A Short History of Using **Cameras for Weld Monitoring**

XIRIS
Inspection Solutions with Vision

Background

Ever since the development of automated welding, operators have needed to be able to monitor the process to ensure that all parameters are properly adjusted, that the welding head is properly aligned with the weld seam and work pieces, and that the weld pool, weld bead, and other features are all formed correctly.

For this monitoring, fabricators have long relied on operators to directly view the process using welding helmets and protective screens, which contain a dark green filter to remove most of the harmful content of the radiation coming from a welding arc.

With the advent of video camera technology in the 1950s, numerous attempts have been made to use video cameras to acquire images of an open arc weld and thereby relieve operators from working in hazardous proximity to the welding process and provide a better view of the welding arc.

The problem is that most standard video cameras—even with the better technology available today—are only able to capture a range of brightness of about 1000:1 in an image, whereas the range of brightness in the vicinity of an open arc weld exceeds 10,000,000:1. In using a standard video camera, the resulting image of the weld is usually completely saturated, providing no valuable information about the brightest area of the image.

To properly monitor welding processes with a camera, the camera needs to be able to capture content at the low end of brightness (namely the background around the weld) as well as at the high end of brightness (namely the weld arc in the foreground). Many methods have been tried over the years to achieve this extended range of imaging, known generically as High Dynamic Range (HDR) imaging.

Methods and technologies on the market today to achieve HDR imaging of a live welding arc include:

> Optical filters strategically placed to reduce the light to accommodate the normal dynamic range of a camera in a particular location;

> Multiple images each acquired with different exposures that get mathematically combined back together to provide a virtual HDR image;

> Photosensitive lens components (photochromic imaging) to darken the image;

> Special sensors with advanced sensitivity schemes.

Most of these approaches do not allow for reliable evaluations of the welding process due to overexposure or underexposure of some portions of the weld environment. The result is lost content in the image that masks critical detail of the welding environment, limiting the ability of the welding operator to maximize the performance of the welding process.

This whitepaper outlines the evolution of techniques used in HDR imaging with a video camera for monitoring open arc welding processes.

Early Efforts: Achieving HDR Imaging with Optical Filters

The simplest way to see the detail of an open arc is to reduce the amount of light available to a standard camera by using a dark filter across all or part of the lens. If a dark filter is used across the entire lens, there are two main problems that need to be addressed:

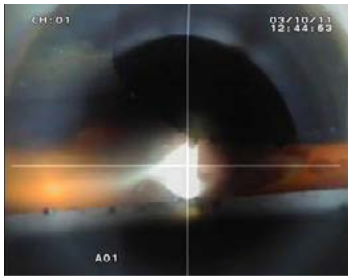
> How to remove the filter when there is no arc;

> How to view the background area that has significantly less brightness than the arc region.

Early cameras were equipped with dark filters that were not removable. They provided good definition of the weld arc, but not much was visible. A number of techniques were developed to be able to remove the filter from the optical path of the camera when no arc is present. The first successful idea to better see the background—and one that is still in use today—was to implement a dark spot filter in front of the camera, aligning the spot with the open arc, thereby obscuring the brightest part of the arc weld.

The problem with this approach is that the image has to be properly lined up with a spot filter with the right size and darkness to sufficiently darken the weld. If the alignment, filter size, or darkness isn't correct, the resulting image doesn't appear ideal. Even with the best setup, light from the weld arc often bends around the dark spot and creates hot spots on the rest of the image.

And when the arc is turned off, the dark spot remains in the field of view—impairing the operator's ability to see all the details of the weld work environment with the welding gun off.



Making a Better Spot Filter

To clearly see all the details in a weld environment when the weld arc is not present, some designers have incorporated a switchable iris into the spot filter. This provides for some significant improvement to the image quality because the spot filter can be removed, when not required, by pulsing the iris.

The original switchable iris systems were electro-mechanical. While achieving a better image than a stationary spot filter when there is no welding present, the reaction time of the electro-mechanical system to change the brightness was too slow to be a useful light shuttering technique, especially with processes of huge brightness swings, such as short-circuit GMAW processes.

A slight improvement on a switchable iris system was a switchable polarizing filter. In this approach, a single filter was put in place and the second filter, the polarizer, was rotated until the polarizing element created a dark filter. With better designs, the polarized element was a single spot in the middle of the optical path. However, polarizing filters are still not dark enough for some type of welding processes and need to be activated quickly to respond to the arc-on condition.

Instead of polarized spot filters, there are now liquid crystal display (LCD) filters that can switch very rapidly from clear to dark. However, the design of such LCD filters results in the clear state still being fairly dark and the dark state not being dark enough for some types of applications. However, in order to drive the display, the filters need a photodiode to detect if the weld is on.

Achieving HDR using Multiple Image Exposures with Tone Mapping

Original Raw Images: Underexposed (a) and Overexposed (b)

Resulting Image of Both Images Combined Using Tone Mapping, Showing Greater Detail

A non-optical technique now used to achieve HDR imaging is combining multiple images of the same scene taken extremely quickly with different exposures.

This multiple-exposure technology has been in use for years in selective industrial applications, and it has now made it into some standard commercial photographic cameras, giving them the ability to dynamically change the exposure time for successive frames. In such cases, a composite video frame can then be created by mathematically combining together multiple consecutive frames taken with different exposures using a Tone Mapping operator.

This method, known as the Wyckoff method, works well with relatively slow-changing scenes, as long as the parameters used in the mathematical combination are well-defined and unchanging. But in welding, the scene brightness can change so fast that two consecutive frames may differ in brightness in many parts of the images.

Consequently, it's very difficult to create a single mathematical combination of consecutive images that generates a final image with smooth light gradations across all the different types of welding, their various pulsing modes, and other varying parameters.

This method also faces another challenge—a reduced frame rate. To keep a smooth frames/second video rate, the camera must actually produce many times that frame rate to provide enough frames to be mathematically combined. The result is that this process tends to have extensive computer or electronics hardware that makes it quite expensive.

Photos courtesy of http://hi.eecg.toronto.edu/wyckoff.html

Photochromic Optics

Another approach to providing an all-optical solution to creating an HDR image is to use photochromic optics. A photochromic lens contains a chemical layer that automatically darkens on exposure to ultraviolet (UV) radiation emitted from a weld source. Once the light source is removed by shutting the weld source off, the lenses gradually return to their clear state. The process is similar to eyeglasses that darken in bright sunlight yet go clear in darker environments.

The drawback to this technology for HDR imaging is that photochromic lenses are slow to darken and even slower to lighten, causing significant delays in the time it takes for a camera to be useful to the operator. The photochromic process also tends to decay over time, eventually not being able to darken enough to be useful.

Achieving HDR Using Knee Point Cameras

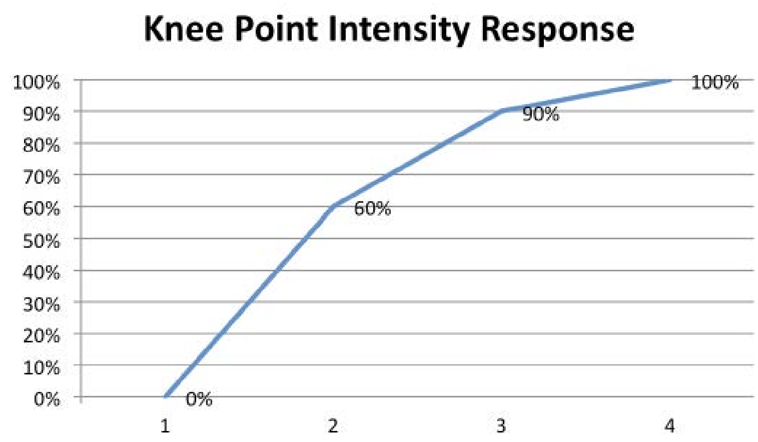
Instead of varying the exposure time of successive images, an HDR image could be approximated by using a camera equipped with an extended shutter. In such a camera, the user is able to set up multiple slope integration curve segments in order to extend the dynamic range of the camera by generating a non-linear response to light.

The multiple slope operation is controlled using knee points (points that define a change of slope between two linear segments of the response curve), where each knee point occurs at a separate time during the overall integration time of the sensor. Each knee point represents a separate reset point for the image, where pixels brighter than a certain value are reset to that value. The value that is set for each knee point is the time from the start of integration to when the knee point occurs. Each knee point must have a greater time than the previous knee point, and all knee point times must be less than the overall integration time.

The effect in the image is to reset the pixel at that time and to integrate until the end of the overall integration time. Hence, as the knee point time becomes longer, the effect is to shorten the integration time and expand the dynamic range in bright areas of the image.

If a camera is equipped with an extended shutter and knee points, an HDR image can be achieved because different rates of brightness compression can be achieved along the brightness curve—reducing the saturation at the high end and stretching the range of brightness at the low end. The user can adjust the knee points to compress or expand certain ranges or to reduce the charging rate of the camera's pixels after they become saturated.

The resulting response curve provides some High Dynamic Range, similar to a logarithmic response. However, there are a number of drawbacks of knee point cameras. Because of their design, there is a possibility of pixel blooming and saturation effects around very bright pixels. In addition, setting knee points can create a suitable HDR image with one set of image brightness parameters; but when the parameters change as they would from one type of welding to the next, the knee points have to be reset by the operator, making such a camera difficult to use across a variety of welding processes.



Natural HDR technology

A few years ago, a new technology was introduced for CMOS sensors based on photo-voltaic pixel sensors. Such sensors have a natural logarithmic response that do not saturate, and there is no blooming effect because there are no accumulated charges. Pixels deliver a voltage proportional to the logarithm of illumination with extraordinary accuracy, generating a dynamic range greater than 140 dB. This is defined as High Dynamic Range imaging, and it has a number of very interesting characteristics, not the least of which is the ability to perform incident light intensity measurement with no integration of the signal on the sensor.

However, background noise is the inherent flaw in such types of sensors and needs to be removed with a special algorithm to minimize its effect on the overall image quality.

The advanced background noise removal method of these sensors make them able to view the scene at normal, and even dark, light conditions while simultaneously viewing bright objects without needing any changes.

As the pictures below show, the same camera with no parameter changes shows the identical image of the scene, under light conditions that differ by 1000 times.

100 Lux

0.1 Lux

Cameras built from such a sensor offer a number of improvements over traditional cameras, namely:

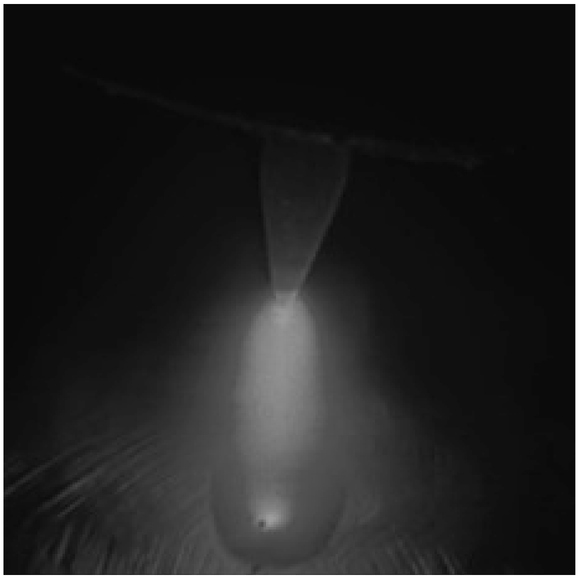
1 A simpler and more stable fixed pattern noise compensation method resulting in better image quality in darker areas of the image.

2 Better sensitivity in low light conditions, allowing better background detail in a weld environment.

3 Reduction of image lag in dim light conditions so that the image can keep up to fast-changing lighting conditions such as those that exist in MIG short circuit welding.

4 More features visible in the weld arc than ever before because the sensors do not fully saturate, keeping the intense light from an open weld arc from saturating the image.

Using HDR to View the Welding Process



TIG Welding Captured Using a Logarithmic CMOS sensor.

In the above image, many details of the welding process, including the arc and background, are visible to the operator for diagnostics, process adjustment, and validation. It is clear that using the logarithmic CMOS sensor with some specialized electronics and image processing provides the best quality of image to the operator.

Other HDR Methods

New techniques continue to appear on the market to try to achieve higher and higher levels of high dynamic range imaging. Numerous sensors have been developed with HDR ranges that approach 100 dB using patented processes such as interlaced lines of an image with two levels of sensitivity with a rolling shutter, dual sensor cameras with different ranges of intensity, and variable integration time sensors that extend the range of brightness. All of these technologies have promise, but end up yielding a lower range of brightness than that available from a logarithmic CMOS sensor.

A Special Note – Global vs. Rolling Shutters

The use of HDR video cameras with welding processes requires a discussion about the type of exposure sequence used in the camera sensor. Originally, all HDR digital camera sensors used a rolling scheme where the sensor is exposed to light one line at a time, so one line would be exposed and its current charges readout, then the next line and so on. In imaging any rapidly changing scene, such as a pulsed welding arc, the resulting image can contain artifacts that result from the arc flash being significantly shorter than the time to expose the full frame.

Fairly recently, global shutters have been implemented in HDR digital camera sensors. A global shutter is an image acquisition process whereby the entire image is exposed at one time. In imaging welding processes, this provides consistent image features across the entire image, minimizing localized artifacts caused by the varying weld arc while the frame is being exposed - all portions of the image are affected equally.

Conclusion

Xiris has reviewed all the imaging technologies available in its search to create the best possible Weld Camera. After a lengthy testing process, we have determined that incorporating a logarithmic sensor into our Weld Cameras offers the best imaging solution for monitoring open arc welding processes.

After several years of research, the XVC-O Weld Camera is now available on the market at a reasonable price for performance previously achievable only from older technologies that required extensive manual setup and intervention. The result is a camera that can see the detail of the welding arc AND its immediate environment in a single image.

Would you like more information?

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