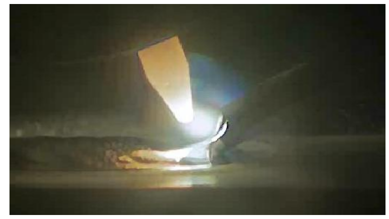
Visible Welding



Portable Video System for Limited-Access Shipbuilding Welds

Welding Technology Panel Project

Final Report

Prepared for:

National Shipbuilding Research Program

Sub-Contract # 2013-424

Prepared By:

Steven D. Edelson, President, Visible Welding

And

Paul A. Blomquist, Applied Thermal Sciences, Inc.

Submitted by:

Visible Welding

7 Sears Road, Wayland, MA 01778-2101

January 31, 2014

Welding Technology Panel Project Final Report

Portable Video System for Limited-Access Shipbuilding Welds

Prime Contractor: Visible Welding, Wayland, MA
Subcontractors: Applied Thermal Sciences, Sanford, ME (ATS)
Shipyard Partner: HII Newport News Shipbuilding (NNS)
Project Technical Representative: Paul Hebert, NNS

Executive Summary

Every shipyard and many other industries encounter areas of limited access in which welding must be done; welding in these areas is typically done using one or more mirrors placed strategically to provide a view of the area to be welded. This takes highly skilled, highly trained, specially qualified welders. “Mirror Welding” is virtually an art form in itself. The reverse image makes the learning curve very steep, and the training is mentally challenging. Worse is the problem of making repairs to “mirror welds” that fail QA – rework can be very slow.

With advances in weld camera technology, it is now feasible to allow a welder to “weld-by-camera” in these areas requiring mirrors. This report describes the effort to test this concept by building a beta-level system suitable for testing by experienced welders testing.

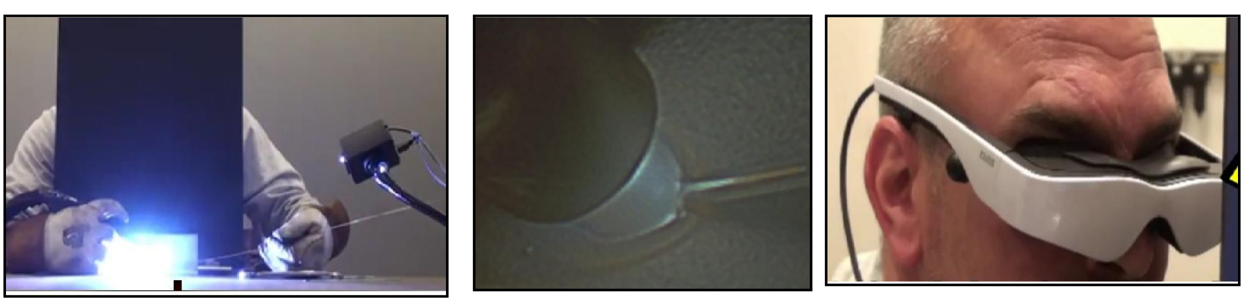
A compact, lightweight, highly portable video system was developed for the tests. The system consists of a small (2” x 2.5” x 3.5”) camera, a controller / image processor, and video display goggles that can be worn under a protective hood. Pictures of the camera and goggles appear below. Features were selected to match the special problems of the blind weld.

The system has been demonstrated and tested in shipyards and other venues, including the AWS Welding Convention (Fabtech).

- Test welders agreed the system delivered excellent image quality, superior to the view in mirrors – sometimes better than direct view through a mask.
- Welders quickly adapted to the system, especially welders who were not experienced “mirror welders.”
- Testers fed back areas for improvement and many of these have been implemented.

Future work is needed to refine the interface with welding hoods and other personal protective equipment. It was also suggested that a 3D version might improve depth perception.

Industry response has been very positive. At this writing, we have a number of purchase orders from shipyards and other industries for copies of the beta system.



In the alpha field tests, a wall blocks the view and the welder must rely on the camera (left photo). The welder relies on the live video feed (center) displayed in the goggles (right).

Concept Description:

Provide a highly portable video system that can be placed near the intended weld joint, coupled with display mounted inside a welding helmet.

Extent of the problem

Conversations with shipyard welding engineers disclosed a wide range of experience with mirror-welding scenarios. For new construction efforts with aggressive Design-For-Assembly (DFA) strategies, fewer than 5% of the workforce may be required to be trained for mirror welding; in the non-DFA world of Modernization, Conversion, and Repair (MCR), that number may be as high as 20%. Similarly, the increase in time to make these critical welds may range from 2.5X in DFA situations to well over 60X (yes a job that would take minutes could take HOURS) in the MCR world. Providing a more intuitive solution can reduce the training and time to make difficult-access welds; savings can be as high as 50-75%. Further, the quality level will be increased, again by virtue of giving the welder a clear view with no image distortion. Finally, inspection of these welds will be facilitated as well.

Why is such a system needed?

Commercial-Off-The Shelf (COTS) video equipment was found to be inadequate. Both inexpensive components and higher-end systems for weld viewing suffer from limited dynamic range – either the sensor is overpowered by the arc light, or heavy filtering is used, or very expensive strobe lighting and filtering (resulting in a monochromatic image) are used. Visible Welding's larger-scale Patent-Pending Ultra-Dynamic Range Video systems already provide unparalleled visibility of the weld by means of optimized sensors and sophisticated algorithms for image processing.

All that was needed for the success of this project was the necessary miniaturization of camera and display, and improvements to the image processing software. The real unknown was not the camera, but how such a camera system would help the welder learn and execute the blind welds.

Other Benefits

This equipment can be configured to offer multiple displays, allowing a trainer or other observer to view and coach the welder. This can be done in a training facility or just as easily at the job site. It may also be used for other applications where enhanced observation of welding processes is required or desired. User testing highlighted the fact that this system would provide critical benefit when used on critical weld joints that had to be made "right the first time."

Project Strategy:

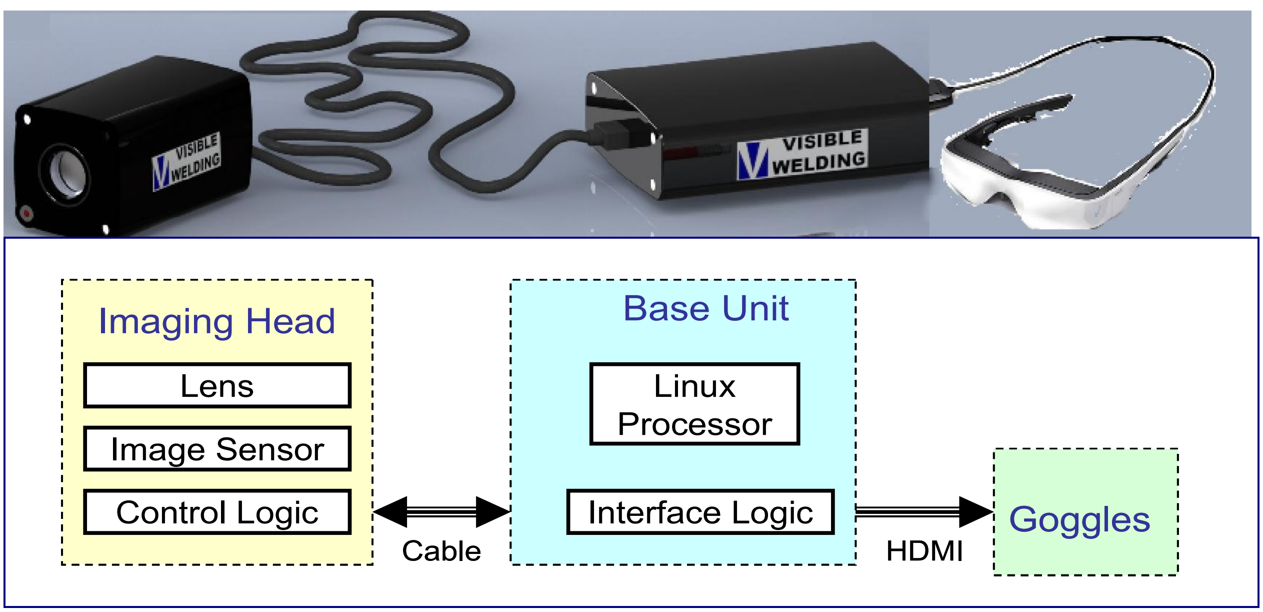
It was necessary first to determine the technical and functional feasibility of the project.

- Technical (Can it be built?)
    - Paper design of system
    - Build prototypes of critical elements
    - Software implementation and test of other significant elements

- Functional (Does it help the welder?)
    - Construct a system with which welders can weld to test the concept.
    - Test system does not need to be a polished product, but must work well enough to get a reliable reaction.
    - Test, improve and re-test.

- **Idealized End-Product:**

  The paper design started with an idealized end-product with features anticipated to be necessary and useful. It is composed of a small camera imaging head (half the camera) to put near the seam to be welded, a belt-worn controller that controls the camera imaging head and creates the video from the raw imager head. The welder views the live video on HD goggles worn under the helmet.



The ideal system would be composed (left to right) of a camera head, controller which produces the images, and a pair of HD video goggles (right)

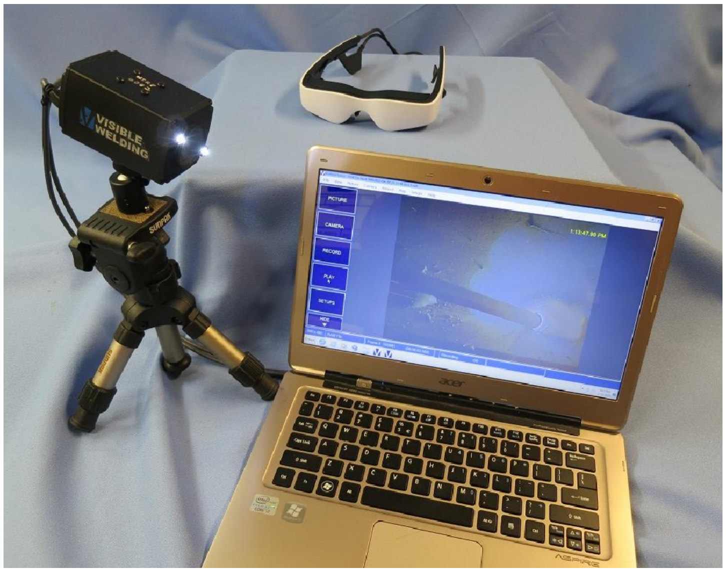
- Camera Imaging Head
    - UDR (Ultra Dynamic Range) to see under the arc
    - Small to work in close quarters.
- Belt-worn camera controller
    - Controls camera
    - Performs image processing
    - Outputs video to goggles
- HD Goggles

    - Quality Goggles which fit under welding hood.
    - OLED goggles from Zeiss

Constructed for Test:

- Imaging Head
    - UDR (Ultra Dynamic Range) using latest logarithmic color sensor
    - Small to work in close quarters (2” x 2.5” x 3.5”)
    - Remote-controllable lens
        - Remote-control allows sealed aluminum case
        - Designed and constructed lens controller based on Arduino Nano
        - Focus distances from 4“ to 6 feet for flexible positioning
        - 10x optical zoom for close-up video, even when camera must be at a distance

- Controller functions implemented in software on a laptop
    - Using a PC simulation allowed functional test without the delay of building a controller.
    - Special version of Visible Welding program created to control the new Imaging Head
    - Performs image processing.   Image processing of Visible Welding software modified to match needs of new imaging head
    - Outputs video to goggles on standard HDMI connector
    - The feasibility of a belt-worn controller was explored and proven separately
- Goggles
    - State-of-the-art commercial OLED (Organic LED) HD goggles from Zeiss



The test configuration combined a fully functional camera-head prototype
with a PC performing all the functions of the belt-pack controller.
The HD OLED video goggles are from Zeiss.

Technical Feasibility

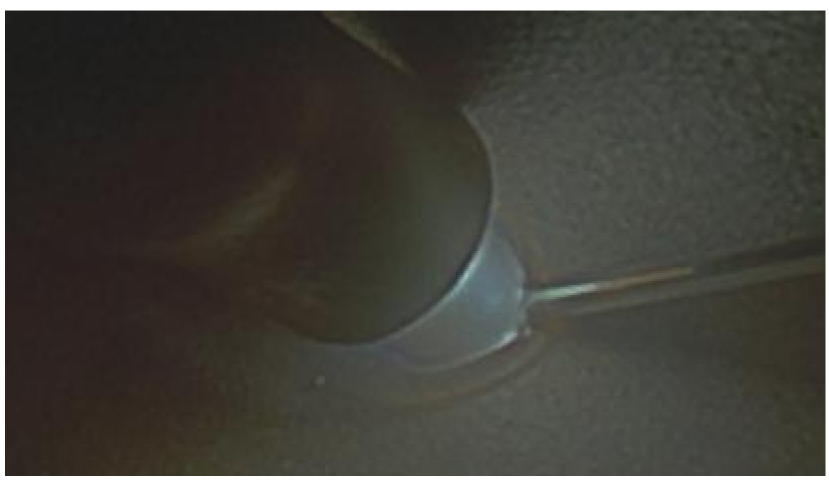
- Imaging head constructed and performed well in field test.
    - Images sharp
    - Remote-control operation appreciated
- Controller feasibility tested with bench-demonstrations of functionality
    - Nitrogen ARM processor board (3” x 4.5”) can fit into a belt pack
    - Demonstrated major functions in real-time
        - Camera head control
        - Video input and processing
        - Video output
        - Operator controls displayed over live video
    - Measured power consumption to verify battery operation feasible
        - Battery drain 10W total (2A @ 5V)
        - A typical laptop battery (50 WH) can power this for several hrs.

An ARM-based processor board proved it could process live weld video and support a touch-screen operator interface. At 3” x 4.5” the board could fit into a belt-pack case.

Functional Tests

- Performed 4 rounds of testing with improvements between trials.
  - 3 rounds at ATS
  - 1 round at NNS
- Multiple weld fixtures were set up with obstacles to block welder's view of seams to be welded.
  - Fillet, butt-joint, consumable insert
  - Stick, TIG, MIG,
  - Stainless and CuNi
- Welders practiced until they were comfortable (range of 10 to 30 minutes)
- To evaluate, welders worked, at their own pace (range 30 to 60 min)

In the alpha field tests, a steel wall was used to block the view.
The welder welds using the live video feed from the beta camera (on right in photo)



In-goggle view, as seen by the welder.
With 10x optical zoom plus 8x digital zoom, the welder can choose their view.

Beta camera on a tripod.
The LEDs help illuminate the work during setup when arc is off.

High-Def video goggles give the welder a close-up view of the weld.

Results

Hypothesis: "A welding camera providing quality close-up video could prove easier and more effective than a mirror."

- This was confirmed by the test welders' own comments, informal and formal.
    - The system's video images provided a superior view of the weld
    - In welders' opinion the system shortening learning time
    - In welders' opinion the system improved welding process.

- The evaluation raised issues and suggested improvements.
    - Issues
        - Goggles need to be made compatible with safety-glasses and helmet
        - Setup is awkward when wearing goggles because peripheral vision is blocked.
        - During weld, lack of depth perception made it difficult to place the torch for starting and made it difficult to gauge spacing of the torch above the seam. This slows work and can lead to scars from errant-strikes.
            - This suggests that a 3D version of the system may offer a significant improvement in ease-of-use and resultant quality.
    - Suggestions
        - Integrate goggles with helmet so they flip up easily together
        - An automatic wide-angle view for setup (for in-camera peripheral view)
        - Reduce camera image "blind" time when arc turns off.

Tech Transfer Activities

- NSRP All-panel meeting
- Demos at Electric Boat
- NSRP-Day at Navy DC
- 2013 SNAME Ship Production Symposium
- Demos at General Dynamics Electric Boat
- Demos at HII-NNS
- At Fabtech, the PC-based system was on was on display, as a technology show-piece, in the Intertest booth. There was always a small crowd looking at the system or watching the video loop.
- Go-to-market has started. We have several purchase-orders for the camera with PC-based controller, like the system used for field testing in the study. Delivery Q1, 2014.

Going Forward

- In the short term, some of the suggestions from NNS have been implemented
  - Follow-the-arc movement has been extended and smoothed.
  - Video dead time when arc turns off has been cut in half with software. This can be improved, again, in future camera hardware.
- The PC-based camera system, as tested, is being transitioned to product status. Orders have been received from education and power industries as well as shipbuilding. First commercial deliveries will be in Q1, 2014.
- The embedded processor controller box development is continuing as an IRAD project. It is expected to be operational in Q2, 2014.
- The battery power-pack development is on back-burner.

Remaining Research Topics

- **Helmet mounting of video goggles**: The logistics of the goggles, helmet and safety goggles needs attention. Two major issues centered on safety requirements and simplifying setup with an easy way to remove glasses for setup and replace quickly for welding.

  If the video display could be integral to the helmet and flip up and down along with a protective mask, this could solve many of these issues and make use much easier.

  The mounting will likely be linked to require a new helmet face-shield design. Any follow-on project would be best in conjunction with a helmet maker (e.g. Miller, Lincoln, etc.).

- **3D for easier setup and welding**: The welders had some difficulty in judging distances from the video. It has been suggested that a 3-D view, created with dual cameras, may allow a better view and better welding. Building, testing and demonstrating such a system is about the right size for a panel project.

- **Tele-remote welding:** If 3D is effective for depth perception, it is a logical step to combine the video system with a tele-operated remote robot arm to advance from “blind” welding to “remote” welding.