Panel Project Final Quarterly Report #4
for
3-D Vision for Welder Training and Production Welding

Reporting Period: 9/1/17 – 12/1/17

Technical Progress/Major Accomplishments

- The team completed the second, final testing round
  - In-yard testing with experienced welders indicated that stereo was promising for blind / mirror welding
  - The in-school testing showed that the weld-by-video was very popular with students, but stereo was not judged to give any substantive training benefit; stereo seemed irrelevant.
- Dr. Foster presented his results at the NSRP joint panel meeting at Quonset RI, Sept 13.

Details

The team completed the second field testing round

Because phase 1 found that students couldn't appreciate the difference of stereo, the second testing phase focused on experienced welders. Mirror-welding tests were designed to differentiate the benefit of stereo (3D) over mono cameras by experienced welders.

Tests were designed and executed by Dr. Foster of ODU as a subcontractor. Testing was done at 3 locations:

- Newport News Shipbuilding
- Austal Maritime Training Center
- Thomas Nelson Workforce Development Center

Experienced welders successfully used the system to weld in blind spots where they would normally need a mirror to see. The experienced welders could effectively use the improvement of the video-view without worrying about how to weld.

They liked the stereo over mono for general quality, but not specifically for depth perception. Stereo gives an improved look that is pleasing to the eye and brain. It just seems 'better.'

Although the camera did provide depth perception, it remained awkward for the welders to get their hands into the proper position before the weld. Of course, there will always be awkwardness when welders are reaching around obstacles to weld 'backwards', no matter what the optical situation.

The entire testing report, from Dr. Foster, is attached as Appendix A.

An Unexpected Result

One unexpected result of the testing was that the favored camera orientation was in the position where the stereo cameras were above each other instead of being side by side (see photos A and B, below).

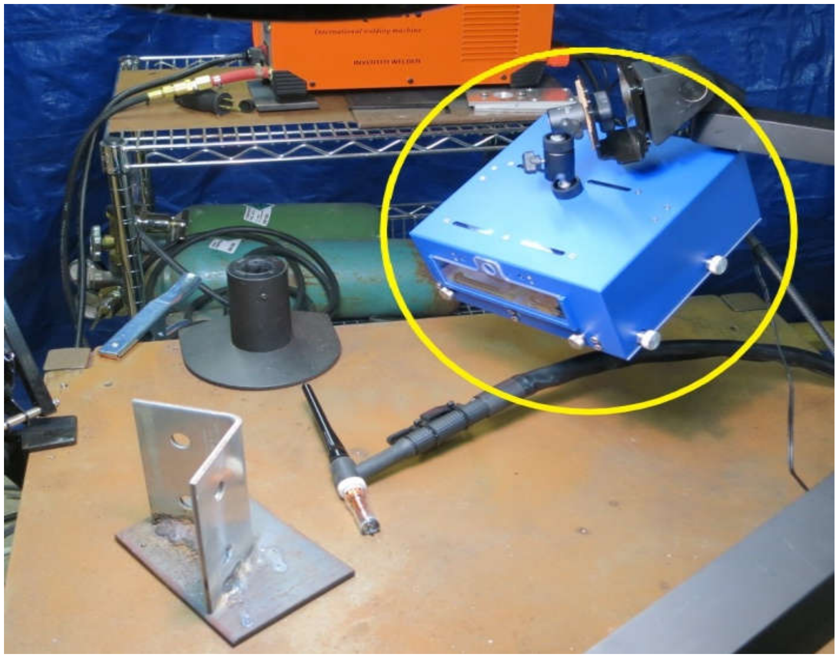

Photo A: Horizontal orientation with cameras Left and Right

Photo B: Vertical orientation with cameras Above and Below

Tech Transfer Activities:

At the Joint Panel meeting in Quonset, Rhode Island on Sept 13, 2017, Steven Edelson provided an overview of the project and Dr. Foster presented his testing results.

At Fabtech, Nov, 2017, in the Intertest booth, we displayed the cameras, including stereo video captured during the project.

Progress against Schedule: Project has completed on-schedule and within budget.

Problems/Issues: There are no problems or issues at this time.

Upcoming Activities: This report completes the project.

Appendix A: Testing Report

3-D Vision for Welding Training and Production

Final Report

September 25, 2017

(Dr. Daniel Foster, Expert Engineering and Education)

Executive Summary

Overall, participants reacted positively to the 3-D Vision System. Participants enjoyed the incorporation of technology into welding, although there was not a strong correlation between enjoyment and recruitment ability. For most participants, utilization of a second welding camera increased depth perception for system.

The major educational value of the system is through its use as a mirror welding training tool. Mirror welding is a difficult skill to teach using traditional training methods but through utilization of the system, the student and instructor can see the same image behind an obstruction. This allowed for increased instructional capabilities.

There is minimal educational advantage during traditional (non-obstructed) welding training using the 3-D welding system. The system doesn't yield an exceptionally better view of the weld that would provide a significant educational benefit when using the 3-D system compared to a traditional welding mask.

There is significant potential for use of the system in obstructed production welding. Current obstructed welding methods are very simplistic (small mirrors that use magnets or clay to attach to baseplates). Using the 3-D Vision System, obstructed welding can be performed in an easier manner compared to traditional mirror welding, and a 300% or more increase in production rate was achieved due to the larger viewing angle. The 3-D Vision System has the potential of providing a better alternative to "mirror welding." To be properly implemented several feasible technological challenges must be overcome to develop a production-ready product.

Purpose

The goal of the welding testing was to evaluate the items below. Testing was broken up into two phases. After Phase I, updates were performed on the equipment and software of the system by *Visible Welding* based on Phase I test results.

I. Phase I Testing
    a. Determine the effectiveness of 3-D welding goggles on training and production welding.
    b. Determine the effectiveness of 3-D welding goggles on training and production "mirror-welding."
    c. Determine recruitment value.
II. Phase II Testing
    a. Depth perception comparison of single vs dual cameras.

Testing

Testing Locations

Phase I Testing:
Tidewater Community College
Ingalls Shipbuilding
Bollinger Shipbuilding

Phase II Testing:
Newport News Shipbuilding
Austal Maritime Training Center
Thomas Nelson Workforce Development Center

Procedure

The following procedure was used during testing with welding participants:

1. Explanation of research goals
2. Explanation of equipment operation
3. Welders utilize the equipment during welding for 15-30 minutes
    a. Traditional welding without obstructions
    b. Obstructed welding
        i. Stereo Video
            1. Phase I Testing
        ii. <u>Alternate between Mono-Video and Stereo Video</u>

            1. Phase II Testing
            2. Roughly a 50/50 mix

    c. Welding processes
        i. Flux-Core Arc Welding (FCAW),
        ii. Gas Metal Arc Welding (GMAW)
            1. Pulse,
            2. Short-circuit,
        iii. Gas Tungsten Arc Welding (GTAW)
    d. Welding performed in flat, horizontal, and overhead positions
4. Participants provide feedback on experience

Setup


Instead of a mirror, the welder uses
hi-definition video goggles and
a special Visible Welding Camera

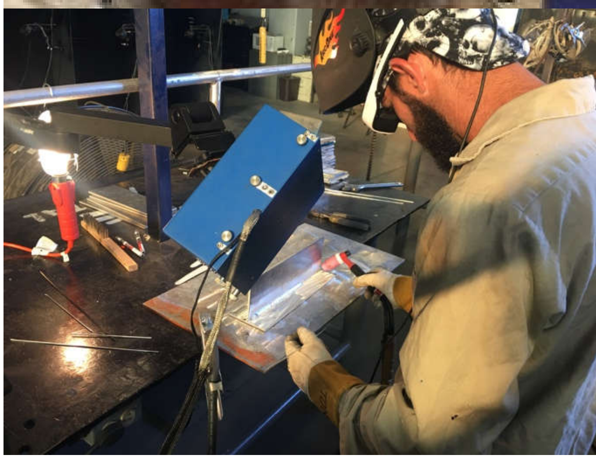

Figure 1: 3-D Goggles used during testing (Upper Left), Experimental setup prior to welding (Upper Right), View of welding when the system is in use (Lower Left), View of welding utilizing the camera system (Lower Right)

Testing equipment consisted of welding goggles, camera(s), a laptop, and lighting. Participants first put on the welding goggles, which were then calibrated for each participant's vision. The image from the camera system was focused and calibrated (That image was displayed in both the goggles and on the computer screen). The camera system was set to stereo or mono camera mode, and lighting was adjusted as needed. At that time, the welder could begin welding. Figure 1 displays the typical welding setup using the equipment as well as an image of welding utilizing a single camera.

Optimal setup

During initial testing, various equipment configurations were investigated. The most successful configuration was found to be when the vision system was on the side of the welding participant, rotated in a vertical camera alignment, approximately 1-2 feet away from the weld sample (See Figure

2). Adjustments in the precise camera angle relative to the welding samples were made by the user based on preference. Setup in this manner produced a view of the weld with the least visual disorientation and the greatest depth perception for the user.

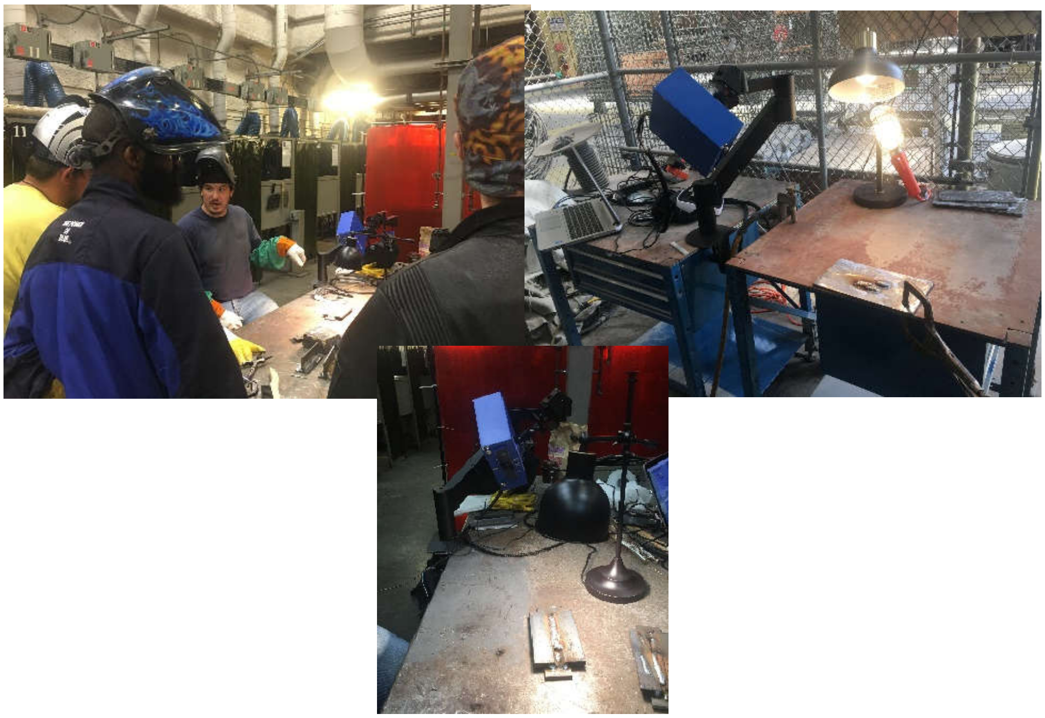

Figure 2: Example of the 3-D Vision camera angle

Results

Ability to the learn the system

The ability of the participants to understand and utilize the equipment varied. Some participants picked up the system quickly, making great welds beginning on the second pass. Other participants struggled greatly, never producing a good weld. Overall, younger participants (less than the age of 50) picked up the system quicker than older participants. In general, most participants had basic proficiency within 5 minutes of use.

Welding processes used with the system

The 3-D Vision System worked well with GMAW and GTAW but worked poorly with FCAW (dual shielded and self-shielded). The system was not tested with SMAW. Welding with FCAW resulted in a very dark picture of the weld with limited joint visibility due to welding fumes from electrode flux. Limited welding process compatibility may restrict the adoption of the system at certain facilities. Therefore, infrared capabilities should be added so that all applicable welding processes can be used with the system

Obstructed welding

Many participants saw great potential for the system as a replacement for mirror welding. Greater field of view can be achieved using the 3-D system than with a typical mirror. Traditionally, small mirrors are used to weld around obstructions. Due to the size of the mirrors, only 3-4 inches of weld can be deposited at a time before the welder must stop, remove any slag or weld debris, grind, clean the next weld area, reposition themselves, and reposition their mirror, before welding can continue. Thus, there is constant start and stop as well as significant delay between each deposition of metal. The 3-D Vision System can provide a 12-inch or more viewing field which allows for less grinding, cleaning, and a shorter overall welding processing time. Under the correct circumstances, utilizing the 3-D Vision System could increase welding process rates by 300% or greater. An example of this can be seen in Figure 3 (bottom photos), where an entire 12-inch length of an aluminum filet weld was welded, without a direct line of sight, in one pass utilizing the 3-D goggle system.

Figure 3: Aluminum welding gun and aluminum welds produced during testing (Upper Left), Bind welding of overhangs (Upper Left), Views of Blind welding of a 12-inch length before (Lower Left) and after (Lower Right) welding

Mirror welding involves moving the operator's hands in the opposite direction to the view seen in the mirror. Because a mirror produces a flipped image of what the user is observing, welders must train themselves to go against their instincts and move their hands in the opposite direction of the view they are seeing in the mirror. Using the 3-D welding system, the image can be flipped an additional time using the system settings, so the resulting image that the user sees is not reversed. Utilizing a "normal," non-flipped, view results in less mental fatigue and an easier ability to instinctually correct unexpected problems that may arise during welding.

With a remote camera system, better ergonomic welding positions can also be achieved. When using mirrors, the welder must get in a position that allows their hands to access the weld, fits/supports their body weight and allows a line-of-sight to the mirror around an obstacle. This often results in welding in uncomfortable positions that increase welder fatigue and restrict optimal welding angles. Both of which reduce weld quality and slow productivity. A remote camera system removes the space needed for a mirror and the space needed for the line-of-sight for that mirror. The removal of this limitation allows for more comfortable/ergonomic body and hand welding positions that reduce welder fatigue and allow better access to the weld.

Effectiveness on improving traditional welding training

Welding students enjoyed using the welding equipment, rating the equipment as fun to use, see Figure 4. As can be seen in Figure 5, 65% of participants would like to be trained using the system in the future. The incorporation of the equipment is a good way to capture attention and make welding more interesting. Although students enjoyed the equipment, students did not think the equipment significantly improved traditional welding training (Figure 6 and Tables 1-3). This data indicates that students enjoy incorporating technology into welding training and/or the novelty of the device, although only marginal improvement in welding training was achieved.

Rate your level of fun learning to weld with the 3-D Weld Vision System.

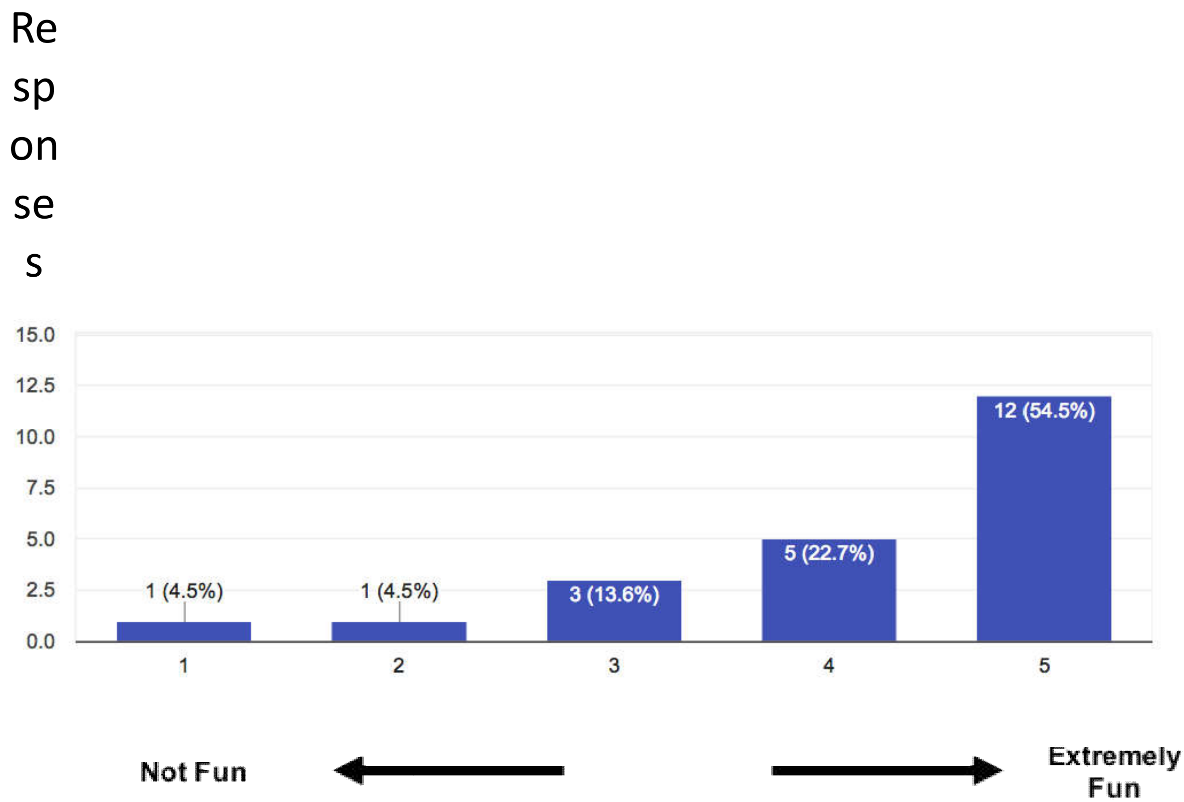

Figure 4: Plot of survey responses regarding the level of fun had when using the 3-D Weld Vision System

If you were trained in the future, would you like to utilize the 3-D Weld Vision System?

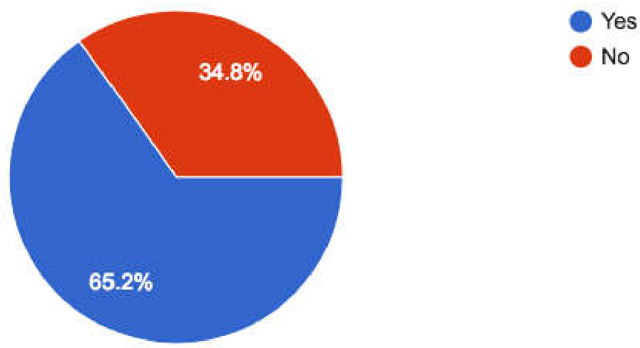

Figure 5: Desire to be trained utilizing the 3-D welding system in the future

Rate the ability of the 3-D Weld Vision System to aid in traditional welding training.

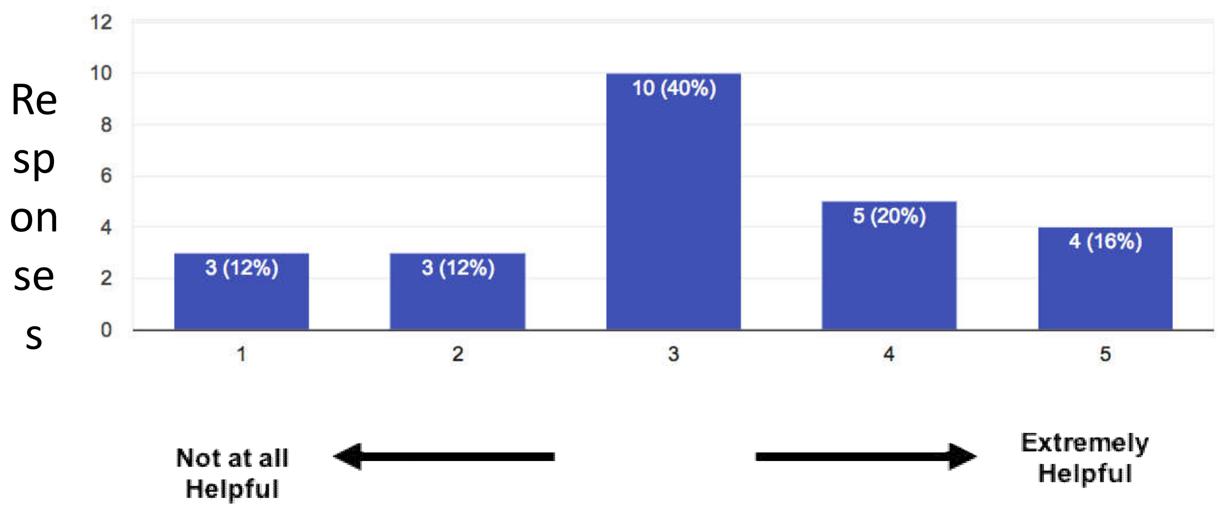

Figure 6: Plot of survey responses regarding the ability of the system to aid in traditional welding training

Have you gained any additional insight into welding using the 3-D Weld Vision System? Please explain.

24 responses

No. (7)

N/A. (2)
Somewhat. (2)
Explained what could be used for in future.
I think it's cool but would have to get comfortable moving to the direction of the camera.
Yes, it allows the replay to instantaneously fix problems.
Allows me to clearly see my puddle and focus on using the puddle to guide my weld.
The goggles allowed me to see the puddle in a different way, the viewing angle is better in some ways.
Yes, it makes blind welding using mirrors much more impressive.
Yes, may be useful for working in blind spots or around obstructions.
Pretty much.
It's possible. Delay in camera is problematic.
Perspective is extremely important. Being able to change view by simply moving your head.
I think with newer technology and a better smaller camera this technology could be helpful where joints can't be seen.
In some way.
Matter of getting control of the mind and sequence of welding.

Table 1: Long answer survey responses regarding the additional welding insight that was gained using the 3-D Vision System

Did you notice any aspects of your own technique (Good or Bad) that became apparent when using the 3-D Weld Vision System? Please explain 23 responses

No. (5)
N/A. (3)
Hand placement was hard to see due to camera angle.
Harder to see technique.
Kind of difficult.
Yes.
Yes, the replays help pinpoint angles/technique problems.

Travel speed and fusion were clearly seen and adjusted from weld pool observation.
I feel like my technique was not as consistent when using the goggles, and I don't think it's very comparable with traditional welding.
Yes, not have the best torch control in TIG made it difficult to make passes.
Lag time between what you see and what is actually happening.
Good.
Good for beginners.
Multiple passes are more difficult. Depth perception.
In a way.
Somewhat.
Just learning to adjust the gun nozzle and angle looking at the camera.

Table 2: Long answer survey responses regarding observations of welding technique when using the 3-D Vision System

How did the 3-D Weld Vision System improve your welding technique?

23 responses

N/A. (6)
None. (2)
Did not improve.
Did not.
I don’t think it has.
Showed angles and bad movements.
Didn’t.
Can’t answer, need to spend a lot more time with it.
First time using MIG.
Focus on puddle instead of trying to use a constant speed/angle.
I don't think it did.
It will improve.

Same.
Help for welding joints that aren't visible.
Need more time with it.
It just gave me a new experience.
Didn't, just welded the same way as I would with a mirror.

Table 3: Long answer survey responses regarding the ability of the system to improve welding technique

Obstructed welding training

Significant time is not spent on mirror welding during welding training. Once a welder passes all of the examinations of the welding school, there is a brief (less than hour) mirror welding lesson. After this brief lesson, the student is expected to be able to mirror weld even though he/she has not been extensively trained in the technique. This results in numerous challenges for the welder to produce satisfactory mirror welds in the short-term, post-graduation.

Mirror welding is a difficult skill for a welding instructor to teach. As displayed in Figure 7, a small change in the viewing angle in a mirror between the instructor and student will result in the student and instructor viewing different regions on the same welding sample. It is often difficult for the instructor to give meaningful advice to the welder during mirror welding because he is not seeing the same image as the student.

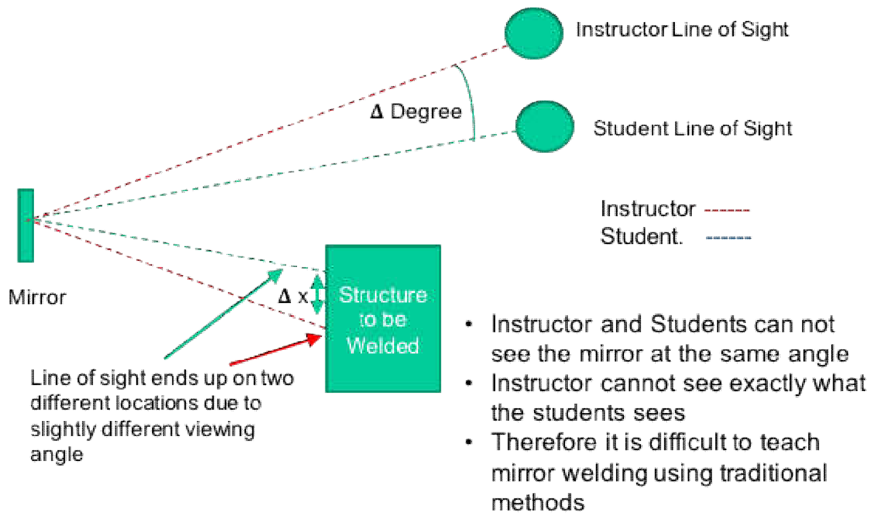

Figure 7: Schematic of difficulties teaching mirror welding

Utilizing the 3-D Vision System, the instructor and the student will see the same view that is captured using the camera system. The instructor can watch welding on an external monitor (in this case the laptop screen) and see the same image as the student utilizing the goggle system (See the lower left image in Figure 1). Using this method, the instructor can give feedback on exactly what the welding student is doing. Therefore, this system could be used as a training tool for mirror welding. New hires and welding students can be properly trained on mirror welding techniques, increasing welder skills and weld quality.

Recruitment Value

As mentioned in Figure 4, welding students had a fun experience with the 3-D welding equipment, although students gave the equipment an overall marginal recruitment value, Figure 8-9. Recruitment value may be higher on future iterations of the equipment as a simplified setup, optimal equipment utilization and more robust equipment would create a better initial user experience, likely increasing the immersive experience of the user.

When deciding on a career field, would technology like this influence your decision toward welding?

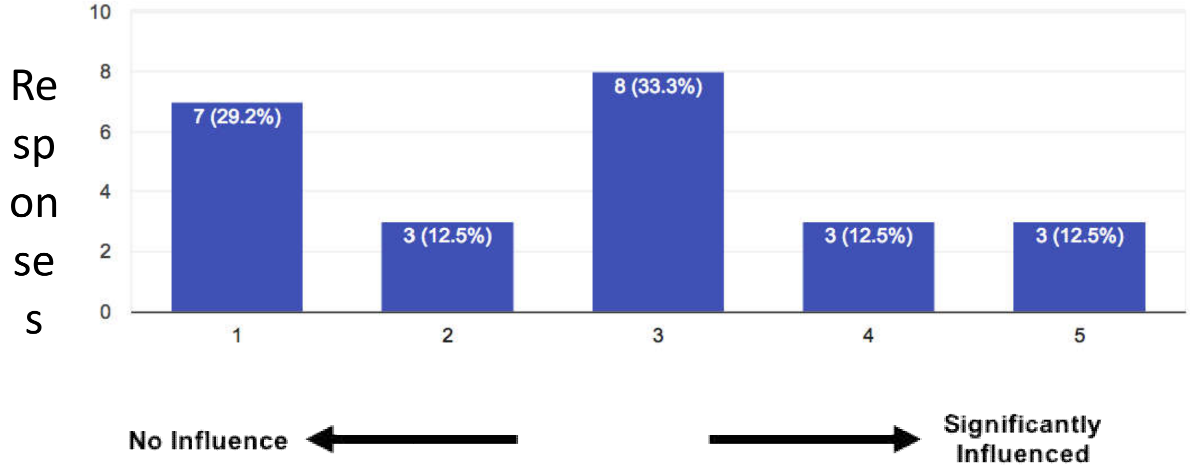

Figure 8: Plot of survey responses regarding the impact on welder career choice if introduced to the 3-D Weld Vision System

Thinking of your friend who did not choose welding, do you think that technology like a welding camera might have changed their decision?

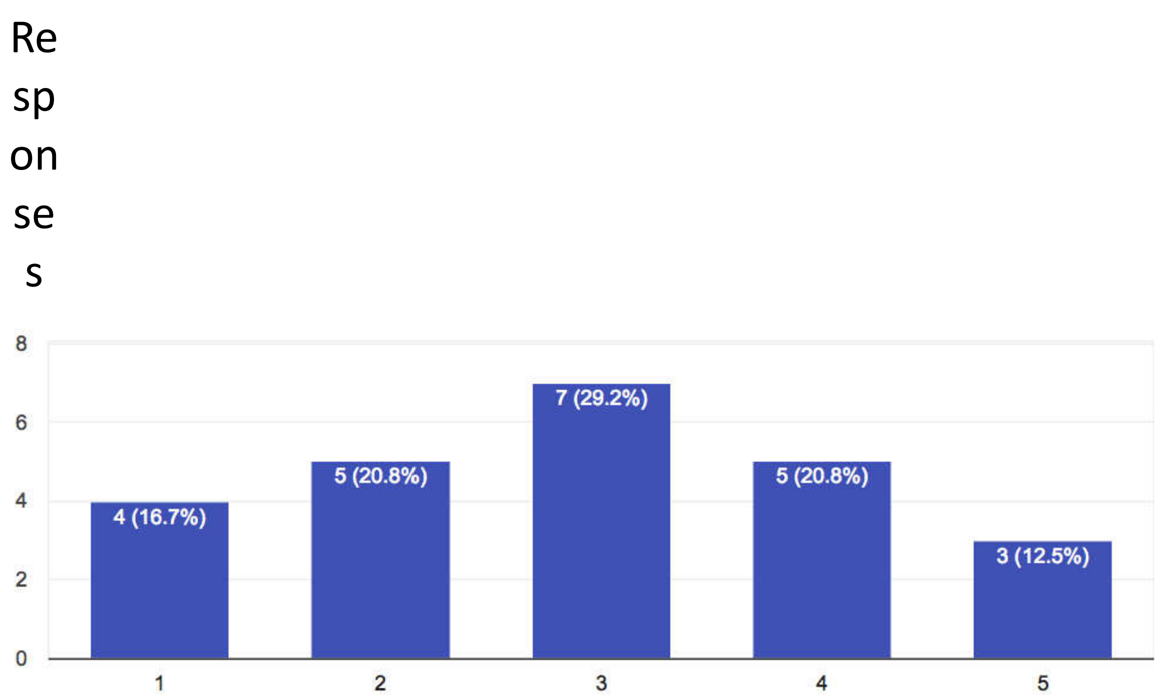

Figure 9: Plot of survey responses regarding the impact on welder career choice of friends if introduced to the 3-D Weld Vision System

Mono-Camera vs Single Camera

Overall, welders preferred stereo vision compared to mono vision. Of participants tested, 58% preferred stereo vision, 28% had no preference, and 14% preferred single camera vision. Welders that preferred stereo vision, remarked "better depth perception," "increased ease in welding," or remarked their preference without being able to describe in words why they liked stereo vision. This was especially true of GTAW welders, where the vast majority preferred stereo vision. GTAW is more complicated than GMAW, involving significant coordination between the right and left hands when welding with filler metal. Although many students noted an increase in depth perception using the stereo camera system, it was not a "Night and Day" difference, but instead, it was a noticeable feeling of improvement.

Some participants had no preference. Remarks from these participants included, "both views were the same," "It doesn't matter for me."

A few students preferred the utilization of a single camera. This odd result may be due to the fact that the camera used in the single camera view was slightly clearer than the stereo cameras. These results may indicate that for these students, image clarity was more important than depth perception.

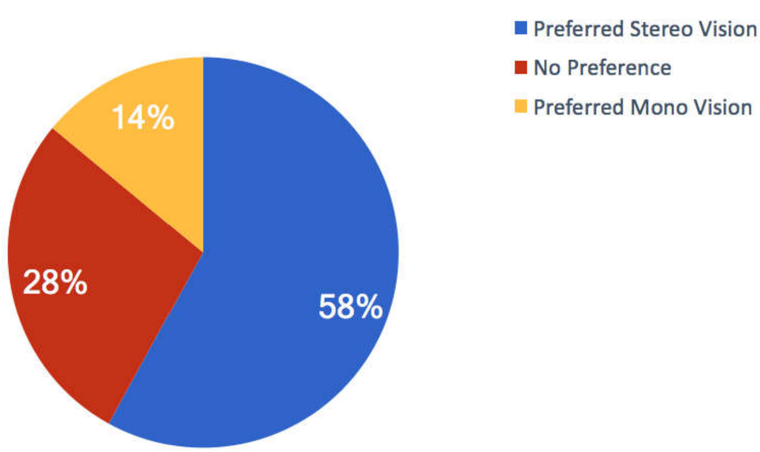

Figure 10: Welder preference: Stereo Cameras vs Single Cameras

Suggested Future Work

The research study demonstrated the potential of the system to be used in training and production welding. In order for these objectives to come to fruition several technical challenges must be overcome to achieve the operational capabilities needed.

Miniaturization

The current system is roughly the size of a large dictionary. This size is not capable of fitting into the small spaces needed during typical obstructed welding. Miniaturization to roughly the size of a *Go-Pro,* or smaller, is needed to be implemented in practical applications.

Wireless

The current system consists of multiple wires for power, communication, and processing. A wireless device is needed to in order to eliminate placement restrictions due to cumbersome wires that can get tangled during regular use. Also, there is a fire hazard due to polymer wires being close to a high intensity heat source.

Video feed built into the welding shield

The current system uses a set 3-D googles that have to be worn under the welding hood in order to use the equipment. A better implementation would be incorporating the 3-D vision system into the welding helmet in some manner, increasing the ease of use for the welder.

Automation

Currently, an operator is needed to calibrate, focus and manage the video when using the system. The final version of the system needs to have these functions integrated into a user-friendly interface that automatically performs these functions when the system is in use.

IR camera integration

The system interprets the visible light spectrum to produce a view of the welding arc. In many cases this produces a clear detailed view of the welding, but smoke from flux processes (FCAW or SMAW) or certain materials (E.g. aluminum) can obstruct the camera view, creating a blurry or undiscernible image. Infrared camera systems can be utilized to eliminate problems with interference from smoke due to its utilization of infrared energy and not the visual light spectrum, allowing the system to work on all commonly used arc welding processes.

Optimization of visual clarity

At times, welding positions, lighting conditions, joint types, or 3-D vision equipment can cause a non-ideal image (blurry and/or dark) when using the system. Optimization should be performed in order to produce a high clarity image in a variety of welding environments.

Ruggedizing

Shipbuilding is a harsh environment. Tools are dropped and banged, as well as exposed to extremes in heat and cold. Therefore, extreme durability is necessary to have a practical service life during ship construction

Conclusions

I. Stereo vision improved the depth perception during welding compared to a single camera, for most participants
II. Stereo vision provides minimal additional educational value during traditional welding training
III. Stereo vision has the potential to be an excellent tool to teach mirror welding
IV. Although many participants liked the equipment, it did not significantly affect recruitment metrics
V. The system can be used as an alternative to mirror welding
VI. Because the camera system has a larger field of view compared to traditional mirror welding, obstructed welding production rates can be increased 300%