Macro drop and droplet profile detection during PGMAW process by image processing library

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Abstract. This document describes the preparation of an article using LaTeX 2_ε and `iopart.cls` (the IOP LaTeX 2_ε preprint class file). This class file is designed to help authors produce preprints in a form suitable for submission to any of the journals published by IOP Publishing. Authors submitting to any IOP journal, i.e. both single- and double-column ones, should follow the guidelines set out here. On acceptance, their TeX code will be converted to the appropriate format for the journal concerned.

1. Introduction

A better comprehension of welding objects behavior presents a PGMAW process as macro drop and metal transfer drop (droplet) could help to improve numerical simulations and enhance welding quality in manufacturing process [?], [?]. An example to this are the problems linked to productivity. To some process, increase productivity mean increase weld speed, however some welding defects related to bad shape, as the hump formations, limit the maximum weld speed [?] and therefore the productivity. In a PGMAW process the weld quality is strongly relates with the metal transfer process stability (the droplet deposition), then control of metal transfer process implies control of weld quality [?]. In both example cases a macro drop kinetic study and a droplet dynamic analysis could help to better understand some GMAW related phenomena as humping formation [?], droplet fluctuations [?] or guarantee the welding quality. In both case, the kinetic and the dynamic analysis, required the monitoring [] and the geometrical analysis of macro drop and droplets in order to extract qualitative information of these welding objects.

There have been many studies on visual sensing techniques for observing weld pool image [?] and metal transfer process during welding [?]. Optical sensors like high speed CCD cameras and lighting systems have been widely use in GMAW process to realize image acquisition [?], control process [?], parametric studies [?] and droplet dynamics analysis[?]. Then image processing plays a critical role in extracting useful information from visual scenes [?]. Nevertheless the strong interference from the arc lightning required more than standard image treatment to analyses the raw images of the welding process [?]. Previous work has shown that is possible to perform geometrical analysis in weld pools or droplets [?]. Parameters such as macro drop or droplets surface, volumes or height has been measure using different and specifics processing images algorithms [?], [?], [?], [?]. However, to date, effectively automatic images processing of metal transfer has not been developed, possibly due to the level difficulty involved for welding researchers [?].

To perform geometrical analysis in macro drop and droplet; a multipurpose C++ based library (erCv) was developed by the Weld/Assembly group of LMGC laboratory. These library results from selected functions join from highly reliable open source libraries to images treatment, geometrical analysis, graph theory applications and image visualization.

In a first step, and despite the different static and dynamic weld conditions, as well as different current regime. A reliable 2D profiles and geometrical parameters from macro drop and droplets, has been obtained using the mentioned library. Using this, a dimension and dimensionless analysis has been performing. The intention is to help to simplified futures numerical models of humping phenomena and quality process.

2. Problems description

Bradstreet was the first researcher to experimentally study the bead hump formation [**?**]. Humping was defined as the series of undulations of the weld bead. Further studies as computer simulation made by CHO et al. [**?**] shown a relation between the droplet momentum deposition and the hump size. Same relations has been found between metal transfer process and welding quality []

Then the shape and size kinetic analysis of macro drop and droplets could help to better understand and enhance the PGMAW process. To monitoring the shape and size of these welding objects, to a first step, a 2D approach would be sufficient. Therefore a shadowgraphy technique, or back lighting, is the natural choice to record the droplets and macro drops profiles [**?**], furthermore is one of the only way to access these quantities. Due to the arc light interference and the relatively high speed of wire feed process, a high speed camera and an effective image processing algorithms are required [**?**]. The typically frame rate acquisition to metal transfer drop kinetic analysis is 3000 per second [**?**]. Therefore the algorithms have to be able to extract the geometrical information (area, size and others) from the macro drop and droplets, from a huge amount of data. In addition, the voltage and current signals are directly related with the droplet formation at the wire [**?**]. Good synchronizations methods have to be applied between shadowgraphies frames and electrical signals.

3. Image processing background

Some definitions and brief description of generals principles used in image processing are required to better understand how is work the algorithms utilized by the erCv library.

3.1. Some definitions

A numerical grey image can be describe as 3D surface discretized by a grid mesh in the X,Y plane. Each mesh represents a pixel and the relief surface at Z axis, the grey level.

A strong relief change or high gradient greyness values at the image are perceive by human eyes as light changes, and can be interpreted as objects edges. Sometimes, a regular relief patrons or regular greyness variation can be distinguish. The human eyes can perceive these patrons as texture and interpret the space between different textures zones as edges. There exist a large spectrum of algorithms to image treatment, in particular to edges detect. Most of them can be classified by the way that his operate above the image pixels and grey level.

3.2. Filters

The filters are algorithms that operate as mathematical functions f above the X, Y or both axis of the image ($Z = f(X, Y)$, $f(X)$ or $f(Y)$) modifying his greyness value or Z component. Different kind of filters can be mentioned as median, Gaussian, impulse,

adaptive and others. The impulse filters such Canny are widely use to edge detection [**?**]. These filter have an impulse response to most important greyness gradient in the image; this allows the filter a better edges localisation (see figure **??**). For this reason, Canny filter is widely use at erCv library to detect the welding elements edges. However, it is sensible to noise or secondary greyness gradients in the image and, in consequence, it have some difficulties to define closer surface.

3.3. Snake and level set

Curve propagation is a popular technique in image analysis for object extraction, object tracking, edge detection and others (see figure **??**). The central idea behind such an approach is to evolve a curve towards the lowest potential of a cost function. However at each stage of curve evolution, each curve point potential has to be computed. A lot of point (better curve resolution) take a lot computing time, and therefore are not yet apply to real time detection or relatively speed automatic image processing. For this reason snake algorithms are not used at erCv.

3.4. Segmentation

Let B an image and let R_i a region of B such:

$$B = \bigcup_i R_i \forall i R_i \neq \emptyset \forall i, javec i \neq j \ R_i \bigcap R_j = \emptyset \tag{1}$$

A B segmentation is an image treatment which generate a B partition in R_i regions. Each region is a connected set of pixels with common properties (intensity, texture,...) [**?**]. The partition is generated by operations or comparisons methods between regions. Generally, this treatment offers a good detection edges if the elements and surrounding area have different textures (see figure **??**). Note that different regions can belong to the same partition and not be placed together, therefore the surface is not always connected and, in consequence, the edges of the interest regions are not always closed.

[Weld pool image in static GTAW process][width=3.5cm,height=3.5cm]photo-explication-patron.png [Canny filter treatment][width=3.5cm,height=3.5cm]photo-explication-filters.png [Snake treatment][width=3.5cm,height=3.5cm]photo-explication-snake.png [Segmentation image by 2 cluster sample comparison][width=3.5cm,height=3.5cm]photo-explication-segmentation.png

Figure 1. Samples of different methods technique for image processing

4. Image treatment library (erCv)

As mentioned, a multipurpose image processing library was developed and currently use at the laboratory, in order to analyze welding process objects. erCv is able to perform

[width=7cm,height=4cm]schema-erCv.png

Figure 2. Flow diagram of erCv library composition

edge detection and geometrical analysis in a different welding objects such: Macro drop, droplets and weld pool. erCv is a modular library assembled in a oriented object C++ language. Then erCv is a scalable and portable library able to perform real time contour detection. erCv is build in Phyton scripts link to C++, making it relatively convivial to use. erCv is compose by four processing modules based in C, C++ and python language (see figure **??**). These modules are:

Image Treatment: Due to weld process conditions such arc lightening, heat and electrodes positions; the raw image registered by CCD camera are not calibrated and present light inhomogeneities and noise. In order to obtain the real shape and size of weld elements, this module include calibrations algorithms. To detect the welding objects contours it is necessary to improve the weld element image. This module has the pre-processing treatments to noise reduction and image enhancement. Then to start the edges detection process, this module includes processing algorithms as segmentations by samples comparators, watershed transformation, filters edge detectors and histogram based methods.

Geometrical Treatment and Analysis: This module has to end the edge detection process, completing and in some cases extrapolating the weld elements edge. It is also responsible to compute the geometrical data of welding elements such weld pool surface and metal transfer drop volumes. This module uses a full geometry algorithm library, which include different algorithms such as triangulations and mesh generation, alpha shape and convex hull generation and polygonal structures.

Graph Theories: To compute the geometrical data of welding elements it is necessary to extract the welding object edge from the image; this required some criteria such as continuity, length or closer condition. This module use graph algorithms to convert edges pixels points into connected segments, and therefore, identify and select the welding element edge using the criteria. This module is compose by connect segments, estimates minimal cut, determine largest chain segments and others algorithms.

Visualization: This module is a set of functions use to execute, show and/or register the different steps at the image process.

5. Experimental Setup

5.1. Multi-physics platform

The objective is to perform geometrical analysis and measure characteristic times of the macro drop and the droplet in a PGMAW process. Notes that geometrical analysis

[width=7cm,height=4cm]schema-platform.png

Figure 3. Experimental platform and specific device

[width=7cm,height=4cm]schema-montage-experimental-GMAW.png

Figure 4. Experimental setup to detect macro drop and droplet edges in GMAW process

refers to area section of droplets, height profile of macro drop and wetting contacts angles of the macro drop. And characteristics times measures refer to time to height stagnation of macro drop and fall time of droplet between electrodes. The methods choose is the image treatment of recorded image of PGMAW static process by a high speed CCD camera.

To perform the geometrical analyses, different signals have to be synchronizes and recorder [**?**]; therefore an accurate, reliable and synchronizes systems are requires due to the high amount of data and highly noisy environment (electromagnetic noise and arc light radiation).

A platform has been developed at the laboratory to perform multi-physics measures in arc welding process (see figure **??**). The platform was conceive with an automatically procedure to synchronize, to acquire, to manage and to exploit large flow of multi-physical experimental data (up to 2 Go per test). This characteristic allows synchronizing (in time) the current and voltage signals with the acquired images.

To compare and analyze the data two open source numerical libraries have been developed: The BAME (multi-physics measures data base) for all general data and the erCv specific to image treatment (including the spreading of welding pool geometry during welding).

5.2. Image acquisition setup

The PGMAW static process is recorded by Shadowgraphy optical method. A halogen lamp is use to light the weld process. To guarantee a homogeneous illumination of the welding process, a light diffuser is place in the optical path closer to the halogen lamp. Finally the shadows of welding elements are projected to the other side of the welding place. A Phantom V5.0 high speed camera is place and align at this side above the optical path (see figure **??**).

To enhance the image contrast of the weld elements inside the electric discharge, the intensity rate between arc light and halogen lamp have to be reduce. In order to this a 650 ± 10 nm band pass filter is place in front the camera lens, to attenuate the arc light. Nevertheless, the raw images remain highly noisy by the arc light.