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Field evaluation of a hull block assembly process assisted by advanced optical 3D measurement systems

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Abstract:
This paper presents the results of a field study where advanced 3D measurement systems were applied to assist the assembly of hull blocks. The block-wise construction technique is discussed and the concept of measurement-assisted assembly is presented. The robotic total station and the indoor-GPS (iGPS) measurement systems used in the field test are described. The measurement strategy for the realization of the field test is reported. Advantages and drawbacks of both systems are discussed. The potential of measurement-assisted assembly for the reduction of production time in the shipbuilding industry could be confirmed. The experience with this qualitative study will be used in the development of an experiment to simulate an automatic block assembly using a Stewart Platform.

Keywords: measurement-assisted assembly, iGPS, robotic total station, shipbuilding, block assembly, Stewart Platform.

1 – Introduction

In order to enhance productivity and reduce production complexity, block-wise construction technique is widely adopted for medium to large size vessels (Dias Júnior, 2012, Eyres, 2012). Each block is composed by panels, structural profiles, machines, pipes and other parts. The blocks are constructed independently and afterwards taken to a building dock, where they are positioned, aligned and welded to form the vessel. This final assembly process is called erection (Lamb 2004). Equipment with high load capacity, such as platform vehicles, cranes and hydraulic jacks are needed to accurately position and align the blocks. Theodolites, laser levels, plumb-bobs and measuring tapes are frequently used as measurement systems. This assembly process is highly time consuming since it has to be done iteratively, intercalating positioning/alignment and measurement tasks. Also, the quality of the assembly is limited to the accuracy of the measurement equipment.

A paradigm shift in large-scale assembly is expected through the development of measurement-assisted assembly (MAA). MAA consists in using advanced measurement systems to enable accurate, fast and sometimes even automatic part-to-part assembly without iteration. Quality and productivity enhancement and thus cost reduction is expected by implementing MAA (Marpoulus et al., 2014). Laser trackers, robotic total stations, photogrammetry systems and indoor-GPS (iGPS) are some of the measurement technologies available for MAA.

Successful MAA applications for aircraft assembly have been reported (Marpoulus et al., 2014, Mosqueira et al. 2012). However, these results may not be directly transferrable to ship construction due to the harsh environment typically found in shipyards. To the best of our knowledge, no specific research on MAA for shipbuilding has yet been conducted.

The field experiment presented in this article is part of a research project that aims to explore the potential of MAA for shipbuilding applications. MAA processes enabled either by an iGPS system or by a robotic total station were tested in a real shipbuilding environment. The goal of the experiment is to qualitatively evaluate aspects such as functionality, productivity and. Also, the current assembly process adopted by the shipyard was observed in order to enable the development of an experiment to simulate an automatic block assembly using a six-degrees-of-freedom (6-DOF) robotic platform (Stewart Platform).

2 – Materials and methods

The field test was performed in a shipyard in Navegantes/SC, Brazil, where the assembly of a keel block of a platform support vessel (PSV) was underway. MAA measurements were done simultaneously to the conventional process conducted by the shipyard staff.

The shipyard uses a platform vehicle, similar to the one depicted in figure 1, to position and align the blocks. This equipment is able to perform movements in six degrees of freedom (6-DOF). Mobility in the horizontal plane (surge, sway and yaw) is possible through the displacement of the vehicle. Heave, roll and pitch movements are generated by hydraulic actuators.

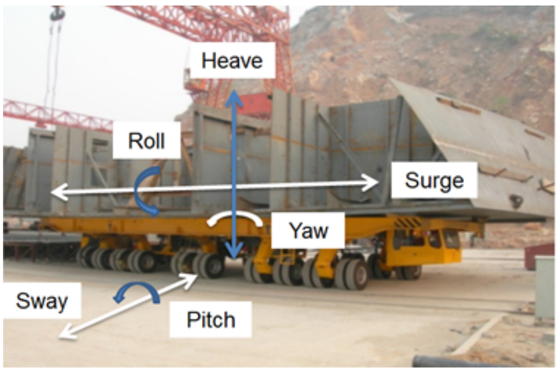

Figure 1 – Identification of the six degrees of freedom of a platform vehicle. Source: adapted from Unta, 2015.

2.1 – Measurement equipment

2.1.1 – Indoor-GPS

The optical measurement system iGPS, also known as rotary-laser automatic theodolites (R-LAT), operates according to the triangulation principle (Depenthal and Schwendemann, 2009). On triangulation-based systems the position of a target point is determined based on azimuth and elevation angle measurements from at least two stationary measurement stations with known position and orientation.

The system consists of three basic components: transmitters, which act as measurement stations, receivers (or detectors) and position calculation engines (PCE). The transmitters are equipped with a rotary head that sweeps two fan-shaped laser beams. Additionally, a LED ring emits a strobe signal at the beginning of each second rotation. Photosensitive sensors in the receivers detect the light pulses and convert them to an electrical signal. This signal is amplified, digitized and further processed in the PCE units that send receiver position and orientation data to a workstation. The rotation frequency of the rotors lies between 40 and 50 Hz. Each rotor operates with a slightly different frequency, enabling signal isolation (Mosqueira et al., 2012).

The angle measurement principle is depicted in figure 2. Azimuth is calculated from the strobe time t_1 and the average of t_2 and t_3 and elevation is derived from the difference between t_2 and t_3 (Muelaner et al., 2010).

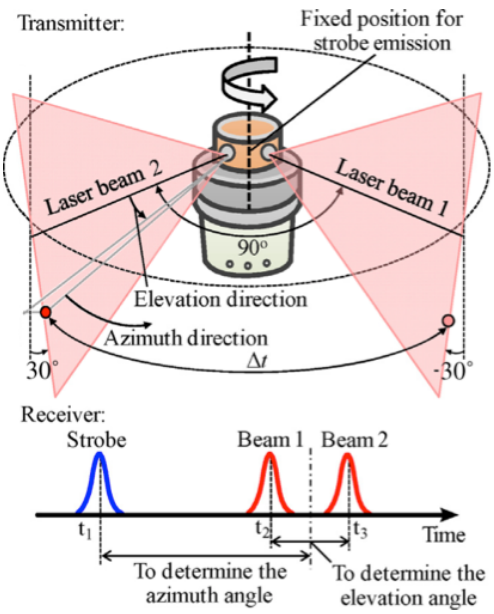

Figure 2 – Azimuth and elevation angle determination of a transmitter-receiver vector. Source: adapted from Depenthal et al., 2009

The receivers are integrated in measurement tools. The measurement tools available in our system are the scale-bar, which is used in the system setup, the mini vector bars, used as static reference points (monuments) as well as in dynamic tracking tasks and the hand-held vector bar probe (HHVB) which is the device used to capture single points. Each one of these tools is equipped with two receivers, enabling the determination of position and orientation in 5-DOF.

A 6-DOF tracking frame is created by fastening at least two mini vector bars to the object to be tracked. We used this type of frame to assess the alignment and positioning movements during the assembly process.

The typical maximum length measurement error of the iGPS under good environmental conditions is 0.5 mm (Depenthal and Schwendemann, 2009). Our iGPS system is a Nikon Metrology (formerly Metris) model iSpace 6i, manufactured in 2008. Experiments performed by our group confirmed the applicability of this system in assembly processes with production tolerances down to 1 mm (Heiden and Porath, 2016).

2.1.2. – Robotic total station

Total stations are measurement equipment derived from theodolites. Comparing to those, total stations are not only capable of measuring azimuth and elevation angles but also the distance to the point of interest, thus embodying a spherical coordinate system. Total stations were developed originally for geodetic surveying. More recently, accuracy enhancement, the possibility of reflectorless measurement and added robotic (motorized) functionalities have enabled industrial applications (Scherer and Lerma, 2009, Schmitt et al., 2016).

Robotic total stations are able to locate and track a target automatically (Scherer and Lerma, 2009). This feature can be used to track a moving structure during an assembly process. However, only translations (three degrees of freedom) can be tracked with one single total station.

Our equipment is a Leica TS 12, produced in 2015 (figure 3-left). The manufacturer states a maximum length measurement error of 1.0 mm + 1.5 ppm and a maximum angle measurement error of 7". The measurement range for the length measurement system is up to 3500 m. All specifications are valid for measurements using an appropriate reflector as target (Leica, 2016). In our experiment, 38.1 mm (1.5 inch) diameter spherical mounted cube-corner reflectors (SMR) were used as targets (figure 3-right).

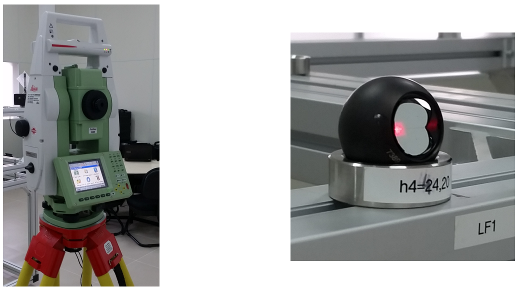

Figure 3 – Robotic total station (left) / Spherical mounted reflector - SMR (right).

2.2. – Experimental procedure

Due to visibility issues related to the presence of the platform vehicle, all measurement equipment had to be placed on one side of the hull. Five iGPS transmitters and the total station were installed on tripods on the floor of the assembly hall on the starboard side of the vessel (figure 4).

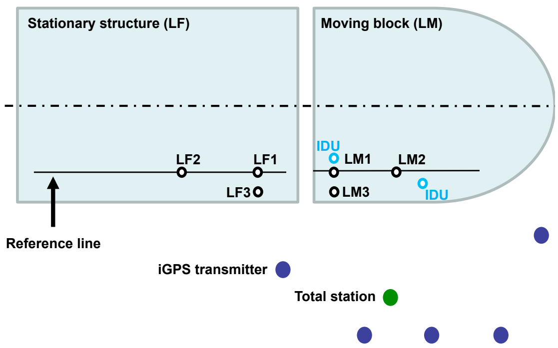

Figure 4 – Measurement setup.

All measurement targets were fastened with hot glue on the bottom of both the stationary structure (LF) and moving block (LM), also on the starboard side. For the iGPS, two IDU were used to track the displacement of the moving block (figure 5-a). Three conical nests (figure 5-a) were applied to mark the points of interest on the stationary structure (LF1-LF3) and other three nests on the movable part (LM1-LM3). Reference lines marked on the hull by the shipyard staff were used to correctly place the nests. These nests are metallic parts with inner cones that allow high reproducibility on capturing points with the spherical tip of the hand-held vector bar of the iGPS (figure 4-b) or with the SMR of the total station. A reference frame (coordinate system) was defined on the stationary structure (LF) using points LF1 to

LF3. For the iGPS, a second frame was defined on the movable block (LM) using points LM1 to LM3. After setting up the iGPS frame on the movable part, three total station SMR where glued on nests LM1 to LM3 (figure 5-c).

Figure 5 – Measurement targets.

The measurement data of the iGPS was displayed on a laptop (figure 6-left) and also streamed to a wireless portable device (figure 6-center), enabling the shipyard staff to track position and orientation of frame LM in relation to frame LF in real time. Also the coordinates of the points of interest LM1-LM3 regarding frame LF were displayed in real time. The coordinates of each one of points LM1-LM3 were also tracked with the total station and displayed on the wireless field controller of the equipment (figure 6-right).

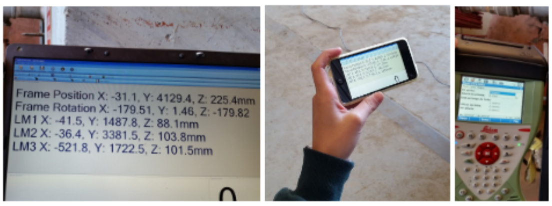

Figure 6 – Presentation of the measurement data.

3 – Results of the field tests

Both measurement systems could successfully be applied to track the displacement of the moving block in relation to the stationary structure. However, the meaningfulness of the measurement results could not be ensured due to the need of placing the measurement equipment on one single side of the hull. This in an evidence of the importance of appropriately planning the measurement strategy, considering all possible restrictions of the assembly process.

We could observe that the coordinates assessed by the total station and by the iGPS agreed within ±1 mm during the whole assembly process. However, a systematic experiment with an appropriate statistical evaluation has to be carried out to confirm this result.

An apparent limitation observed for the iGPS is that it is not able to provide a reliable measurement signal when an arc welding process is being performed close to an IDU. We are also planning to experimentally confirm this limitation in our laboratory. No other limitations related to the environmental conditions could be identified.

For MAA applications, the main advantage of the iGPS compared to the robotic total station is the possibility of tracking position and orientation and also simultaneously track several points of interest of a moving block. The robotic total station is able to track only the 3D-coordinates of one single point at a time. On the other hand, the total station is very portable and robust against environmental influences. Also, the cost of the equipment is at the order of 10x lower that the cost of a standard iGPS system. These characteristics are summarized in Table 1.

Table 1 – Comparison iGPS x robotic total station.

	iGPS	**Robotic total Station**
6-DOF tracking?	yes	no
Multiple points tracking?	yes	no
Robustness	↓	↑
Portability	↓	↑
Cost	↑	↓

↑: higher ↓: lower

4 – Outlook

In order to improve even more the efficiency of the erection process, a feasibility study on the automatic block assembly applying the MAA concept has been started. The goal is to use the measurement data provided by one of the 3D measurement systems to guide a robotic platform without the need of a person to manually operate the equipment, thus reducing process time and costs and enhancing the quality of the assembly. The first step of this study is to design a downscaled robotic platform that features the same mobility as the platform vehicle used in the ship construction process.

In a previous study, several requirements on this platform have been identified and possible solutions evaluated (Amaral and Simoni, 2016, Amaral and Simoni, 2015). Due to budget and working space limitations, the reproduction of a wheeled platform was not feasible. The Stewart Platform topology has been selected because of its appropriate mobility for the intended experiment and the possibility of further applications (Amaral and Simoni, 2015). The Stewart Platform prototype depicted in figure 7 is under construction in the Laboratory of Industrial Geodesy (LGI) of UFSC in Joinville.

Figure 7 – Stewart Platform prototype under development at LGI/UFSC.

The Stewart Platform is a closed kinematic chain (parallel) robot consisting of a moving platform connected to a stationary base by six kinematic chains (legs). The Stewart Platform features six degrees of freedom, i.e., three translational and three rotational movements, as shown in figure 8. Thus, the Stewart Platform meets the requirements of the intended application, since it presents the same mobility as the platform vehicle used in shipyards.

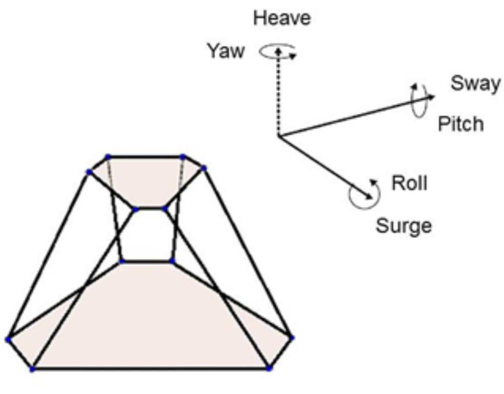

Figure 8 – Degrees of freedom of a Stewart Platform.

The mobility of the moving platform is six, thus six actuators are needed to position the platform in space, being each of it responsible for varying the length of one of the legs (Acunã, 2009). The kinematic design of the platform enables high positioning repeatability and high load capacity, which are fundamental requirements for the intended application.

For the planned experiment, the measurement data provided by the iGPS or by at least two robotic total stations have to be used to guide the Stewart Platform. Based on this data, the coupling trajectory will be planned using Bezier Curves or Splines in order to avoid rough movements. The mathematical model of the Stewart Platform involves the solution of the inverse kinematic and has already been implemented and simulated (Amaral and Simoni, 2016, Amaral and Simoni, 2015). The control of the servomotors is at the final development stage and final tests will be performed as scheduled in the project.

The objective of this experiment is to validate the use of iGPS or robotic total station to assist the automatic assembly of hull blocks. The Stewart Platform will be used to validate the procedure in our lab. The subsequent step is to automate the platforms available in shipyards.

5 – Conclusions

In this paper we reported a field test performed to evaluate the application of an iGPS system and a robotic total station to assist the assembly process of hull blocks of a platform support vessel. Both measurement systems could successfully be applied to track a moving block in relation a stationary structure. Because of unpredicted visibility issues related to the position of the platform vehicle, only measurements from one side of the hull were possible. The iGPS systems presented signal instabilities when arc welding was performed very close to the detector units. The point coordinates provided by both systems agreed within the range of ±1 mm. These results are still to be confirmed in our laboratory through careful experiments and appropriate statistical evaluation. Advantages and drawbacks of both systems have been highlighted.

Through this experiment, the potential of measurement-assisted assembly in the shipbuilding industry could be confirmed. According to the shipyard staff, the use of MAA could represent an important improvement in terms of assembly time and accuracy, when compared to the current positioning and alignment process using plumb-bob, measurement tape and laser-level.

The field test also contributed to the planning of the next experiment, where a downscaled automatic assembly will be demonstrated using a Stewart Platform. The iGPS or the robotic total station data will be used in the closed loop control of the inverse kinematic of the platform.

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