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Procedure for quality inspection of welds based on macro-photogrammetric three-dimensional reconstruction

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ABSTRACT

The results of visual inspection of welds depend on the visual ability of inspector. With the optical macro-photogrammetric low-cost procedure proposed in this paper only a digital single lens reflex camera with a macro-lens and a photogrammetric reconstruction software developed by the authors are needed for the generation of accurate and scaled 3D models of welds directly from images taken by a non-expert operator. This result eliminates the need of an in-situ assessment by the inspector, since it can be done directly using the 3D models generated, which the inspector can consult for the performance of all the measurements required by international standards.

1. Introduction

Within the defectology of materials, the study of the cracking process presents enormous importance in order to ensure the safety of structures, vehicles and machines. The principal innovation in the analysis of crack deformations occurred during World War I [1], when the engineer Alan Arnold Griffith established a new discipline within the mechanical engineering called Fracture Mechanics [2]. The cracking process is dangerous because it may end with the failure of the structural element and thus, a full collapse of the structure with drastic consequences. Therefore, the assessment and characterization of the type of crack is important for the prediction of their propagation direction and the measurement of their rate.

The visual inspection (VT) of welds is an extremely important test, applied to the detection of superficial imperfections and flaws, which are the most frequent defects in welds [3]. VT is important for overviewing the state of the weld and making an early detection of possible defects and imperfections. A welding inspector is frequently an engineer with vast knowledge and experience in welding processes and material engineering who has passed different examinations in order to get a welding inspector certificate [4]. The inspector mandatorily has to visit the welding installations to test the welds and measure them, which entails an economic investment.

There are different advanced techniques to evaluate the quality of welds and/or detect and measure cracks and other flaws with more accuracy than with tools commonly used by inspectors (welding gauge kits for inspection) on VT, some of them are more traditional like ultrasounds [5], electrical resistance [6] and other more novel like scanning cameras [7], laser [8] and 2-D stereo imaging [9]. There are also image techniques that allow the study of propagation and behavior of cracks like the called Digital Image Correlation (DIC) [10]. Direct optical crack observation is usually the most frequent technique in a first inspection.

Currently, close range photogrammetry is applied to numerous fields of industry and engineering, the main fields being the automotive manufacturing (control of materials, adjustment of tooling, etc.), aeronautic industries (antenna measurements, alignment, adjustment of mounting rigs, etc.), wind energy systems (water dams, plants, etc.) [11] and naval engineering [12]. Recently it has also been used to study the strength of materials in the structural industry [13], deformations [14] and welds [15]. Furthermore, photogrammetry has been longtime used as an instrument to make microscopic measures [16]. Endoscopic photogrammetry with two identical and opposite cameras with the symmetry edge aligned has been used to characterize joints in pipes [17].

On the opposite, the photogrammetric technique has also been used supported on macro and microscopic lens to model and measure little objects. Gallo et al. [18] used a digital DSLR camera with a macro-lens to obtain highly accurate photogrammetric models of complex geometries from a large number of images (between 432 and 1296). Atsushi et al. [19] developed a system

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with a digital microscope lens for the reconstruction of a 3D micro model as a triangular mesh using several 2D images of the object taken from different points of view. With the macro-photogrammetric technique proposed in this paper, 3D modeling of welds is possible. Thus, the in-situ visit of the engineer is not necessary since the visual inspection can be performed by the inspector directly from the office, by analyzing a high-resolution and metric 3D model that is automatically generated from images acquired with a DSLR camera by any worker of the welding installation.

The measures for quality analysis on VT have been performed by using different tools (caliper, micrometer or welding gauge kits designed for this purpose) but their use always requires the presence of the inspector (with the obvious drawback of the displacement of the engineer inspector to the installation site) and usually presents high error rates. The success of the measurements frequently depends on the skill of the inspector and the accessibility to the weld. Furthermore, obtaining measures of the depth of the crack is not always possible due to its frequent small dimension, the heterogeneity of the different areas into the crack and the error of the in-situ traditional measuring instrument. For this reason, in this paper, authors propose a new low-cost method where the only tool required is a commercial digital single lens reflex (DSLR) camera with a macro-lens and a self-proprietary software developed by the authors [20], which allows the reconstruction of a scaled 3D model. As a result, a detailed inspection of the weld, including the detection of its surface imperfections and flaws together with its discontinuities is allowed, enabling an easy and automatic documentation and digitization of the quality inspection project (Fig. 1) consisting on the models generated for the different weldings present in the inspected site.

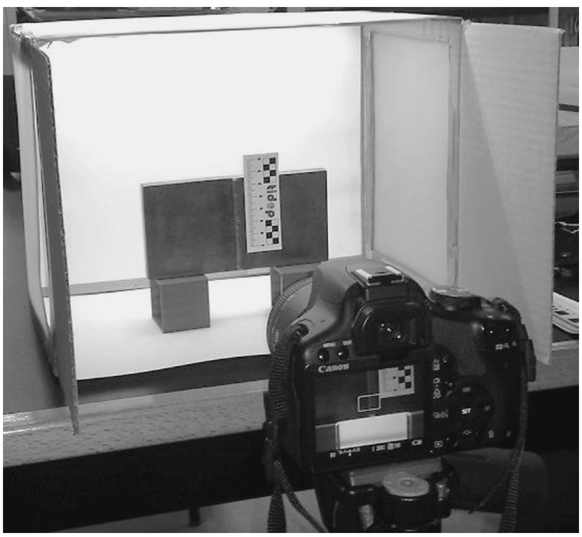


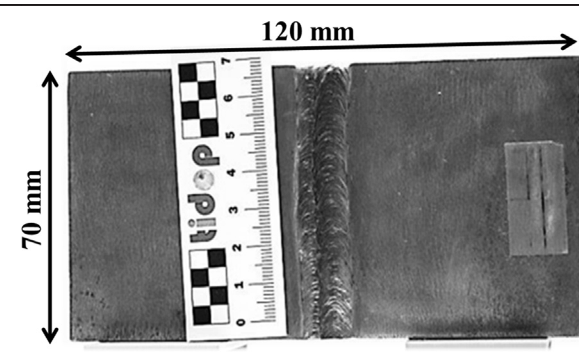
Fig. 1. Data acquisition procedure. Camera-specimen configuration.

2. Materials and methods

2.1. Materials

Specimens consist of welded planar steel plaques (Table 1). The welding procedure used is Tungsten Inert Gas welding (TIG). This kind of specimens has been chosen due to the high usability of both on the material and the welding procedure in the structural and mechanical fields. The specimens present a plane butt-welding, which has been chosen due to its higher and more complex surface and curvature than other welding dispositions like T-welding. In this way, if the technique is validated with a more complex 3D geometry consisting of a complete planar surface, the technique will also be validated for other welding dispositions with simpler geometry.

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	Low carbon steel (thickness 10 mm) which shows butt-welding with edge preparation in V.