Real time Arc-Welding Video Observation System

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Abstract

The arc welding process emits high radiations in the spectrum of IR, visible and UV light. Widely available cameras cannot map the 120 dB high contrast ratio between the surrounding and the welding process to an image. CCD cameras suffer additionally the blooming where highly exposed pixels flood their neighbors with electrons, so that these are sensed as white. Greyscale cameras based on C-MOS technology are available, with a sufficient contrast ratio. Without any additional technique its applicability for welding observation is restricted to uniformly glaring processes. Pulsed welding processes arouse a flicker effect, which diminishes the quality fundamentally.

This article presents an observation system for real-time videos applicable to a wide variety of arc welding processes. The used high dynamic grey level camera is optically synchronized on the welding process and delivers an alternating sequence of under- and overexposure images. In a subsequent algorithm, the image data is merged and results in a video which covers a wider range of contrast dynamics, where the glaring arc, the weld pool and the surrounding scenery is clearly visible at once. This system can be used for stick-out detection to control the welding arc length, weld-pool observation for spread detection and path guidance directly at the process.

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Introduction

The video acquisition from a welding arc process and its environment exceeds the available contrast ratio which can be mapped by an average camera. The welding process with its singular glaring electrical arc, lights the surrounding but raises the ratio between the darkest and the brightest point in the scene to $1{:}10^6$, which corresponds to 120 dB.

Camera systems for welding –mostly for high speed video observation- 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 case of a global welding scene observation as examined in this article. Approaches to view the welding process either use a strong backlight in order to compress the dynamics by increasing the dark areas or light the scene by IR laser [1], [2].

This inherent high brightness dynamic ratio evoked new camera chips using C-MOS technology, which can map such [3]. The widely available Charged Coupled Device (CCD) camera chips do not supply the needed dynamic range as they tend to bloom for high exposures. Blooming is an effect where surrounding pixels of highly exposured pixels are flooded with charges and by that a maximum white blob is produced.

The used C-MOS camera maps the high dynamic range with a logarithmic compression to an 8-Bit greyscale image.

The most important part of the welding scene covers only a small area in the image and is the most challenging information to be clearly accessible by the human eye; the arc. The logarithmic compression impedes the available grey levels per brightness unit in this area. All this urges the need of algorithms for contrast enhancement [4].

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 case of welding the short arc or pulsed welding process. Every time the welding arc ignites the average lightning of the welding scene is changed and a white stripe is effected in the camera image.

Due to the not synchronized camera acquisition and welding process 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 [5]. 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 [6].

Enhancing the available contrast dynamic of the grabbing process can be done by a multiple shot technique. Several images with different camera parameters are taken being under- to overexposed. By calculating the inverse camera mapping function, the images may be reversed to the radiance map of the view. A high dynamic range increase is gained and produces an image which contains the merged information of several shots [7], [8]. As we are not bounded by a low contrast dynamic ratio of our camera but with insufficient data domain of 8 Bit, the radiance map is not needed and we suggest a simple and effective approach to spread the data domain.

Content

Camera Trigger

As introduced the camera technology usable for direct welding observation is a specialized C-MOS camera chip. We use a camera with a greyscale FuGa1000 camera chip. One inherent property of the MIG/MAG process is that the welding arc flickers during welding. Only in 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.

The process and the camera are not synchronized, so that the ignition of the welding arc does not happen at the same moment as the alternating process. So the bright stripe occurs in a consecutive image at different horizontal position (see Figure 1).

Figure 1 Flickering white stripe without camera synchronization

Examining the opportunities of achieving 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 2).

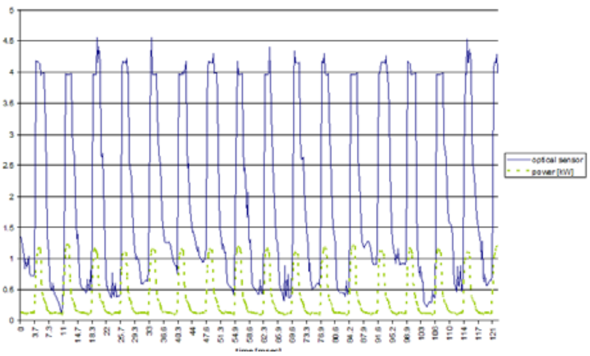

Figure 2 Characteristics of power and brightness sensor

The extraction of the trigger can be done on the raising edge of the brightness, which delivers the most robust criteria. A simple implementation uses a light sensor measuring the brightness signal which gets amplified and differentiated to sense the edges. A Schmitt-Trigger with its hysteresis adds stability to the extraction and forms a clear logical signal (see Figure 3). Additional bandpass filter of the measured sensor signal raises the robustness of the system against noise.

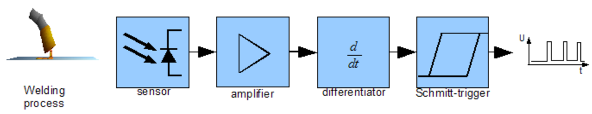

Figure 3 Setup for an optical trigger on the welding process

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 4).

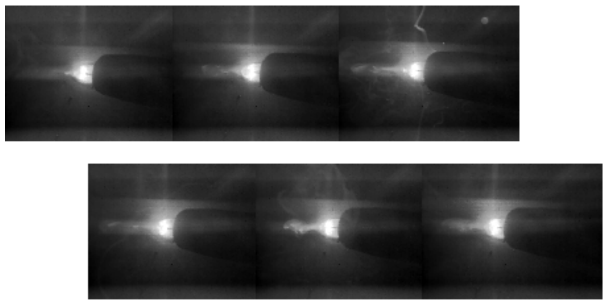

Figure 4 Image acquisition synchronized by optical trigger

In 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 for welding observation is achieved.

High Dynamic Range Increase

Merging several shots using a CCD camera needs inverse response function of the acquisition process. The shutter time or the aperture is the information which is used to calculate the extended information for the radiance map, delivered by several images. In case of a high dynamic C-MOS video camera a shutter time does not exists as the pixels react instantly to changing lighting conditions, as introduced. It is more the problem of exploiting the conversion process from radiance to a digital pixel value. The available data domain of the used Analog/Digital (A/D) converter bounds the value representation for the acquired image. If an 8 Bit A/D converter is used, the domain of 2^8=256 grey levels constricts the mapping of the huge amount of 1:10^6 contrast ratio to a pixel.

Between the light sensitive pixel and the A/D converter an offset control and amplifier adjusts the output of the pixel to the input range of the A/D converter (see Figure 5).

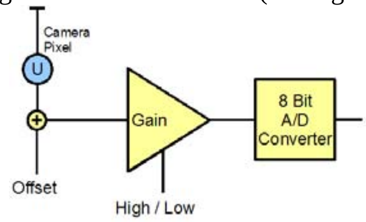

Figure 5 Pixel conversion

If the highest voltages delivered by the brightest pixels exceed the upper input range of the A/D-converter ($U_{A/D\,max}$), then these values saturate the digital output to its maximum value. In case of a 8 Bit A/D converter the values are saturated to 255 (see Figure 6).

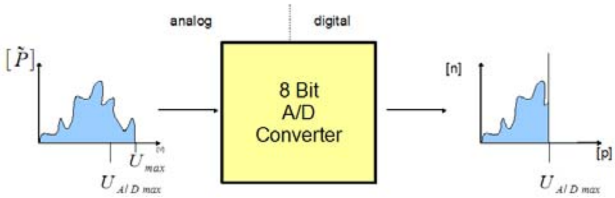

Figure 6 Clipping of histogram by saturated A/D converter

In order to cover the complete range of voltages delivered by the pixels, a gain factor and offset can be chosen, not exceeding the limits of the A/D converter. In this case the scenery will be mapped to 256 or less grey values.

In order to increase the amount of available pixel range, the idea is to acquire an image by two measurements. The first measurement covers the low voltages while saturating the upper pixel voltages and the second measurement with an offset subtraction converts the higher voltages while too low values are clipped to zero. In order to distinguish the pixel values from the first measurement to the second measurement the formerly subtracted voltage has to be re-added as a digital offset (see Figure 7).

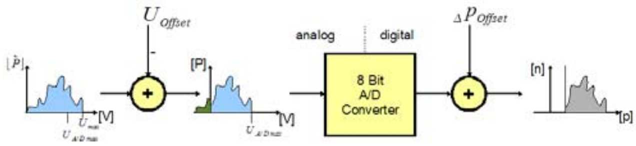

Figure 7 Clipping of histogram by dark pixels

By comparing the two measurements it can clearly be seen, that parts of the image information are complementary, so that the fusion of both image result in an image with more information. The information exceeds the maximum of 255 because the negative offset was re-added. Optimally the ranges of these two measurements do not overlap but are directly neighboured. But if overlapping exists these mid-range areas with data from both images are fused by taking the average of both measurements I_1, I_2 (see Figure 8).

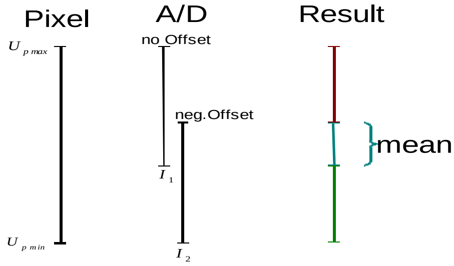

Figure 8 Image fusion for multiple shots

The resulting image is calculated:

$$I'(u,v) = \begin{cases} I_2 & if\ I_1(u,v) = 255 \\ I_1 + \Delta p_{Offset}, & if\ I_2(u,v) = 0 \\ \frac{I_1+I_2}{2}, & else \end{cases} \qquad (1)$$

$$\Delta p_{Offset} = U_{Offset}\ \frac{2^n}{U_{A/D\,max} - U_{A/D\,min}} \qquad (2)$$

With n : number of bits for A/D converter.

Measurements

The acquisition of images is done with the resolution 450 by 600 pixels. The frames per second (fps) rate depends, due to the optical trigger on the welding process. An example for an under- and overexposed pair of images will be used to exemplarily show the functionality of the algorithm. In the underexposed image, which contains the information of the high radiance areas a huge part of the environment is clipped to black and no information is available there. The glaring areas like the welding arc contain precise information within several grey levels (see Figure 9).

Figure 9 Underexposed image

The overexposed image contains explicit information about the environment, while the glaring areas are saturated to pure white with 255 as pixel value (see Figure 10)

Figure 10 Overexposed image

Using (1) the information from these images can be divided into low, mid and high range pixels (see Figure 11).

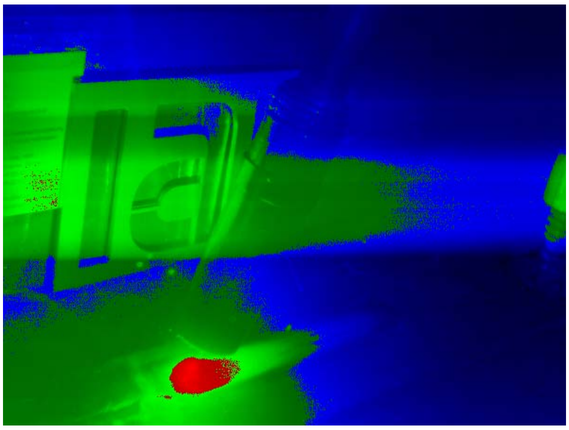

Figure 11 Composition from high (red), mid (green) and low (blue) radiance information

The composition may result in a grey level image with maximum 512 levels. The introduced example covers a range of 351 different grey levels. It results in an image where the environment and the welding process are visible at once (see Figure 12). The high amount of grey levels can neither be used for the direct view on a monitor device with the ability of only 256 grey levels, nor can the human eye distinguish such a high amount [9], [10]. In order to segregate more clearly the available information, a pseudo-color image is calculated (see Figure 13).

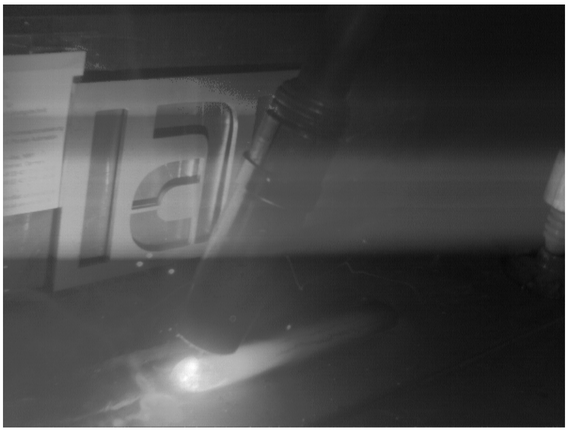

Figure 12 Resulting image by merging

This image shows distinguishably the full amount of the existent 351 grey levels. It can be seen that the information at the welding pool makes the arc and the pool with its temperature gradient visible. This step beyond the technical and human abilities does not impair the ability of using the data for image processing, segmentation and information extraction.

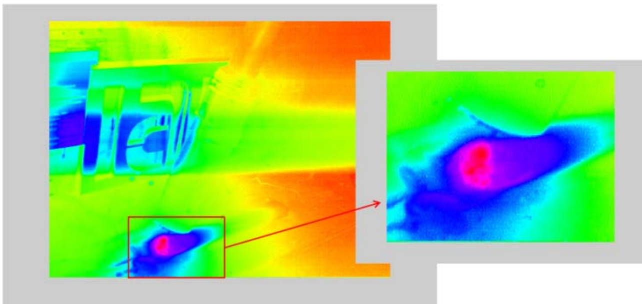

Figure 13 Pseudocolour image

Conclusion

We have introduced a simple algorithm to enhance the camera dynamic of a high dynamic C-MOS camera without touching the hardware. The only a priori knowledge is the value Δp_{Offset} which gives the radiance difference in pixels between the multiple shots. The image information is enhanced by toggling the camera parameters. An automatic offset control will be a useful feature to broaden the applicable range of such a camera for different welding currents i.e. different bright welding arcs.

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