Direct welding arc observation without harsh flicker

A machine and process independent approach for real time video recordings

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Abstract: **Video observation of a welding process is a challenging issue due to the glaring arc of the welding process and in comparison a low lighted environment. This article describes the setup and algorithmic for the direct welding observation using a C-MOS camera and a subsequent image processing queue.**
The C-MOS technology with its advantages and drawbacks for welding arc observation is described. One issue is a bad image quality, if the welding process and the image acquisition are not synchronized. Due to the direct and immediate reaction of the C-MOS pixels, the welding process flickers during short arc and pulsed processes cause distortions on the image. A synchronization method to abolish the distortions is described and evaluated with the effect of a fluent consecutive video stream. Beside the flicker problem, the C-MOS technique delivers images with noise and poor contrast. The contrast is poor as the huge dynamic is mapped to an 8-bit gray level which means a ratio of 1: 1:10$^{2.6}$ in comparison to a dynamic of 1:10^{6} in the observed scene. In order to achieve a better contrast without loosing valuable details an optimal noise filter and a region based improvement is implemented. The built-up of the real-time image processing queue is described with a comparison of different algorithms and setups.
The results give the ability for direct welding arc and pool observation. A stand-alone system for MIG, MAG (pulsed, short arc and spray transfer) and TIG for welding observation in teaching demonstration, quality assessment or booth presentation is achieved.
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Index Terms: Welding observation, Video recording, Welding, C-MOS camera

I. INTRODUCTION

This article describes a system for acquiring and improvement of high dynamic images from a welding scene. The welding process with its glaring electric arc causes a scene with high dynamic brightness conditions. The arc presents a singular bright light source while in comparison to it, the surrounding area supplies very low lighted regions, mostly defined by the surrounding metal sheets. Camera application for welding are available to observe the welding process itself in order to examine the droplet transfer, pinch effect, arc blow etc. without caring about the surrounding environment. By concentrating solely onto the welding arc and pool the brightness dynamic is confined to a smaller amount than in the case of a global welding scene observation as examined in this article.

The ratio between the darkest to the brightest spot depends for the darkest spot on the surface and therefore on the reflectance ability of the metal. The brightest spot, as given by the arc, depends on the process parameters forming the overall power of the arc. This inherent high brightness dynamic ratio evokes a camera technology, which can map such to an image. Cameras using the CMOS technology are available which can map a brightness dynamic ratio of up to $1:10^6$, which corresponds to 120 dB [1]. Cameras with a CCD chip do not supply the needed dynamic range and for high exposure region they tend to bloom, which means that the surrounding pixels are flooded with charges and by that produce a maximum white blob.

The used camera maps the high dynamic range with a logarithmic compression to an 8-Bit grayscale image. This mapping follows the idea of the well known Weber-Fechner law, which models the relationship between the physical magnitudes of stimuli I_s and the perceived intensity of the stimuli A of the eye (k :constant, I_0: lower bound stimuli reaction depending on the eye adaptation).

$$Weber-Fechner\ law: A = k \cdot \log\left(\frac{I_s}{I_0}\right)$$

Logarithmic mapping of the camera in conjunction with the performance of the display media (e.g. TFT-monitor, beamer, print) does not cover precisely the reception modality of the eye. Additionally the image content is defined by the glaring welding arc and weld pool while the surrounding shall be still visible for orientation and visible handling of the welding torch. The most important part of the image covers only a small area of the image and is the most challenging information to be clearly accessible by the human eye. The logarithmic compression impedes the available gray levels per brightness unit in this area. All this urges the need of algorithms for contrast enhancement.

The pixels of the camera chip have different zero currents, which arise as an offset to every single pixel. If the camera is facing a monochrome area, the resulting image gives a normal distribution with the surface color as the mean value. The offset for every pixel in 2D differs but is constant over time. As it is a 2D distribution over the camera chip, it is called the fixed pattern noise [fpn]. The correction of the fpn can be done by subtracting the differences to the mean of a monochrome image from the images in the video stream as it is mostly implemented in C-MOS camera. Additional to the time independent fpn in the 2D space domain of the camera chip, the time dependent noise caused by the signal processing affects the image quality. This effect produces over time small changing values on the camera chip. It can be well seen if a plain-colored surface is in the view of the camera and the grabbed video stream shows a slightly partial changing surface color [2].

A specialty of the used and most available high dynamic range C-MOS cameras is the absence of a global shutter functionality, which can freeze the pixel values on the camera chip at a certain moment. In comparison to the CCD camera technology, the C-MOS technology reacts instantly to brightness changes. If now the C-MOS camera chip has a line by line readout for grabbing a complete image frame, then changes in the ambient lightning affect the following pixel lines with a changed average of the brightness; a brighter or darker horizontal stripe occurs in the image. Sources for such a lightning change can be neon lamps, flashes or in the case of welding the short arc or pulsed welding process. Every time the welding arc ignites the average lightning of the welding scene is change and a white stripe occurs in the image.

Due to the camera acquisition and the welding process are not synchronized this white stripe occurs on different horizontal position in the video stream for flickering arcs. The impression of the flickering stripe results in an uncomfortable welding video. This problematic is known from image acquisition with neon lightning, where the camera system is synchronized to the flicker frequency [3]. The manual welding using the MIG/MAG short-arc and pulsed processes do not produce a static ignition frequency, whereby a fast reaction for the trigger is induced.

Welding observation is closely related to the welding process and so to the camera synchronization [4]. The approach presented here gets independent of a direct physical linkage between the camera system and the welding process by suggesting an optical sensor for the trigger extraction and so for the synchronization.

II. System Setup

The system is described following the queue from the image sensing with the camera synchronization to image pre-processing and finishes with the image improvement.

A. Camera technique and trigger

As introduced the camera technology usable for direct welding observation is a specialized C-MOS camera chip. One inherent property of the MIG/MAG process is that the welding arc flickers during welding. Only in the case of a pure spray transfer arc the flicker is not visible, as it is for electronically controlled pulsed arc or for the classical short arc.

The average brightness of the scene corresponds to the average brightness of an image line at the moment of its readout. If the arc ignites the average brightness in the scene changes as well the average brightness of the current image line readout. The shape of the arc energy over time, form the progression of the bright stripe occurring in the image (see Figure 1).

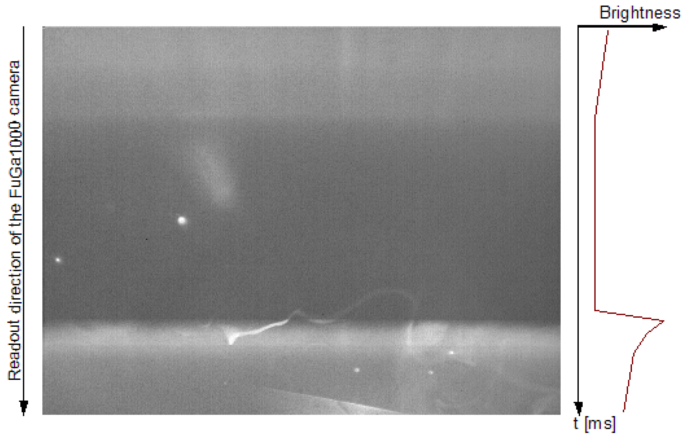

Figure 1 Bright stripe generated by one pulse of the process

The process and the camera are not synchronized, so that the ignition of the welding arc does not happen at the same moment of the alternating process. So the bright stripe occurs in consecutive image at different horizontal position. (see Figure 2)

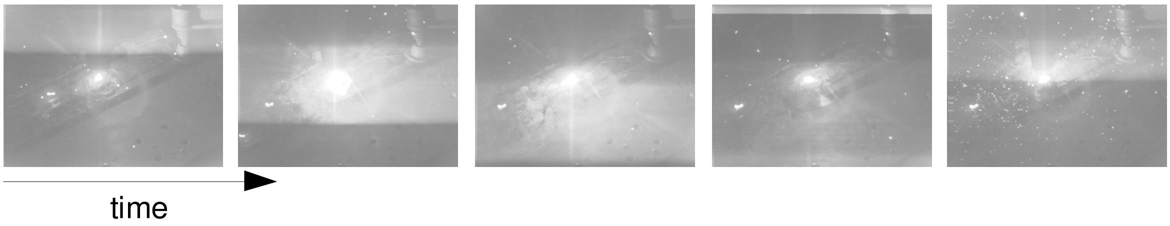

Figure 2 Flickering white stripe without camera synchronization

One approach to synchronize the cameras is to receive a trigger signal similar to the pulse of the process, directly from the welding machine or by measuring electrical parameters (voltage, current). One disadvantage here is that only for the pulsed processes a valid trigger signal is available. The short arc flicker is not machine driven but process driven and thereby the ability of getting a signal from the machine is not a standard implementation. The measurement of electrical signals to extract a trigger criteria needs additional bulky and costly equipment.

Going further in examining the opportunities of achieving a synchronization between camera and process, the measurement of the brightness with an optoelectronic device supplies the most independent access to the process. The brightness measured by an optical sensor is correlated to the power supplied to the process (see Figure 3)

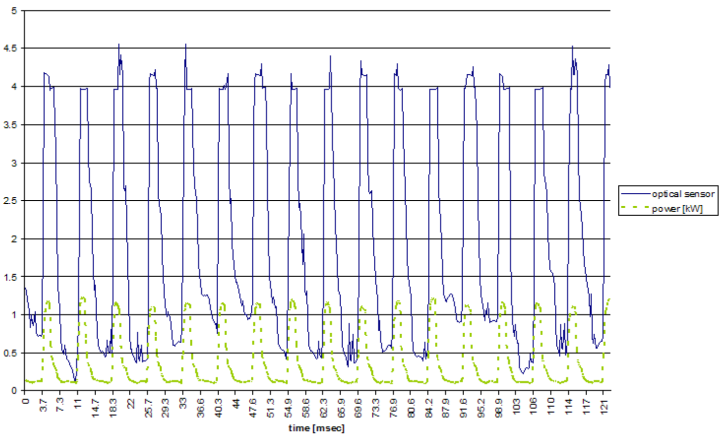

Figure 3 Characteristics of power and brightness sensor

The extraction of the trigger can be done on the raising edge of the brightness, which delivers the most robust criteria. The sensor measuring the brightness signal is amplified and the followed differentiator senses the edges. A Schmitt-Trigger with its hysteresis adds stability to the extraction and forms a clear logical signal (see Figure 4).

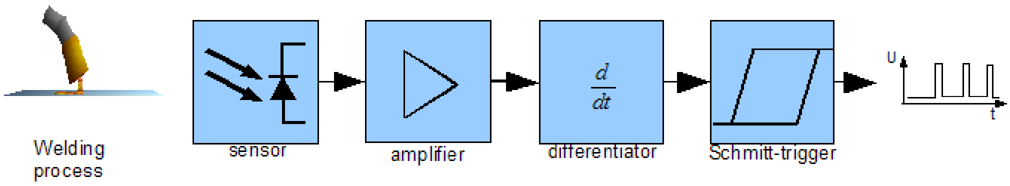

Figure 4 Setup for an optical trigger on the welding process

The synchronization between the camera and the process gets independent from the welding machine and the process. No matter neither which machine nor which process is used, the direct brightness measurement gives the ability to abolish the flickering bright stripe (see Figure 5).

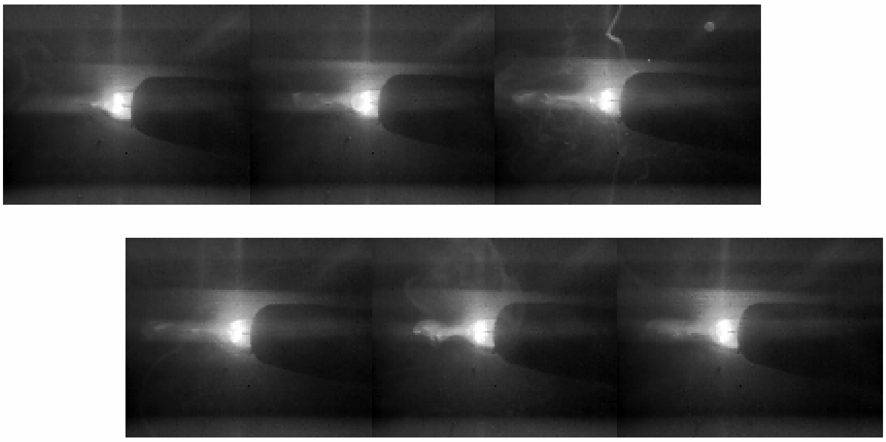

Figure 5 Image acquisition synchronized by optical trigger

In the case of DC processes like TIG, non welding or if no optical signal is sensed a default trigger frequency is supplied to the camera. With the optical trigger a technical improvement welding observation is achieved.

B. Image noise filter

The directly grabbed image from the camera includes noise, which gets amplified in the consecutive image processing steps and needs to be filtered. Noise filtering is often made by using a Gaussian filter. If images are filtered with a Gaussian filter, then not only the noise, but as well edges in the image are smoothed. An optimal filter like the Wiener Filter preserves locally the edges but filters noise from a Gaussian process [5].

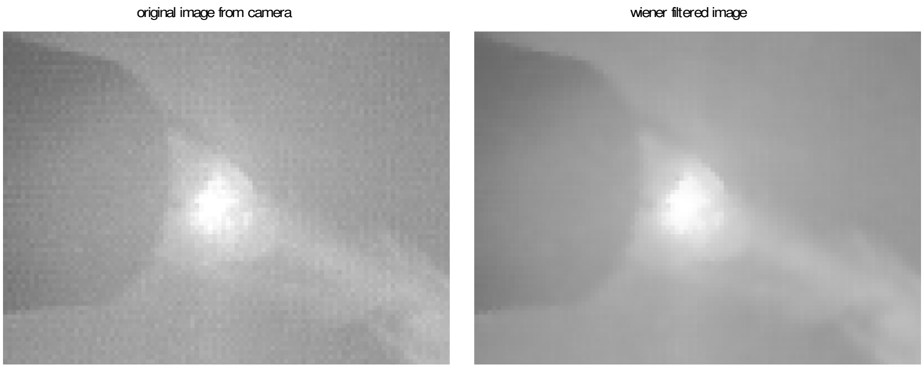

Figure 6 Original and Wiener filtered image

The result of the Wiener filter operation is convenient for lowering the (Gaussian) noise, which will not get dominant in the following contrast enhancement process due to reduction.

C. Contrast enhancement

To enhance the dynamic of an image the first common strategy is to use the complete available colour space without changing the information. For gray scale images one approach is to apply a global histogram stretching. In the case of the welding scene, the arc is the brightest point and the surroundings deliver nearby black pixels. Depending on the camera parameters, these two extremes lie at the outer bound of the 8 Bit greyscale space. By using the global histogram operator the information of the image is not changed, because only the distance between the single colour steps gets enlarged and so neighboured gray values get better distinguishable.

An image operator, which improves the contrast locally changes the mapping of the source to the destination image from a bijective to a surjective mapping. This means that the same gray levels in the destination do not obligatory correspond to the same gray levels of the source image. The operation of the adaptive histogram equalization puts in the region divided image, locally the contrast to its maximum by histogram equalization. For nearly monochrome surface with residual noise the contrast is changed to its maximum while the noise gets amplified, too. To add a restriction to the contrast enhancement as it is done with the contrast limited adaptive histogram equalization (CLAHE), it can be assured that regions with low contrast get enhanced, without over-amplification the noise [6]. Although the image processing improves the contrast, the image is lacking quality due the very narrow available colour space, which is formed by the 256 gray level, only.

D. Complete System

Subsuming the different parts to a running system, the welding observation system can be implemented by using the optical trigger for the right acquisition timing and the image operations to achieve an improved result (see Figure 7)

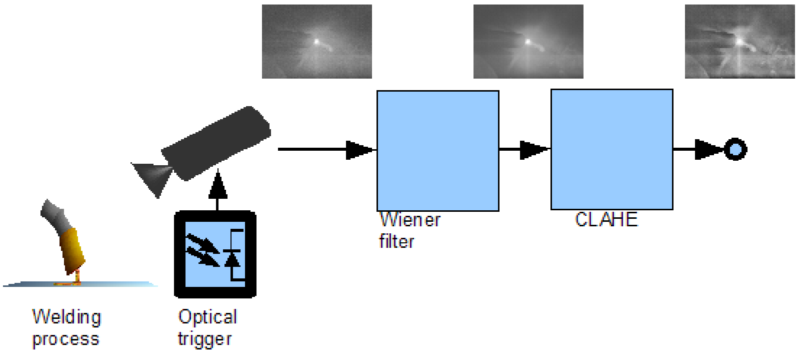

Figure 7 Setup for a welding observation system

III. RESULTS

The result shall give an overview about the welding observation system.

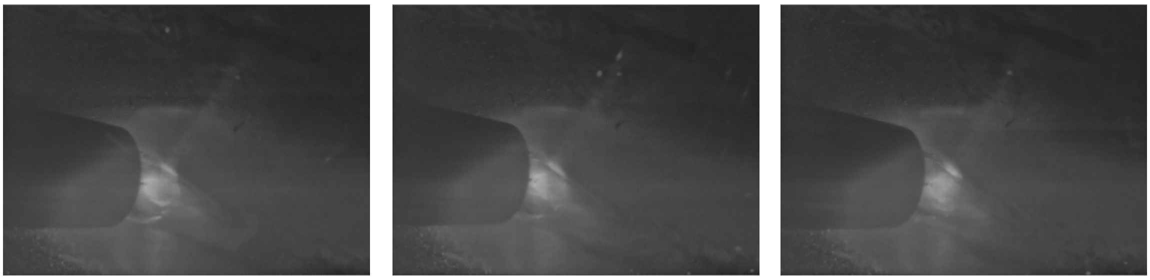

Figure 8 MIG, 112A, pulsed, AlMgZn

Figure 9 TIG, 183 A, INOX

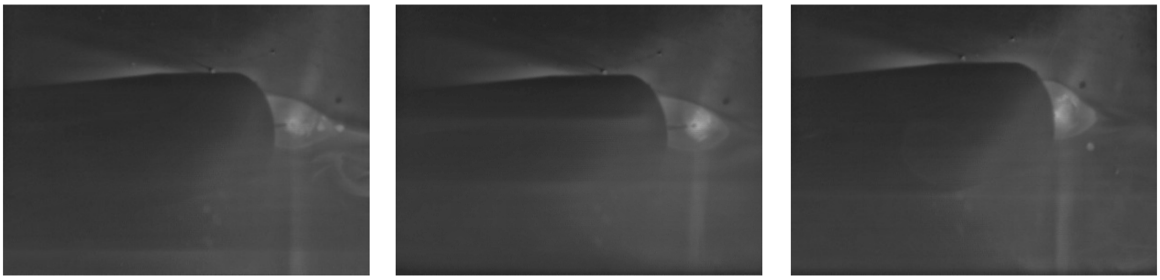

Figure 10 MAG, 120A, pulsed, mild steel

IV.CONCLUSION AND FUTURE WORK

In this article a running setup for the observation of the manual welding process is presented. The image acquisition with the optical trigger technique and the image quality improvement give an impression about what is achievable for welding observation.

The suggested optical trigger extraction improves the former approach of directly measuring the electrical signal or connection to the welding machine.

With new developments in camera techniques e.g. cameras with higher brightness dynamic or colour pixels, the information content of the grabbed video will be improved. The application of a welding video can be the presentation at welding fairs, for educational purposes, robot path control during welding or quality assessment for documentation purposes.

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