# DEDICATED NEAR-INFRARED VISION SYSTEM FOR MONITORING WELDING PROCESSES

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***Abstract.*** *Fully automatized welding process has been a challenge for researchers and research centres worldwide. Although the idea of having a total independent system, capable of responding to any variation on the welding process, is surely desired, it has not been accomplished. In addition, puzzling conditions, such as high-productivity and underwater processes, must be solved in the welding scope. A promising tool to accomplish this task is based on visualisation, i.e., by using a Vision System. Vision Systems have been studied and developed under different approaches. However, while the metal transfer studies are consolidated, the weld pool visualization and studied are scarcely and demands development. Therefore, the objective of this work is to show all the capability and potentiality of a dedicated Vision System developed using diode-led illumination at 905 nm and an optical bandpass filter at the entrance of a CMOS camera at 25 frames per second (fps). The main feature of the developed system is its low cost and robust utilisation. Different results are shown for different process and parameters. It is concluded that the Vision System is a straightforward and powerful tool for the welding process imaging.*

***Keywords****: Welding, CMOS, Infrared, Monitoring.*

## 1. INTRODUCTION

In mechanized arc welding, the ideal method of controlling the welding operations is to record the size and shape of the weld pool. Unfortunately, the intense arc light prevents the information being recorded by a camera based control system. Previous attempts to eliminate, or at least to reduce, the amount of arc light reaching the camera by the use of filters has been only partially successful (Lucas & Smith, 2000). The problem when using a filter with an infra-red or low cost CCD camera was that the arc light could not be totally eliminated. Thus, as the edges of the weld pool could not be clearly recorded, it was difficult to take precise measurements of the size and shape of the weld pool which are necessary in order to control its behavior.

The work reported in this paper details the research work carried out over the last decade at the University of Liverpool in developing vision based system for monitoring and control of arc welding processes. The systems developed include (Houghton et al., 2007 and Abdullah et al., 2007):

- CCD camera with narrow band-pass filter.
- CMOS camera with long pass filter.
- Q Switched flash-lamp solid state Nd:YAG Laser illumination
- Low cost semiconductor laser diode illumination.

In welding, as sensor system costs are to be minimized, the emphasis has been directed at producing a low cost illumination system. Research has recently culminated in the use of laser diodes which have proved to be highly effective in eliminating the arc light from masking the image of the weld pool. Application studies have been carried out at The Welding Institute (TWI) to demonstrate the potential of the new laser diode illuminated vision system for both TIG arc welding.

## 2. EQUIPMENT

### 2.1. CMOS camera with long pass filter & fine shutter control

The basic principle here, just like a welder's visor, is to attenuate and filter the arc light to an acceptable level and range of wavelengths. It was observed that a filter operating in the near infra-red gave best results operating close to the camera's upper wavelength sensitivity (Balfour et al., 2004).

There are three main types of cameras which can be used in vision systems:

- Charge Coupled Device (CCD)

- Complimentary Metal Oxide Semiconductors (CMOS)
- Infra-red.

CCD and CMOS cameras have a much lower cost than infra-red cameras. However, the principle advantage of the infra-red camera is that it operates with the least arc light interference of the weld pool scene. In terms of performance, CCD and CMOS cameras have a superior frame resolution with pixel resolutions of 1024x1024 available which are more than adequate for most welding applications.

Recently, CMOS cameras became available with a lin-log light intensity to grey value conversion. Welding scenes involving scenes of high intra-scene contrast can be compressed. This means the lower light levels can be expanded and bright light levels compressed reducing the loss of useful information due to saturation (white-out). The lin-log CMOS camera in terms of light intensity dynamic range is typically larger than the standard CCD camera. CCD cameras, however, operating in linear mode, offer twice the dynamic range in terms of signal to noise ratio. With very short exposure times, for example as used in laser illumination, CCD offer better image quality due to lower noise and pixel response uniformity.

CMOS cameras are available with either rolling or global shutter. In terms of shuttering, especially capturing fast welding events, one should ensure a global shutter is used to prevent image distortion.

In this work, a photon focus CMOS camera (752x582 pixels), having a natural anti-blooming architecture, was chosen. Camera control was provide by programmable exposure control down to 10us thereby freeing the camera to accept less optical filter attenuation.

A long pass filter, which transmits near infra-red from 850nm upwards, gives the effective combined filter and CMOS camera response as shown in Fig. 1. By increasing the bandwidth from 15nm, the weld pool image illumination has been improved. The wider bandwidth allows more radiation from the hot arc root relative to the outer arc-light contours. The welding images have the appearance of a brighter, narrower, arc root illumination source giving clearer views of the weld pool (Fig. 2).

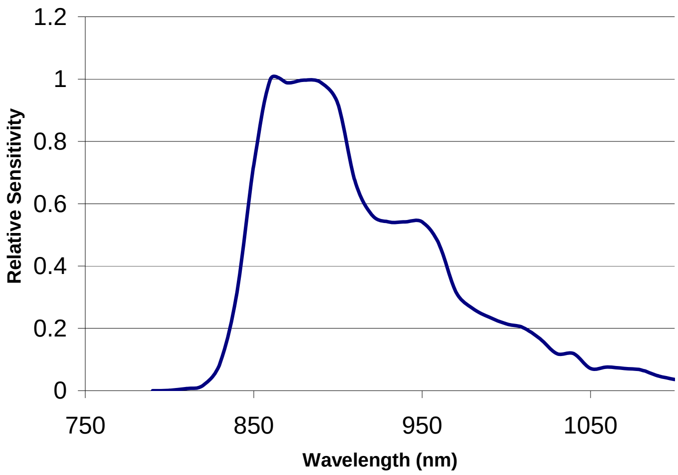



Figure 1. Effective CMOS camera response with long pass infra-red (IR) filter.

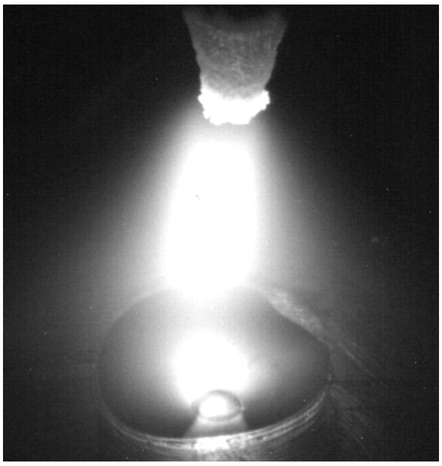


Figure 2. TIG on mild steel 100A, pure Ar.

**2.2. Laser illumination**

The basic principle here is to use a uniform illumination source much brighter than the weld pool that the arc light effectively disappears from the camera image. To maximise the laser light relative to arc light detected by the camera is achieved by three techniques:

1 As in flash photography, the laser is closely synchronized with the camera shutter

2 A band-pass filter closely matched to the laser wavelength (1064nm) allows only the camera to view only the laser light

3 The laser pulse has high intensity relative to the arc light to eliminate the arc light.

For each camera frame, the Nd:YAG laser is initially excited by a flash-light and is then triggered via a Q-switch to lease the energy in a short but intense pulse of radiation at 1064nm wavelength. Nd:YAG is a solid-state crystal device. A typical YAG laser, costing £10,000, will produce 30mJ @ rep-rate of 30 Hz in the pulse providing enough energy to use back illumination, i.e. with the light source mounted near the camera lens, as in standard flash photography. In Figs. 3 and 4, images of welding processes for both TIG and MIG are shown using this technique. The weld pool is clearly visible with minimal arc-light being observed.

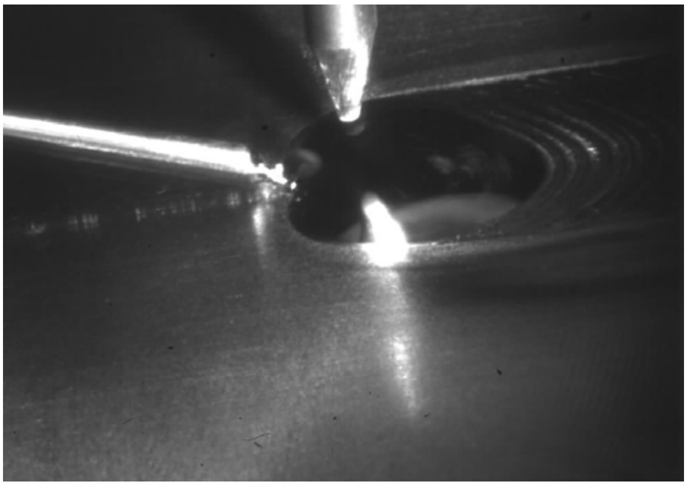


Figure 3. TIG Weld pool images.

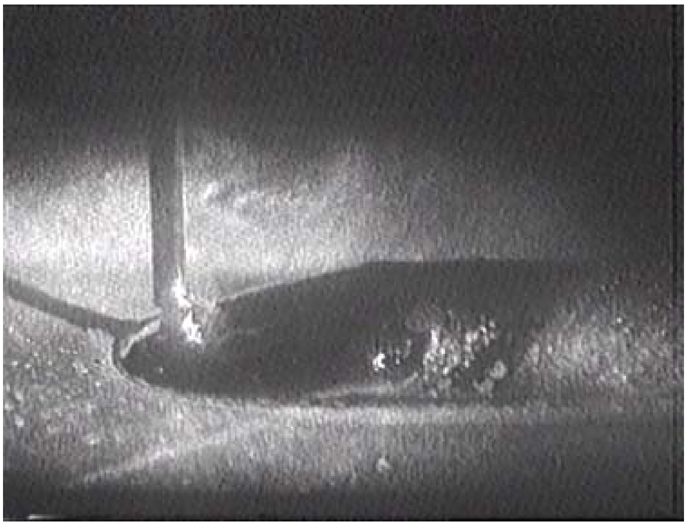


Figure 4. MIG Weld pool images.

One of the main goals of welding fabrication is to reduce costs. Moreover, the associated devices, mechanisms, sensors, instrumentation and controls must follow this trend of cost reduction. Therefore, it is very important that the illumination system stands for a low cost sensor. In this way, the solid state technology provides the answer as low cost laser diodes.

Semiconductor laser diodes are a potentially lower cost alternative to semiconductor lasers (e.g. Nd:YAG laser) as means of illumination. The laser diode illumination system is shown in Fig. 5. The 16 diode cluster is mounted on the laser array driver. A frame rate generator acts as the ‘master’ in synchronising both the camera shutter and the laser cluster pulse timing which both act as ‘slaves’. The frame rate can be set from 5 to 25 frames per second in 5 frames per second steps. Each laser diode has a beam divergence of 11° x 25° giving an elliptical illumination pattern. A lens table holding the 16 clustered laser diode devices and a concave lens arrangement focuses the light into a viewing area width of 20mm for a lens distance of about 100mm. Concerning costs, each laser diode costs around £10, which is much more affordable than above cited YAG laser.


Figure 5. Low cost Semiconductor Laser diodes (Copyright © TWI Ltd).

The components and system arrangement is shown schematically in Fig. 6. When using the camera for video recording, the frame rate is typically 25 frames per second. Each frame exposure time is synchronised with a 10μs the laser diode pulse. The laser diode power output is approximately 17.8W with a pulse energy of 178μJ. In order to eliminate the arc light, it was found that 16 diodes were required which provided laser pulse energy of 2.85 mJ (285W of total power in the pulse). Driving the laser diodes at this pulse width with a semiconductor junction temperature change of 15 deg C is not recommended by OSRAM (manufacturer) as the laser diode life-time is reduced.

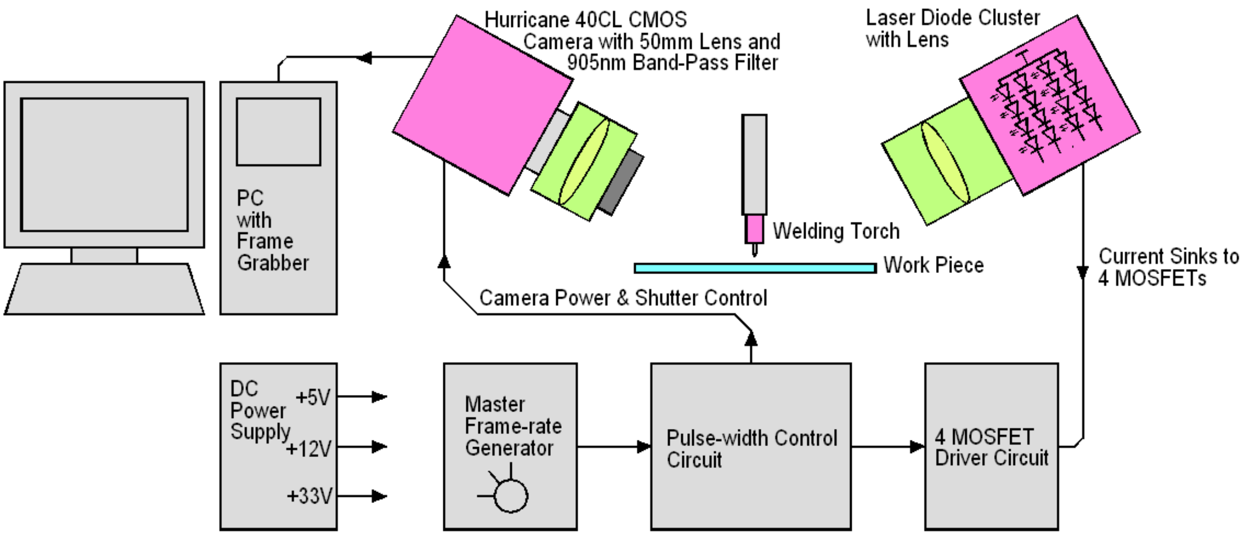



Figure 6. Block Diagram of the Lost cost Laser Illumination system.

## 3. APPLICATION

The vision systems using laser diodes for illumination has been used for monitoring TIG welding process by using the experimental rig shown in Fig. 7.

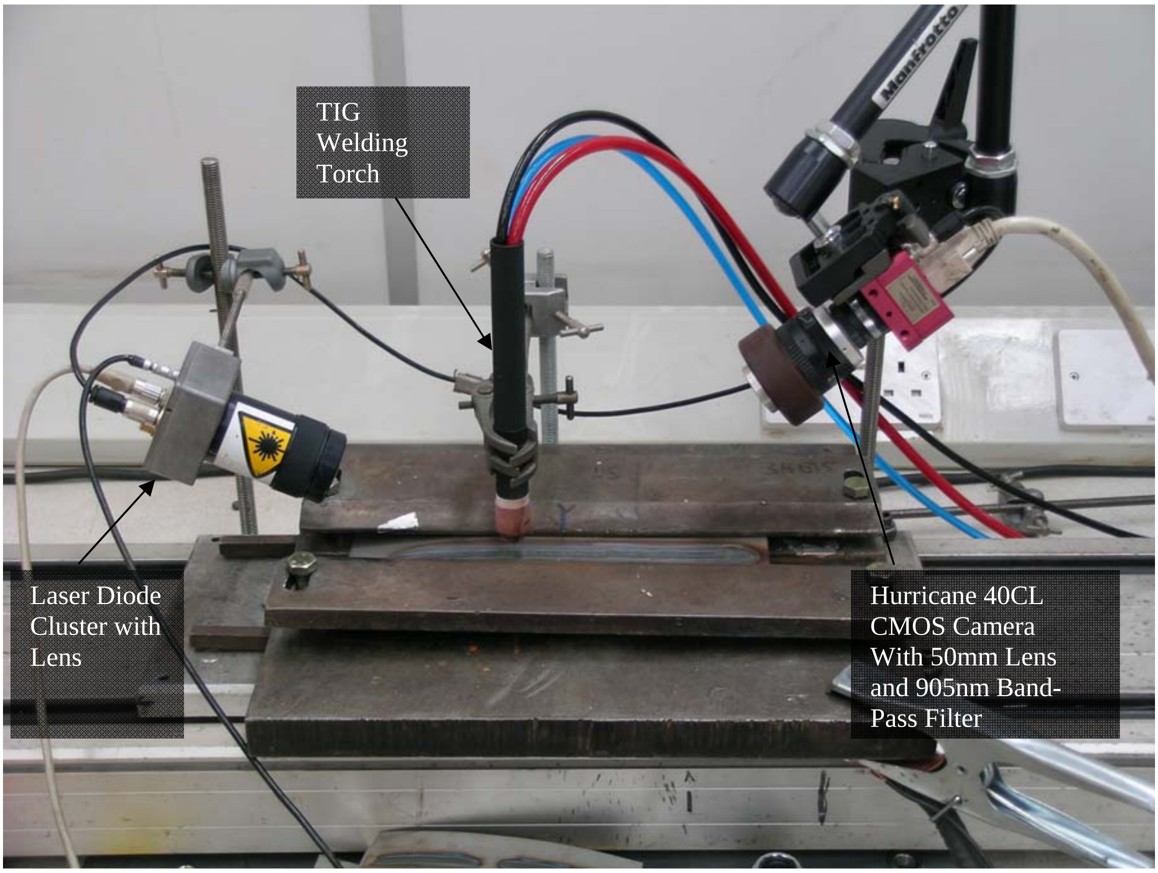



Figure 7. The pulsed laser source and camera system applied to monitor the tungsten inert gas (TIG) welding process (Copyright © TWI Ltd).

The vision system has been employed in a study of the mechanism for increased weld pool penetration when TIG welding with an active flux (A-TIG process). The vision system consisted of the diode laser, Type IIIB, with a 16 laser diodes array to illuminate the weld pool area at a wavelength of 905 nm and a CMOS camera fitted with a 905nm band pass filter.

TWI's flux was sprayed on an austenitic stainless steel SUS304 plate (125 x 38 x 4.7 mm), giving a coating thickness of 8±2 microns (PosiTestDFT, 2004). The welding current was set at 150A which produced full penetration on the flux coated section and only partial penetration on the uncoated section. The other welding parameters were:

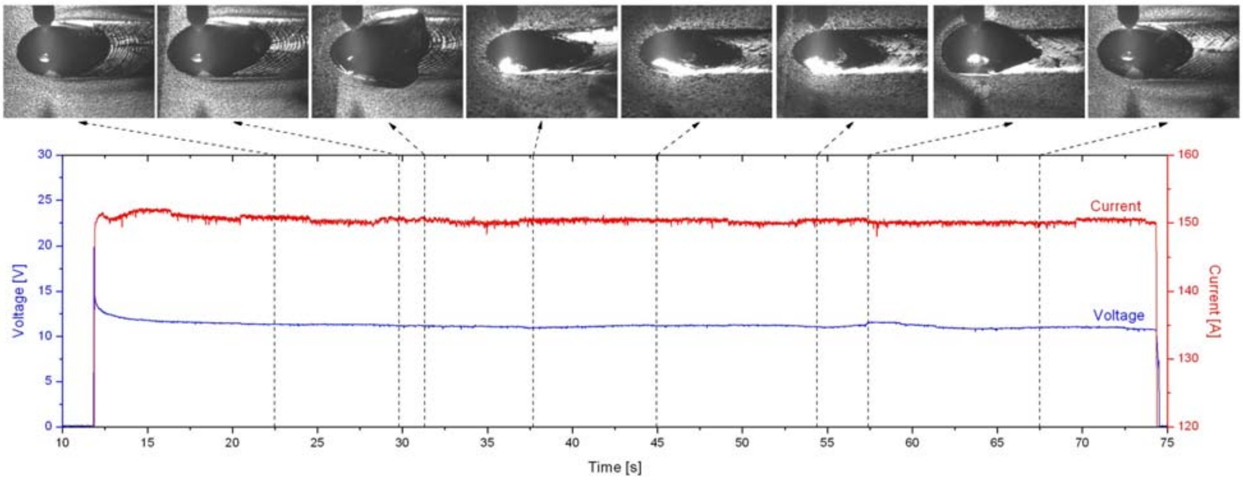
- Travel speed: 100 mm/min
- Shielding gas: argon at 12 l/min
- Nozzle diameter: 10 mm
- Electrode W+2%Th, diameter of 2.4 mm, with a stick-out of 10 mm to facilitate weld pool visualization

The arc length of 3 mm, which should be the smallest possible and at the same time make possible to see the weld pool. Voltage and current signal was record by an acquisition system set at 1 kHz per channel.

The obtained results are shown in Fig. 8, where it is possible to observe the behaviour of the weld pool when moving between the uncoated and coated parts of the test piece (the coating image has a rough surface compared to the plate one). As the arc was eliminated, the constriction of the weld pool could be clearly observed, Fig. 9.

The mechanisms of A-TIG are not the subject of the present paper. They are currently under investigation and some initial ideas are going to be presented elsewhere (Vilarinho, et al., 2009).

There is also the option of not applying the bandpass filter on the camera entrance. This procedure certainly allows the arc light to reach the CMOS and appears on the image (Fig. 10). However, since the CMOS sensitivity is low at the UV-visible range, the arc light is tenuous. It is suggested here that this option can be used in the research and development of arc-welding processes. On the other hand, with the bandpass presence, the visualisation can be straightforward used as a joint tracking system, for instance. This maximizes the use and potentiality of the dedicated infrared vision system described here.




Figùre 8. Images synchronised with electrical signals for A-TIG run (electrode diameter: 2.4 mm) (Copyright © TWI Ltd).

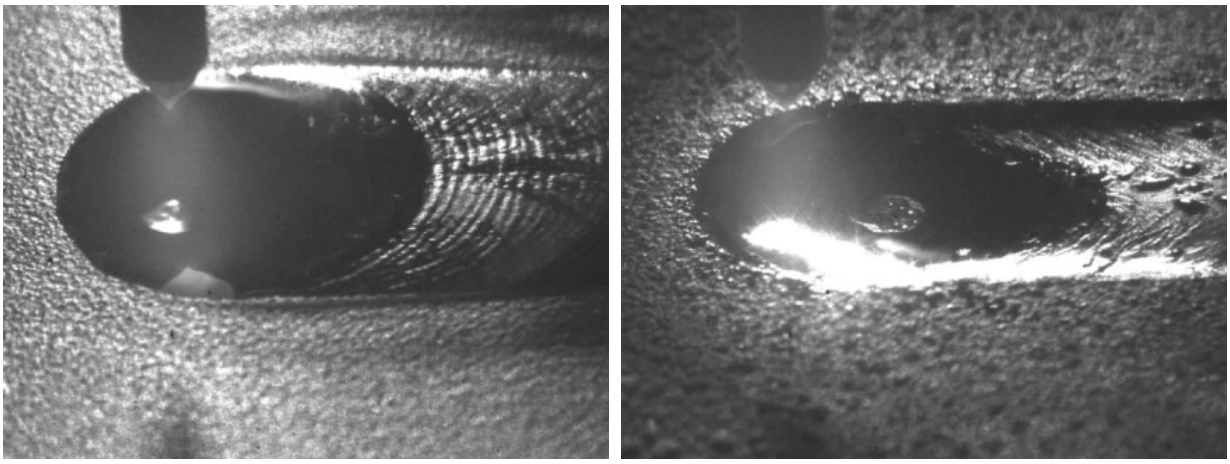
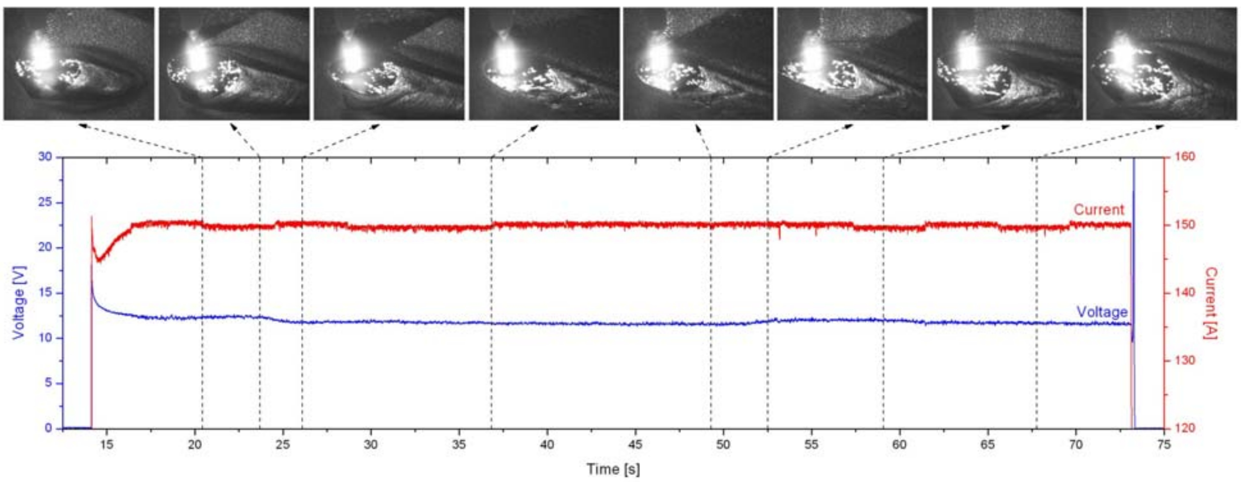


Figure 9. Frames from outside (left) and inside (right) the A-TIG flux (electrode diameter: 2.4 mm) (Copyright © TWI Ltd).




Figùre 10. Images synchronised with electrical signals for A-TIG run, with no bandpass filter on the camera entrance (electrode diameter: 2.4 mm) (Copyright © TWI Ltd).

## 4. CONCLUSION

It is possible to concluded that the low cost vision system developed and applied to visualize TIG welding (in specific the behavior of A-TIG process) was fully capable of providing clear images of the weld pool, with great expectation of acting as joint tracking or further applied on research and development of welding process.

## 5. ACKNOWLEDGEMENTS

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