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Machine vision in gas metal arc welding process: a case study

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Abstract: Machine vision is a trend in many industries, due to improvements obtained from its application and high precision on visual information extraction. In the welding researches, the use of machine vision is ample with application on the measurement of drop diameter, observation of molten pool oscillations, recognition of spatter pattern and many other dynamics. In this work, a study about machine vision is provided, where some machine vision algorithms, which are applicable for welding processes analyses, are discussed. As a case study, the discussed algorithms were applied over images obtained from a high speed camera by shadowgraphy technique of mass transfer in a Metal Inert Gas/Metal Active Gas (MIG/MAG) process by globular transfer mode. The aim of applied algorithms is turn evident the edges of weld droplet to identify their radius. This is an initial step of a bigger work, where this information will be synchronized with electrical signal of voltage and current transducers and weld bead image, creating a dataset. The dataset information will be crossed with a weld bead quality evaluator, which will point when, where and what is the possible cause for weld defect as oscillations in current or voltage for training of an intelligent controller. The information of droplet diameter also allow relate the material volume which is transferred for the molten pool, then with properly calculation, it will be possible to calculate the generated spatter.

Keywords: Machine vision; Image processing; Computer vision; MIG/MAG welding process.

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1. Introduction

Welding is a common process applied on the fabrication and repair of metal pieces in many industries as manufacturing, automotive, aeronautic, aerospatial and others industrial fields. Among welding processes, Gas Metal Arc Welding (GMAW) process is the most widespread joining operation for metal pieces in manufacturing industries (Evald et al, 2017). Some good reasons for the popularization of this process are the efficiency and high productiveness (Bera et al., 2013). Furthermore, equipment for GMAW process combine versatility and mobility (Evald et al, 2017), what are excellent properties for industrial environment.

Some advantages of GMAW process in relation to the other welding processes are the possibility of weld all commercial metal and their alloys, low generation of slag and facility of process robotization. Moreover, this process can be realized in any position and used to weld thin weld beads for thin metal plates. In addition, the consumable material has low coasts (Ueyama et al., 2005). On the other hand, the process is complex, because it presents highly sensible and coupled parameters, time-dependency and uncertain. This complexity is associated to the multi-influential nature of the process as metallurgy, heat transfer, chemical reaction, arc physics and magnetization (Baskoro et al., 2011).

The GMAW process generates an electrical arc between solid electrode and shielding gas (Rudas et al., 2015), that melts the electrode by heating provided by Joule effect and the own heat inherent of electrical arc. This process use shielding gas to isolate the arc and molten pool from ambient contamination (AWS, 1987). In relation to the shielding gas, GMAW process can be divided in two categories: if shielding gas is inert, then the process is called MIG (Metal Inert Gas), on the other hand, if shielding gas is active, then the process is called MAG (Metal Active Gas) (Evald et al., 2016; Wëglowski et al., 2008).

Traditionally, in welding processes, human experts perform quality control through visual inspection (Mital et al., 1998). Although there are many other approaches, this methodology is commonly utilized until nowadays, and not limited to weld quality evaluation (Rodríguez-Gonzálvez et al, 2017). However, humans cannot monitor the process when it is occurring, because the radiation light emitted from the electrical arc is harmful for the eyes (Nakashima et al, 2017, Nakashima et al, 2016). Thus, an alternative is realizing the monitoring of welding process using machine vision techniques. Among them, the two most famous are stereo vision method and structured light method (Wang, 2014). Some successful works that applied stereo vision methods are (Zhang et al., 2012; Zhao et al., 2009; Mnich et al., 2004), and works that

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successful applied structured light method are (Wang et al., 2013; Wei et al., 2011; Lu & Zhang, 2006).

In this work, a weld droplet analyzer was constructed to analyze images acquired with high speed camera with structured light method and shadowgraphy technique. Moreover, these images were treated with some image processing algorithms to turn evident the droplet edge. Although, this research is in its initial steps, their aims are well defined for this work, among them: employ machine vision on weld dynamics analyses through application of image processing and estimate droplet radius by analysis of acquired image from high speed camera and shadowgraphy technique.

2. Literature review

Image processing is an important technique to extract useful information from visual process data and this method has been used in welding industry for multiple aims from quality analysis until seam tracking, measuring weld pool geometry and process monitoring (Tsai et al., 2006; Saeed & Zhang, 2003). As mentioned by a set of researches as Balfour et al. (2004); Miller et al. (2002); Yamada & Masubuchi (2000); Wu et al. (2004) and Modenesi & De Avelar (1999), real-time sensing of weld pool dynamics are very important to improve feedback for control techniques. Moreover, it was highlighted by Yu et al. (2009) that vision-sensing system is one of most relevant methods to capture and process weld droplet and molten pool images. Thereby, in this section, some works which use machine or computer vision with image processing algorithms on weld dynamics analysis are discussed.

Shao et al. (2011) developed an image processing algorithm to analyze droplets contours. This algorithm was based on K-mean clustering algorithm, used to remove edges far from droplet common shape. Experimentally, authors shown the effectiveness of proposed algorithm for edge detection of weld droplets and their sub-regions. This recognition was used to formulate polar coordinate equations, which was a reasonable approach for a droplet-forming model. In addition, the image processing was used for droplet radius measurement and feedback a control law that adequately controlled droplet formation size in GMAW process, supported by a laser to detach weld droplets.

The research realized by Baskoro et al. (2011) consisted on the use of a Charge Couple Device (CCD) camera to capture images from the molten pool of a GMAW process using mild steel and monitoring the pipe welding with machine vision to understand process dynamics. In the image treatment, it was applied filters to turn image in grayscale, followed by threshold process. These treated images were used to train a neural network with Levenberg-Marquardt

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algorithm. Then, this expert neural network was used for simulation of weld bead width behavior.

Yu et al. (2009) used classic methods of processing image to extract weld pool edge in images captured by a CCD camera. A narrow band filter was utilized to reduce arc light reflection on metal transfer, spatter and other sources efficiently. It was implemented a traditional image processing algorithm and identified some disadvantages for using it in GMAW process with Aluminum alloy. Therefore, a new method to avoid these issues was proposed. This method was based on dilation, erosion, opening and closing of arc and so on, that is, the algorithm expresses the interaction among object and structural elements. The algorithm was named Morphological Image Processing. Then, a fuzzy logic controller was used to control molten pool width and experimental results proved that this new algorithm shown feasible control feedback usability. These are only some works selected from the literature, there are many others works on weldng researches using machine vision and image processing algorithms, with different purposes and not limited to GMAW process.

3. Machine vision

Pitas (2000) defined machine vision as techniques that concern with object model creation from object pictures. In addition, Szeliski (2010) compared machine vision to the human ability to perceive the world, that is, how people recognize shapes, patterns and illumination. Moreover, it is highlighted that machine vision is commonly called as computer vision in the literature.

Figure 1 shows a machine vision system for visual information extraction of a welding process. In this scheme, a computer is used to process images acquired by a camera, which is placed in a convenient local of observation, generally directed for the weld bead of workpiece to capture images of material transfer or molten pool. The regions of observation can be illuminated by an auxiliary illumination system (Malamas et al., 2003). The illumination system can be a laser, a set of Light Emitting Diodes (LEDs) or any other. Furthermore, when the control system acts in real-time, it is common use an auxiliary hardware for image processing, as a microcontroller Raspberry pi, instead of a computer.

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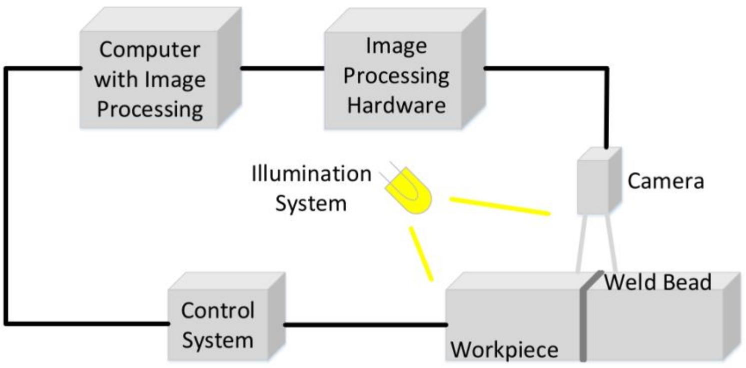

Figure 1 - Machine vision system scheme for welding process

For visual inspection of a system, a usual process is compound by following sequence of procedures:

• Image acquisition: the images are obtained by a camera;

• Image processing: filters can be applied over the acquired images to remove noises or unnecessary reflections from the illumination system. For welding process, filters are also employed to deal with overshadow, generated by electrical arc light (De & Parle, 2013; Umeagukwu et al., 1989).

• Feature extraction: information are obtained from acquired image. This information can be size, position, color, contour measurement and texture of the analyzed object (Oyeleye & Lehtihet, 1998)

• Decision making: combination of features in smaller sets are realized to obtain new features with better performance (Malamas et al., 2003).

4. Image processing

Image processing concerns with transformation of an image and its processing by digital computers (Pitas, 2000). These methods has been employed in a high number of applications, especially for feature extraction and to obtain patterns from digital images (Alkoffash et al., 2014). Roesser (1975) emphasized that an umpteen researches highlighted that image processing is focused on two main aim: first line is based on image nature, that is, image restoration, image enhancement, linear pattern recognition, picture coding and bandwidth reduction. By the other hand, the second line includes known linear techniques for image processing treatment.

The image processing methods are widely used to obtain information from images. These strategies are used in many fields of industry. In the welding industry, these techniques are employed to analyze characteristics of material transfer and molten pool, with aim to improve the weld quality. The identification of possible issues is realized associating acquired

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images to electrical signals, ambient conditions and others factors that can influence in the weld quality. Thereby, these techniques can be a powerful tool for welding process monitoring (Saeed & Zhang, 2003; Tsai et al., 2006). The image processing operators modify one or more input images and produce an output image. Too many techniques can be applied on input image, for example: color transformations, filters and distance transformations (Szeliski, 2010).

An important procedure before the image processing is the definition of region of interest (ROI). As said by Tsai et al. (2006), ROI consists in removing most unwanted information. Moreover, the aforementioned authors affirmed that ROI is based on the brightness of regions in captured images.

Other good procedure is the interpolation of data points. This procedure is useful when the used camera has low quality resolution, so the data interpolation can improve acquire images. Interpolation is based on transformation of a discrete matrix into a continuous image (Lehmann et al., 1999).

Furthermore, filtering techniques are very useful tools on image processing. These procedures are commonly utilized to reduce or eliminate noises that are present in the images as showed by Tsai et al. (2006). The discussed procedures are only some ones, in the literature there are others.

5. Shadowgraphy technique

The applications of high speed camera is present in many laboratories. Since 1985, the high speed camera is utilized on researches of welding process as seen in the pioneer work of Arata et al. (1985). Some years ago, Eriksson et al. (2010) created techniques to increase frame rate for obtained more details of images in welding processes. A well-known procedure to welding measurement and analysis supported by use of high speed cameras is the shadowgraphy technique. This technique is a simple and direct method that is largely used to preview mass flows and others features in arc welding process (Schmidt & Settles, 1986). In our work, the images were acquired by high speed cameras and shadowgraphy technique.

In this technique, a laser is incised on a surface resulting in the formation of a shadow projected on a screen, which are filmed by a high speed camera. To visualize the metal deposition rather than the electrical arc, the shadowgraphy technique is one of most successful techniques (Bálsamo et al., 2000). Moreover, to expand the light beams, a set of converging and diverging lenses can be used. The divergent lens receive incoming light beam and the converging lens provide an image with better output accuracy as explained by Weichel (1990) and Steen (2003). Figure 2 shows the required equipment for shadowgraphy technique application.

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In addition to the shadowgraphy technique, some lighting techniques can be used to improve image quality. On the other hand, the illumination need to deal with illumination created by the electrical arc, which causes interference on image obtainment (Abdullah et al., 2008). Kovacevic et al. (1996) highlighted that one of the most common difficulty found on the computer vision in welding applications is the arc light interference. Lim & Cho (1993) and Kovacevic et al. (1995) also reinforced it. Therefore, considering this, to apply shadowgraphy technique, it is necessary an auxiliary light source with light emissions more intense than arc light.

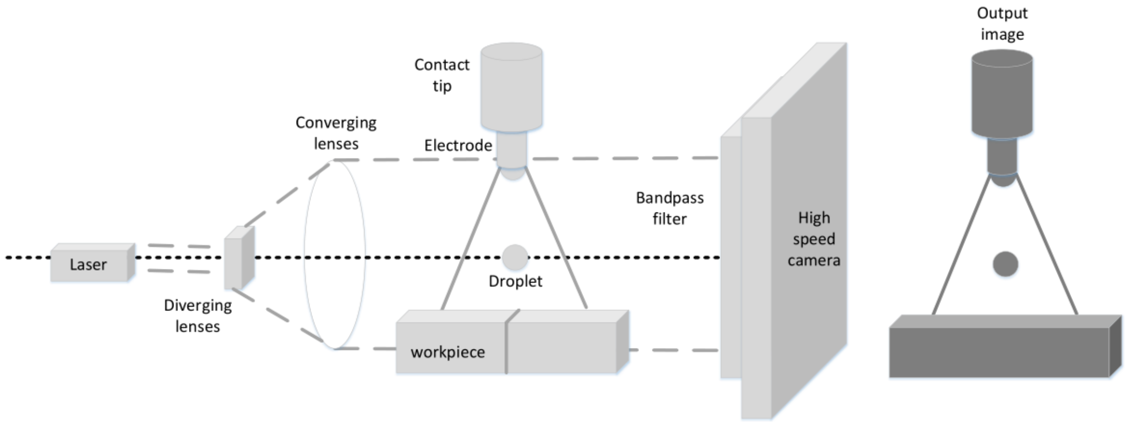

Figure 2 - Shadowgraphy technique scheme

6. Results

Firstly, an image of material transfer was acquired. In Figure 3, an image obtained from high speed camera and shadowgraphy technique with laser source is shown. In this figure, the process of material transfer from solid electrode to the molten pool in globular mode is observed. The globular mode is a mode of material transfer in MIG/MAG process, where the weld droplets are deposited droplet by droplet, with their radius bigger than solid electrode radius.

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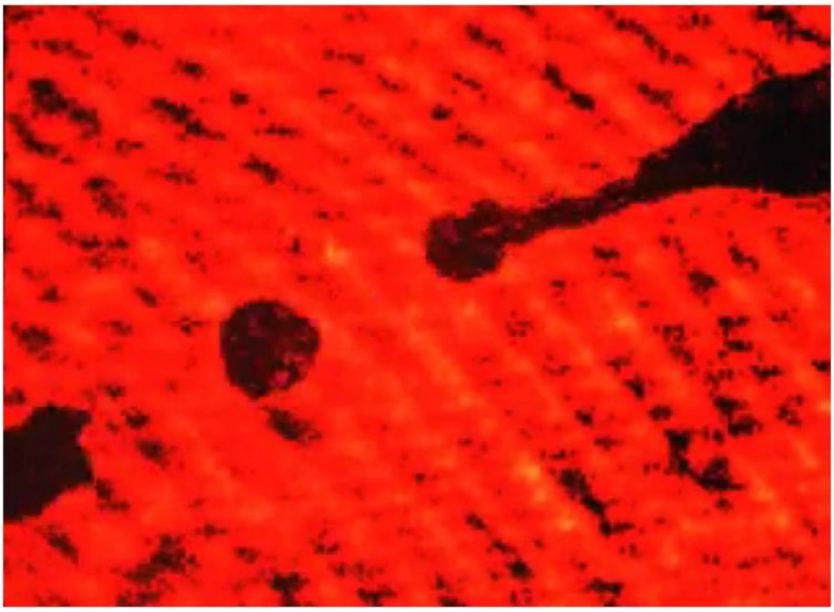

Figure 3 - Image of mass transfer by globular mode acquired by high speed camera and shadowgraphy technique, ceded by: Laprosolda/UFU/Brazil

A tool to analyze the images was developed. Its interface is shown on Figure 4, with the acquired image, shown in Figure 3. This interface was made with software Matlab and it is in continuous improvement. In the current state of it, the acquired images are stored in a database, accessible for the tool, and then there are two options: select one image to analyze, choosing the button 'Select', or see all database images as a slide show, pressing the button 'Play'.

The first algorithm implemented for this tool is to measure the droplet radius, it converts the image pixels in millimeters, assuming that tool is properly calibrated. This algorithm is executed pressing the button 'Measure'. For while, the annotations have been done by manually, that is, the user marks the droplet radius by yourself. Currently, an algorithm to detect this characteristic automatically is in development.

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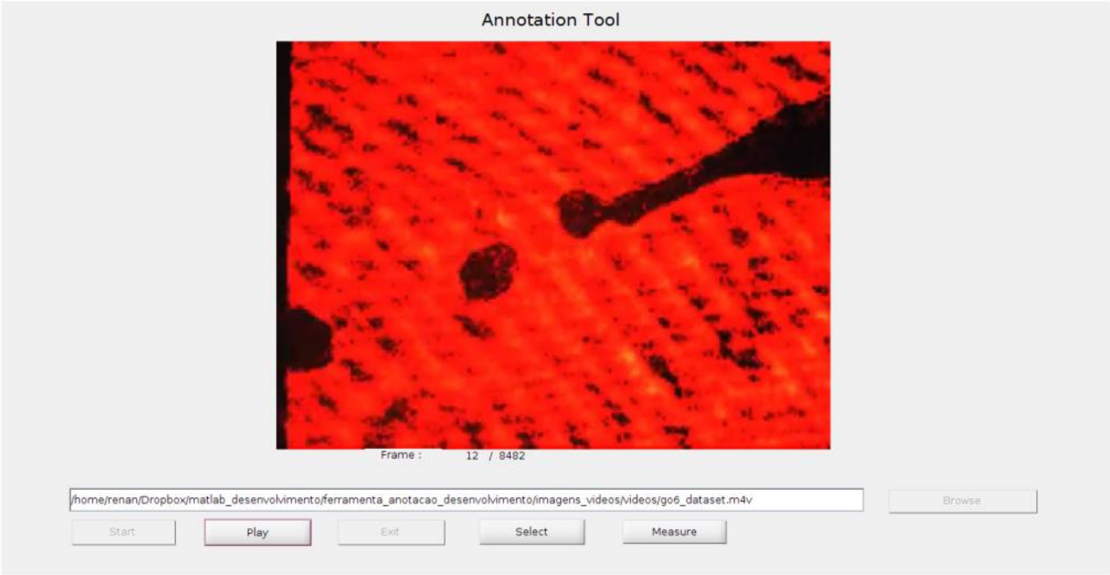

Figure 4 - Developed tool interface with an acquired image

In Figure 5 is shown the marked radius and a box close the selected droplet with the measure. In this example, the radius has 31.09mm.

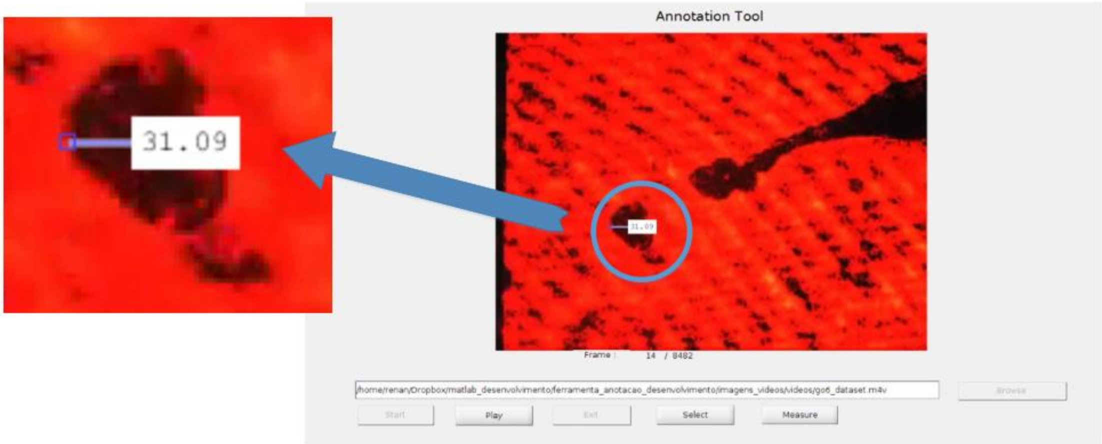

Figure 5 - Measurement of droplet diameter with manual mode

However, it is not practicable to analyze large quantities of images manually. Then, here are implemented some image processing algorithms to turn evident the droplet edge and then allowing an automatic droplet radius measurement. Thereby, filters in the acquired images to reduce smooth, spatter and excessive brightness. These filters are useful to facilitate the detection of weld droplet borders. The implemented filters were Canny and Sobel Operator, Color Filter and Threshold Operator. The Sobel and Canny Operator has a good performance for low frequency noises attenuation and can detect borders with a good precision (Acharya & Ray, 2005). On the other hand, Threshold Operator is better to filter high frequency noises through addition of high level of grey scale to image. In addition, the color filter splits the

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original image in three scales of color: red, blue and green. Therefore, the procedure to detect droplet edge on an acquired image is shown in the diagram of Figure 6.

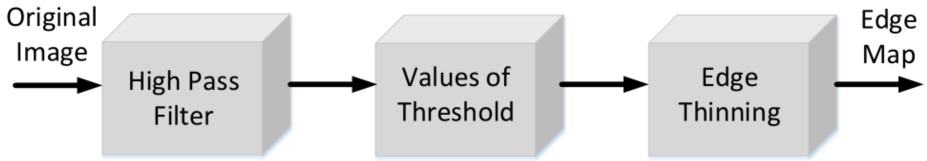

Figure 6 - The procedure to detect edges in an image

First, the color filter based on a high pass filter is applied over the image with the aim to change each pixel of the input image. This filter generates the threshold levels of each pixel into image and then the edge thinning is realized. Figure 7 presents the color filter result. As can be seen in Figure 7, three color specters are generated. For the studied case, the red plan is the best choice to proceed the analysis, because this spectrum was predominant in the original image.

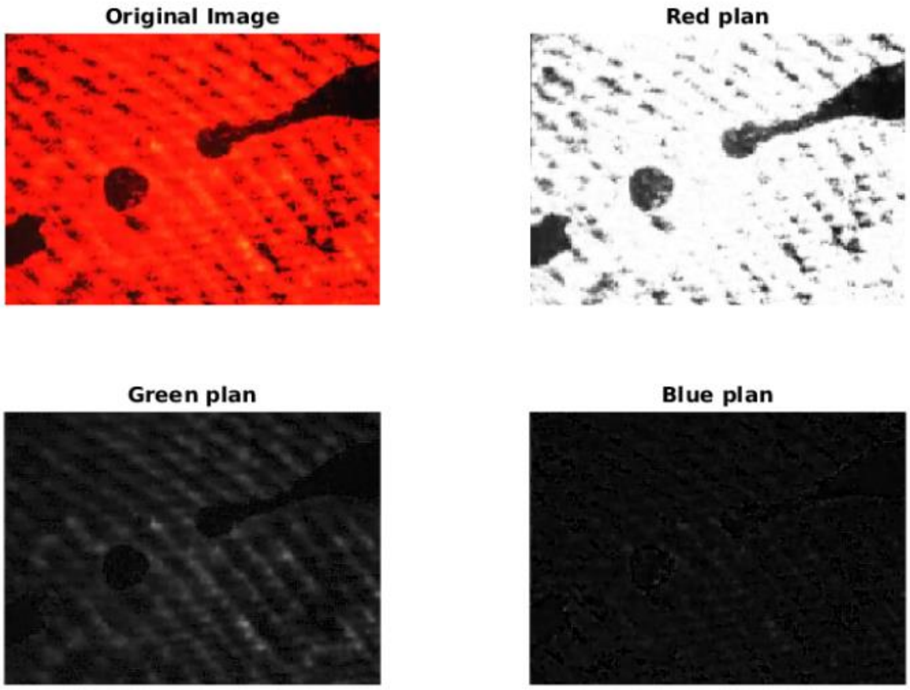

Figure 7 - Color filter resulting image

Thus, the threshold operator was applied over the red plan image. In Figure 8, the resulting image is presented. Note that objects in the image are all in shadows, due to high level of grey scale, which turns easy to separate each object for a human eye. However, for a computer vision system, it still hard to identify the edge. Then, the Sobel and Canny filter was applied over the threshold resulting image. Its resulting image is shown in Figure 9.

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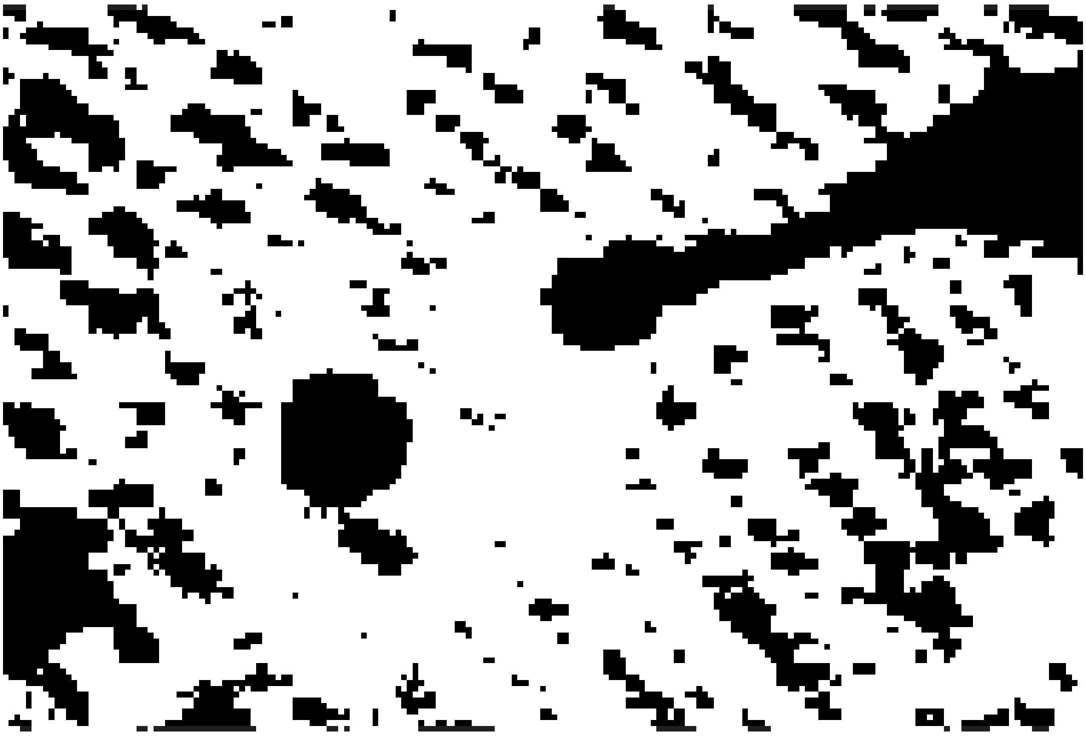

Figure 8 – Threshold Operator resulting image

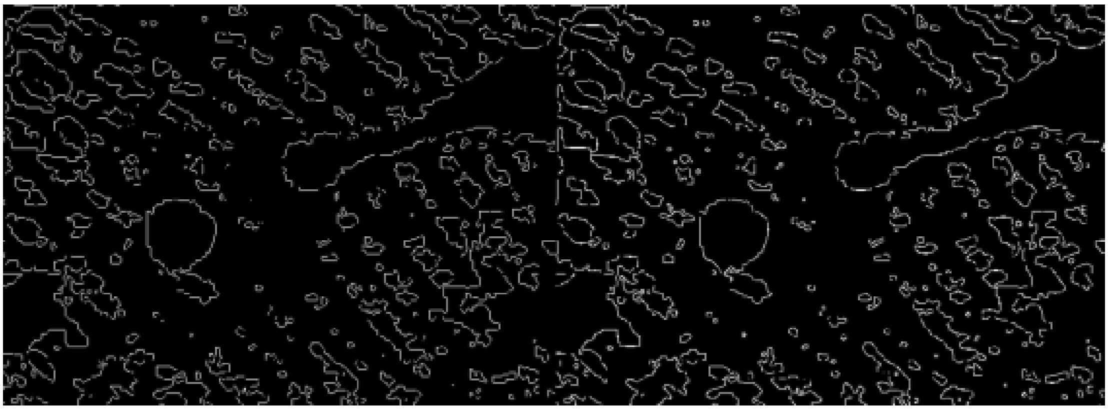

Figure 9 - Sobel and Canny Operator resulting image

Through the application of Canny and Sobel Operators, it was possible the recognition of droplet edges in an easy way, because if is defined an inferior limit for identification, then the spatter will be ignored, measuring only droplet radius.

7. Conclusion

In this work a brief review of vision machine on welding researches were presented, where were discussed the fundamentals of machine/computer vision and image processing. Moreover, some image processing algorithms were applied over an image acquired with a high

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speed camera through shadowgraphy technique and laser source system to turn evident the edge of weld droplet. For while, the annotation of droplet radius is manual, however it has been developed an algorithm for automatic droplet radius annotation in the developed tool. This algorithm will use the image treated with the presented image processing algorithms. Furthermore, in the next experiments, a camera Phantom Miro 310/311 R-series will be used to capture new images of globular mass transfer in MIG/MAG process. This camera was chosen because it has a good performance on noisy process as arc welding operation. In addition, a laser Cavilux Smart will be used as an external red light source. With new images and the finalized automatic annotation tool, a dataset will be provided with acquired images and electrical signal through their synchronization with voltage/current measurement system. This dataset will be useful for training of an intelligent controller.

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