

## **A. In Situ Weld Pool Measurement Using Stereovision**

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### **Introduction**

Our main goal is to develop a robotic, out-of-position welding system using GMAW for welding on pipe. To achieve this we must develop a closed-loop feedback control system for monitoring and controlling the welding process. Most welding processes use the human as the feedback mechanism to close the loop on process control. Automated welding systems do not have a human in the loop and, as a result, most of them are open loop processes (although there may be closed-loop subsystems within the system, e.g. wire feed speed or pulse shape). Closed loop control has been largely confined to seam tracking and weave control. Typical automated welding systems rely on the weld line being horizontal (in-position) in order to remove the effect of gravity. The ability to weld out-of-position is important for automating in-place welding. We are using vision as our primary sensor to assess the state of the welding process. This paper presents our most recent work on developing stereovision for in situ weld pool measurements using high frame rates in order to capture weld pool oscillations and process the stereo image pairs in real-time.

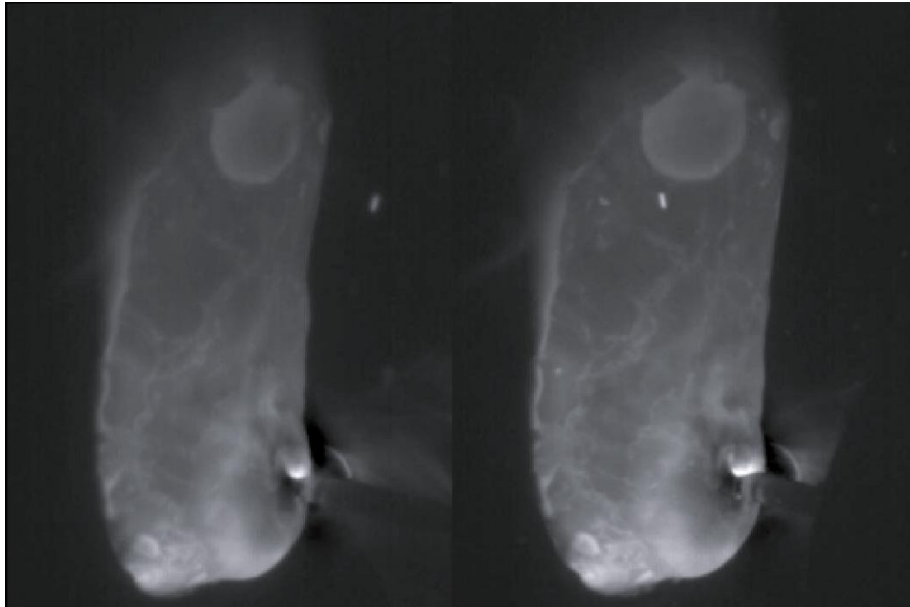
### **Procedure**

Our welds are produced using a Fanuc 100iB 6-DOF robotic welder with a Lincoln Powerwave 455 power source, a Tregaskiss torch, and 0.035 wire. The Gas Metal Arc Weld pulsed (GMAW-p) process uses a shielding gas that is 75/25 Ar/CO<sub>2</sub>. The welds are bead-on-plate welds with the plate in a vertical (downhill) position (out-of-position). The stereo image pairs are collected using two Basler A504k high-speed digital cameras at an exposure time of 125 $\mu$ s and a frame rate of 250Hz. The baseline distance between the cameras is approximately 10cm and the cameras are positioned about 50cm from the weld. The cameras were calibrated using the Camera Calibration Toolbox for MATLAB developed by Jean-Yves Bouguet at CalTech ([http://newbologna.vision.caltech.edu/bouguetj/calib\\_doc/index.html](http://newbologna.vision.caltech.edu/bouguetj/calib_doc/index.html)). In our experimental setup, no external illumination is used or required. Since we use a GMAW-p process, the weld arc is extinguished about every 1/60 of a second, allowing the weld pool to be visible due to its high temperature radiance.

### **Results and Discussion**

Stereo vision allows us to measure physical parameters of the weld pool such as the height and width. These results are compared to independent measurements on the weld bead after the weld is completed. It also allows us to identify and track the presence of slag and to potentially identify the occurrence of undercut. Figure 1 shows an example of a stereo image pair collected by the procedure detailed above. The left camera image is on the left, and the right camera image is on the right. The weld pool surface is highly patterned, which allows for a correlation based stereo image processing system to compute depth information about the weld pool. The angle of the cameras in relation to the weld pool allow for a little over half of the weld pool (split vertically) to be visible in both images. Figure 2 shows a disparity map computed from the correlation algorithm. This disparity map can be used to determine the three dimensional structure of the weld pool. The lighter tones of gray indicate points that are physically higher off the plate (receding left to right). The pure white points in the

disparity map correspond to areas that did not contain enough variation to determine the correlation between the images, or where the best correlation could not be determined uniquely. However, the disparity map could be computed over a high percentage of the weld pool.



**Figure 1. Stereo image pair of weld pool**



**Figure 2. Depth map from stereo image pair**

### **Conclusions**

Stereovision holds great promise as both an active sensor for closed-loop control of out-of-position welding as well as an in situ quality assurance device for welding processes. This paper presents new results that will promote this new application of stereovision sensing and measurement.