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Macro-photogrammetry as a tool for the accurate measurement of three-dimensional misalignment in welding

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ABSTRACT

Misalignment in welding presents several problems for the integrity of structures and machines. For this reason, the measurement of misalignment is relevant for the correct evaluation of quality in welds. This paper presents a new low-cost procedure based on photographic images acquired with a non-professional camera. The procedure consists on the application of macro-photogrammetry for the generation of a three-dimensional point cloud from the images. Subsequently a mathematical processing based on Principal Component Analysis (PCA) is applied to the generated point cloud in order to fit a plane to each welded plaque. The evaluation of the orientation between fitted planes allows the accurate measurement of the angle of misalignment for the welded union. The method is validated by the comparison of the results with those obtained with the metrological techniques.

1. Introduction

The analysis of steel and aluminum welded elements is especially relevant because their failure can affect severely the safety and stability of structures and machinery. For this reason, quality requirements [1–3] are very demanding regarding geometry of welds and presence and characteristics of imperfections or flaws.

Misalignment in welding is an imperfection that has to be evaluated, since it relates to deviations from the correct position or alignment of the joint. In this way, misalignment can be linear or angular (or both). Linear misalignment consists on the linear sliding between the welded elements, while angular misalignment is an angular distortion with respect to the desired angular position of the weld (desired angle between welded elements [3]).

The principal cause of misalignment is the stress derived from the shrinkage, which provokes a distortion in the material. This distortion misalignment can be located and analyzed (Fig. 1); it can be acceptable if it is evenly distributed, whereas in other cases it may render the whole structure unfit for its purpose. In a ship's hull, for instance, buckling of the hull plates could induce turbulence and increase dragging; in piping, it can restrict fluid flow; while in architectural applications it can be aesthetically unacceptable [4].

Defects such as angular misalignment in welded joints for steel and aluminum can produce premature failures. The existence of misalignment could be the cause of undesired shrinkage in stress accumulation zones [5], especially in welds subjected to dynamic stresses but also in welds subjected to static stresses.

For this reason, the angular misalignment and other type of flaws in welds are mainly studied and evaluated through Non-Destructive Techniques (NDT). One of them is the visual inspection technique (VT) of welds; it is an extremely important test applied to the detection of superficial imperfections and flaws, which are the most frequent defects in welds [6]. VT is important for having an overview of the state of the weld and making an early detection of possible defects and imperfections. A welding inspector is the person who evaluates the quality of the welds; who is frequently an engineer with vast experience in welding processes and material engineering who has passed different examinations in order to get a welding inspector certificate [7]. The inspector mandatorily has to visit the welding installations to test the welds and measure them, which entails an economic investment. Normally, welding inspectors use gauge kits for VT, designed to measure the principal geometrical parameters of welded unions including angular misalignment. However, these tools are inaccurate due to its manual nature, and misalignment in welds may be difficult to detect visually. More accurate and advanced techniques to evaluate the quality of welds, although less used by inspectors, are ultrasounds [8], electrical resistance [9] and novel techniques like scanning cameras [10], laser [11], 2-D stereo imaging [12] and thermography [13]. New procedures for the specific evaluation of angular misalignment in quality control of mechanical elements based on ultrasounds and vibrations have

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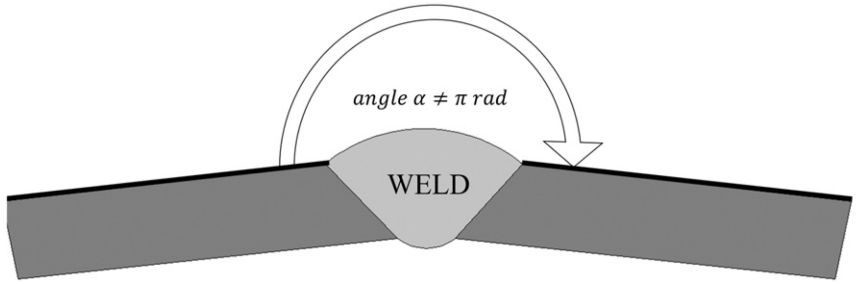


Fig. 1. Misalignment in a weld appears when the desired angle α between the surfaces of the welded plaques does not match with the real angle.

been proposed [14]. In this work, the shaft arrangement in a typical 2 MW wind turbine is tested. The displacement of the shaft is detected with proximity sensors and compared through vibration analysis and acoustic emission techniques.

Regarding the photogrammetric reconstruction of welds, the actual state of art is very limited, consisting on a few recent examples of application. In [15] a macro-photogrammetric process is proposed to evaluate the quality of welds under the international standards [1,2]. In this work, a 3D model of the welds is obtained through this technique, and flaws and imperfections are evaluated through the sectioning of the 3D model.

A remote evaluation of misalignment in welding is presented in this paper. The need for the development of this evaluation method is justified by the importance of ensuring the physical integrity of the welds of different materials, using non-invasive methods. In this way, the objective of this paper is to propose a new efficient low-cost procedure based on the only use of photographic images, which allows the remote measurement of the angle of misalignment in butt-welds and filled-welds with high accuracy through the application of fitting plane procedures and the mathematical study of their orientations. In order to analyze the accuracy of the method, results obtained are compared with the data obtained with a metrological Coordinate Measuring Machine arm.

The paper is structured as follows: first, the Materials and Methodology section where the different materials and approaches used are described. Then, the Results section includes all data obtained. Next, the Validation section is established in order to analyze the adequacy of the results. Finally, the Conclusions section is included.

2. Materials and methods

2.1. Materials

Specimens used for the study consist on welded metallic plaques (Table 1). The first of them is a welded steel planar plaque (from a ship's hull), which is used to apply the procedure and to establish a differential study between the different methods shown in the following section. The second of them is an aluminum T-welded plaque (automotive bodywork), used for the validation of the technique.

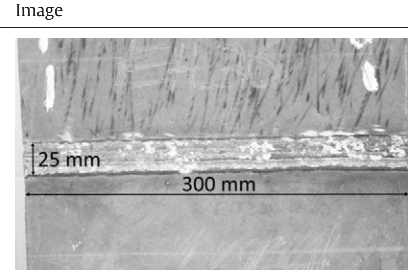
The welding procedure used for both specimens is Tungsten Inert Gas (TIG) welding. This typology of specimens has been chosen due to the high usability of both the material and the welding procedure in the structural and mechanical sectors.

A commercial Digital Single Lens Reflex DSLR camera Canon EOS 700D with a Canon 60 mm macro lens is used; its technical characteristics are defined in Table 2. A tripod is used for the stabilization of the camera given the high exposure times required. In order to homogenize and optimize the illumination conditions, two halogen lamps (2×50 W) are used.

Finally, the photogrammetric process is performed on the self-proprietary software inteGRAted PHOtogrammetric Suite (GRAPHOS) [16]. GRAPHOS provides an easy-to-use platform for both non-expert and expert users, incorporating the recent developments in photogrammetry and computer vision, for their use in complex scenarios and the 3D reconstruction of complex objects.

For the accurate assessment of the obtained results, a Hexagon Romer Absolute Arm 7325 SI 3D scanner is used. The system can be used for scanning and for spatial geo-referenced positioning of probe

Table 1
Description of specimens used for the experiment.

Weld	Description	Image
1	Low carbon steel (thickness 7.5 mm) which shows butt-welding with edge preparation in V.	
2	Aluminum (thickness 2 mm). T-joint. Filled-weld.