Real time synchronization of weld pool image acquisition in the dip mode of metal transfer GMAW processes

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Abstract. *This paper describes the development of a weld pool monitoring system which uses the detection of the short circuits, during a dip mode of metal transfer GMAW (gas metal arc welding) process, to produce a synchronization signal for triggering a progressive scan camera. Weld pool image analysis is a very powerful technique for real time monitoring the weld quality, since it can provide the operator or a control system with information on several weld features. The main problem associated with vision monitoring is the utilization of adequate illumination of the scene, which is very difficult to obtain if a welding arc with time varying brightness is present on the image. In order to eliminate this source of image noise, a short circuit monitoring system was developed to produce a triggering signal for a progressive scan camera in such a way as to start and finish the image acquisition during the short circuit period. This resulted in the consistent acquisition of images free of the arc light, thus providing pool information only through the weld pool own light. This technique improves the robustness of weld control systems based on weld pool monitoring in robotic dip transfer GMAW processes.*

Keywords: *Weld pool monitoring, Gas metal arc welding, Direct vision sensors, Short arc triggering ,Dip mode of metal transfer*

1. INTRODUCTION

This work presents a technique for monitoring the weld pool in the short circuiting GMA welding process. The technique is based on the acquisition and real time analysis of the welding electrical signals in such a way as to extract a triggering signal for opening the shutter of a high speed progressive scan camera. The triggering signal is generated from the detection of the short circuits that occur when the molten metal is transferred from the welding wire to the base metal during the process.

It is well known that the use of image acquisition in welding processes is hindered by the excessive brightness generated by the arc. To reduce the arc brightness and consequently to improve the definition of the images two techniques are proposed: (a) the use of an optical filter in the infrared band and (b) the synchronization of the image acquisition based on the analysis of the voltage waveform.

In agreement with Balfour et al. (2006) and Koike et al. (1999), the use of optical filters would reduce the excessive brightness, thus limiting the viewing scene to what really interests: the welding pool. The synchronization of the image capture with the short circuit periods was proposed by Koike et al. (1999), since in her work the main problem faced was the selection of image frames free of arc light. According to this author and to Adolfsson et al.(1999), the best period for weld pool image acquisition would be during the short circuits, since the arc is off and the only source of light is the weld pool, whose light emission ranges mainly from the visible to the infra-red wavelengths.

The detection of the short circuits was also the basis for the development of the dip resistance stand-off monitoring technique, first proposed by Philpott (1986) and latter modified by Carvalho (1997). The first developed an electrical circuit for measuring the resistance during the short circuits and correlated the measurements with the stand-off. The latter defined a threshold for the voltage samples under which the dip resistance could be directly calculated from the welding voltage and current acquired during the short circuits. Such a threshold was based on the extraction of statistical features from a window (a fixed amount of data) of welding voltage samples.

In this work, the authors studied three different techniques for defining the best synchronization period between the arc dynamic variation and the image acquisition. The 3 techniques were classified by efficiency to be used on in real time application.

2. THEORETICAL ANALYSIS

The weld pool monitoring task mentioned in the previous section can be subdivided in three problems to be solved: (a) the choice of a proper filter; (b) the analysis of the welding voltage waveform and (c) the definition of time when to acquire the weld pool image.

The filter to be selected should eliminate the visible band and to exhibit only part of the short infrared (750 to 1400 nm). The CMOS (Complementary metal oxide semiconductor) camera used in this paper presents a physical restriction on the spectral responsivity that limits the image capture to wavelengths between 450 to 800 nm , so were tested only band or high pass filters of frequencies above 600 nm.

The analysis of the data from arc voltage waveform determines how images will be captured, in other words, images with a little or any arc glare. As (Adolfsson et al., 1999) the smallest amount of bright in a process GMAW on short-circuit mode of metal transfer happens when the welding wire touches the workpiece, on that moment the voltage practically arrives to zero causing the extinction of the welding arc and fast elevation of the current sees Fig. 1.That is the ideal moment to capture a good image of the melted pool without a single bright.

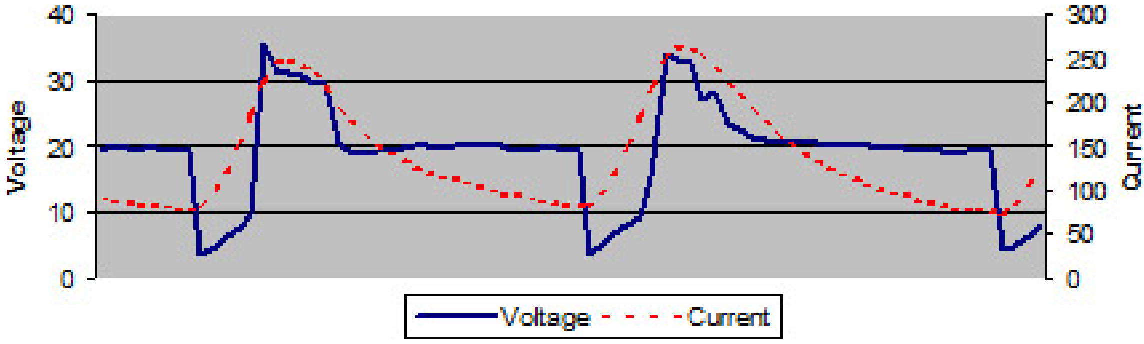

Figure 1. Example of Current Vs Voltage on two short-circuit period

A good example to use the analysis of arc voltage waveform is shown in the sequence of 4 images (from 1 to 4) captured to 130 fps without any analysis of the waveform, notice in Fig. 2 that the light intensity varies from an excessive bright (1), when the arc is open, to an image with only the welding pool (4).

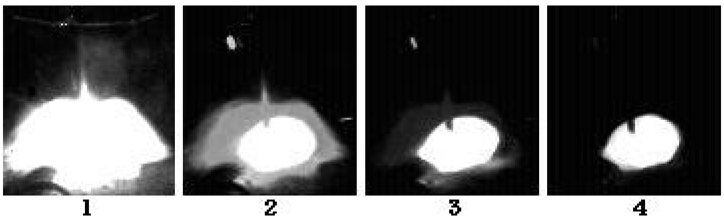

Figure 2. Image sequence captured without arc voltage waveform analysis

The proposed technique to detect the moments of short-circuit is the use of a threshold filter application with two value levels one high and one low that analyzes only the arc voltage transforming the received waveform in a trigger sign see in the Fig. 3 applied the filter and result on their own proportions.

The techniques proposed by (Adolfsson et al., 1999) and (Carvalho, 1997) about using of windows of data associated to a group of movable averages in the analysis of the voltage of the welding arc allow to define dynamically the threshold limits values adapting the variations of the short-circuit metallic transfer process that it is a stochastic process.

Starting from the sampled window with N_W samples of the arc voltage W_i, calculate the mean voltage W_{mean} Eq. (1), then classify the in two voltage groups in high W_pi or smaller W_bi than the mean voltage and calculate the low mean voltage W_{bk} Eq. (2) and the high mean voltage W_{pk} Eq. (3).

$$W_{mean} = \frac{\sum_{i=1}^{N_W} W_i}{N_W} \tag{1}$$

$$W_{bk} = \frac{\sum_{i=1}^{N_b} W_b i}{N_b} \tag{2}$$

$$W_{pk} = \frac{\sum_{i=1}^{N_p} W_b i}{N_p} \tag{3}$$

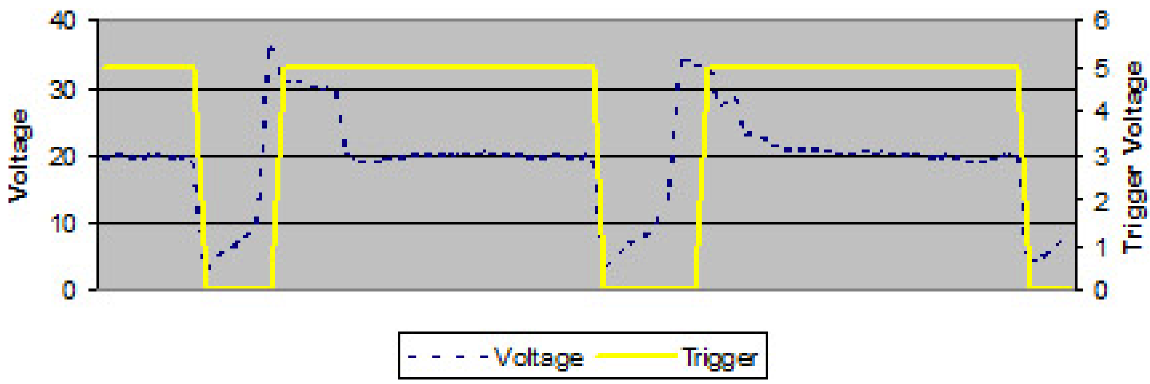

Figure 3. Threshold filter generating a trigger signal

Those 2 values of low and high averages will update the values of threshold of the filter sees the example of the illustration 4 note how really the high and low mean values can be used as limits of the threshold filter. This technique allows an automatic adjustment of the arc voltage limits avoiding the need of using fixed parameters.

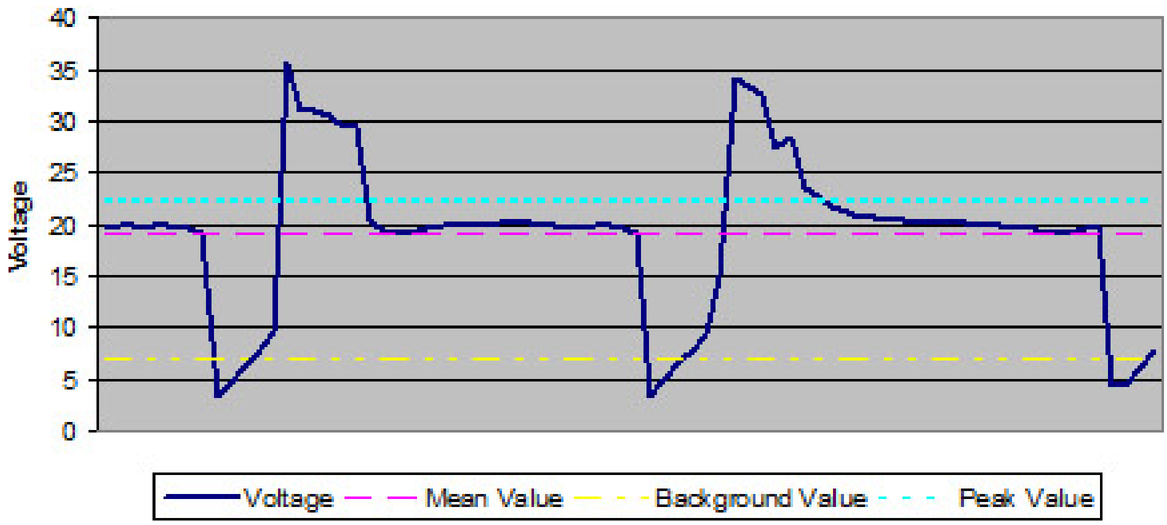

Figure 4. Example of low and high mean values as threshold filter limits

The group camera and frame Grabber to be selected for the system should have a fast answer to guarantee the capture of great part of short-circuit the transfer, the minimum time of capture varies among 8 to 9 ms (Norrish, 1992) to values of 2 or 3 ms that implicates that the camera must capture images at least 125 fps. The tests implemented in this paper used a maximum sampling of 130 fps.

3. EXPERIMENTAL SETUP

The system, of Fig. 5, it was set up to accomplish 2 studies on the efficiency of data capture in real time. The experiments of Fig. 5 were set up in the following way: A robotic static arm holding the GMAW torch, a linear motor table, a welding machine with interface for monitor and control, 2 linked computers by ethernet cable: one to control the welding machine, capture and analyze the voltage, trigger the image capture, other computer is dedicated only for image capture. For another study a dedicated microcontrolled board was directly linked between the welding machine and the image capture computer to analyze the arc voltage and to trigger the image capture.

The process in Fig. 5 it presents 3 colored ways : the green - **X**, red - **Y**, blue - **Z** those indicate 3 different experiments. The basic operations of the 3 experiments are the same both would capture values of the arc voltage generated by the welding machine then analyze and finally determine the best moment to trigger capture computer to obtain a low bright image.

To perform the several experiments were developed a series of softwareŠs in C, C++ (training reference book (Deitel, 2006)) and Labview. The basic program used to accomplish all the experiments was created in labview to control the welding source, and linear table direction.

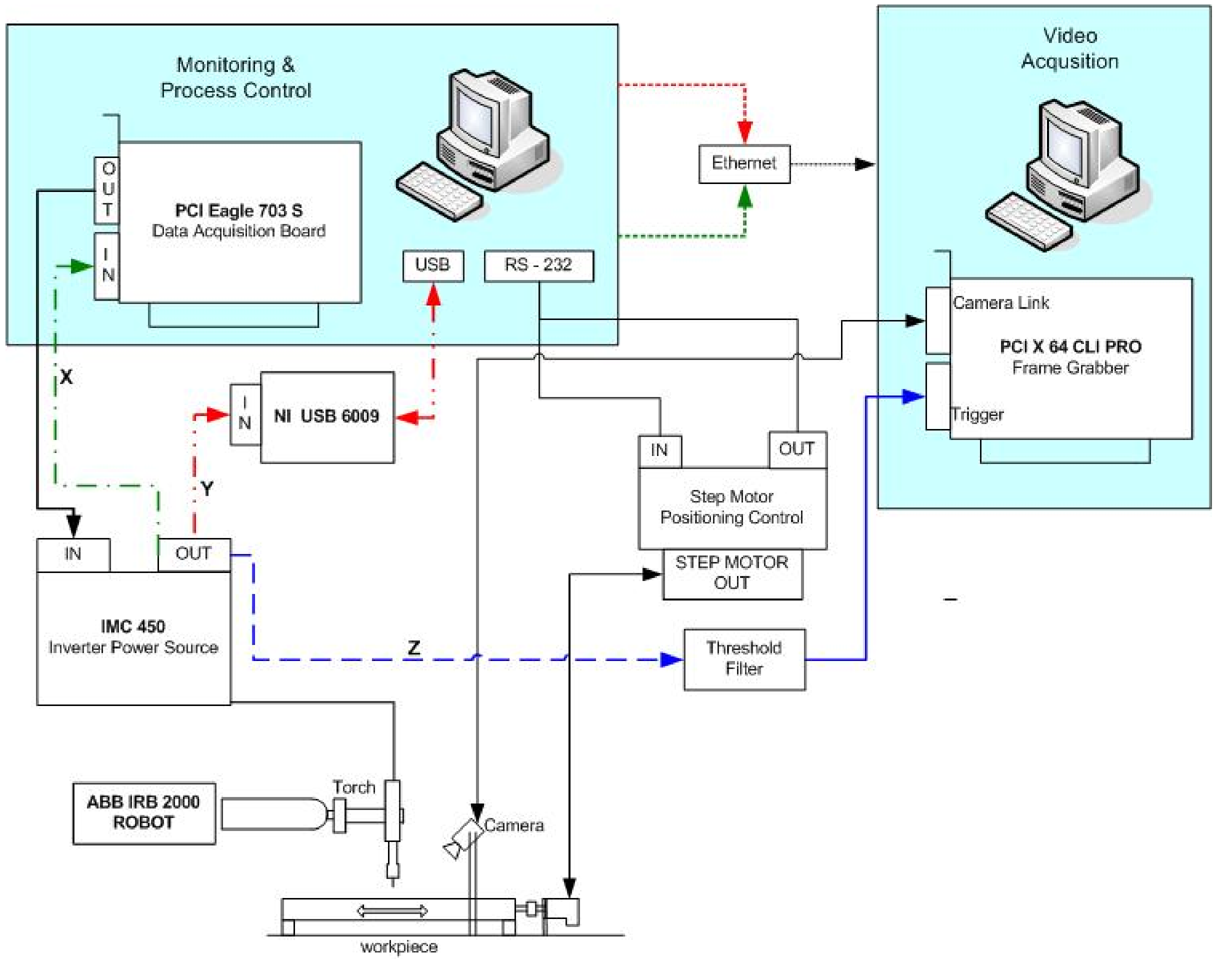

Figure 5. Main diagram of all experiments

This basic software works with a PCI acquisition board from EAGLE manufacturer's model PCI 70316A that have two DA channels, 16 AD channels of 14 bits for data monitoring working at maximum rate of 400 Khz and 8 I/O digital channels. On the inverter power source control process was used 2 DA channels to define the initial voltage or current of weld process and more 3 digital channels to open the protection gas, to feed wire and to trigger the welding torch.

To control linear table a serial protocol was developed to communicate of with a the microcontrolled board that controls the speed, direction, time movement of the experiment and monitor safety's conditions of the step motor of coupled linear table.

The program of image capture computer was developed in C using an API (SAPERA LT 6.2) supplied by the manufacturer of the frame grabber (DALSA) that has two objectives according to with the experiment. The first experiment is to capture images in continuous mode and only analyze frames that were marked as useful frame by a remote server through an ethernet link socket of 100 Mb/s. The second experiment is to capture images only if a trigger directly connected to the frame grabber starts the process.

The image capture software works with PCI 64 frame acquisition board from the manufacturer's DALSA CORECO model X64-CL iPro. This board it is a powerful frame grabber capable to acquire images of to 2 cameras to an independent rate of 510 MB/s with monochrome definitions of 8/10/12 bit or 24 bit RGB through connector called CAMERA LINK.

The vision system uses a CMOS area scan camera from the manufacturer DALSA model DS-21-001M0150 with 1024x1024 resolution 8 bits monochrome with a maximum frame rate of 150 fps. To increase the efficiency of the capture of images was used system called ROI (" REGION OF INTERESTING ") to reduce the size of the captured image, and needed buffer image on capture computer.

The available filters to be used in experiments and the image quality obtained with them results are presented for each filter in Tab. 1:

The best choice for available filters was using the band pass 624 to 644 nm filter because Narrow band 633 to 636 nm filter gets just smoke and, high pass 800 nm filter can only get good images running at lower capture speeds (bigger exposure time demanding 100 fps) due low CMOS gain after wavelengths higher than 800 nm.

The inverter power source used in all of the experiments was developed from IMC (www.imc-soldagem.com.br)

Table 1. Available filters and image quality

Filter [nm]	Can Be used	Image Quality
Band Pass 380 to 430	No	-
Band Pass 503 to 520	No	-
Band Pass 624 to 644	Yes	Good
Narrow band 633 to 636	Yes	Poor
High pass 800	Yes	Regular

manufacturer model Inversal 450 . This welding power source has the capacity to work with GTAW / GMAW process. This machine has 3 digital inputs to control the gas, wire and trigger, 2 analog input to adjust voltage and current and 2 analog outputs for voltage and current monitoring used on weld process. That source can work with maximum voltage of 60 V with current of 450 A peak.

The welding parameters defined for experiments firstly were adjusted manually to find the short-circuit metallic transfer stable parameters. The optimal short-circuit settings were found at: 20 V arc voltage, 1 mm (steel-carbon) wire, protected by argon / 20$\%$ of CO_2 gas mixture, pressurized with 12 $l/60s$ and a 15 mm Stand-off torch from the work piece.

3.1 GREEN LINE EXPERIMENT - X

The experiment consists in analyzing the arc voltage waveform sent by the welding source and to use the theory of the windowing means defined in the item 2 to detect periods of short circuit. If a short-circuit occur a character is sent asynchronously through socket to the image capture computer which assumes that next frame to be grabbed must be processed and captured.

The program for this experiment was developed in C Builder using an API (EDRAPI) supplied by the manufacturer EAGLE this API provides data capture using pooling to get one value or window to get a group of values. The communication via socket was implemented using windows API WINSOCKET.

The obtained results were not satisfactory due a the long delay that appeared between the acquisitions they were about than 50 ms using in pooling , and 30 ms using window this is caused by the intrinsic characteristics of the board and of API that were made to monitor at high speeds but not to generate data in real time.

3.2 RED LINE EXPERIMENT - Y

Trying to avoid the problem that happened in the previous experiment another data acquisition equipment, supplied by National Instruments model NI USB-6009. It presents a smaller acquisition speed, 44 Khz, but enough for dip metallic transfer and using only one channel.

The program was developed in Labview using a native API of the program and using sockets, however the windowing means system was substituted by one more simplified by using fixed parameters of threshold.

The obtained results were less satisfactory than the previous experiment with delays up to 200 ms for sampling in pooling. The same problem of the last experiment occurred.

3.3 BLUE LINE EXPERIMENT - Z

The best solution was to apply a threshold filter directly in a microcontroller system linked between the frame grabber trigger input and welding power source monitoring port . The filter implemented was is also a simplified form using fixed parameters. The arc voltage limits are 10 V for low and 30 V maxim. The frame grabber trigger is almost instantaneous (according to the manufacturer 100 ns) mainly because is hardware implemented.

The filter board is compound of a microcontroller from MICROCHIP manufacturer model PIC-18F452 running on 20 Mhz frequency that makes AD conversions each 50 us and generates a rectified square wave similar to a Schmitt trigger filter, however adjusted with different voltage parameters. Tests using signal generator showed that the filter can work on 1Khz without show a phase delay between the received sign and correspondent.

The obtained results represented Fig. 6 show a good efficiency in the image capture, because it was possible to obtain images with little (a) or any bright (b), however due the dip metallic transfer process be stochastic it stillŠs possible to capture images with excessive bright (c) caused for short-circuit period smaller than 7 ms.

The bright problem can be solved: increasing the image rate capture; decreasing the size of the windows used in the calculations of the mean and increase the accuracy of the threshold limiters. Studies to improve the system continue after the publication of this paper.

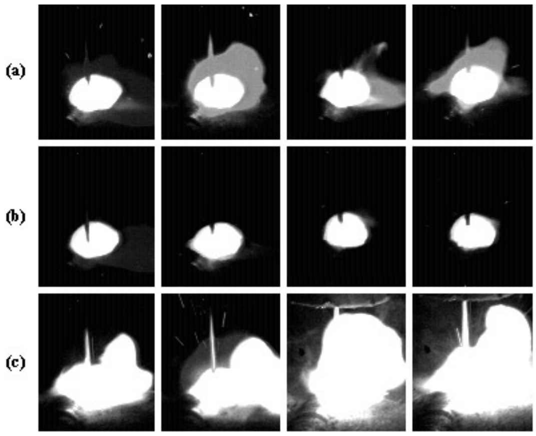

Figure 6. Acquisition results (a) little bright (b) no bright (c) a lot of bright

4. CONCLUSION

The great advantage of this monitoring system applied on GMAW short-circuit metallic transfer mode process is making possible the real time inspection through computer vision processes mainly because reduce the number of acquired images, this reduces the load to be processed and consequently the answer time of a future computer aid welding control system.

5. REFERENCES

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