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

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Abstract.

1. Introduction

A better comprehension of welding objects behavior presents in a PGMAW process as macro drop and metal transfer drop (droplet) could help to improve numerical simulations and enhance welding quality in manufacturing process [1], [2]. For example, the increase of productivity means often increase of weld speed, however some welding defects related to bad shape, as the hump formations, limit the maximum weld speed [3, **?**] and therefore the productivity. In a PGMAW process, the weld quality is strongly relates with the metal transfer stability (the droplet deposition). The control of metal transfer process will improve weld quality [4]. In both example cases a macro drop kinetic study and a droplet dynamic analysis during static PGMAW process could help to better understand some GMAW related phenomena as humping formation [5], droplet fluctuations [4] that 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 [6] and metal transfer process during welding [1]. Optical sensors like high speed cameras and lighting systems have been widely use in GMAW process to realize image acquisition [7], control process [6], parametric studies [8] and droplet dynamics analysis[1]. Image processing plays a critical role in extracting useful information from visual scenes [4]. Nevertheless the strong interference from the arc lightning required more than standard image treatment to analyses the raw images of the welding process [9]. Previous work has shown that is possible to perform geometrical analysis in weld pools or droplets [2]. Parameters such as macro drop or droplets surface, volumes or height has been measure using different and specifics processing images algorithms [4], [2], [**?**], [9]. However, to date, effectively automatic images processing of metal transfer has not been developed, possibly due to the difficulty involved for welding researchers [4].

To perform geometrical analysis in macro drope and droplet; a multipurpose C++ based library (erCv) was developed at the lab. These library results from selected functions 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 will be done. The intention is to help to simplified futures numerical models of humping phenomena and quality process.

The paper is organized as follows. First, the purpose of the library is explained, then the experimental setup to study macro drop analysis is detailed. The library and the algorithms developed are explained and some results are shown on the macro drop and droplet study.

2. Problems description

Bradstreet was the first researcher to experimentally study the bead hump formation [5]. Humping was defined as the series of undulations of the weld bead. Further studies as computer simulation made by CHO et al. [5] 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 [8], 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 [4]. The typically frame rate acquisition to metal transfer drop kinetic analysis is 3000 per second [4]. 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 [8]. 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 1(b)). 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 1(c)). 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:

$$B = \bigcup_i R_i \tag{1}$$

$$\forall i \in \{0, \text{numbers of regions in B}\} \tag{2}$$

$$\text{with} R_i \neq \emptyset \tag{3}$$

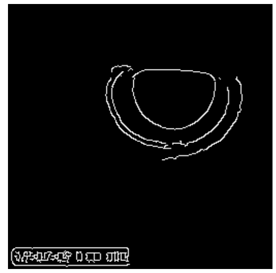
$$\text{and} R_i \bigcap R_j = \emptyset \forall i, j \text{ with } i \neq j \tag{4}$$

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 1(d)). 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.

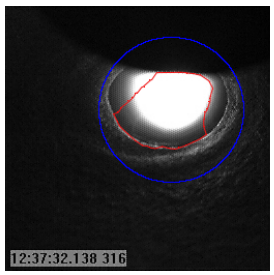
4. Image treatment library (erCv)

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 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

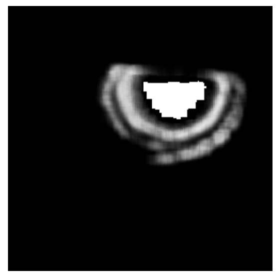
(a) Weld pool image in static GTAW process



(b) Canny filter treatment



(c) Snake treatment



(d) Segmentation image by 2 cluster sample comparison

Figure 1. Samples of different methods technique for image processing

use. erCv is compose by four processing modules based in C, C++ and python language (see figure 2). 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

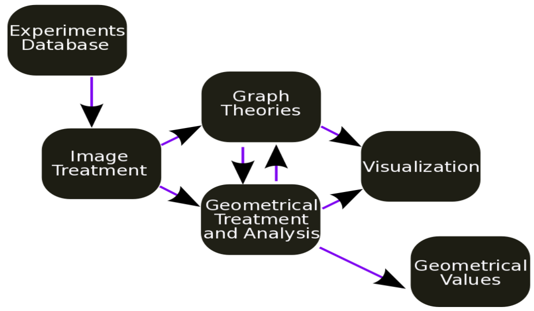


Figure 2. Flow diagram of erCv library composition

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 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 [3]; 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 3). 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).

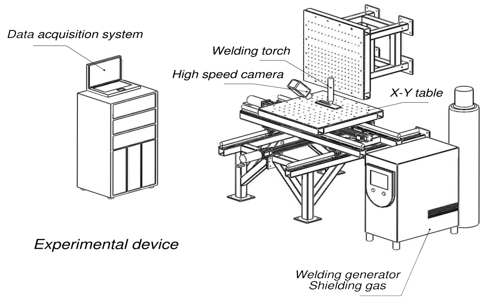


Figure 3. Experimental platform and specific device

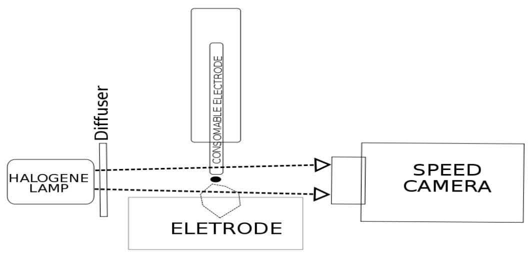


Figure 4. Experimental setup to detect macro drop and droplet edges in GMAW process

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 4).

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.

5.3. *Welding condition*

Stationary spots weld are made using the GMAW process with the Oerlikon CitoWave 500 generator. The target is a steel disk of 10 mm of thickness and ER70S steel welding wire. The test campaign began by a reference test, with parameters fixed to: welding time 4 s, wire feed speed 6 m/min, frequency droplets 113 Hz and percentage of shielding gas (CO_2) 8 (so 92% argon). Welding parameters values are summarize in tables 1 to static and 2 to variables parameters.

Welding wire type	ER70S
Wire diameter (mm) or drw	1
Contact tip to work distance (mm)	20
Shielding gaz flowrate (l/min)	18

Table 1. Determined constant welding parameters used in experiments

Welding wire type	ER70S
Wire diameter (mm) or drw	1
Contact tip to work distance (mm)	20
Shielding gaz flowrate (l/min)	18

Table 2. Variable welding parameters used in experiments

Welding current and arc voltage are recorded at 30 kHz sampling rate. The images are recorded at 4000 frames per seconds, which is enough to measure macro drop radius and apparent liquid-solid contact angle histories. The images and electrical signals are synchronize, thanks to the automatically approach made in the multi physics platform.

Measurements are made using the erCv library.

6. System definitions

6.1. Macro Drop

The purpose is to study the evolution of weld pool object in a GMAW process or macro drop. Therefore it is necessary to study the shape and spreading of the macro drop according depositing droplets of feed wire.

At figure 5 appears the geometrical elements to be study at the macro drop: the macro drop radius at the base R_m, the macro drop center height h_m, the macro drop volume V_m, the penetration below the surface level p and the wetting angles: $\Theta_{m(al)}$, $\Theta_{m(ar)}$ (apparent) and $\Theta_{m(rl)}$, $\Theta_{m(rr)}$ (real). With the indices l and r refer to left and right angles. The indices: m refer to macro drop, g refer to gaz, l refer to liquid, s refer to solid/substrate and a refer to the droplet.

6.2. Metal Transfer Drop

To the droplet or metal transfer drop the geometrical parameters to identify are: The estimate volume V_a and the estimate radius R_a. Finally in order to better understand the droplet dynamic [], the physical elements to identify are: the fall time t_a and the average speed U_a (see figure 5).

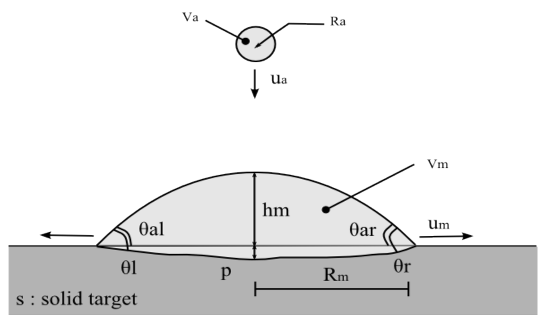


Figure 5. Profile schematics of welding objects in a GMAW process

7. The Analyze methods

7.1. Image Calibration

As was shown in section **??**, the camera recording a shadow projection of the welding process. The projection is supposed to be a section of the welding process image, orthogonal to the optical path. Therefore, to a first approach, not image projection correction is necessary. Only to calibrate the image dimension (at pixels) to the real objects dimension (at millimeters), a conversion scale is made with the known width of the welding wire $conv = 1\ mm/20\ pixels$.

7.2. Image Treatment

The idea is to extract the macro drop and droplet shapes from the raw image and therefore to extract the geometrical information. The most common approach is to segment the image [4]. That means to separate in two fields (color) the image. The macro drop and droplet in one color and the rest of the image in other [**?**]. Thanks to the optical method acquisition (shadowgraphy) the images are already segmented between light and shadow zones (see figures **??**); where the shadows zones are the projection of the macro drop and droplet.

However objects within the arc may differ only by few intensity light level from the background. In these images areas a contrast enhancement is necessary. Objects outside the arc, as the some regions of the macro drop profile, are clearly visible against the background. In these regions a contrast enhancement can lead the image quality and thus an incorrect segmentation [9]. Therefore the contrast enhancements, or threshold, have to be adapted par regions in the image.

To simplify the contrast enhancement, the images are converted from RGB image color to grey levels image (see figure 6(b)). To reduce the grey level noise, a first smooth classical filter (Blur) is applied over the image. The filter replace the grey values of squares of 7×7 pixels by they average value (see figure 6(c)). In consequence, the homogeneity quality is improve into the light and shadows regions, despite the edge contrast reduction induce between these regions.

Then, a regions adaptive threshold can be used to enhance the difference between shadow elements and light zones. To the adaptive threshold it is important to choose the correct size region where it will be applied. Small regions to threshold will generate isolates patters (groups of pixels). Big regions will generate a classical like threshold image [10]. The region size dominium choose to threshold application is 23×23 $pixels$. The threshold criteria choose is binary: $greyL_{thres}(x, y) = max_value$ if $greyL_{origin}(x, y) > threshold(x, y)$ or $greyL_{thres}(x, y) = 0$ otherwise, $\forall(x, y)$ inside the region to threshold [**?**]. Where $threshold(x, y)$ is the threshold parameter, max_value is the grey level value choose to identify the pixels above threshold parameter, $greyL_{origin}(x, y)$ is the grey level value of pixel before threshold and $greyL_{thres}(x, y)$ is the pixel grey level after threshold. $threshold(x, y)$ is obtain by subtraction between the average grey level of region pixels neighborhood and a constant parameter $C_{threshold}$. Small edge defects can still be found, due to the previous smooth filter and some arc light interference regions, which are bigger than regions size to threshold (see figure 6(d)).

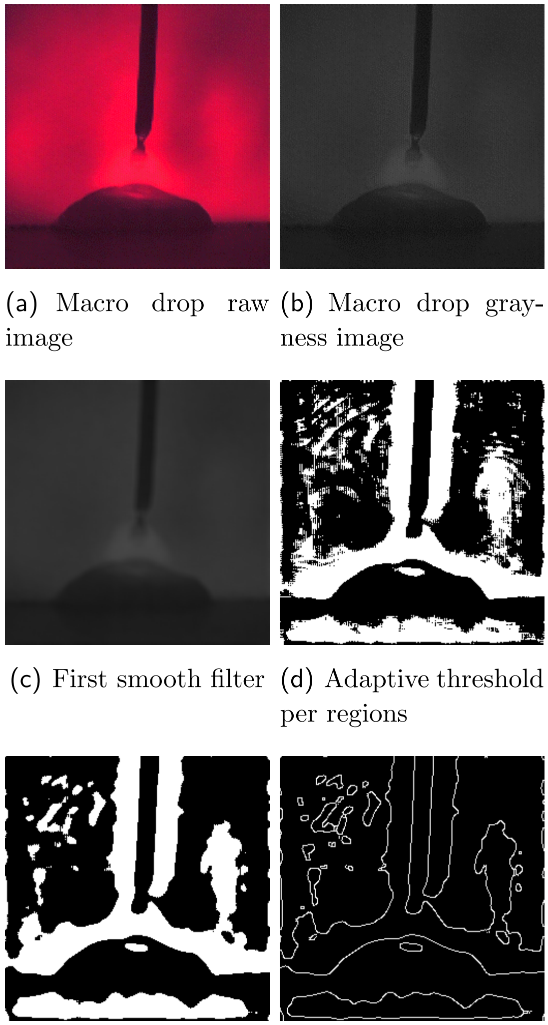
A second filter type median is necessary to improve the previous threshold treatment. This filter compute the grayness median value over 7×7 $pixels$ region. The image, which is already binary type due to adaptive threshold processing, is enhancing in his mixed black white regions depending of median value. In consequence contour quality between light and shadows regions at the binary image are improved (see figure 6(e)).

Finally an impulse response filter to grey level gradient (Canny) is applied to extract the principal edges at image. In a binary image, all edges are principals, therefore canny detect all edge at the image (see figure 6(f)). Nevertheless to guarantee a full detection of droplet and macro drop profile, the canny parameters are adjusted to maximum, which means maximum edge detection sensibility.

7.3. Edge extraction

Despite performance achieve by the image treatment, Canny filter generate many edges, or cords, in the image. These cord are composed by white pixels, interpreted by the algorithms as an individuals points. In order to automate the edge extraction process, geometrical and graph algorithms are used to isolate the cords corresponding to macro drop profile and edge section droplet.

To the macro drop profile a user interaction algorithm is responsible to extract the continuous cord (white pixels) corresponding to the profile into a list. Note that the macro drop and the substrate have the same continuous profile (see figure 6(f). The substrate shadow projection is always the same if the optical path doesnt change. Therefore the users have only to choose, to first image in the experience series, one extreme of the cord corresponding to substrate profile (see figures 7). Then the algorithm finds all new white pixels inside a small neighbor around the pixels selected by the user. Each new white pixel is added to the profile list. Starting at each new pixel, this process



(a) Macro drop raw image (b) Macro drop grayness image

(c) First smooth filter (d) Adaptive threshold per regions

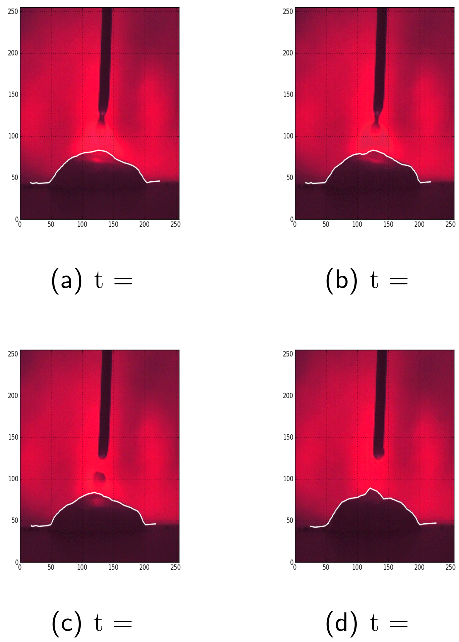
(e) Median filter (f) Canny filter

Figure 6. Image treatment step by step of PGMAW process

continues, automatically, until the other extreme of the cord, until the last image of the series.

To the droplet edge section, the white points cord defines the surface of the droplet. Note at figure 8(a) that the biggest closer cord correspond to the droplet section. The idea is to build segments around the cords, and take the longest closer segment.

Give S the set of points in the space image. The segments could be building between wherever two points of S. However, to fulfill the cords with segments, only the points placed together could define a segment. To choose the correct points of S a Delaunay triangulation is made over S [**?**]. Each point of S is a vertices of a triangle and then each potential segment is a side of a triangle. The Delaunay triangulations guarantee a unique solution with minimal internal angles for each triangle, which means minimal length sides to the triangles [**?**]. Give β the cord surrounding the external hull of the Delaunay triangulation of S. An alpha shape algorithm uses a $\alpha \in N$ parameter,

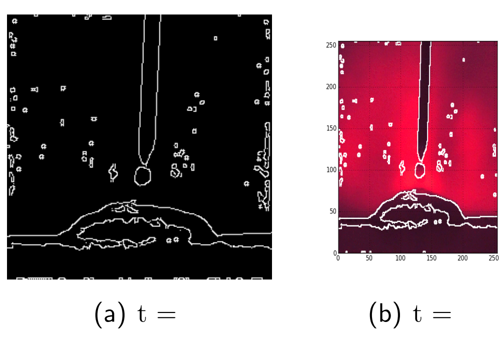


(a) t = (b) t =

(c) t = (d) t =

Figure 7. Images series of macro drop profiles

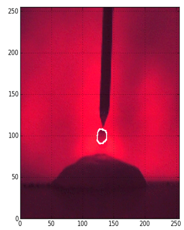
or square radius of a test circle, to travel from outside β to inside the triangulation. The circle has to go through the triangles sides without touch the vertices. Give n the number of triangles sides of triangulation and l_i with $i \in \{1, n\}$ the length of each side, if $\sqrt{\alpha} > l_i$ with $i \in \{1, n\}$, a segment is build between the respective vertices or points. At the end of the process, a segments set know as α-shape has been created. Note if $\sqrt{\alpha} > l_i \forall i$, the circle cant be go inside β, then α-shape is β [**?**]. If $\sqrt{\alpha} < l_i \forall i$ the circle go through every side in the triangulation, then no segment are created and α-shape became S. The points that compound the droplet section are all contact neighbors. Then $\alpha = 1$ is sufficient to create a segment set around the droplet (see figure 8(b)).



(a) t = (b) t =

Figure 8. Images series of macro drop profiles

A graph algorithm connects this segment and finds the longest closer segment. The longest closer segment corresponds to the metal transfer drop profile (see figure 9).



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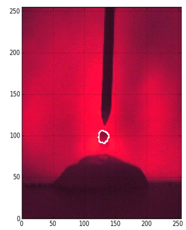

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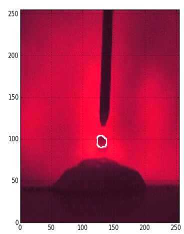

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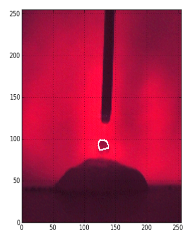

(d) t =

Figure 9. Images series of macro drop profiles

7.4. Geometrical Analyze

Now it is possible to determine the geometrical parameters shown at figure 5. In order to this, it has been developed several functions linked with the BAME and erCv libraries. For example, to wetting angle measures, linear regressions or least squares (parabolic, ellipse, circle) are taken from the processed macro drop extracted profiles. A loop algorithm applies this method to all frames at the experience to compute the wetting angles. Same procedure is use to estimate the macro drop radius and volume [3].

8. Results

8.1. Macro Drop analyzes

8.2. Droplet analyzes

9. Conclusions

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