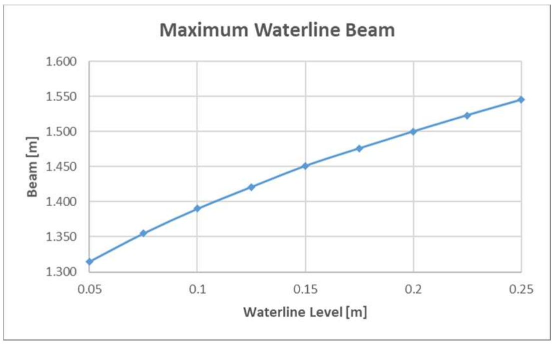

Fig. 18. Max. waterline beams at different water levels

Maximum waterline beam values of the boat at different waterline levels are shown in ‘‘Fig. 18’’. As shown in the figure, the boat's enlargement in the transverse direction is not as rapid as in the longitudinal direction.

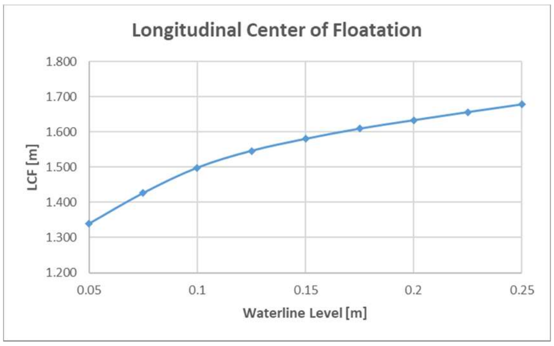

Fig. 19. Longitudinal centers of floatation at different water levels

Longitudinal center of floatation values of the boat at different waterline levels are presented in ‘‘Fig. 19’’. Because of the fact that the aft peak of the boat represents the coordinate center, the values above show the distance from the stern of the boat to the longitudinal center of floatation.

Table 5. Center of buoyancy coordinates at different waterline levels [in meters]

Waterline	X	Y	Z
0.050	0	1.259	0.0215
0.075	0	1.302	0.0357
0.100	0	1.346	0.0499
0.125	0	1.386	0.0641
0.150	0	1.421	0.0782
0.175	0	1.450	0.0923
0.200	0	1.475	0.1065
0.225	0	1.497	0.1205
0.250	0	1.518	0.1346

''Table 5'' indicates the center of buoyancy coordinates at different waterline levels. All coordinate values are presented according to the coordinate system specified in the ''Fig. 13''.

4. DISCUSSION

This study shows that 3D models of ships can be obtained with high accuracy by using mobile phone-based photogrammetric survey method which is an easy-to-use, low-priced, and efficient method. Although all processes were done in high quality in the software, the results are satisfactory. Higher accuracy could have been achieved if it was made in ultra-quality.

The results obtained correspond to the aim of the study. Although there are no technical drawings, measurements and details of the boat in the inventory, it is seen that all these can be obtained by using this method.

The results obtained have been added to the boat inventory and can be used in activities such as repair, maintenance, modification and restoration in the future.

The 3D model and drawings reconstructed in the study were acquired by processing the images of the boat. Since the surface is slightly indented in the first data processed, the smoothing process was carried out. If the processes were done with a higher quality, such a step would not be necessary and the surface lines would be modeled exactly.

In future studies, the results can be improved with a hybrid method by using a terrestrial laser scanner in measurements.

5. CONCLUSION

There are various reasons for utilizing reverse engineering. One of the essential purpose of selecting RE as an engineering calculation method is the deficiency of 3D CAD models of the existing parts. As a result of conducting this research, it is clear to be seen that accurate 3D CAD models of existing ships and their engineering calculations can be created/made by using mobile photogrammetric surveys and common engineering softwares.

The aim of this study was to obtain the digital CAD data of a boat's hull using a mobile phone-based photogrammetric survey method. In addition, the boat's lines plan was generated. Finally, as a case study, simple hydrodynamic calculations of the boat were performed.

The findings of this study indicate that mobile photogrammetric methods can provide ships with quick, precise, and accurate 3D documentation. Analysis of the 3D model's accuracy reported that less than 0.5 cm accuracy can be achieved without difficulty.

This study also presents that many engineering calculations can be made by using 3D models of the ships.

All things considered, for reverse engineering calculations, mobile phone-based photogrammetric survey is an effective, easy-to-use and accurate method.

In future researches, the findings could be developed and expanded by using a hybrid approach that includes measurements with a terrestrial laser scanner.

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