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# Low cost digital close range photogrammetric measurement of an as-built anchor handling tug hull

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ABSTRACT

A close range photogrammetric (CRP) model of an as-built 40 m anchor handling tug hull located in an open space shipyard was constructed in this study through the use of a low cost amateur digital single-lens reflex camera, together with a modestly priced photogrammetric software. Through a series of comprehensive statistical tests, the constructed CRP tug hull model was quantitatively evaluated and analyzed by comparing the CRP measurements with the manually measured tug hull offset data from a lines-plan drawing. The statistical tests showed that most of the measured target coordinates were considerably accurate in this study, with absolute mean of error 4.1 mm and absolute standard deviation of error $\pm 4.5$ mm. Paired Student *t*-test showed that the modeled CRP *Z*-offset data ($Z_{CRP}$) is not statistically different from the actual *Z*-offset data, $Z_{OFF}$ ($p > 0.05$). Linear regression analysis also illustrates a near perfect linear relationship between these two variables. The accuracy achieved in this study is considerably good and sufficient for usual metrological measurement in small- or medium-sized shipbuilding industry, despites the presence of disturbances related to the characteristics of the open space shipyard. In future, a better targeting approach or target material should be used to further improve the CRP measurement accuracy.



## 1. Introduction

An accurate and reliable 3-dimensional (3D) ship model is often required in shipbuilding industry for several purposes: for example, ship safety assessment, post-shipbuilding verification, ship survey, interior refurbishment, and damaged hull shape retrieval for subsequent maintenance and repairs (Ahmed et al., 2012; Kulur et al., 2004; Maas and Kersten, 1994; Ordóñez et al., 2009). Despite the importance and increasing employment of 3D ship model in shipbuilding, some shipyards are reluctant to provide the owner with the detailed 3D ship drawings, for fear of potential intellectual property conflicts, where the owner might take the design to the other shipyard for low cost duplication of the ship vessel (Norbury, 2013). Authentic 3D ship design model also could be unavailable sometimes, owing to the unreliable documentation and design practices in the past, or losing ship model documents during the sale and purchase of second-hand ship. To regain this 3D ship information, reverse 3D modeling technique is thus required, involving reconstruction of shape, geometry, dimension, and semantic information of the targeted ship. Conventionally, this is achieved by manual measurement, which is difficult, inefficient, and could be severely constrained by the size of the ship, not to mention that the ship hull is complicated with abundant free-form curves and shapes that are impossible to be measured by this method (Koelman, 2010; Sparacino and Arguto, 1991; Yaakob et al., 2014).

Nowadays, the most used instruments for reverse 3D ship hull modeling are active sensors, due to its high speed and distinctively accurate range data acquisition. Laser tracker, for example, is capable of measuring points with an accuracy of 0.1 mm at a distance of 10 m (Menna et al., 2009), whilst laser scanner, which is meant to give denser 3D point cloud model, was reported to give measurement noises of 1–15 mm for various types of scanners (Boehler and Marbs, 2003; Kersten et al., 2009). Despite the highly accurate 3D measurements of these active sensors, they are expensive and represent a significant investment capital to both medium and smaller shipyards. Active sensors are also bigger in size, and are inherently restricted to measuring objects within its line of sight only. This imposes a great challenge to the use of laser scanner in the reverse 3D modeling of ship hull, as there will not be a single position from where the whole ship hull surface is

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visible by the sensor. In some cases, the ship hull parts may have been concealed and can only be accessed through a very narrow passage or manhole. As a result, sizable measuring device like laser scanner is inapplicable in this kind of situation (Koelman, 2010).

Another industrial 3D measuring technique resorts to the use of a more modestly priced passive sensor, i.e. digital close-range photogrammetry (henceforth, CRP). This technique provides digital photo images of the targeted ship hull, which is then processed to establish the geometric relationship between the camera photos and the target, and hence the derivation for the target's 3D coordinates information (Mikhail et al., 2001). Through the established mathematical model of camera geometry, it allows the use of a wide variety of non-metric cameras, like the amateur or consumer grade digital single-lens reflex (SLR) cameras. The tolerated use of digital SLR camera has significantly suppressed the initial investment capital for CRP, and thus rendering it a standard technique for precise industrial inspection. With careful planning, calibration, and strictly controlled human errors, good accuracy of CRP measurement is attainable and comparable to that of the TOF-based terrestrial laser scanner (Koelman, 2008; Remondino et al., 2005). Typical CRP measurement precision was reported to be in the range of 1:100,000 to 1:200,000 with the former corresponding to 0.1 mm for an object of 10 m size (Luhmann, 2010). Unlike laser scanner, CRP is versatile, less delicate, and has virtually no restriction to accommodate with the target size and shipyard workspace, making it the most suitable 3D coordinate measuring technique in shipbuilding industry (Koelman, 2008; Menna et al., 2009).

Research on the potential use of CRP in reverse 3D ship hull modeling is not new. By applying CRP technique in a laboratory setting, Ackermann et al. (2008) reported a discrepancy less than 3 mm for the stations offsets of a wooden ship hull of $4.6 \times 0.8 \times 0.4$ m. Russo (2012), on the other hand, employed a sensor fusion technique of laser scanner and consumer grade digital SLR camera to generate the 3D model of a $6.4 \times 2.2 \times 0.82$ m rubber boat hull, achieving a 5.6 mm accuracy comparable to that of the laser radar. In real-world shipyard measurement, Mugnier (1998) was able to generate a reverse 3D CRP model of an as-built 30 m tugboat with the accuracy of less than 10 mm. These research studies represent one of the earliest investigations on the potential use of CRP in the reverse 3D ship hull modeling. In this study, a low cost 3D CRP measurement approach was proposed to be used in the 3D modeling of an as-built 40 m anchor handling tug (AHT) hull in an open-space shipyard. The approach requires only the use of a low cost amateur digital SLR camera, a modestly priced 3D photogrammetric software, and several A4 paper targets, rendering this approach to be astonishingly low cost. The accuracy and feasibility use of this measurement approach in tug hull modeling was eventually evaluated and analyzed through a series of comprehensive statistical tests.

## 2. Methods

This study was conducted at a shipyard in Sibu, Sarawak (Malaysia). An as-built $40 \times 12 \times 6$ m AHT (as shown in Fig. 1) was chosen to be the study target, owing to its accessibility and readily available 3D tug hull offset data by the time of this study. As the name implies, the primary role of the 40 m AHT is to assist in the handling of anchors that moored the offshore installation for station keeping, apart from towing, fire-fighting, and pollution mitigation duties in the upstream oil and gas industry. Prior to the actual on-site visiting and testing procedures, permissions on tug vessel access, and the use of shipyard facilities and equipments, especially the boom-lift, were specifically requested and granted by the shipyard managing authority. The CRP tug hull measurement was then performed, while the newly-built AHT was sitting on the keel blocks waiting for the tug owner's further instructions. The tug was placed in an open-field space, at an average distance of 5 m from the other work sites, and a minimum vertical distance of 0.7 m from the ground. Only one side of the tug hull workspace was free from the obstacles to give better camera vision span and coverage on the vessel.

### 2.1. Tug hull targeting and image acquisition

CRP tug hull measurements were performed using a digital SLR camera (Canon EOS 550D), and its main technical specifications are listed in Table 1. The camera was calibrated by means of camera calibration software provided by the PhotoModeler 2014© (Eos Systems, Inc.), following similar calibration methods as that in (Zhang et al., 2010) and (Pérez et al., 2011). Two camera calibration methods were applied: i.e. laboratory calibration and field calibration processes.

During the laboratory camera calibration process, the principal distance of the digital SLR camera was set to the widest-angle setting of 18 mm, and both of the focus and zoom rings were securely taped so that the focal length remained fixed for the entire image acquisition process. The camera calibration required taking shots of 12 readily printed calibration sheets (each sheet consists of five targets with inner target diameter of 12 mm) that were promptly arranged into a grid area of $1 \times 1$ m$^2$ on a flat floor surface. Four different perpendicular shot angles, i.e., 0°, 90°, 180°, and 270° were acquired for both horizontal and vertical camera positions. Optimal distribution of all target image points should be

Fig. 1. As-built 40 m anchor handling tug (AHT).