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March 21, 2024

Nicholas Laney
ATI Project Manager
Nicholas.laney@ati.org

Task Order Agreement 2019-375-006
EWI Project No. 58091GTH, "FINAL TECHNICAL REPORT: Tele-Welding Shipyard Prototype for Welding (and other) Applications"

Dear Nicholas:

Enclosed is EWI's final report for TOA 2019-375-006. Please feel free to contact me at 614.688.5247 if you have any questions or comments regarding this project.

Sincerely,

Connie LaMorte
Principal Engineer
Automation Group

Enclosure

FINAL TECHNICAL REPORT

Tele-Welding Shipyard Prototype for Welding (and other) Applications

March 21, 2024

Task Order Agreement 2019-375-006

EWI Project No. 59030GTH

Submitted to:

Nicholas Laney
ATI Project Manager
Nicholas.laney@ati.org

EWI Contact:

Connie LaMorte
Principal Engineer, Automation Group
614.688.5247
creichert@ewi.org

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NSRP
NATIONAL SHIPBUILDING RESEARCH PROGRAM™
Taking Shipbuilding and Repair to the Next Level

Final Report

Project No. 59089GTH

on

2019-375-006 – Tele-Welding Shipyard Prototype for Welding (and Other) Applications

Final Technical Report

to

ATI Advanced Technology International

Prepared by:

Connie Reichert LaMorte

April 10, 2024

EWI

1250 Arthur E. Adams Drive

Columbus, OH 43221

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LIST OF ABBREVIATIONS

AI	artificial intelligence
AR/VR	augmented reality/virtual reality
CWI	certified welding inspector
ESO	electrode stick out
GDEB	General Dynamics Electric Boat
GMAW	gas metal arc welding
HI-NNS	Huntington Ingalls Industries – Newport News Shipbuilding
HMI	human machine interface
LAN	local area network
LOF	lack of fusion
NSRP	National Shipbuilding Research Program
NSWCCD	Naval Surface Warfare Center, Carderock Division
PQR	performance qualification record
PT	penetrant tested
ROI	return on investment
RTT	Robotic Technologies of Tennessee, LLC
TTIP	technology transfer and implementation plan
TRL	technology readiness level
WPS	welding procedure specifications

ACKNOWLEDGEMENTS

This task order agreement, 2019-375-006 “Tele-Welding Shipyard Prototype for Welding (and Other) Applications”, was funded by the National Shipbuilding Research Program – Advanced Shipbuilding Enterprise (NSRP – ASE). Representative companies/organization who participated in this project include:

- Robotic Technologies of Tennessee, LLC
  - Provider of portable base motion platform or robotic arm
  - Developer of portable base motion platform for Beta-prototype
  - Co-developer of HMI
  - Integrator of the virtual machine took in 3D environment
- Visible Welding
  - Provider of the welding pool camera system and updated functionality
- HII-NNS
  - Provider of feedback from use of the tele-welding systems
  - Provider of guidance in development of the tele-welding functionality
  - Provider of information on shipyard data integrity management practices
  - Provider of welding personnel to test tele-welding concepts remotely through attempted weld qualification
  - Provider of welding personnel to receive training on the tele-welding technologies prototype system
  - Supporter of installation of tele-welding equipment in lab and test locations in the shipyard
- General Dynamics Electric Boat
  - Provider of feedback from use of the tele-welding Alpha system
  - Provider of guidance in development of tele-welding functionality
  - Provider of information on shipyard data integrity management practices
- Gullco International
  - Provider of the Gullco tractor and idler carriage with aluminum plate used in the Beta prototype system

INTRODUCTION

The overarching goal for this technology area was to create a method for workers to get exposure, gain confidence, and guide future efforts in remote-controlled manufacturing technologies.

Background on RA-2019-375-001

The project team, consisting of EWI, Robotic Technologies of Tennessee, LLC (RTT), Visible Welding, Huntington Ingalls Industries – Newport News Shipbuilding (HII-NNS), and General Dynamics Electric Boat (GDEB), developed and demonstrated an alpha-prototype tele-welding system during RA-2019-375-001. In this project, the project team developed a system that allowed workers to operate welding equipment from a remote location and created a method for workers to get exposure, gain confidence and guide future efforts in remote-controlled manufacturing technologies. Two motion platforms were developed and demonstrated the tele-welding technology to the shipyards: a portable cobot arm and a mechanized crawler system. Both tele-welding systems were demonstrated at EWI and one at each shipyard. Shipyard welders and personnel tele-welded on their representative weld joint applications and provided feedback on the technology. The tele-welding systems received overwhelmingly positive responses from shipyard welders of all experience levels. The project team developed a tele-welding roadmap for the shipyards including implementation and commercialization. Based on the success of the 2019-375-001 alpha-prototype system, the project team developed a scope work and proposed a follow-on project to convert the tele-welding system currently at TRL 6, into a shipyard-rugged, beta prototype of TRL 7, for evaluation and development of weld procedures by trained tele-welders at the shipyard.

Project 2019-375-006 Goal

The goal of 2019-375-006 was to extend the progress gained in the 2019-375-001 project to build a shipyard-ready beta-prototype with a Technology Readiness Level (TRL) of 6-7 and perform extensive testing in the shipyard.

The alpha-prototype tele-welding system was further developed into a beta-prototype operational system focused on remotely welding selected shipyard non-production weld joints. After the conclusion of this project, the beta-prototype was ready for shipyard implementation and then commercialization.

PROJECT OVERVIEW

This project proposed to further develop and implement new tele-welding functionality into a Beta-prototype system. This effort focused on the refinements that decreased the mechanical complexity of the existing alpha-prototype and improved the overall capabilities of the system, with the goal of increasing the experienced welder's desire to use the system. The system was delivered to a shipyard and tested by shipyard personnel on non-production welding joints. Feedback from the shipyards was collected, and a plan for shipyard implementation was reported.

Three main technical aspects of the tele-welding system were focused on for improving or advancing the system and creating a beta-level prototype, capable of being operated by shipyard personnel in a shipyard environment.

1. Welding Process and Environmental Feedback
    a. Camera and arc process sensory feedback refinements focused on improvement of the arc-process camera view as the main feedback to the welder for the arc and puddle. The following functionality updates were investigated and reviewed for potential additions to the Beta-prototype system:
        i. Implementation of a higher-resolution mode or a separate camera for post-weld inspection
        ii. The improvement of the arc camera's arc-filtering techniques to allow for a better image of the joint and previous weld beads
        iii. A method of recognition of welding orientation as part of the environmental sensing, so that the weld procedures match qualification welds.

2. Welder's Responses for Controlling the Welding Operation
    a. Control of the mechanized equipment was completed by the stylus integrated in the alpha-prototype in the previous project. Improvement to the timely and accurate capturing of the operator's motions was completed by updating existing alpha system features or by adding new functionalities. The following functionality updates were investigated and reviewed for potential additions to the Beta-prototype system:
        i. Refinement of the haptic feedback applied to the hand-held manipulator (stylus) device based on feedback from the alpha-system use
        ii. Damping, which could be applied to the welding operator's motions to help maintain steady motion during welding
        iii. Analytics of the user motions collected during tele-welding, which could be used to help determine training requirements or methods
        iv. Real-time response of the robotic hardware
        v. The robotic hardware and motion platform were upgraded based on feedback from the shipyards on the performance of the alpha-prototype evaluated during the previous project and newer models of the hardware that have become available.

3. Ease of Use and Overall Simplification
    a. The control hardware for the system was combined and repackaged into a field-survivable module which will include the ability to safely stream or transfer camera and audio feed to a shipyard LANs, or for un-networked operation, directly to the operator's control station. Additional functionality was evaluated for implementation onto the beta-prototype including evaluation of the following items that would increase ease of use or functionality without adding hardware:
        i. The use of a single camera to accomplish line-up, arc-views, zooming, or inspection
        ii. The implementation of a "cruise control" travel speed mode based on initial welding operator's travel speed motions

iii. A method to memorize the path movements for analytics that could be used to aid in multi-pass procedures as well as for development of other facets of the Beta-prototype system such as training or path/travel speed suggestions
iv. Further reduction in lag time and latency of the video and sound, using web protocols that maintain data integrity and compliance with shipyard data integrity management systems and practices
v. Analytics of the user's motions collected during successful tele-welds to be used to superimpose a virtual, followable motion path on the user's PC screen while welding
vi. Definition of the role of the on-site robotic welding aide or welder helper for robot placement and retrieval and system readiness to enable the welder to begin controlling the robot remotely.

TECHNICAL PROGRESS

This report details the progress completed during execution of this project.

OVERVIEW AND OBJECTIVES

The alpha-prototype tele-welding system built during RA-2019-375-001 was further developed into a Beta-prototype operational system that focused on remotely welding selected shipyard non-production weld joints. After the conclusion of this project, the beta-prototype is ready for shipyard implementation and then commercialization. The beta-prototype system is completely controlled by a welding operator who is remote from the operation. The welding operator will receive feedback from the welding operation and the surrounding environment using the welding sensors and cameras which have been identified, vetted, and tested during RA-2019-375-001.

Suggested changes to the alpha-prototype system obtained from use by shipyard personnel and other requirements for integration were used to direct development of the system into a beta version. The tele-welding beta-prototype in use at the end of this project allows shipyard welders to use their welding knowledge to weld joints from a remote location within the shipyard.

Beginning with the framework of the alpha-prototype, the project team upgraded, integrated, and validated a beta model that is rugged enough to endure longer-term shipyard testing. The beta-prototype makes use of standard mechanized or portable robotic motion systems to provide a device that verifies shipbuilding economy, allowing development of a commercial offering.

<u>The objectives of this project included</u>:

- Creating and integrating a shipyard-ready beta-prototype with TRL of 6-7 that allowed refinement of the alpha-prototype system and incorporated into operational performance as qualification and training issues were addressed.

- Merging tele-welding sensors, real-time feedback methods, and shipyard welder's and operators' suggested changes into a commercially supported beta-prototype.
- Identifying classes or a selection of shipyard welds that can be welded remotely with the beta-prototype system using existing qualified procedures.
- Developing new, intelligent technologies including path recording capabilities to allow expert welder motions and parameters to be recorded for analytics.
- Maintaining shipyard data security and integrity by operating within existing data integrity management protocols by tele-welding from within the shipyard.
- Developing the key requirements for a remote welding training course for experienced and new users.

Scope of Work for the Shipyard Receiving the Beta-prototype Tele-welding System

The scope of work performed by the shipyards for this project included:

- Identification of a shipyard welding joint application that could be used to allow shipyard welders to practice tele-welding the joint with the beta system.
- Provided details about the selected joint include WPS and welder qualifications requirements for a welder who would be tasked to complete this weld joint.

There were fourteen tasks in this project completed over a two-year period. These tasks included:

- Task 1: Project Kickoff Meeting at EWI and Monthly Project Team Meetings
- Task 2: Review Results from RA-2019-375-001 Alpha-Prototype System
- Task 3: Validate Tele-Welding System Operational Steps
- Task 4: Identify and Vet Technologies to be UPDATED or Newly Developed for the Beta-Prototype System
- Task 5: Identify and Confirm Selected Weld Joint and Initial Use Case for the Beta-Prototype System
- Task 6: Creation of the Beta-Prototype System
- Task 7: Test Remote Welder Performance Qualification
- Task 8: Year 1 Project Progress Report and Briefing to Team Members
- Task 9: Year 2 Project Kick-off Meeting and Monthly Project Team Meeting at EWI
- Task 10: Develop Schedule and Plan Testing of the Beta-Prototype at HII-NNS Shipyard
- Task 11: Develop Qualification
- Task 12: Explore the Framework of a Potential Remote Welding Training Course in Conjunction with Team Members
- Task 13: Identify a Range of Shipyard Processes that can be Potentially Tele-Operated
- Task 14: Final Reporting and Review of the Beta-Prototype Use in the Selected Shipyards

The deliverables for this project are outlined in Table 1 below:

Table 1. Project Deliverables

Task	Deliverable
Task 1	• Phase I kickoff meeting at EWI and report of meeting • Demonstration of the alpha system at EWI • Project management plan
Task 2	• Report summarizing suggested updates to the alpha system from the welders and a document listing the requirements, precautions, and limitations for operating remote machinery within the shipyard
Task 3	• Welding operator requirements specification for the beta-prototype system based on shipyard skill level or job grade designation
Task 4	• Report of the technologies evaluated and ranked based on value, technical complexity, and ease of integration into the beta-prototype system • Video demonstration of at least one new sensing technology evaluated
Task 5	• Report of the beta-prototype system functionality specification for the selected weld joint or class of weld joints • Weld mockup assembly design
Task 6	• Design of beta-prototype system architecture • Live demonstration at EWI or RTT
Task 7	• Report on the manual welder remote performance qualification • Outline of abridged AWS GMAW weld course suggested for tele-welding
Task 8	• Year 1 Summary Report
Criteria for "Go/No-Go" Decision on Subsequent Phase	• Beta-prototype system demonstrated live to a shipyard stakeholder with agreement to accept delivery of system into the shipyard for testing
Task 9	• Phase II kickoff meeting and report of meeting
Task 10	• Demonstration of beta-prototype system at EWI or RTT before shipyard delivery • Report – including results of weekly discussions, observations from visits to shipyards, and any updates/changes made to the beta-prototype system or use of the system
Task 11	• WPS and PQR forms
Task 12	• Course requirements outline for experienced and new welders for tele-welding training
Task 13	• Report on other tele-weldable shipyard processes, their ranking based on ease of implementing the capability using the Beta-prototype system, and recommended next steps
Task 14	• Final Report

As part of the final report, return on investment (ROI) results are updated to include addressing ROI differences between initial estimates and final results.

Hardware and software to be provided to NSRP at the end of this program includes:

- Tele-welding platform with integrated tele-welding sensors and control
- An executable version of the software running on the control system which operates the tele-welding hardware
- An executable version of the software running on a PC that accepts user inputs

TASK 1: PROJECT KICKOFF MEETING AT EWI AND MONTHLY PROJECT TEAM MEETINGS (EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)

Typical project management activities were performed during this project including subcontract management, resource allocation, financial tracking, schedule tracking/updates, contract modifications, and project team communications.

1.1 – A project kickoff meeting was held on March 9, 2022, at EWI in Columbus, Ohio, to review the project plan, align project team members, identify the communication plan, and confirm the project work scope and timeline. Representatives from all project partner organizations attended via teleconference. Throughout the project, project team meetings were typically held monthly to update and discuss task progress. The alpha-prototype system was demonstrated at EWI to remind the project team of the capabilities of the status of the technology and prepare for the subsequent task of collecting feedback regarding the alpha system functionality.

1.2 – Quarterly Reports: Quarterly reports were provided to NSRP throughout the project and contained a Technical Status Report and a Business Status Report.

1.3 – Status/Deliverable/Milestone Report: All deliverables identified as milestones in the Schedule of Milestones were submitted to NSRP. Below are the deliverables required as part of Task 1 and the date of submission to ATI:

- Milestone 1: Quarterly Report – submitted 4/11/2022
- Milestone 2: Quarterly Report – submitted 6/21/2022
- Milestone 3: Quarterly Report – submitted 9/21/2022
- Milestone 4: Quarterly Report – submitted 12/20/2022
- Milestone 5: Year 1 Report and TTIP Update – submitted 9/15/2023
- Milestone 6: Quarterly Report – submitted 3/21/2023
- Milestone 7: Quarterly Report – submitted 6/21/2023
- Milestone 8: Quarterly Report – submitted 9/26/2023
- Milestone 9: Quarterly Report – submitted 12/19/2023
- Milestone 10: Final Project Report – submitted 3/21/2024

TASK 2: REVIEW RESULTS FROM RA-2019-375-001 ALPHA- PROTOTYPE SYSTEM **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to ensure that user feedback from the alpha-prototype system was reviewed and evaluated for inclusion in the beta-prototype system. The alpha-prototype system was demonstrated and evaluated at shipyards by shipyard welders in the previous project. The result of those demonstrations and the feedback accumulated from the shipyard personnel was evaluated by the project team.

The project team reviewed shipyard welders' comments and suggested changes to the alpha-prototypes performance, ease of use, and overall functionality. The feedback was evaluated to determine if common themes emerged.

Review Comments

EWI accumulated all comments and feedback from the alpha prototype demonstrations at NNS and GDEB shipyard in 2021. Since each demonstration at each shipyard was completed with a different motion platform, two separate feedback meetings were held.

An alpha feedback discussion meeting with GDEB personnel was held on April 12, 2022. During this meeting, video from the May 2021 demonstrations at GDEB were reviewed to remind the shipyards of the performance of the alpha prototype system. Feedback from welders and observations from the EWI welder also at the demonstration were reviewed. The alpha prototype system was demonstrated at GDEB using a portable cobot arm from Universal Robotics. Figure 1 is an image of the alpha-prototype, cobot-based system demonstrated to GDEB in 2021.

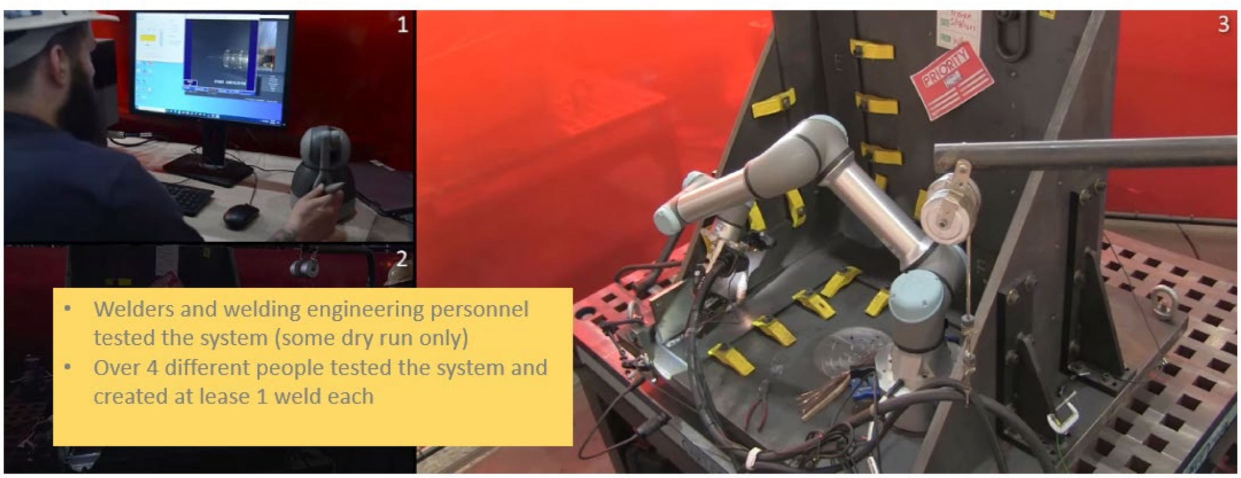


Figure 1. Alpha-protype cobot-based tele-welding system demonstrated at GDEB in May 2021

An alpha feedback discussion meeting with NNS personnel was held on April 14, 2022. During this meeting, video from the June 2021 demonstrations at NNS was reviewed to remind the shipyards of the performance of the alpha-prototype system. Feedback from welders and observations from the EWI welder also at the demonstration were reviewed. The alpha-prototype system was demonstrated at NNS using a portable magnetic crawler from RTT. Figure 2 is an image of the alpha-prototype crawler-based system demonstrated at NNS in 2021.

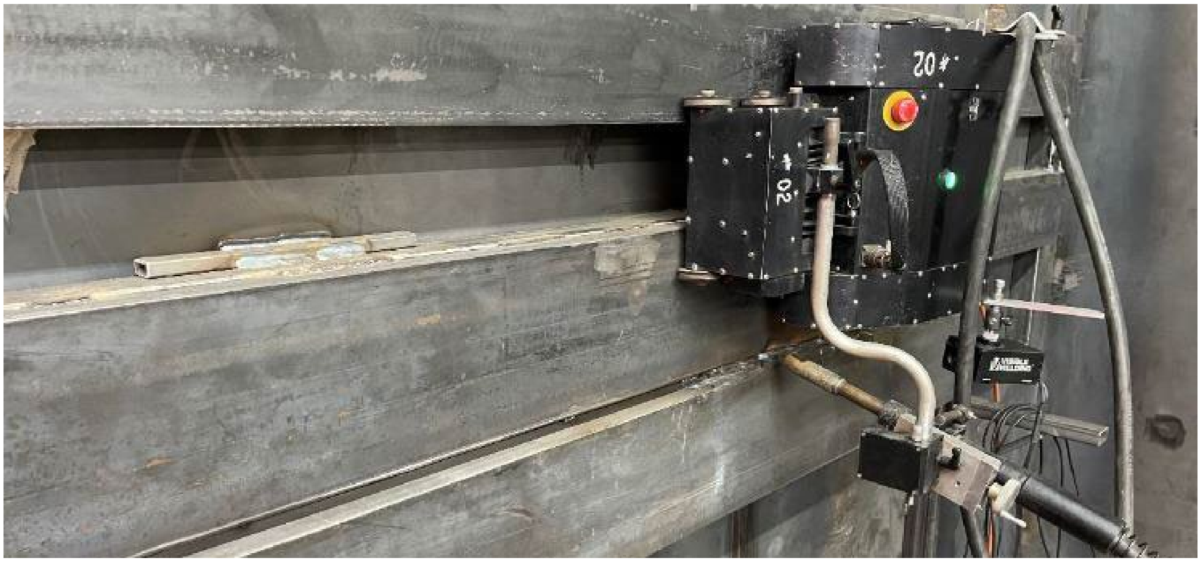


Figure 2. Alpha-prototype, magnetic crawler-based tele-welding system demonstrated at NNS in June 2021

Common themes emerged from the feedback reviews. The comments were matched to solutions or features to be added or to be used to improve the tele-welding alpha system functionality. A document for each motion-platform alpha system was created, listing the features and a rating system to identify the importance of each feature. Project members ranked the features and returned the document to EWI. The documents are found in Appendix B.

The main overarching feedback received from the NNS was the need to use a track-based system. NNS is the project partner shipyard that will receive the beta system and perform testing. This prime feedback influenced and directed the design of the tele-welding beta prototype.

Review Shipyard Requirements

NNS and the project team discussed commercial motion systems and determined the key aspects of using a robotic welding system versus a mechanized crawler-type system.

The project team discussed existing shipyard requirements, permissions, and limitations for remote operation of machinery or systems in the shipyard. This discussion helped to detail the differences between mechanized and robotic terminology as it relates to new system qualification requirements before use in production at the shipyard, depending on motion system type. NNS required full understanding of how remotely operated equipment would be classified before the new beta prototype motion platform was to be designed. A cobot arm that automatically executes a robot program would fall within the specification as a robotic process. A system defined as mechanized or semi-auto is still under the supervision or constant direction of an operator. NNS existing track-based shipyard welding equipment falls within the mechanized equipment specification. Figure 3 is an image from a manufacturer of mechanized welding systems that operator on tracks.

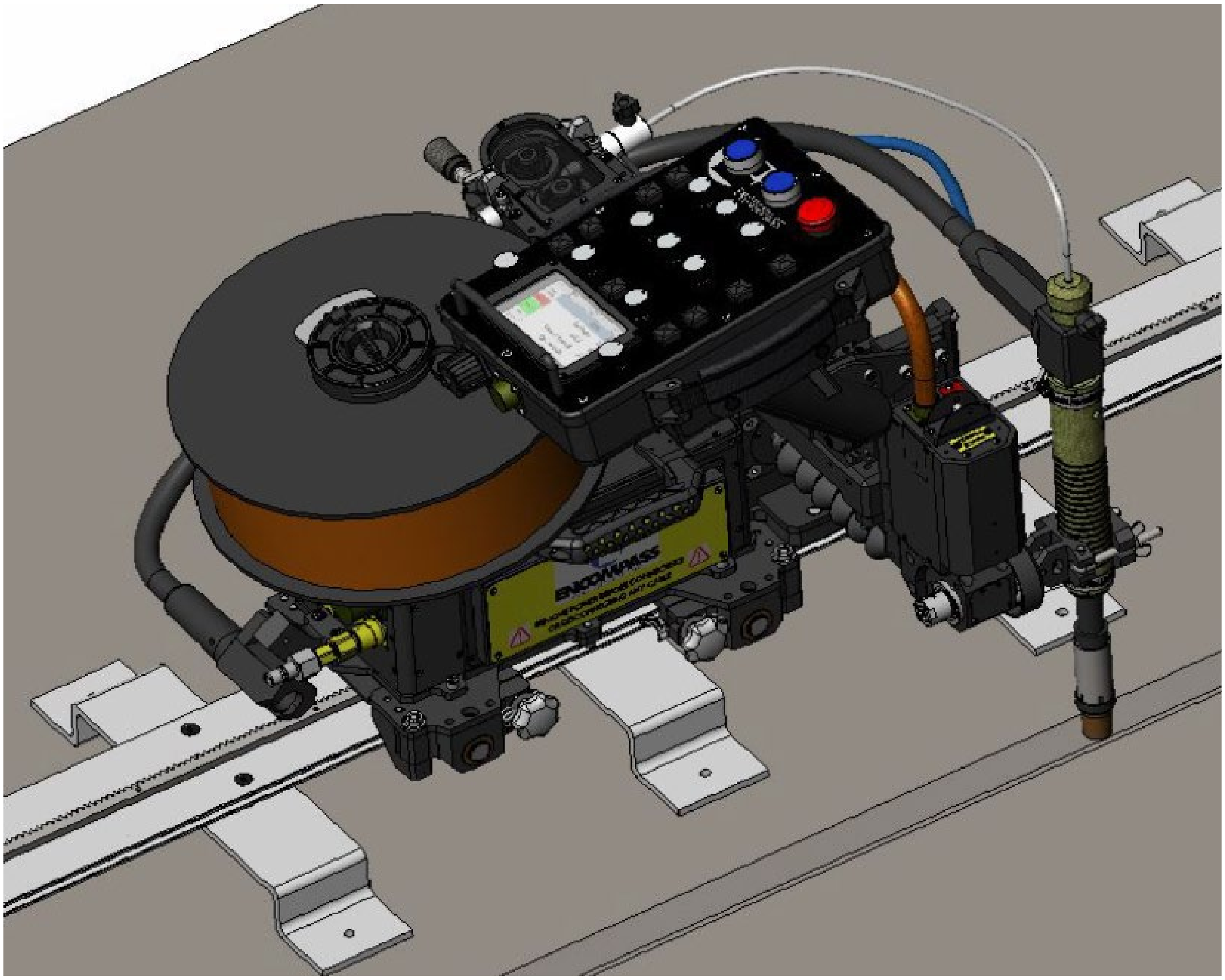


Figure 3. Image of a mechanized welding system that runs on a track. This system is the PAWS system, available from Encompass.

NNS desired to maintain the same specification to comply with the Tech Pub 248 and not require requalification of the procedure in order to use a tele-welding system. The shipyard referred to and the team discussed Tech Pub 248 and Revision 1. A meeting was held in November 2022 with the Naval Surface Warfare Center, Carderock Division (NSWCCD) to discuss the use of remotely controlled equipment.

Data Integrity Management Protocols

Data integrity management protocols and or data security procedures were evaluated to determine the best way to communicate with the remote equipment and what would be acceptable within the shipyard as far as communication. As learned in the previous project, the benefits of tele-welding will most likely be realized with the welder still in the shipyard but removed from close proximity to the welding arc and strenuous conditions. This could be in an office at the shipyard or even just 20 ft away from the arc, neither of which will require transfer of information outside of a local area network inside the shipyard. Communication options included an isolated local area network (LAN) limited to a certain shipyard area, access to a wider area shipyard network, or no access to shipyard networks and making use of a point-to-point connection option.

The project team met representatives from the NNS IT department and the welding engineering staff and discussed the potential methods for allowable communication in the shipyard including if access to the local area network was allowed. It was agreed upon that the beta prototype testing at shipyard, which is on non-production parts and of a short term of one to two month time period, was permitted to use an external PC but must be wired directly to the equipment. This was closed communication and did not require use of the shipyard network or LAN.

Approval was needed to use the arc camera or any other camera that would be on the tele-welding equipment, and the camera would not be able to record and store any images or video.

The operators of the tele-welding equipment were required to follow a practice of ensuring any Wi-Fi capability was physically turned off on the PC or any devices in the system design capable of Wi-Fi communication.

Future system implementation, if completed, that would be available to be used on production parts could potentially have a communication protocol designed to create a safe method to use the internal NNS network.

Once the beta prototype testing has occurred and if the tele-welding technology is implemented into the shipyard, the shipyard will determine the location where the tele-welding equipment would be implemented, and then the IT staff can help determine the best method for connecting to the NNS internal network.

Open communication to and from the internet will not be permitted when using the tele-welding system.

The following items were delivered as part of Task 2:

- A report detailing the common themes from shipyard's feedback on the alpha system and detail of shipyard requirements for operation of remote machinery.

TASK 3: VALIDATE TELE-WELDING SYSTEM OPERATIONAL STEPS **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to ensure the steps required to operate the beta prototype will suit operation by shipyard personnel in accordance with existing shipyard welder or job grade skill levels. The project team reviewed the Task 2 feedback from shipyard welders and determined that the steps required to operate the equipment would be like the steps required to operate the alpha prototype.

The purpose of this task was to ensure that the user requirements for operating the tele-welding beta-prototype system or any pre- or post- tele-welding process will be modeled after existing shipyard skill level groups or job grades.

The steps required to complete shipyard welds using the tele-welding system were reviewed and updated. A high-level flow chart of operator decisions and potential operator screen functionality was designed. Figure 4 is a flow chart of the operator choices available for selection when first deciding to use the tele-welding system. The main choices include selecting a manipulation device (stylus or joystick) and either welding with the system or jogging the system into a position. If the operator makes the choice to select welding using the user interface buttons, another set of choices will be presented to the operator by the user interface. Figure 5 shows the flow chart of operator choices and system actions that would occur if the operator made the choice to weld. Lastly, if the operator decides to weld, the actions and choices that would occur while welding with the system is displayed in the flow chart in Figure 6. Additional sensors or functionality to be evaluated in Task 4 were not included in the assessment of operator skill level requirements.

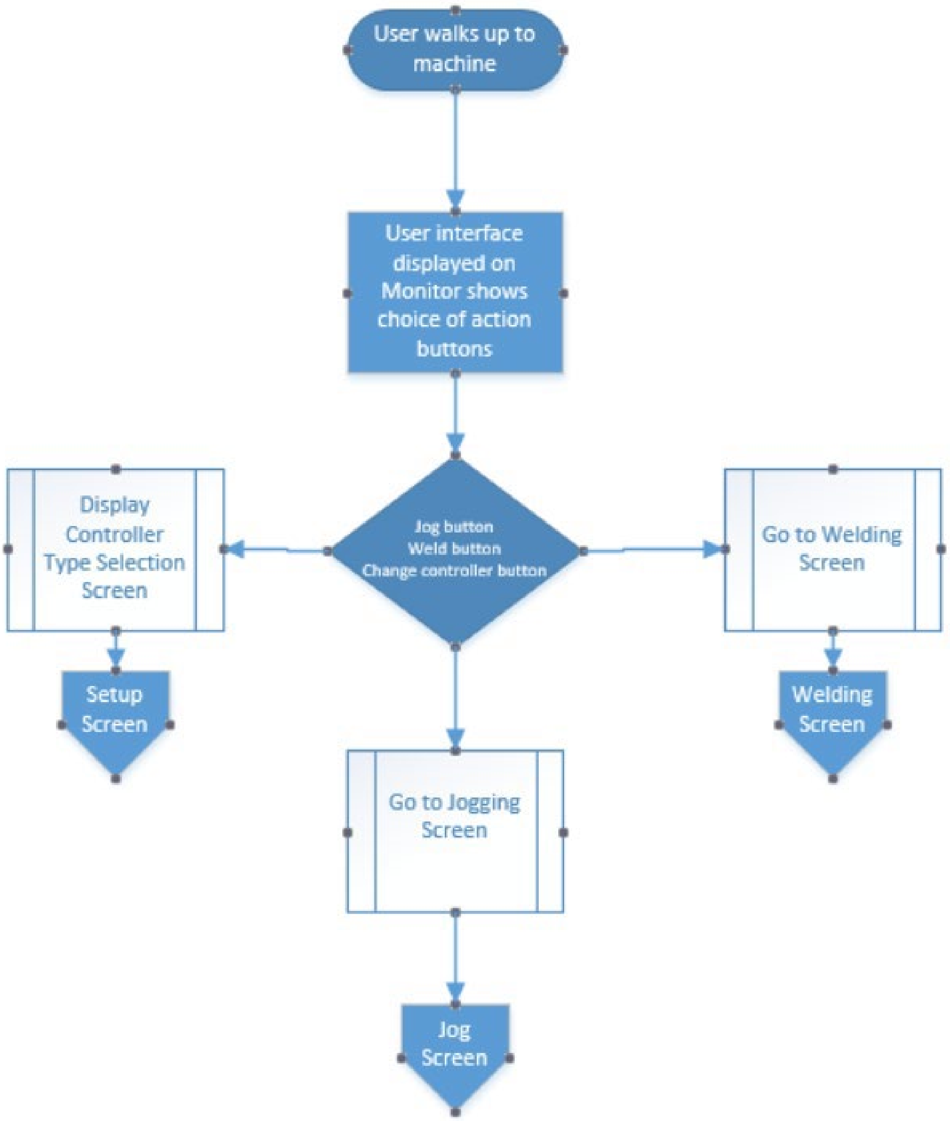


Figure 4. Flow chart of user interaction with a tele-welding system

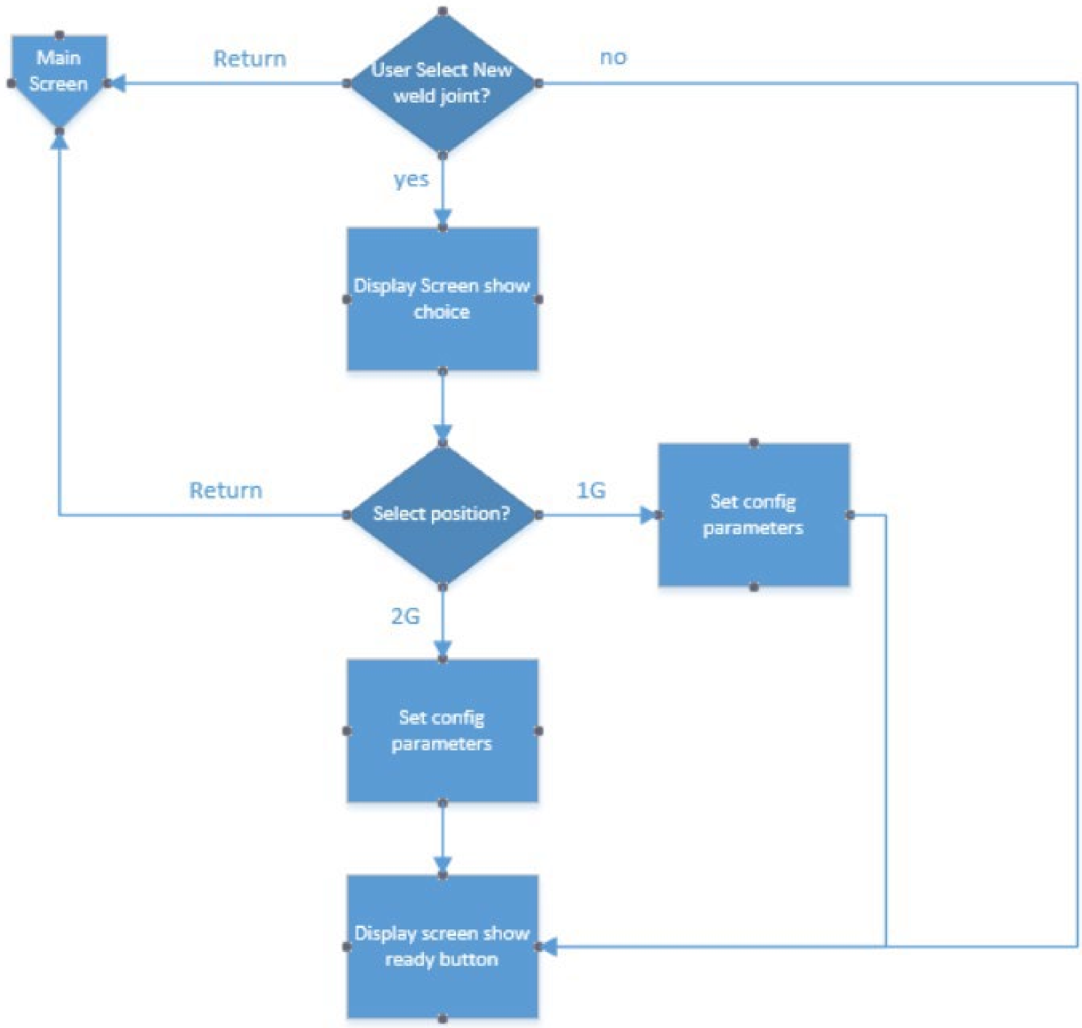


Figure 5. Flow chart of user interaction and decision-making for tele-welding joint selection

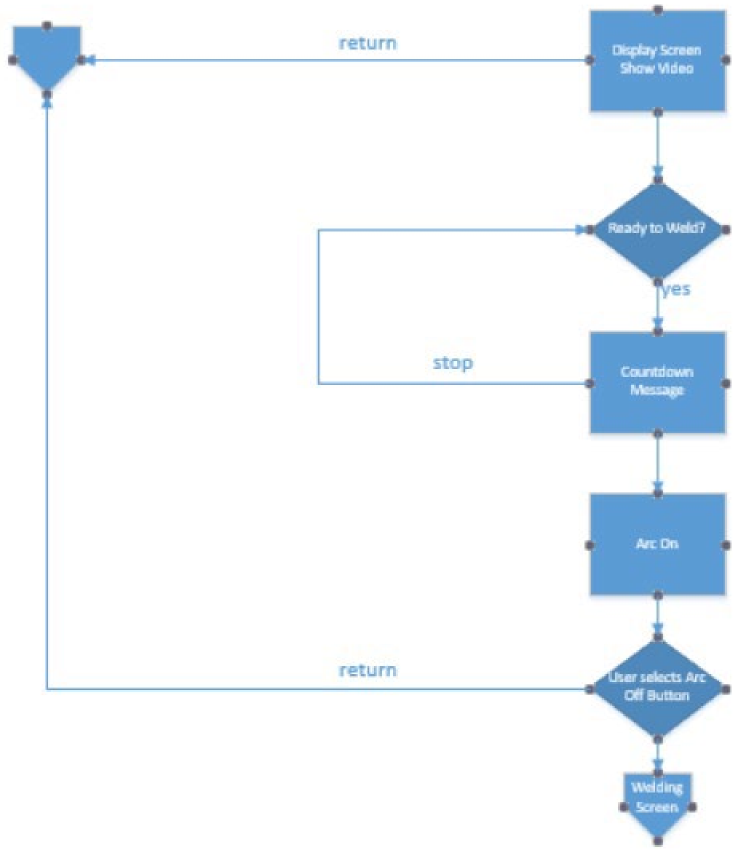


Figure 6. Flow chart of user interaction with a tele-welding system during a live weld

The result from this task detailed the following major outcomes:

- The alpha- and beta-prototype systems developed under these NSRP Research Announcements require the same skills to operate. Figure 7 below shows the same stylus-based manipulator device and the same video or monitor-based viewing apparatus used for both the designs.
- A tractor-based platform, commonly used in shipyard production as a system, would not require new skills to learn to use or operate. Figure 8 shows the typical track and platform based mechanized system already in use in shipyards.

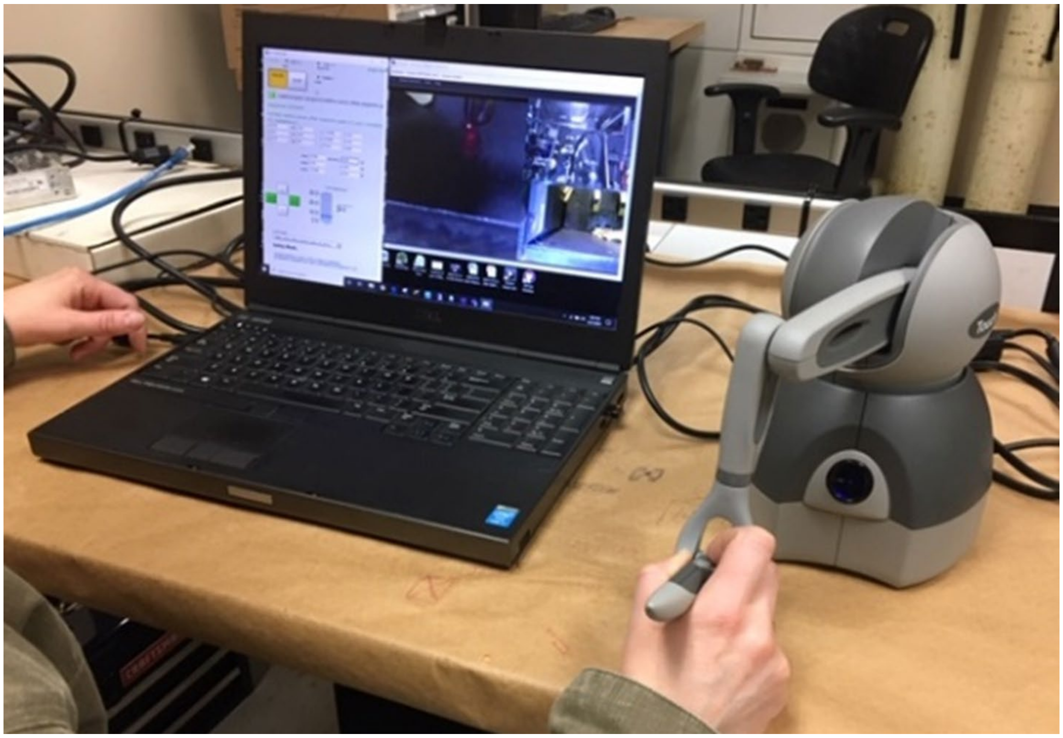


Figure 7. A hand-held stylus device from the alpha system was the same manipulation device used in the beta system design.

Figure 8. A typical mechanized welding system is a Gullco KAT, which runs on a track.

The project team assembled a list of minimum capabilities required of an operator to perform tele-welding:

- Ability to view the welding arc and weld puddle livestream video displayed on a monitor
- Ability to listen to the arc welding process as provided in real-time, simultaneously with the arc and puddle video livestream
- Ability to hold and maneuver a stylus device and view the motions of the remote equipment as shown on the monitor at the same time
- Ability to respond to visual information on the monitor from the arc video livestream by adjusting the stylus position in a timely manner
- Ability to respond to haptic feedback felt by the operator by adjusting the stylus position in a timely manner
- Ability to interact with a local user interface monitor or touchscreen to start or end the remote arc process using on-screen buttons incorporating text and/or color cues indicting to start or stop of the welding arc
- Welding skills that enable acceptable welds, resulting from interpretation of a welding arc, arc puddle, and arc sounds and the adjustment of manual positions.

Below is the deliverable required as part of Task 3.

- The proposed list of steps to complete shipyard welds and the associated operator requirements for each step, based on shipyard skill level or job grade designation.

TASK 4: IDENTIFY AND VET TECHNOLOGIES TO BE UPDATED OR NEWLY DEVELOPED FOR THE BETA-PROTOTYPE SYSTEM **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to select the updates or changes to the functionality of the alpha prototype that would be applied to convert the system to a beta prototype. The improvements and suggestions of features to add were from user feedback, selected shipyard welding application requirements and anticipated future needs. The project team researched methods employed by other industries using automated welding, remote robotics, or tele-presence technologies to determine if these technologies would be beneficial to tele-welding.

The technologies investigated included the following:

- VR/AR environment with haptic controller
- Path memorization for analytics
- VisibleWelding weld pool camera updates
- Additional camera technologies
- Sensors for displacement and temperature
- Joystick and mouse-based controller options
- Path guidance from path superimposed on user interface
- Damping to reduce jitter or to ignore accidental movements

• Torch height range feedback on user interface.

VR/AR Environment

The haptic controller used with the alpha-prototype system could be programed to operator in a virtual environment with software libraries included with the controller. The project team researched this technology and used sample programs to evaluate how this could be used with the tele-technology. The functionality provided by the software library provided with this controller displayed a virtual environment shown on a PC screen that allowed the user to view their motions along with the stylus device operating in the virtual environment. A proposed use in this project was to program the virtual stylus to look like the welding torch within the virtual environment. The benefit to incorporating this virtual environment into the tele-welding prototype beta functionality was to provide an additional method to immerse the user into the welding application. Figure 9 shows an example of how a real weld joint (1) would be first converted to a point cloud (2) and then importing into a virtual environment showing that weld joint represented virtually (3).

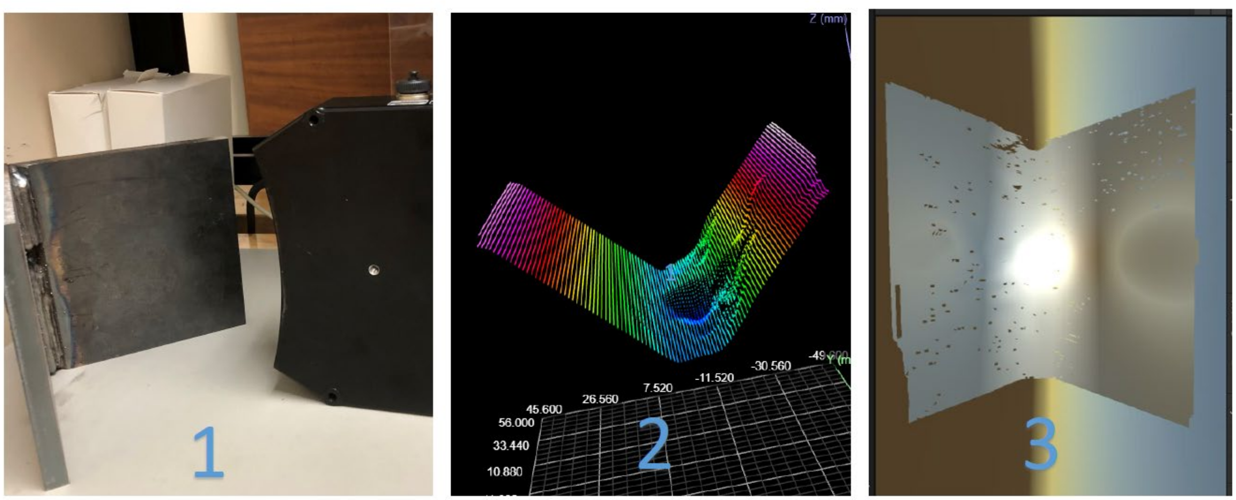
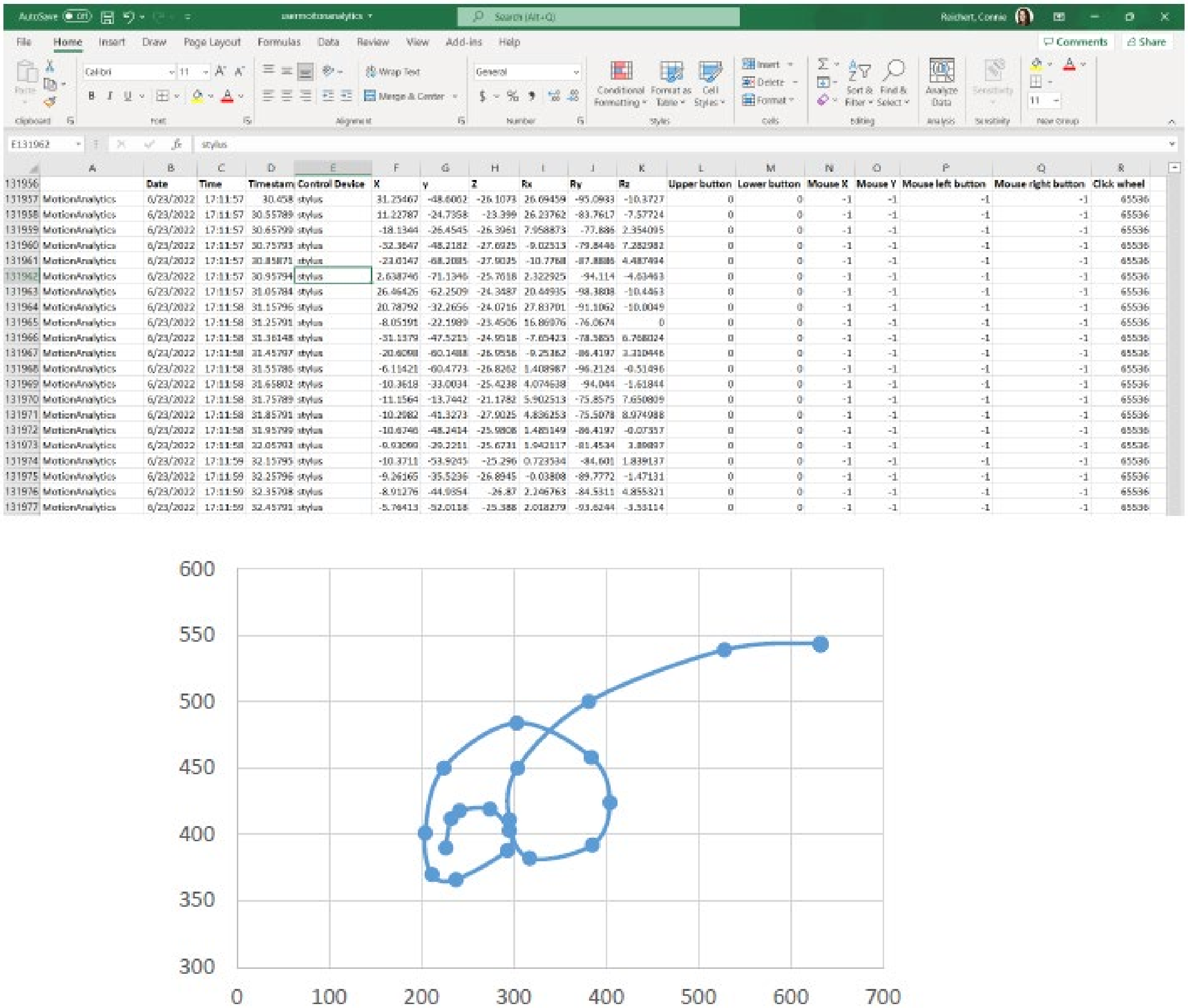


Figure 9. Converting a real weld joint into a virtual weld joint in a virtual environment

Path Memorization for Analytics

Path memorization is a function where all robot motions are recorded into a file for use at a later time for either playback or analysis. The tele-welding software was updated to save all movements from both the robot and the stylus into a file. Figure 10 shows an image of that data and a sample plot from the memorized path data, indicating that any previous path the user or the robot made can be save or used.



131956		Date	Time	Timestam	Control Device	X	y	Z	Rx	Ry	Rz	Upper button	Lower button	Mouse X	Mouse Y	Mouse left button	Mouse right button	Click wheel
131957	MotionAnalytics	6/23/2022	17:11:57	30.458	stylus	31.25467	-48.6062	-26.1073	26.09459	-95.0933	-10.3727	0	0	-1	-1	-1	-1	65536
131958	MotionAnalytics	6/23/2022	17:11:57	30.55789	stylus	11.22787	-24.7358	-23.399	26.23762	-83.7617	-7.57724	0	0	-1	-1	-1	-1	65536
131959	MotionAnalytics	6/23/2022	17:11:57	30.65799	stylus	-18.1344	-26.4545	-26.3961	7.958873	-77.886	2.354095	0	0	-1	-1	-1	-1	65536
131960	MotionAnalytics	6/23/2022	17:11:57	30.75793	stylus	-32.3647	-48.2182	-27.6925	-9.02513	-79.8446	7.282982	0	0	-1	-1	-1	-1	65536
131961	MotionAnalytics	6/23/2022	17:11:57	30.85871	stylus	-23.0347	-68.2085	-27.9035	-10.7768	-87.8886	4.487494	0	0	-1	-1	-1	-1	65536
131962	MotionAnalytics	6/23/2022	17:11:57	30.95794	stylus	2.638746	-71.1346	-25.7618	2.322925	-94.114	-4.63463	0	0	-1	-1	-1	-1	65536
131963	MotionAnalytics	6/23/2022	17:11:57	31.05784	stylus	26.46426	-62.2509	-24.3487	20.44935	-98.3808	-10.4463	0	0	-1	-1	-1	-1	65536
131964	MotionAnalytics	6/23/2022	17:11:58	31.15796	stylus	20.78792	-32.2656	-24.0716	27.83701	-91.1062	-10.0049	0	0	-1	-1	-1	-1	65536
131965	MotionAnalytics	6/23/2022	17:11:58	31.25791	stylus	-8.05191	-22.1989	-23.4506	16.86976	-76.0674	0	0	0	-1	-1	-1	-1	65536
131966	MotionAnalytics	6/23/2022	17:11:58	31.36148	stylus	-31.1379	-47.5215	-24.9518	-7.65423	-78.5855	6.768024	0	0	-1	-1	-1	-1	65536
131967	MotionAnalytics	6/23/2022	17:11:58	31.45797	stylus	-20.6098	-60.1488	-26.9556	-9.25362	-86.4197	3.310446	0	0	-1	-1	-1	-1	65536
131968	MotionAnalytics	6/23/2022	17:11:58	31.55786	stylus	-6.11421	-60.4773	-26.8262	1.408987	-96.2124	-0.51496	0	0	-1	-1	-1	-1	65536
131969	MotionAnalytics	6/23/2022	17:11:58	31.65802	stylus	-10.3618	-33.0034	-25.4238	4.074638	-94.044	-1.61844	0	0	-1	-1	-1	-1	65536
131970	MotionAnalytics	6/23/2022	17:11:58	31.75789	stylus	-11.1564	-13.7442	-21.1782	5.902513	-75.8575	7.650809	0	0	-1	-1	-1	-1	65536
131971	MotionAnalytics	6/23/2022	17:11:58	31.85791	stylus	-10.2982	-41.3273	-27.9025	4.836253	-75.5078	8.974988	0	0	-1	-1	-1	-1	65536
131972	MotionAnalytics	6/23/2022	17:11:58	31.95799	stylus	-10.6746	-48.2414	-25.9808	1.485149	-86.4197	-0.07357	0	0	-1	-1	-1	-1	65536
131973	MotionAnalytics	6/23/2022	17:11:58	32.05793	stylus	-0.93099	-29.2211	-25.6731	1.942117	-81.4534	3.89897	0	0	-1	-1	-1	-1	65536
131974	MotionAnalytics	6/23/2022	17:11:59	32.15795	stylus	-10.3711	-53.9245	-25.296	0.723534	-84.601	1.839137	0	0	-1	-1	-1	-1	65536
131975	MotionAnalytics	6/23/2022	17:11:59	32.25796	stylus	-9.26165	-35.5236	-26.8945	-0.03808	-89.7772	-1.47131	0	0	-1	-1	-1	-1	65536
131976	MotionAnalytics	6/23/2022	17:11:59	32.35798	stylus	-8.91276	-44.9354	-26.87	2.246763	-84.5311	4.855321	0	0	-1	-1	-1	-1	65536
131977	MotionAnalytics	6/23/2022	17:11:59	32.45791	stylus	-5.76413	-52.0118	-25.388	2.018279	-93.6244	-3.33114	0	0	-1	-1	-1	-1	65536

Figure 10. Saved robot and user motions in a text file can be used for a record, analysis, machine learning, or programming.

The benefit of using path memorization is to have a record of robot and welder motions used to complete a weld for the future use for analysis, data science, artificial intelligence (AI), or robot programming method.

VisibleWelding Weld Pool Camera Updates

VisibleWelding completed upgrades to the arc monitoring camera system in response to the feedback regarding resolution and camera size. An increase in resolution on VisibleWelding puddle view camera improved the quality of the weld pool image and the clarity of the arc in the video. A decrease in camera size provided smaller payload on the robot arm and smaller real estate of the camera itself. The tradeoff between using the different camera bodies was that the smaller body camera did not include automatic arc filtering. The arc filtering automatically adjusted the light level of the video image as soon as the arc was detected. With the smaller body camera, the video filtering was at a constant level which means the video was dark until the arc was on. To solve this issue, two cameras were needed so that one camera could see when the arc was off and one camera could see when the arc was on.

Visible welding preformed research and testing using a different camera body style and using different lenses to improve the quality of the images in the video. Figure 11 shows the increase in quality as was observed before and after images taken from videos using the original functionality and then the improved functionality.

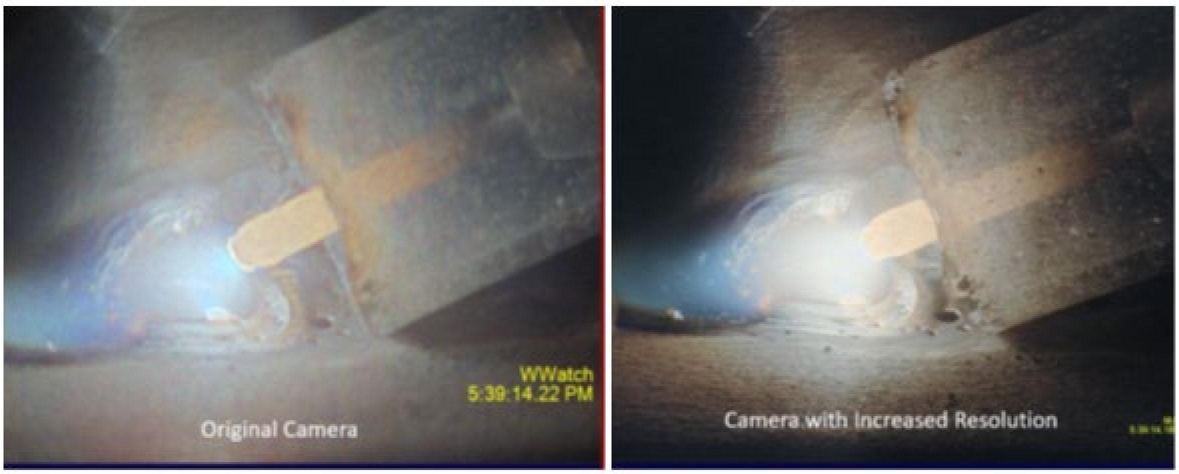


Figure 11. Shows the comparison of the original arc monitoring camera image and the improved arc welding camera image.

Figure 12 also shows the comparison of the two camera bodies. The larger, original camera body was behind the new, smaller camera body.

Figure 12. Two cameras side by side to compare size of the camera body

Additional Camera Technologies

Other commercial camera technologies were investigated including 360-deg cameras, 3D cameras, and LIDAR or spatial distance cameras. The functionality to be gained in using a different camera technology was to gain further depth perception in the surrounding environment and to provide that information to the tele-welding operator as another form of feedback. The benefit was more depth perception information for the operator, and the detriment was that an additional software program may be required to view or show the 3D view to the operator.

Figure 13 shows a sample of spatial information provided by a 3D camera added to a standard 3D image by using color depth topography.

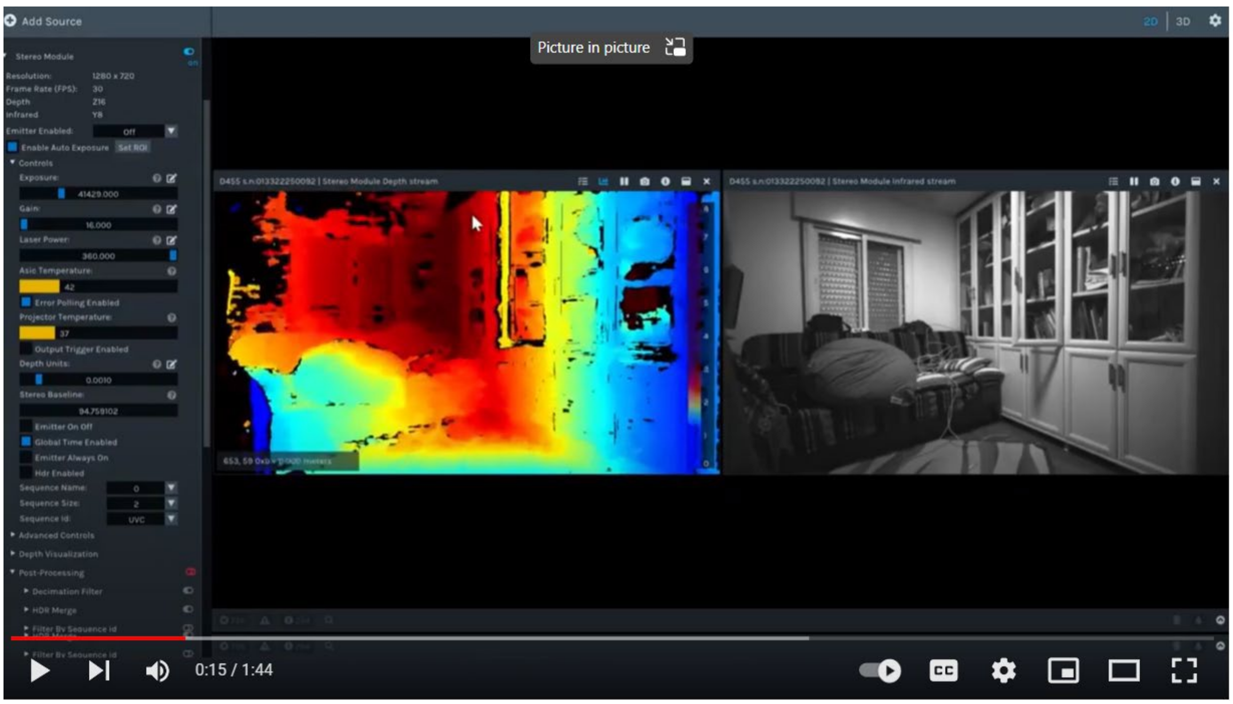


Figure 13. Software program from a 3D camera showing spatial information by superimposing a color onto the 2D image, indicative of proximity.

Sensors for Displacement and Temperature

Additional types of sensory information requested by the shipyards and investigated during this task included temperature and displacement or distance feedback. With this additional information, the tele-welding operator was able to monitor from the remote location the inner temperature between weld passes. The operator could also know the measured distance between the robot end effector, or torch, and the surface. This information can be used to inform proper contact tip-to-work distance or help the operator control the welding voltage to maintain proper welding parameters.

Figure 14 shows a small sensor that could be used to measure temperature. A laser displacement sensor could be used to measure height and could be attached to the robot arm or welding torch fixture.

Figure 14. An example of a non-contact temperature sensor that could be used to measure temperature of the part during tele-welding

Joystick- and Mouse-Based Controller Options

Additional options for the manipulator – the device the operator uses to control the robot movement – were evaluated. The functionality of the manipulator was to provide a physical device that the operator can move around and direct the remote robot movements. The benefit of investigating devices other than the haptic stylus device that was used with the alpha prototype was to make the tele-welding technology more easily accessible by using lower-cost items such as joysticks and standard computer mice. The other benefit was to cater the tele-technology to computer and video gamers who may already have experience with joysticks and more traditional gaming controllers. Figure 15 shows a gaming joystick that is readily available for $30. The drawback to using the joystick and the lower-cost PC mouse was that they do not typically provide a haptic response, especially at the low-cost price point.

Figure 15. Gaming or flight stick simulation joystick is an alternative to the haptic stylus device.

Path Guidance from Path Superimposed on User Interface

One suggestion from the tele-welding alpha prototype testers was to provide a path for the tele-welding operator to follow. The function of this path would be to superimpose the correct path or motion that the operator should follow to create the weld. This path would help a new tele-welder see how an experienced tele-operator welded a joint. Such a path also could be used as a training guide and could reduce the effort required of the tele-welder to know how and when to adjust position during welding.

Damping to Reduce Jitter or to Ignore Accidental Movements

Damping of the tele-welder operator's motions was also suggested by tele-welders from the shipyard. The functionality of this type of control was to smooth out user motions. The benefit of this damping was preventing unintentional robot movements that might occur if the stylus was accidentally dropped or if the user's hand motions are not smooth. EWI investigated applying a smoothing routine into the software and performed testing on simple motion path filters. Figure 16 shows the output of one of the tests performed where simple filters were used to smooth the motion performed by the operator moving the stylus.

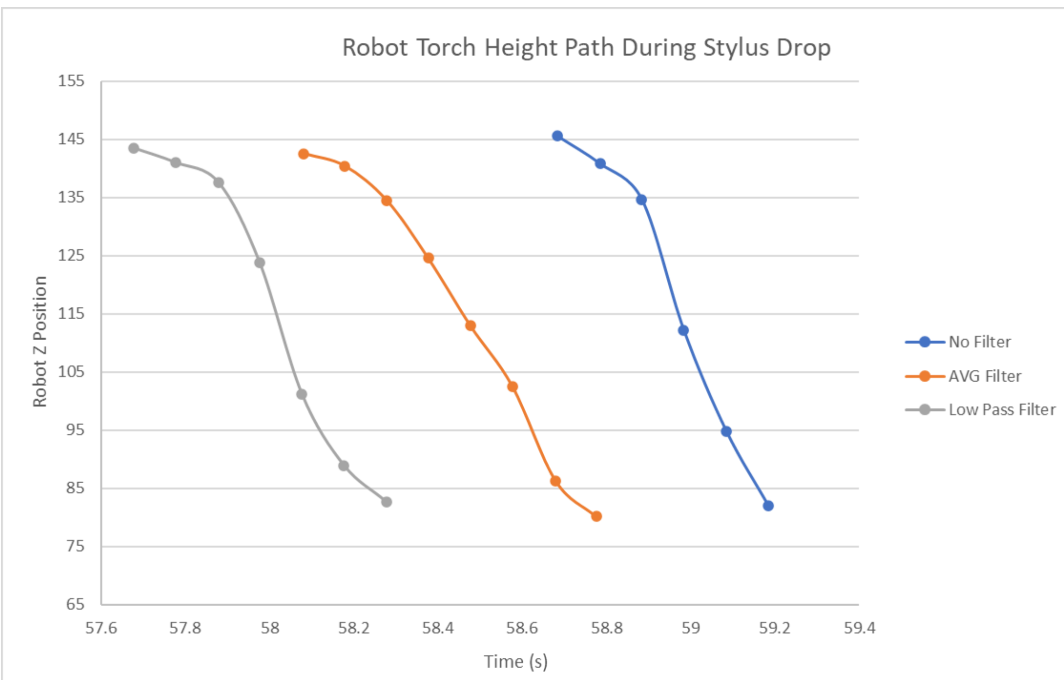


Figure 16. Different motion path smoothing techniques were evaluated to attempt to filter out unwanted user motions such as jitter or dropping the stylus device.

Torch Height Range Feedback on User Interface

Another feature requested by welders who tested the alpha-prototype system was a visual indication of the torch-to-part distance during welding. The functionality would be a physical graph or indicator on the software screen that would indicate proximity to the surface. The benefit of providing this indicator on the user interface was an increase in weld quality because the user would have a constant visual indication of the correct torch height-to-workpiece distance (electrode stickout). EWI added this functionality to the user interface software screen on the alpha-prototype system to test the benefit. Figure 17 shows the user interface screen and the visual indication of distance to workpiece.

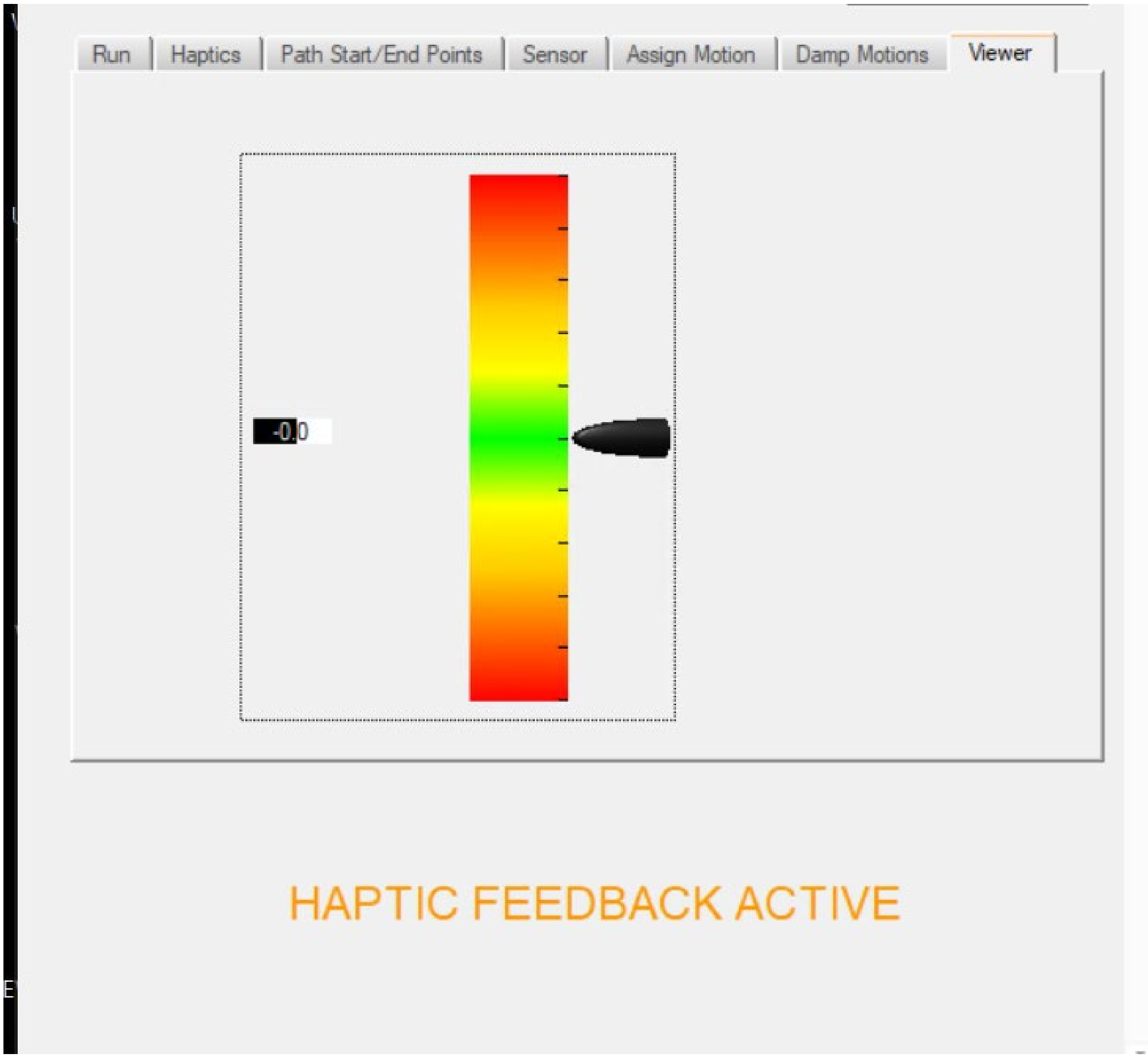


Figure 17. A simple color ramp is used as a height gauge to indicate proximity to the weld surface.

The project team investigated and then integrated and tested several new additional functions using the alpha-prototype system. These new features were ranked based on technical difficulty to implement, cost to implement, and ease of implementation into the beta-prototype design. The project team gave feedback and indicated the preference and ranking of importance of the features. The results from the ranking of the top features were then down-selected to the three listed below to be included in the beta-prototype system's functionality:

1. Path memorization
2. Joystick controller option
3. Torch height feedback on user interface.

Additionally, a new sensor was added to the system to measure non-contact temperature.

This task included the ranking of the improvement updates and down-selection by the project team.

Deliverables: The deliverables for this task included a report on the technologies evaluated and ranked based on value, technical complexity, and ease of integration into the beta-prototype system. A video demonstration was provided showing the path memorization functionality as implemented onto the alpha-prototype system. A video showing joystick control as implemented onto the alpha system and also a video showing the visual torch height feedback indicator was delivered to the project team.

TASK 5: IDENTIFY AND CONFIRM SELECTED WELD JOINT AND INITIAL USE CASE FOR THE BETA-PROTOTYPE SYSTEM **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to review the weld application selected by the shipyard in the previous project and then determine a range of welding applications that would be selected for the beta-prototype system to be able to weld. A functionality specification was developed for the beta-prototype system and a mock assembly was created for testing the system at EWI. NNS shipyard selected a weld to be used to demonstrate and test functionality of the system. A double-side V groove welded in the 2G positions was selected as the weld joint type and position. EWI and NNS shipyard detailed the following joint characteristics and welding conditions to be used during testing.

- A 1-in. plate can be used with a double V joint preparation.
- The V prep will have a 60/40 bias, front/back side.
- At least three layers of weld fill need to be welded per side.
- Welding will occur in the 2G horizontal position.
- The material will be HY80.
- Ceramic backing will be used.
- Preheat will be used.
- The backside will be carbon arc gouged.

The welding conditions were converted into a functionality specification to aid in the design of the beta-protype system.

Figure 18 below shows the weld joint schematic.

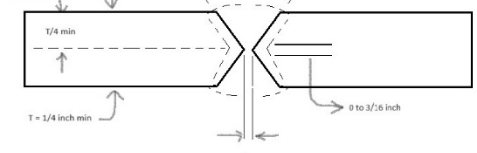


Figure 18. Selected welding joint type for testing the beta-prototype tele-welding system

EWI designed a testing table that allowed for welding the selected weld joint in the correct position and welding conditions. Figure 19 shows the schematic of the design of the table.

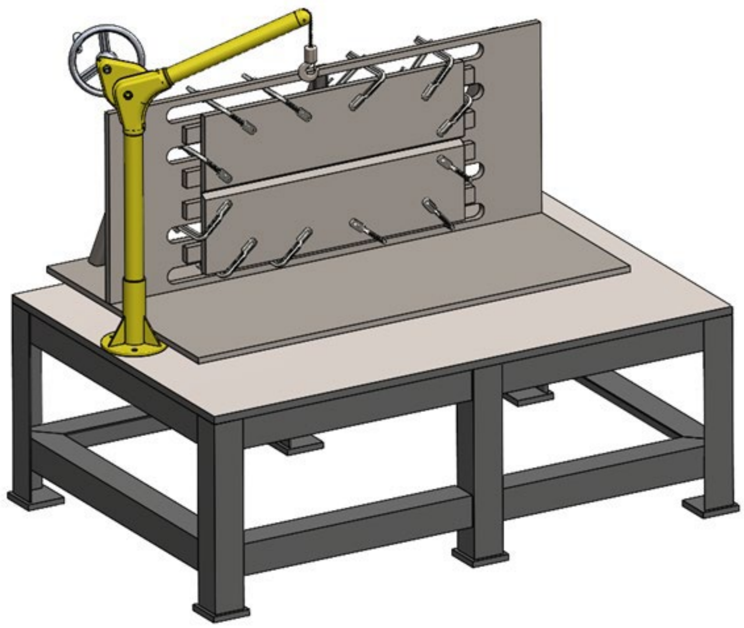


Figure 19. Schematic of the weld mockup assembly and testing station to be fabricated to enable tele-welding the selected weld joint

Deliverables: The deliverable for this task included the functionality specification for the beta-prototype system and the weld mockup fixture design drawing.

TASK 6: CREATION OF THE BETA-PROTOTYPE SYSTEM **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to create the design and development of a beta-prototype tele-welding system, based on the alpha-prototype design and updating the functionality as down-selected in Task 4.

The original intent of the project was to use a magnetic-based crawler from project partner RTT. RTT completed a design concept for the magnetic crawler system and submitted it to the team for review. This design concept was based on a smaller, more rugged system than the alpha-prototype and was designed with different magnetic attachments and many other improvements. The system concept was based on updating an existing RTT product that would provide the following main changes from the alpha-prototype system:

1. New robot design
    a. Suspended magnet platform with machined and cast wheel treads

   b. Integrated tool manipulator on the front of crawler (left on top, bottom on right)
   c. Tool manipulator achieves high speeds and longitudinal travel over 80% of robot width
   d. Onboard controls of all motors plus user interface controller
2. Switchable magnets, non-magnetic wheels, no tracks
3. Onboard active guidance to ensure accurate heading (any heading from vertical to horizontal).
4. Laser line-enabled alignment system for aligning and maintaining alignment with speed

Figure 20, Figure 21, and Figure 22 show the updated RTT system that resolves the issues associated with alignment and seam tracking control and would be used as the base system and then adapted into the beta-prototype design. Figure 20 shows the RTT crawler with active torch and Miller 8VS ARC reach suitcase. Figure 21 shows a laser-alignment system for quick setup. Figure 22 shows in-lab testing of the system for basic welding operations. Note in this operation, it is not being used in the tele-weld configuration, but the system is capable of either using local controls or tele-weld controls.

Figure 20. RTT crawler with active torch and Miller 8VS ARC reach suitcase

Figure 21. Laser alignment for quick setup

Figure 22. In-lab testing of the trackless RTT beta system prototype (Note, local, not tele-welding controller shown in this image)

Payload testing was performed on this platform with payload in overhead position exceeding 500 lb.

The project team shifted the direction of the design for the motion platform based on the shipyard need to use a track-based system that could run on commercially available tracks. A design for the updated system architecture for a mobile, track-based platform was completed and submitted to the project team. The platform was based upon a commercially available Gullco travel carriage and trailer.

The benefits to using the cobot arm for the tele-control was that any base motion platform such as RTT's magnetic platform or a track-based system such as Gullco could be used as the cobot simply sits on top of the base platform. The cobot and base platform had the following design characteristics:

- Cobot arm performs the tele-controlled motions and was mounted onto any crawler platform.
- Crawler platform performs travel motion only, so it could be magnetic, track-based, etc.
- Crawler platform's motion direction and speed could be coordinated with the cobot arm.

The benefits to this approach included:

- Potential for selection of any type of base or crawler platform to be used (magnetic, track-based, stationary clamp).
- Make use of the existing tele-welding control technology for cobot arms already developed on the alpha-prototype.
- The selected cobot manufacturer, Universal Robots, offered several models of cobot arms providing plug-and-play interchangeability for different payloads.
- Future projects could be used to integrate a shipyard's preferred motion platform with the tele-weld technology, enabling use of the RTT magnetic crawler design and upgrades created during this project.

Gullco provided equipment that was used in the design as the motion platform for travel along the weld path/joint. The tele-control technology developed on the first alpha-prototype system was used in conjunction with a cobot arm. The cobot arm design included the cobot attached onto the Gullco platform. The Gullco motion platform provided travel motion along the length of the joint while welding. All other motions were provided by the cobot arm. All motions were remotely controllable by the tele-operator.

The alpha prototype's desktop stylus device was selected as the manipulator, with the option of joystick to be used instead of the haptic feedback stylus device.

The software and user interface were updated to include the new features and functionality identified in Task 4 with the ability to weld the joint and in the position selected in Task 5.

System Hardware Design and Development

The Gullco platform and trailer were used to hold the cobot arm onto the track. Figure 23 shows the cobot attached to the trailing platform pulled by the Gullco motion system.

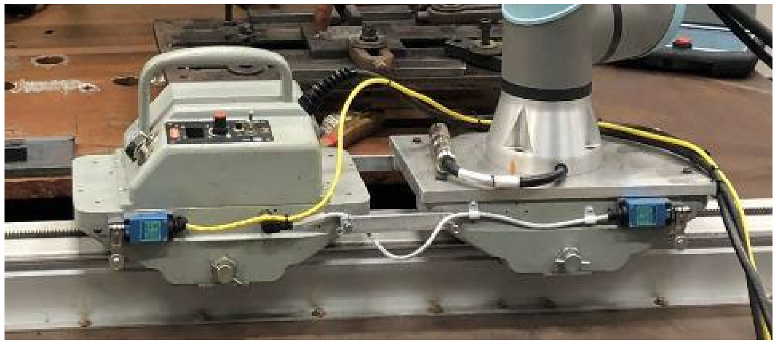


Figure 23. Gullco KAT track-based platform pulling the UR5 cobot arm

The weld mockup and fixture table designed in the previous task were fabricated and assembled at EWI. Figure 24 shows the fixture before the weld joint mockup prep was added.

Figure 24. The fabricated fixture table which holds the joint mockups in the proper position

Parameter development was accomplished using 1-in. thick representative joints in carbon steel. First, the WPS provided by NNS shipyard was followed and the weld was completed using manual gas metal arc welding (GMAW). Figure 25 shows the system during initial welding tests on the 1G position using the 1-in. thick carbon steel plates.

Figure 25. The beta-prototype system during welding tests and parameter development in 1G position on 12-in. long plates of 1-in. thick carbon steel

After the weld joint had been successfully manually welded, the tele-welding system was used to complete the weld. Figure 26 shows the weld joint prep and the welded joint firsts manually and then tele-welded with a remote welder.

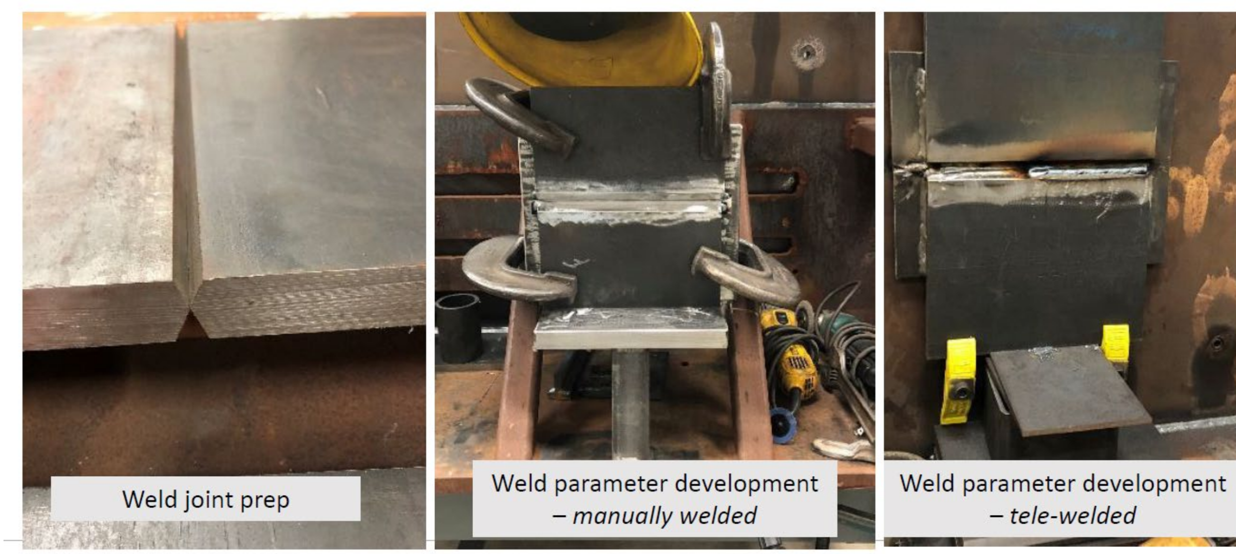


Figure 26. The weld joint selected by the shipyard was first manually welded following the WPS and then tele-welded

After the weld parameters for tele-welding the selected weld joint were developed, several items were changed based on the experienced gained using the tele-welding system. The tele-welding system received the following updates:

- Shelf to support heating blankets
- Shelf to support test pieces

- Crane mount for table
- Shelf for wire feeder to mount onto the table
- Straight barrel weld gun and UR bracket.

Since the WPS required interpass heating, heating blankets were installed onto the fixture table for the tele-welding system. Figure 27 is an image showing the heating coils that will heat the plate during welding.

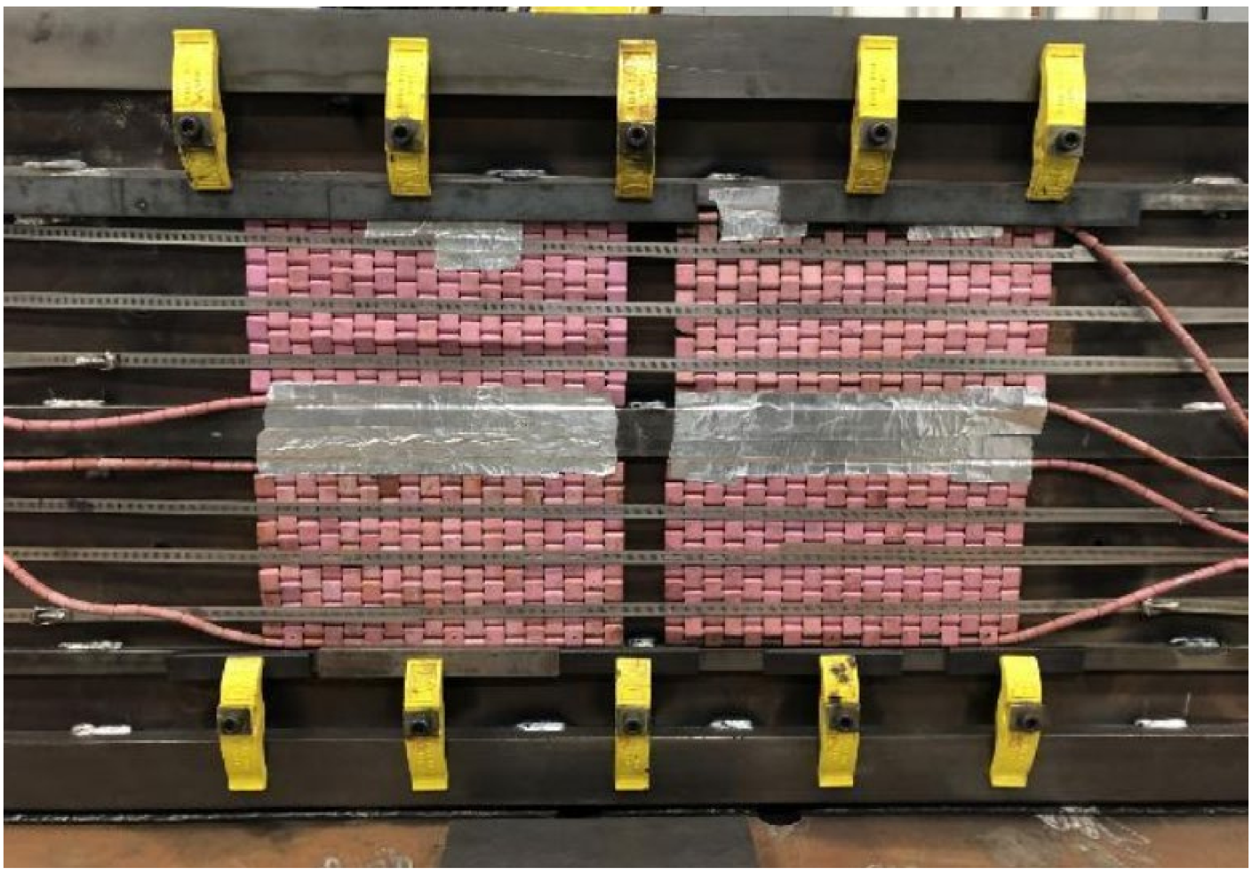


Figure 27. Heating elements that will be behind the weld joint mockup (not shown in the picture)

Due to the weight and 2G welding positions selected for the shipyard weld joint, a shelf was added to help support the weight of the test pieces to be used while tele-welding with the beta-prototype. A small crane was also used to help lift the plates onto the table.

The wire feeder, typically mounted onto the trailer of the track-based system, was mounted onto a swivel platform on the fixture table. This helped wire feeding and provided a local position for the wire that could be remote from the welding power source.

Lastly, a straight barrel, water-cooled welding gun (Figure 28) was purchased along with a UR cobot mounting bracket. This commercially available GMAW torch improved the weld and added the water cooling needed.

Figure 28. The straight barrel, water-cooled torch model similar to what was purchased for use on the beta-prototype tele-welding system

System Functionality Design and Development

The beta-prototype system was developed based on the design create in the previous task. The main functions required for the beta-prototype system included the following:

- Camera for puddle view and peripheral
- Stylus as the manipulator for control of cobot
- Haptic feedback to guide operator
- HMI/user interface for start/stop and camera view
- Automatic arc start/end tied to Gullco travel start/end.

Based on feedback, testing and voting from Task 4, the following features and capabilities were added:

- Path memorization and path guidance on user interface.
- Sensors for temperature.
- Joystick controller options.

The user interface and control software were updated as per the functionality description, feedback, and new features added to the functionality. Figure 29 shows the new use interface design for the beta system.

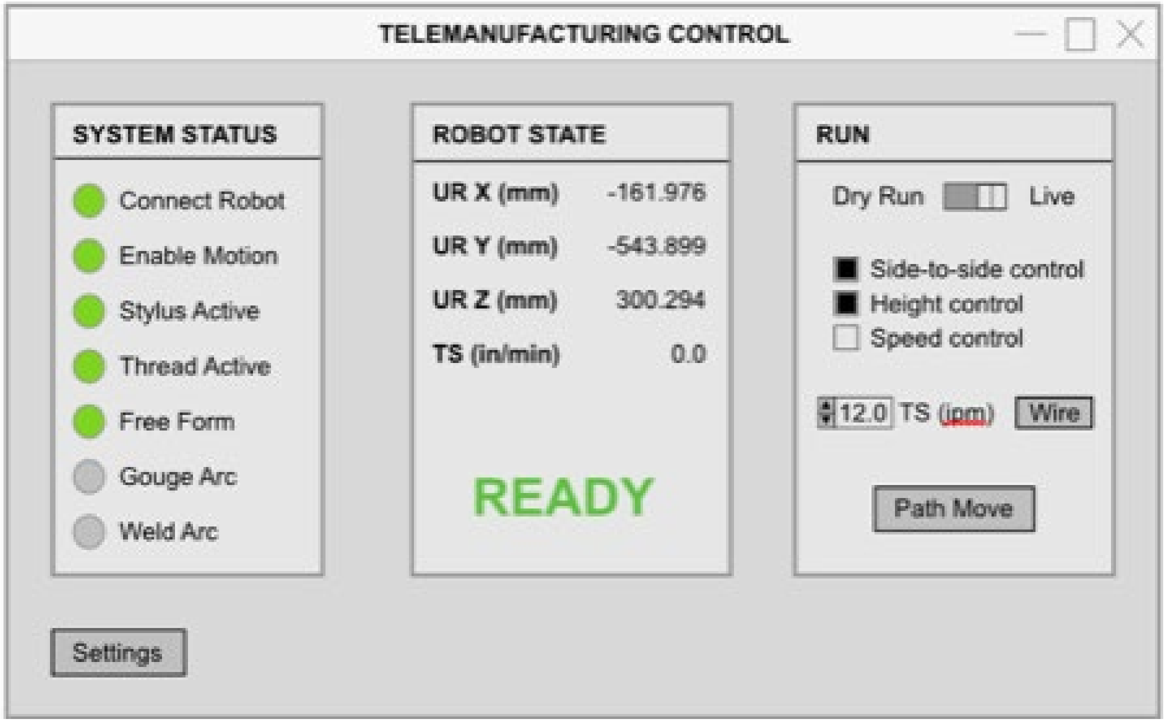


Figure 29. An updated user interface design for the beta system

The tele-welding operator views a PC screen with several views of information. The first view is the user interface which allows the operator to start and stop the tele-welding process and any control of the remote equipment. Another view is the video image from the arc monitoring camera system. Figure 30 shows a close-up of the PC screen and what the operator is viewing, and Figure 31 shows the operator sitting at a desk viewing a monitor remote from the welding operation.

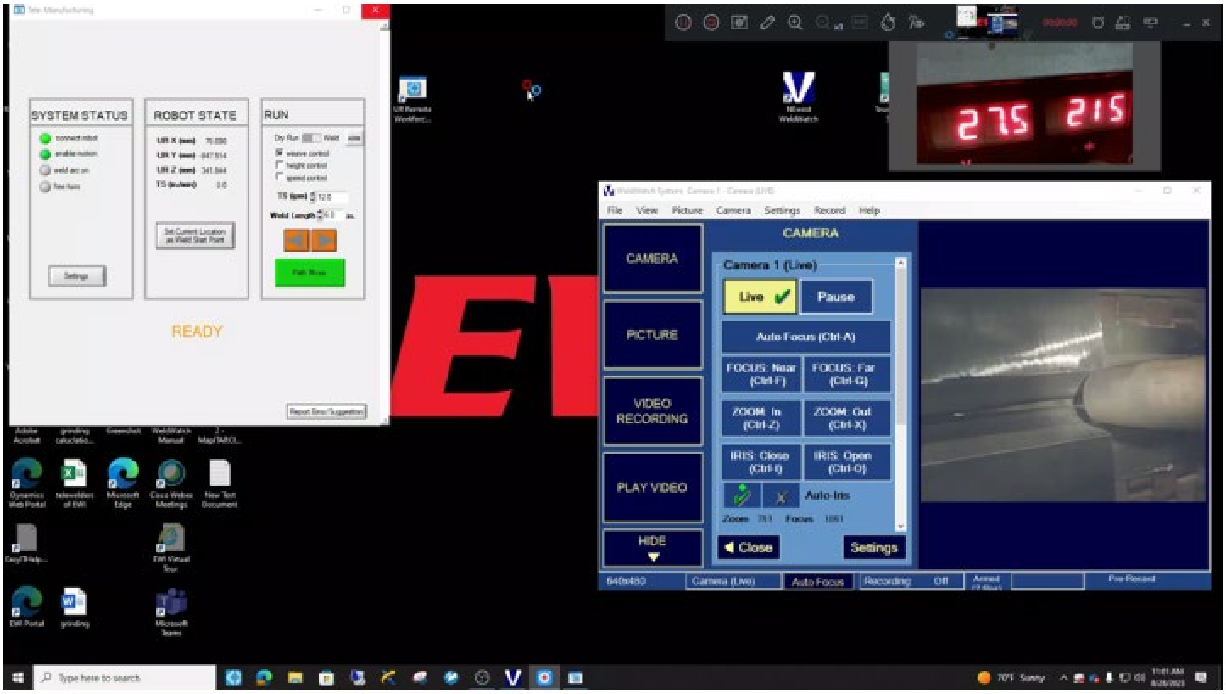


Figure 30. PC screen showing the information the operator can view during tele-welding

Figure 31. Tele-welding operator viewing the remote process and tele-welding using the beta-prototype system

Testing and Runoff of the Beta System at EWI

Once fully assembled, the beta-prototype system was tested at EWI using both 1-in. test plates on carbon steel and on the 2-in. shipyard-selected weld joint prep on HY80 material. Figure 32 shows the prepared joints ready to be tele-welded.

Figure 32. The HY80 material used for testing the tele-welding beta prototype was 2-in. thick plates that were 36-in. long by 12-in. width

The system was further tested on multi-pass 1G and 2G position welding. Figure 33 shows some results during the layer passes completed with the tele-welding system.

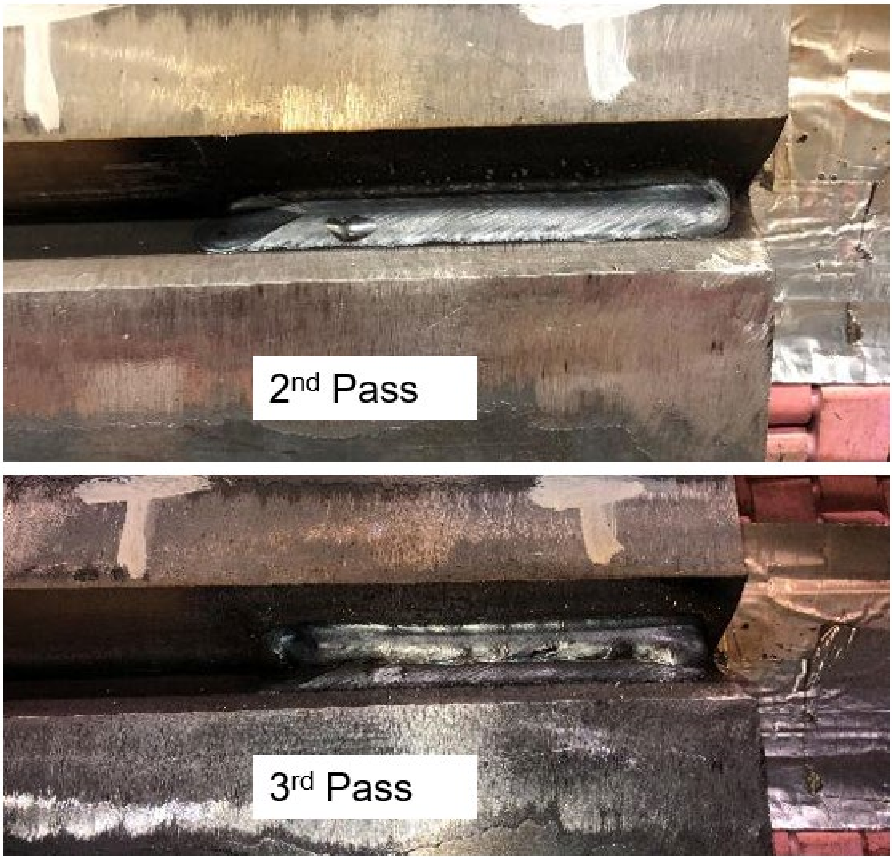


Figure 33. Images from the weld tests on 2G welding of carbon steel

Demonstration and Testing at EWI by Shipyard Personnel

The project team was invited to attend a live demonstration at EWI in Columbus in August 2024. At this demonstration, shipyard personnel from NNS were able to use the system, receive some training on how to use the system, and then perform tele-welding on weld joints. Figure 34 shows EWI personnel providing training to attendees and then attendees tele-welding.

Figure 34. Live demonstrations were held at EWI in Columbus, Ohio, where NNS shipyard personnel used the tele-welding system and practiced welding.

The deliverable for Task 6 included both the design of the beta system and then a live demonstration after the system was assembled and tested.

TASK 7: TEST REMOTE WELDER PERFORMANCE QUALIFICATION **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goals of this task was to provide a means for remote welders to attempt weld qualification using tele-welding equipment using the same procedure qualification testing article used in manual welding and to observe new and expert welders as they attempt to learn or qualify for a welding procedure.

The project team set up hardware at EWI to allow a shipyard welder to attempt remote performance qualification. This testing was completed using the beta-prototype system residing at EWI but with a fixed base and not on a mechanized crawler. Figure 35 shows the setup station with the UR robot and welding table.

Figure 35. The setup tele-welding qualification station at EWI

EWI created test weld blanks as guided by Tech Pub 248 for 1G multi-pass weld tests. EWI set up a station to allow 6-in. plates with a single V weld joint preparation to be tele-welded in the 1G position. A weld qualification testing specification per ASTM was followed for testing the welds. The following tests were completed for each welded joint:

- Visual Test by a certified welding inspector (CWI)
- Radiography by a Level III technician (ASNT)
- Bend Test at 2 locations as per ASTM E190/E290

Figure 36 shows the drawing for the bend testing of the welded plate.

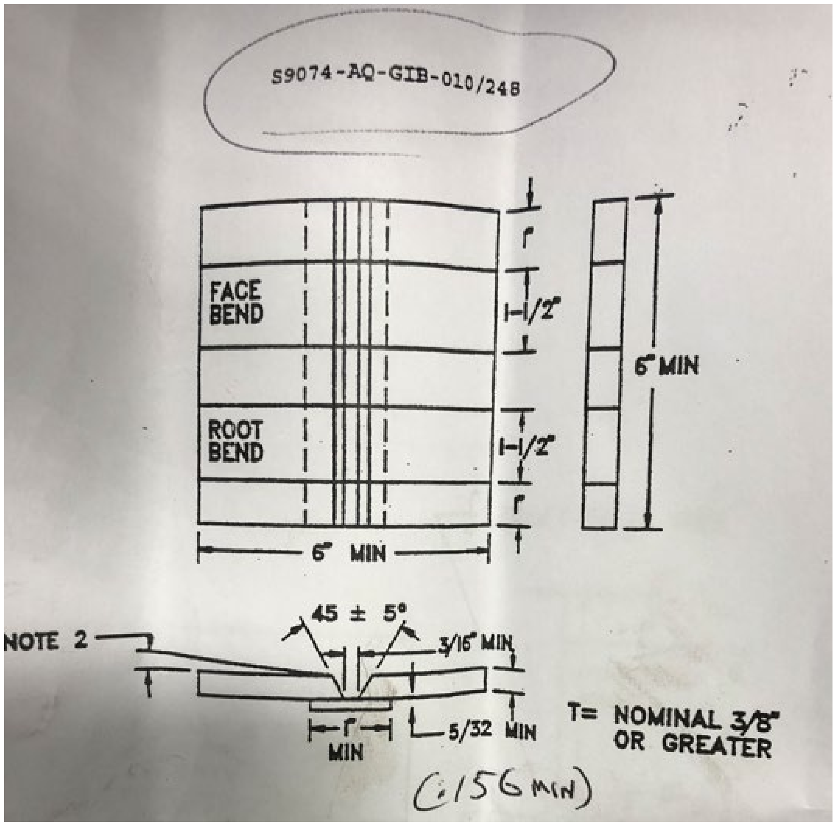


Figure 36. Bend test instructions for evaluating the performance of the tele-welding system

Three people attempted qualification using the tele-welding system. Welders' progress and attempts to qualify were recorded by video to gauge the validity of a tele-welding qualification method. There were three levels of proficiency of manual arc welder, selected for attempting qualification using tele-welding:

1. Expert welder
    a. 30+ year of experience
    b. AWS-certified manual welding instructor
2. Advanced welder
    a. 20+ years of experience
    b. 10 years robotic welding experience
3. Beginner welder
    a. New welder with no experience
    b. Never struck on arc or held a welding torch

Each welder followed a bead sequence map to weld up the grove. Figure 37 shows the bead sequence map followed by each welder.

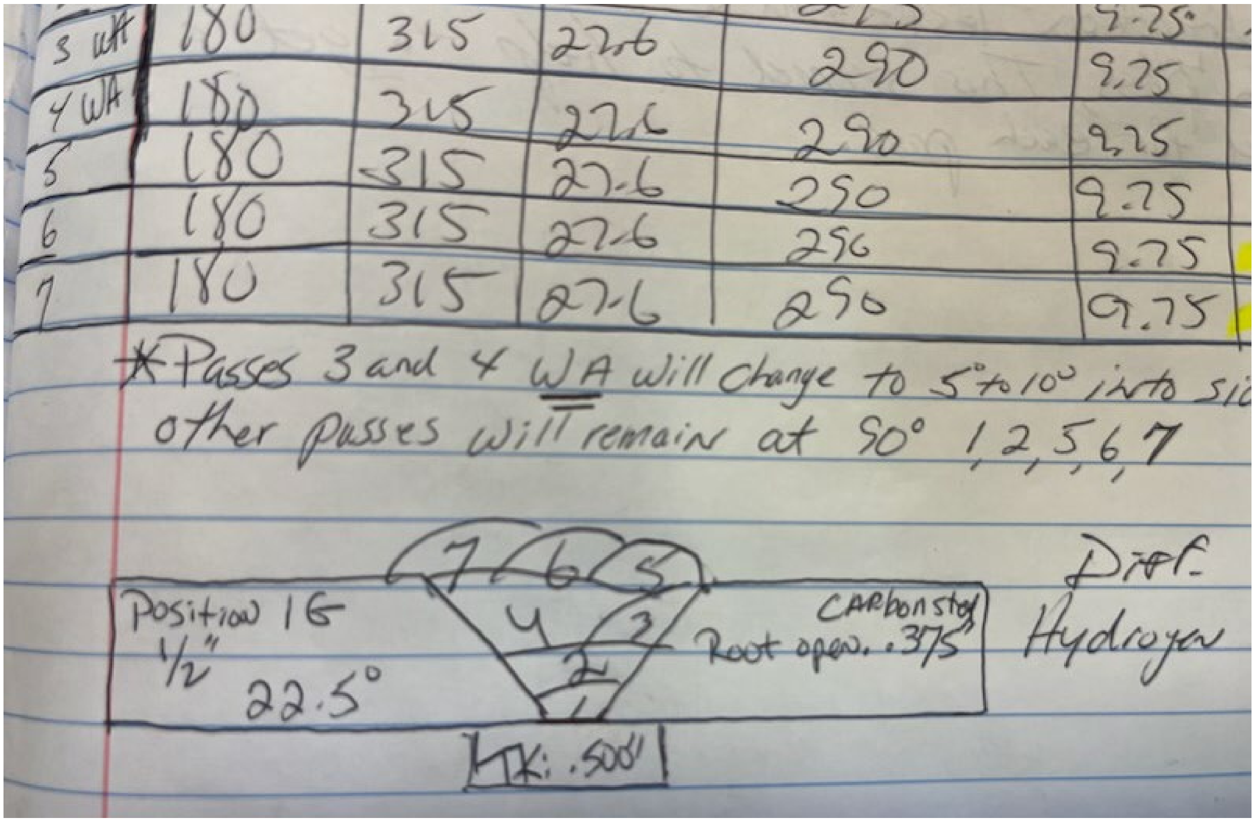


Figure 37. Bead sequence map followed by each welder attempting tele-welding qualification

Results of Welder Qualification Attempts Using Tele-Welding

Each welder received initial training using the tele-welding system. This training included practice dry-running the tele-welding system hardware and then bead on plate welding with arc on, tele-welding. Each weld bead was recorded using the arc data monitoring camera. This was reviewed by the welding instructor after the welding was completed. Figure 38 is the welded test plate before testing. Figure 39 is the result of the visual testing. Figure 40 shows the results of the radiography testing, and bend test results are shown in Figure 41. All three welders' joints were welded and tested.

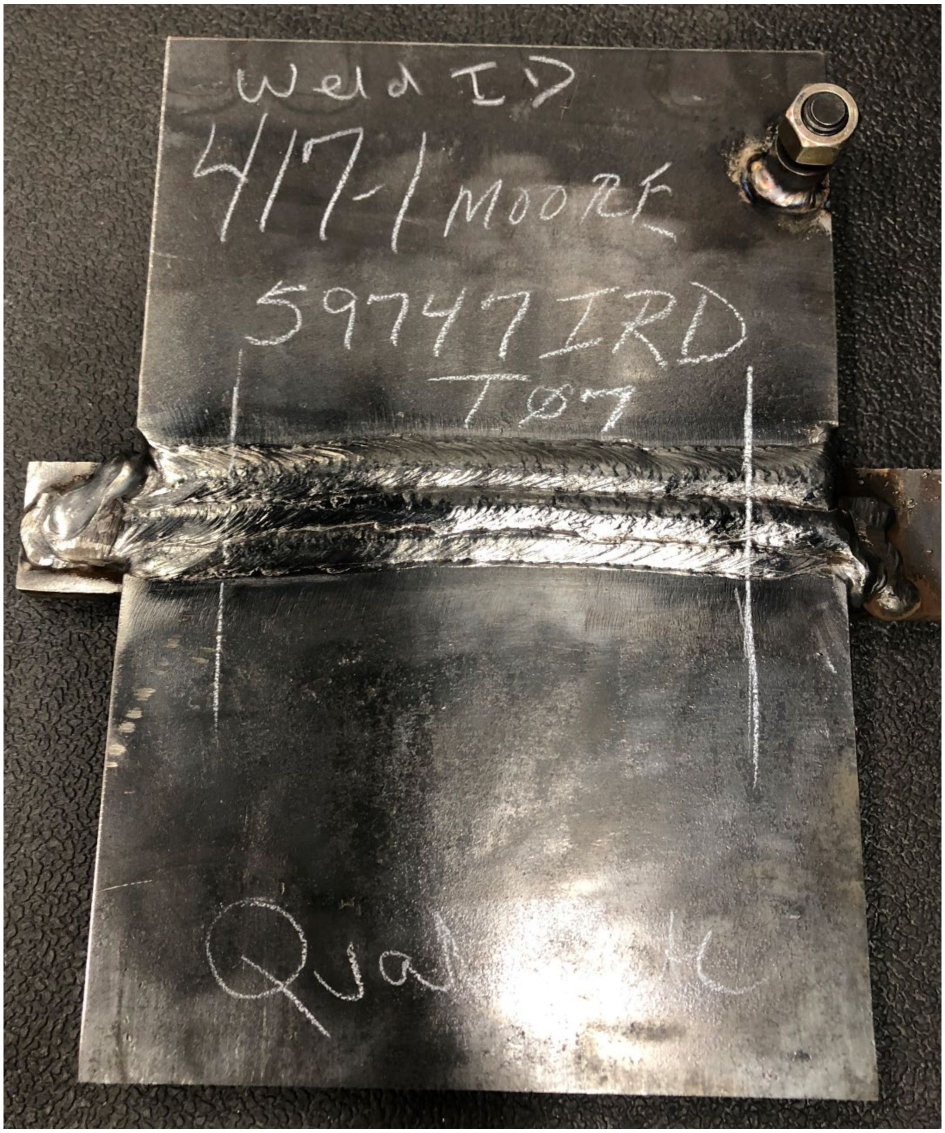


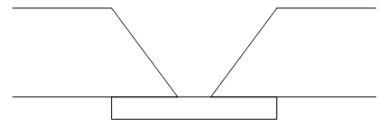
Figure 38. A fully welded test plate sample welded by the tele-welding system

EWI 1250 Arthur E. Adams Drive Columbus, OH 43221 Lab Services

Certificate of Inspection - Visual Inspection Report

Project Number: 59747IRD Weld Number: 417-1MOORE Filler Metal Lot #:
Customer:
Address:
Purchase Order: Date of Inspection: 4/18/23 Filler Metal Type: N/A
Job Number: Customer: Filler Metal Dia.: N/A
Specification: NAVSEA Tech Pub 248 Acceptance Standard: MIL-STD-2035A Filler Metal Mfg: N/A
Reference Standard: Weld Process: GMAW Filler Metal Spec: N/A
Weld Type (groove, butt, fillet, etc.): GROOVE Approved Procedure: Filler Metal Classif'n: N/A

	Comments	Accept	Reject
CRACKS	None	✓	
Weld/Base Metal Fusion	Complete	✓	
Crater Cross-section	Filled	✓	
Weld Profile	Good	✓	
Time of Inspection			
Undersized Welds	None	✓	
Undercut	None	✓	
Porosity	None	✓	



This part passes Visual Inspection.

Inspected By: Randal Dull
Title: Principal Engineer, AWS SCWI 14120028
Date: April 18, 2023

Figure 39. The results of the visual testing completed on the tele-welded plate sample during qualification attempt

Material: Carbon Steel Material Thickness: 0.470 in 11.94 mm
Equipment: Varian NDI 320-23 Source: X-RAY 36 in
Technique: Single Wall Magnification: N/A
Penetrameter Material Group: Group 1 (Steel) Penetrameter Size/Type: MIL-STD-453, .43 Penetrameter Location: Source Side
Shim Material: N/A Shim Thickness: N/A Focal Spot Size: .142"
Exposure Time: 24 Sec. Voltage: 320.0 kV Amperage: 5.0 mA

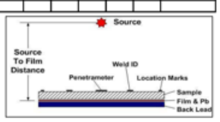
Film

Brand: AGFA Type: D4 Size: 4 ½ x 17 Location: Under Plate
# of Films Used: 1 Screen: Pb, 0.001 in Processing Type: Auto
Processing Time: 8 Min. Processing Temp: 68 F

Radiographic Identification	✓ Accept	Reject	Lack of Penetration	Lack of Fusion	Porosity	Slag	Inclusions	Cracks	Shrink	Linear	Other	Surface Irregularities	Undercut	Comments
Weld 417-1	✓				✓									

Quality Level: 2-2T
Radiographic Result: Accept

Comments: Film Density: 2.80 D



Released By:
Title: ACCP Level III, ASNT #183841

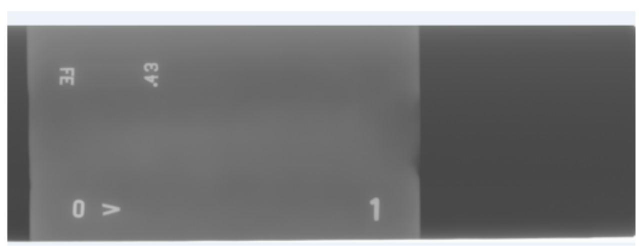


Figure 40. Results of the radiographic testing of the tele-welded plate during qualification attempt

EWI We Manufacture Innovation

Report Revision: 0 1250 Arthur E. Adams Drive, Columbus, OH 43221

Customer:	EWI	**Customer PO #:**	N/A
Contact:	Steve Levesque	**Project Number:**	59747IRD
Address:	1250 Arthur E. Adams Drive Columbus OH 43221	**Authorized By:**	Connie Reichert
		Phone:	614-688-5247
		Email:	creichert@ewi.org
Customer Sample ID:	417-1	**Specification:**	N/A
LIMS Sample ID:	21680-1	**Material Type:**	Carbon Steel
Heat/Lot Number:	N/A	**Date Reported:**	4/21/2023

Bend Test, ASTM E190/E290

Test Type: Semi Guided (ASTM E290, Wrap Around) **Test Date:** 4/21/2023

Test Temperature (F): Ambient **Tested By:** Steve O'Mara

Specimen ID (N/A)	Bend Orientation (N/A)	Thickness (in)	Width (in)	Bend Mandrel Dia (in)	Bend Angle (Degrees)	Elongation (%)	Bend Results (N/A)	Pass/ Fail (N/A)
417-1 FB	Face Bend	0.488 12.4 (mm)	1.665 42.3 (mm)	2.000 50.8 (mm)	120	20	No Visual Defects	Pass
417-1 RB	Root Bend	0.497 12.6 (mm)	1.740 44.2 (mm)	2.000 50.8 (mm)	120	20	No Visual Defects	Pass

Notes: Because of the size of the samples, wraparound tester would not go a full 180 degrees.

Figure 41. Bend test results from the completed, tele-welded plate during qualification attempt

Results from the tele-welder qualification of the three welders is shown in the chart in Table 2.

Table 2. Results of Initial Attempt to Qualify Each Welder Using the Tele-welding Equipment

Welder Skill Level	Hours training on tele-system	VT (visual testing) result	RT (radiography) result	Bend Test result
Expert	1	Pass	Pass	Pass
Advanced	3	Pass	Fail	
Beginner	8	Pass	Pass	Pass

The advanced welder did not pass radiography due to a pore outside the acceptance range. After viewing the video recording during the weld qualification, a roll-over of the weld bead can be seen and is likely attributed to the porosity seen in the testing results.

In summary, weld qualification testing was completed with three levels of welder. Each welder attempted to pass the weld qualification using the tele-welding equipment and methodology. The equipment included a UR cobot, a stylus controller with haptic feedback, a puddle or arc view camera, and an operator in the loop to control the remote welding torch motion and speed. Based on these results, key items that should be taught in a tele-weld training course have been identified. The tele-welding training course sample framework has been developed and is in Appendix C.

Deliverables: The deliverables for this task included a report on the results of the welder qualifications and an outline of a GMAW tele-welding training course suggestion, based on AWS standards.

TASK 8: TASK 8: YEAR 1 PROJECT PROGRESS REPORT AND BRIEFING TO TEAM MEMBERS **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to inform NSRP on the progress through Year 1 of this effort and to request continuation onto Year 2.

The project team was briefed at the monthly team meeting on the Year 1 activities and progress. A Year 1 report wase submitted to NSRP including a request to continue Year 2 activities.

EWI updated the technology transfer implementation plan (TTIP) and also updated the business case based on current project success and information gained from the project team. The TTIP can be found in Appendix D

The two metrics that were assessed during this task included:

- Metric 1: Training Cost per Welder
- Metric 2: Production Labor Cost Per Welder.

New ROI calculations were completed based on the results of Task 7 tele-welder trainer for Metric 1. New ROI calculations were also completed based on the updated method of a track-based system and the requirement to have a welding aid or equipment setter to deliver the equipment near where the tele-welding would occur. Table 3 shows the metrics calculated at the start of this project, and Table 4 shows the metrics updated after the first year of the project.

Table 3. Project Metrics Calculated at the Start of the Project

Metric	"As-Is" Baseline	Project Goal Tele-Welding	Delta	% Change (+/-)	Tracking & Reporting Plan
Training cost per welder	$77,000	$50,000	$27,000	-35%	Compare to typical weld school training time
Production Labor: cost of one welder hour at 12.5% OF vice Tele-welder + set-up helper per hour at 40% OF	$600	$234.38	$365.63	-61%	Compare to typical manual welder productivity on similar jobs **Savings from Higher Operator Factor (includes set-up helper)**

Table 4. Project Metrics Reassessed and Calculated at the Mid-Point of the Project

Metric	"As-Is" Baseline	Project Goal Tele-Welding	Delta	% Change (+/-)	Tracking & Reporting Plan
Training cost per welder	$77,000	$50,000	$27,000	-35%	Compare to typical weld school training time
Production Labor: cost of one welder hour at 12.5% OF vice Tele-welder + set-up helper per hour at 40% OF MANUAL WELDER	$600	$234.38	$365.63	-61%	Compare to typical manual welder productivity on similar jobs **Savings from Higher Operator Factor (includes set-up helper)**
Production Labor: cost of one mechanized tractor operator welder hour at 25% OF vice Tele-welding tractor at 40% OF MECHANIZED WELDER	$300	$188	$112	-37%	Compare to typical mechanized tractor welder productivity on similar jobs

A new calculation of the predicted decrease in production labor cost has been provided to account for the change in labor between a mechanized welder and the tele-welder. This was added as a new metric in Table 4. A mechanized welder is described as a welder who has experience operating the Gullco tractor system.

At the completion of Phase 1, the NSRP Executive Control Board (ECB) approved for this project to continue into Phase 2. The project team was eager to continue work on this project during Phase 2.

Deliverable: The deliverable for Task 8 was the Year 1 Project Summary Report with results of "Go/No-Go" decision and an update to the TTIP.

TASK 9: YEAR 2 PROJECT KICK-OFF MEETING AND MONTHLY PROJECT TEAM MEETING AT EWI **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

A team meeting was held to review the Year 2 planned activities and to finalize the beta-prototype system testing at HII-NNS Shipyard. Regular project team meetings were hosted throughout the remaining period of performance of Phase 2

The deliverables for this this task included meeting notes following each team meeting.

TASK 10: DEVELOP SCHEDULE AND PLAN TESTING OF THE BETA-PROTOTYPE AT HII-NNS SHIPYARD **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to schedule the time frame, define expectations for the testing of the beta-prototype at the shipyard, installation at the shipyard, and the receipt of continuous feedback on tele-welding use by the end-users at the shipyard.

NNS personnel selected a location within their facility where testing was to be accomplished and prepared the location for receipt of the system and testing.

Shipyard personnel visited EWI and were trained on use of the system before shipment to NNS. A few adjustments were suggested by the NNS welding engineers, and EWI updated the system to reflect the changes. Two main updates were made to the system before it was shipped to NNS:

1. Straight barrel weld gun with UR bracket

2. Added electrode stick out (ESO) control.

Figure 42 shows the new torch that was added to the system after NNS visited and before it was sent to the shipyard.

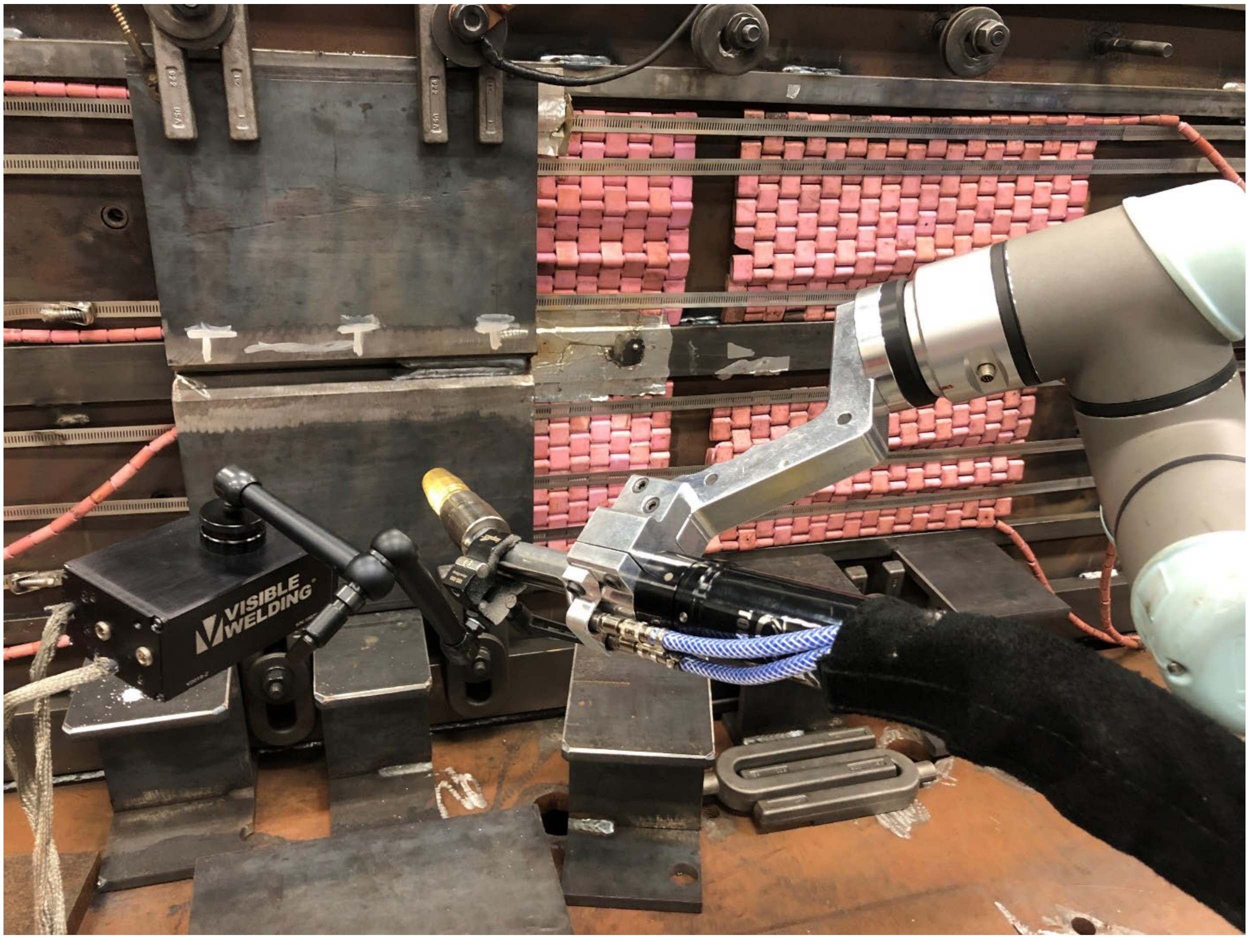


Figure 42. The new straight barrel welding torch was attached to the system before shipping to the shipyard.

Figure 43 shows the new electrode stickout functionality added to the system after NNS visited and before it was sent to the shipyard. The ESO functionality allowed the user to adjust the electrode stickout using keyboard arrow keys.

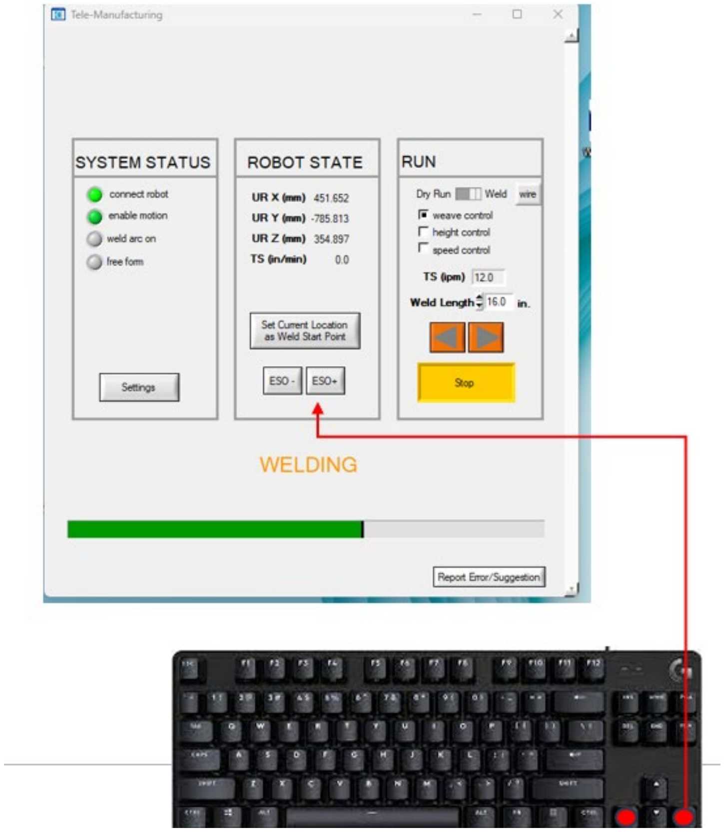


Figure 43. New functionality to adjust electrode stickout was added to the system. Keyboard arrow keys can now be used to adjust stick out during tele-welding.

The beta-prototype system was delivered to NNS, and EWI set up the system onsite on September 20, 2024.

EWI demonstrated the system and performed training and hand-off of the system to NNS. A user guide was developed and delivered with the system.

NNS personnel were able to use the system on non-production mockup joints to access the system performance, ease of use, and other factors. The system was onsite until November 16, 2024.

The project team met during two scheduled discussions with the shipyard personnel to review usage of the beta-prototype and receive feedback on the system use. These two meetings occurred on October 5, 2023, and November 7, 2023.

Feedback and comments received form the shipyard included the following:

- Benefits from using the tele-welding technology
    - Improves weld quality
    - Ergonomics improved
    - Learned to use it quickly
    - Quick, easy setup of 5-10 min

- Detriments or suggestions for using the tele-welding technology
    - Still need a person to do some process before and after the weld
    - Would like to tele-weld one pass and then automated next passes
    - Game controller might be better.

In summary, NNS shipyard personnel visited EWI and tested the tele-welding prototype in August 2023. The system was sent and set up at NNS shipyard, and for about two months the shipyard personnel were able to test the system. NNS provided feedback during scheduled meetings to evaluate use of the system during the testing period.

Deliverables: The deliverables for this task included a demonstration of the beta-prototype system at EWI before shipyard delivery and a report including results of weekly discussions, observations from visits to shipyards, and any updates/changes made to the beta-prototype system or use of the system after shipyard evaluation.

TASK 11: DEVELOP QUALIFICATION

The goal for this task was to generate recommended welding procedure specifications (WPS) and performance qualification records (PQR) if needed for compliance with Tech Pub 248. Using the existing WPS, EWI used the beta-prototype system to weld the sample weld joint selected in Task 5. All welding parameters used to weld the joint, including the bead sequence and adjustments that the tele-welding operator made, were documented. The weld joint was welded up following the procedure obtained from NNS. This included the following steps:

1. Weld frontside joint – two layers
2. Flip plate and gouge backside
3. Gouge out ¼ in. total (1/8-in. land + 1/8-in. of first pass)
4. Dye penetrant test back side
5. Weld out back side
6. VT backside
7. Flip plate and weld out front side
8. VT frontside
9. RT the completed plate

The deliverable for this task was a draft of the detailed parameters used following the WPS and any adjustments required to complete the weld joint using the beta-tele-welding system on the shipyard weld joint.

Material Preparation, Welding Sequence and Resultant Bead Map

HY80 plates were machined to the correct bevel, and the width of each plate measured 10 in. and the length of each plate measured 12 in.

There were two sides to the weld joint, Side 1 and Side 2. After the first four layers, on Side 1 the plate was flipped to Side 2 and the ceramic backing was removed. The weld was back gouged to clean weld metal from Side 1 and then ground to remove gouge marks. The weld was penetrant tested (PT) to verify no defects or lack of fusion (LOF) existed before continuing to weld Side 2. Side 2 was welded up through pass 17 at which point the weld joint was flipped over, and welding resumed on Side 1 until it was completed. Once Side 1 was completed, the weld joint was flipped again and welding on Side 2 was completed.

EWI followed the WPS when welding both sides of the weld joint. Figure 44 shows the side one bead map determined by the tele-welding operator and the welding parameters used for side one are listed below.

- Average Amp: 324
- Average Voltage: 27.8
- Average Weld Duration: 49.1
- Weld Length: 10 in.
- Preheat Temperature: 150°F / Interpass Temperature: 225°F.
- Average Heat input: 44.1Kj/in.
- 21 Passes/9 Layers Side1/ Weld Sequence: Page 5

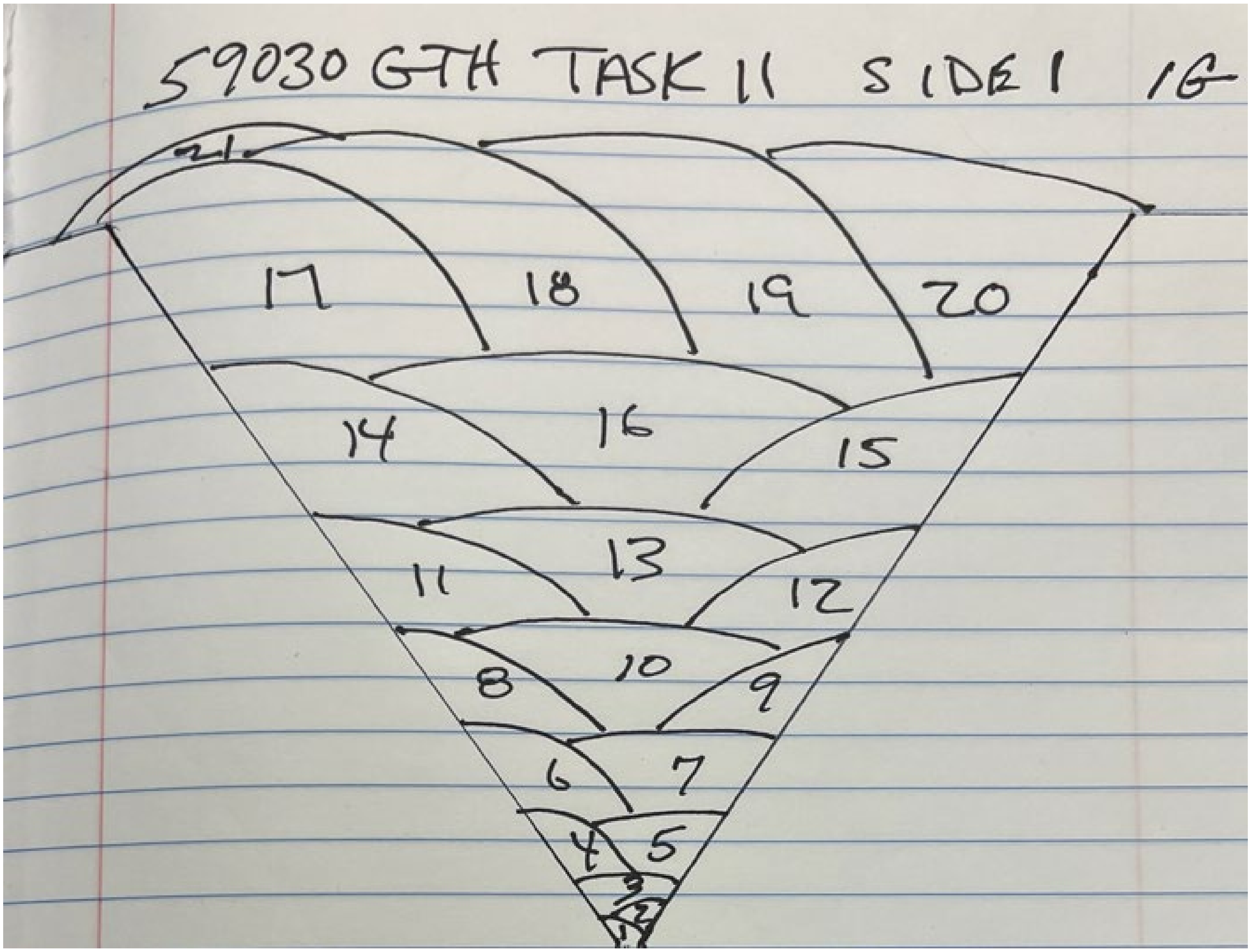


Figure 44. The tele-welding operator's bead placement map, as followed during welding Side 1 of the weld joint.

Figure 45 shows the side two bead mapping as determined by the tele-welding operator and the welding parameters used for side two are listed below.

- Average Amp: 325
- Average Voltage: 27.7
- Average Weld Duration: 49.1
- Weld Length: 10 in.
- Preheat Temperature: 150°F / Interpass Temperature: 225°F.
- Average Heat input: 44.21Kj/in.
- 26 Passes/9 Layers Side 2/ Weld Sequence: Page 6

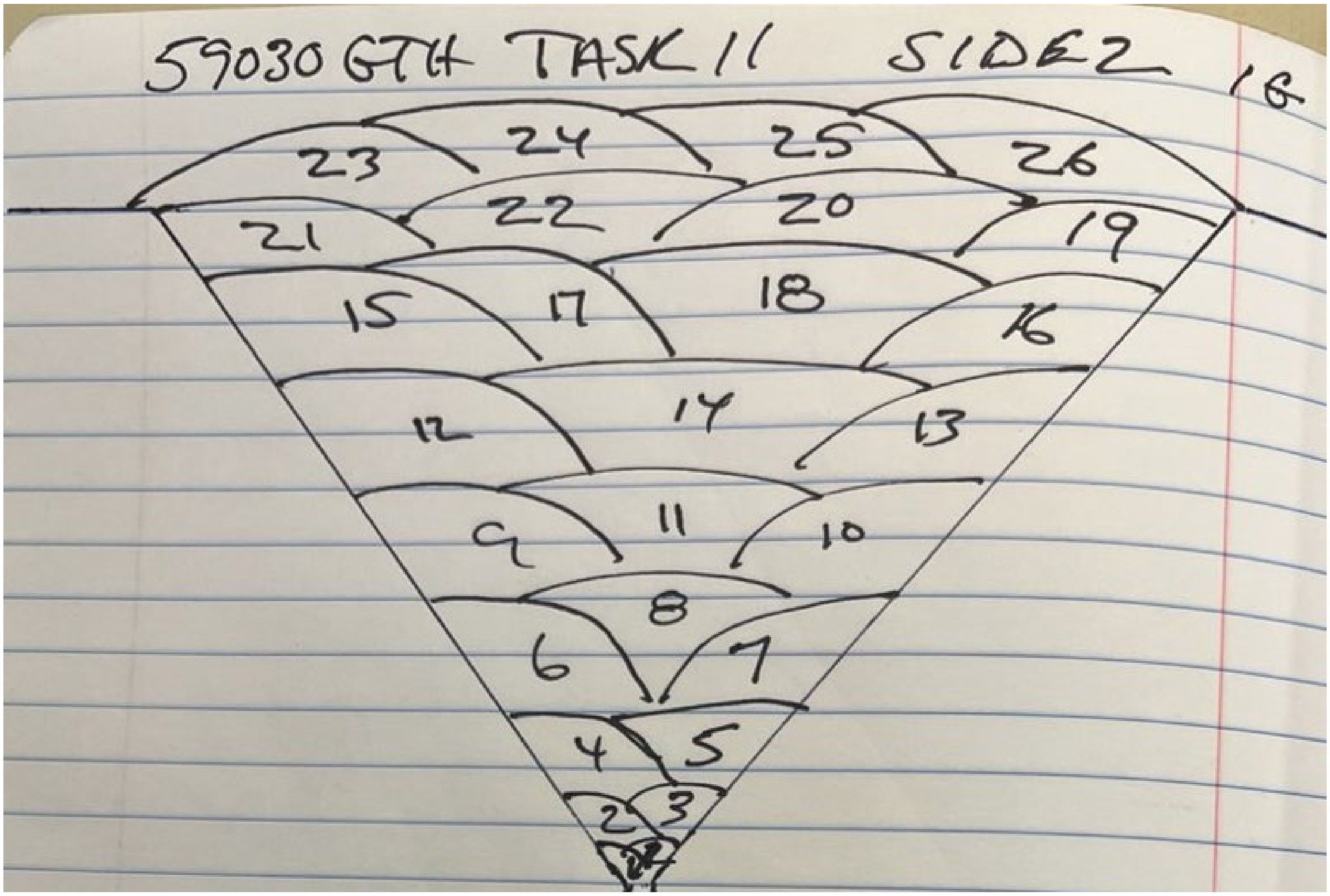


Figure 45. The tele-welding operator's bead placement map, as followed during welding Side 2 of the weld joint.

Tele-welding Operator Comments on Tele-Welding following the WPS and Procedure

Weld Nozzle

When starting Side 2, the operator had to modify the nozzle to reach into the root of weld joint. The nozzle was squeezed enough to fit into weld joint, but position was very tight in the root area along sidewalls, preventing oscillation with the tele-welding system. Once out of the root, the nozzle fit better.

Arc Blow

Arc blow became an issue halfway through the weld length on the second side. This was remedied by alternating the start and stop location of the welding, after each layer. Due to the arc blow and weld nozzle fit for the root and hot passes, a few passes were manually made to repair the effects of these two conditions. The manual repair was completed following the WPS.

Tele-welding Operator Assessment of Tele-welding

- The root area weld passes with 1G or 2G position will be difficult for the tele-welding system to fit down into the weld joint to achieve proper electrode stick out. Figure 46 shows the root pass on Side 1. This could be corrected by a different sized nozzle and use of a slight oscillation to help with the toe lines.

- The tele-weld system did a great job once the weld joint began to fill and had a good foundation to build upon. The nozzle then fit properly allowing for adjustment of the electrode stick out and side to side motion. Figure 47 through Figure 50 show weld fill level at various heights during the weld joint fill.
- During the final cap passes, it became harder to view the arc with the camera. This could have been from lack of light now that there was no reflection from the sidewalls or fume. To remedy this, additional illumination and a fan to gently blow the fume can be used to increase the quality of the lens.
- The tele-welding system allowed freedom to remedy problems seen in previous passes as the operator has control and capability to make real-time decisions on all welding parameters.

Testing Results

- A visual test as per Mil-STD-203 Class 1 was performed on Side 1 and Side 2 of the joint, and the weld passed.
- The penetrant testing of the gouged area performed before welding Side 2 was clean and showed no defects. Figure 51 shows the results of the dye penetrant test.
- The radiography was not performed due to the suspicion that the arc-blow-induced gouging into the sidewall would show porosity or lack of fusion in the result.

Figure 46. Side 1, root pass

Figure 47. Side 1, fill passes

Figure 48. Side 1 fill after passes 11, 12, and 13

Figure 49. Side 2 fill passes after pass 17

Figure 50. Side 2 cap passes

Figure 51. Clear, defect-free dye penetrant test on back-gouged Side 1 welds before starting Side 2 welds

Recommended Adjustment to WPS or Procedure

- The WPS was followed, so no changes or adjustments are recommended.
- Due to the tight joint opening, the root and hot passes would be better completed with a manual welder. The tele-welding system could then be used on all passes after the hot pass with no clearance issues.
- A narrow nozzle that fits into the weld joint is recommended if the tele-welding system is to be used for root and hot pass welds in this joint.

Conclusion

The benefit to using a tele-welding system to weld the selected shipyard joint was validated.

- The operator was able to weld each fill pass remotely, using the system and accomplish an acceptable weld.
- The operator was able to adjust travel and work angle, electrode stick out, weaving and torch placement while tele-welding.
- The operator was able to make decisions and adjust welding parameters in real time, remotely, using the tele-welding system.
- The tele-welding system allowed the operator to reside in a different location than the welding process and while sitting in a comfortable position.

The deliverable for this task was a draft of the detailed parameters used following the WPS and any adjustments required to complete the weld joint using the beta tele-welding system on the shipyard weld joint. The operator's report can be found in Appendix E.

TASK 12: EXPLORE THE FRAMEWORK OF A POTENTIAL REMOTE WELDING TRAINING COURSE IN CONJUNCTION WITH TEAM MEMBERS **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal for this task was to use the data and observations gathered during Task 7 and Task 11 and to assemble suggested training requirements for skills needed to tele-weld using the beta-prototype system.

EWI developed a sample course outline to be useful for training a new or an experienced welder to tele-welding using the beta-prototype tele-welding system and tele-welding methodology.

New or Unexperienced Welder – Tele-welder Training Details

The goal of the training program is to enable a non-experienced welder to use tele-welding equipment to produce acceptable tele-welds. The main themes to be taught for the inexperienced welder include:

- Safety in the welding environment
- Arc welding terms
- Joint types
- Equipment required for welding
- Tele-welding.

The total time estimated for training an unexperienced welder to tele-welding is 40 hours. This is broken down into the following activities:

- Classroom – 6 hours
- Dry Run – 2 hours
- Tele-Welding – 32 hours

Experienced Welders

The goal of the training program for experienced manual or robotic arc welders is to enable an experienced manual welder to use tele-welding equipment to produce acceptable tele-welds. The main themes to be taught for the experienced welder should include:

- A review of
    - Safety
    - Arc welding terms
    - Joint types
    - Equipment required for tele-welding
- Tele-welding

The total time estimated for training an experienced welder to tele-welding is 25 hours. This is broken down into the following activities:

- Classroom – 3.5 hours
- Dry Run – 1.5 hours
- Tele-Welding – 20 hours

The deliverable for this task was the course requirements outline for experienced and new welders for tele-welding training. The sample course outline documents can be found in Appendix C.

TASK 13: IDENTIFY A RANGE OF SHIPYARD PROCESSES THAT CAN BE POTENTIALLY TELE-OPERATED **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The goal of this task was to work with the shipyards and end-users to determine other manufacturing operations that can be considered for future tele-control. The project team identified other operations that are existing shipyard processes that are candidates for tele-operation. These two main operations include gouging and grinding applications. The team also identified potential opportunities for use of tele-welding within the shipyard and these included:

- Smaller components that require welding.
- Places that you cannot crawl into or have limited access to send a person for welding.
- Place tele-welding robot on a table and bring parts to the tele-welding system.

The project team evaluated and then ranked the gouging and grinding shipyard processes as to ease of implementation if adapting the beta prototype equipment and then recommended next steps for implementation by the shipyard.

Tele-gouging – Key point in Evaluating Ease of Implementation

- Tele-gouging is an already proven technology that uses the same hardware as tele-welding.

- Tele-gouging is operator friendly, and automating the electrode feed rate (as on option) eliminates the need for the operator to physically maintain the arc.
- The operator's HMI can be minimal, with the camera view and audio as the only required visual and audio aid.
- Stylus or joystick button can be used to indicate arc on/arc off.

Tele-gouging – Next Steps

Shipyard tele-gouging could be implemented after the following high level work scope has been completed. Steps include:

1. Create fixture for carbon arc gouging torch.
2. Update functionality of tele-welding system to allow an operator to jog robot to desired location on part and select gouging start/stop locations.
3. Update power source to allow the robot to automatically power on the power source only when the user is gouging, which increases safety.
4. Investigate integration of commercially available automated gouging rod feeder. Determine how much this functionality increases operator efficiency and arc on time for gouging.

Tele-grinding – Key Point in evaluating ease of implementation.

- Tele-grinding has been demonstrated at EWI.
- Tele-grinding requires compliant fixturing and different sensors than have been used on the tele-welding system.
- Many commercially available end-effectors for compliance and for grinding tools can be immediately used with the tele-technology hardware.
- Tele-grinding can be accomplished using manual angle grinders typically used in the shipyard. The robot is capable of applying a range of forces including that of a typical manual grinder (about 13 lb and greater).
- The operator's HMI can be minimal, with the camera view and audio as the only required visual and audio aid.
- Stylus or joystick buttons can be used to power on/off the grinding tool which increases operator safety.
- Grinding patterns can be tele-taught, semi-automating the process.

Tele-grinding – Next Steps

Shipyard tele-grinding could be implemented after the following high-level work scope has been completed:

1. Integrate a compliant fixture or end effector for grinding.

2. Update the grinding tool's power source/hardware to allow the robot to automatically power on only when the user is actively tele-grinding.
3. Update functionality to allow operator to use the tele-controls to jog robot to desired location or identify an area or perimeter for grinding.
4. Update functionality to provide a measurement of the amount of material removed from the surface using sensors.
5. Determine amount of operator alerting or amount of semi-automation that can be employed by the tele-system to help guide operator or prevent error.

The deliverable for this task was a report on the additional manufacturing processes identified by the shipyard, their ease of implementation, and a high-level scope of work for the next steps in evaluating these processes for tele-control.

TASK 14: FINAL REPORTING AND REVIEW OF THE BETA-PROTOTYPE USE IN THE SELECTED SHIPYARDS **(EWI [LEAD], RTT, VISIBLE WELDING, GDEB, HII-NNS)**

The final task of Year 2 of this project was to provide this final report, review feedback from the shipyards, and summarize key findings.

Implementation Roadmap

The roadmap for tele-welding in U.S. shipyards involves the four stages outlined below in Figure 52. This project completes the second stage of the work, beta-prototype, and at its conclusion, has resulted in a shipyard-ready beta-prototype that will allow the shipyards to begin implementation.

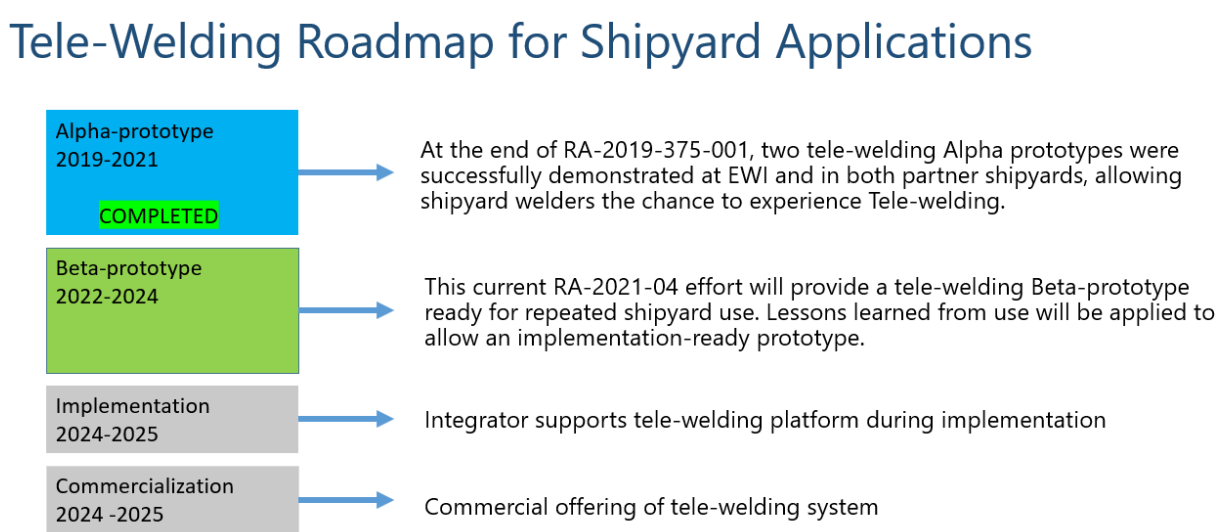


Figure 52. Roadmap for tele-welding in shipyards

Table 5 below shows further detail in the roadmap regarding the updated time frame and goals, features, and metrics for each stage.

Table 5. Detailed Roadmap

Date	**RA-19 Year 1 2019-2020**	**RA-19 Year 2 2020-2021**	**RA-21 Year 1 2021-2022**	**RA-21 Year 2 2022-2024**	**Shipyard Implementation 2024-2025**	**Commercialization 2024-2025**
Name	Tele-welding Technology Demonstration	Tele-welding Alpha Prototype	Tele-Welding Beta Prototype at EWI	Tele-Welding Beta Prototype at Shipyard	Tele-Welding System Implementation	Commercialization
Goal	Prove capability to tele-weld: weld remotely with human control of the welding process.	Provide shipyard welders the experience of tele-welding using tele-welding system on representative mock joints at their shipyard.	Complete a beta-prototype of the tele-welding system at EWI for shipyard welding operators to operate remotely from the shipyard. Allow shipyard welding operators the ability to practice a traditional manual welder performance qualification test, welding remotely from the shipyard, using the tele-welding system at EWI. Develop suggested parameters	Provide a beta-prototype of the tele-welding system to a shipyard for shipyard use. Shipyard to generate WPS and PQR for tele-welding of selected weld joint. Make changes to beta system based on initial shipyard tests. Develop tele-welder training course.	Implementation of tele-welding system on production welds.	Commercialization strategy developed for tele-welding system (hardware and software).

Date	RA-19 Year 1 2019-2020	RA-19 Year 2 2020-2021	RA-21 Year 1 2021-2022	RA-21 Year 2 2022-2024	Shipyard Implementation 2024-2025	Commercialization 2024-2025
			for typical shipyard production joints.			
Features	Remote control of the weld torch path/position while welding. Real-time feedback of the welding process sound and arc-view. Transfer user's desired motion of manipulator to actual motion at torch.	Motion platform that responds to user's movement of a remote manipulation device (stylus, mouse). User interface that displays real-time arc feedback to remote user. Manipulation device that transfers speed and direction to the remote motion platform.	Integrated hardware and software system that responds to a user's movement of a remote manipulation device, displays real-time weld process feedback on a monitor, and transfers user’s speeds and directed motion to the hardware system to accomplish acceptable welds.	Beta system is used by trained shipyard welders to evaluate features and determine if any changes are needed. Updated features to the beta system's operation based on user feedback.	Tele-welding beta system is approved for use on selected production joints.	Tele-welding system available for purchase.

Date	RA-19 Year 1 2019-2020	RA-19 Year 2 2020-2021	RA-21 Year 1 2021-2022	RA-21 Year 2 2022-2024	Shipyard Implementation 2024-2025	Commercialization 2024-2025
Metrics	A shipyard welding operator at the shipyard welds with the demonstration system located at EWI.	A shipyard welder can perform an acceptable weld using the alpha-prototype system while remote from the welding operation. A shipyard welder makes adjustments in real-time to remote equipment using a local computer mouse or stylus and responding to a livestream of the welding process delivered to a monitor.	A shipyard welder can perform an acceptable weld using the beta-prototype system while remote from the welding operation at EWI in Columbus, OH. A shipyard welder makes adjustments in real-time to remote equipment using a local manipulation device and responds to a livestream of the welding process delivered to a monitor.	A shipyard welder is trained to perform an acceptable weld, following the WPS, using the beta-prototype system at NNS while remote from the welding operation at NNS. The shipyard welder makes adjustments in real-time to remote equipment while responding to a livestream of the welding process delivered to a monitor.	The tele-welding beta system is approved for welding production joints at a shipyard.	Tele-welding system offered for sale.

- The results of the successful completion of the stages of the scope of work will be available first to team members to support implementation following the in-shipyard evaluation of the beta-protype. As part of the effort, EWI will assist and advise team members in long-term planning of hardware and software acquisition and/or downloads to the extent that budget or other funding supports such activities. EWI has a long history of such implementation support across many industrial sectors.
- There will always be potential issues with the way each shipyard approaches the process of vessel construction. The benefit of this project is that the equipment technology and processes

are adaptable to many different scenarios. As the project reaches maturity, the need for welding personnel of all physical and educational statuses will assist in the adoption of these results in much the same way that surgical robots are now becoming the prevailing norm.

- Newport News and Electric Boat have continued their support through the alpha system and are financially committed to this beta-prototype phase of the project and its potential outcome. Other shipyards will be kept up to date on the progress of the project. The project continues to generate interest as it progresses through the four phases from prototype to commercialization.
- There is no limit to the potential number and nature of applications for tele-operation of welding (and other) equipment. The ideal applications are those with difficult access ("dark, dirty, and dangerous" areas) and applications in which personnel must crouch or assume difficult positions for an extended period of time for observation of the weld process. These applications may not be amenable to a current solution of using fixed automation. The unstructured open and flexible mechanization developed in this project avoids the difficulty of one-off programming and complicated software post-processors that are required for many "self-programming" robots proposed elsewhere. The technology will be seen as less intrusive and more capital friendly.
- Detailed information for operation of the system will be generated to support the in-shipyard trial in the second year of the project. The materials will be updated following the tests and will become part of the interim and final project reports. They will be available based on team, Navy, and NSRP rules to other parties that wish to implement this technology. EWI has a long and successful history of training personnel from a wide variety of industries in the technology, operation, and quality attributes of many systems.
- Coaching/mentoring support services using budgeted project resources (within specified limits) will be available based on the conditions noted above and elsewhere in this document.
- EWI can and does provide consulting services by key personnel as needed based on funding limitations and necessary data control aspects as required.
- EWI and team members will determine the type and nature of requirements for visits and tours to see the process equipment in action. Necessary aspects such as Covid-19 restrictions, security, safety, and data restrictions may dictate what can be done. Certainly, demonstrations at EWI can be open to whatever audience the team may allow, as long as it is not disruptive to project progress. Sufficient advance notice tours of team members' facilities for observation of demos, pilot programs, and/or "production" implementations of the technologies developed in the project will be provided.
- Tele-welding training and opportunities to gain experience and explore welder qualification is part of this project work for the participating shipyards. The project team may allow other shipyards to experience tele-welding using the same tele-welding training equipment once the project task regarding training has been completed. That may require other funding for the resources required to service and load practice plates at EWI while the shipyards test out welding with the system remotely from their location.
- The most difficult part of the process is welding, and the team members and other implementers have training protocols and facilities in-house in nearly all cases. The intent of this technology is to simplify and render production welding more operable and appealing to the user. This alone will draw in many users, especially those who have had to suffer with the current constraints for many welding jobs.

ROI Calculation

Shipyard A and Shipyard B are participating in an NSRP Research Announcement project entitled “Tele-welding Shipyard Prototype for Welding (and other) Applications.” The is a Phase 2 project which is funded by $0.9 million of program funds. The Phase 1 project was funded from $0.8 million of program funds. The total Navy funding of both projects (Phase 1 and Phase2) is $1.7 million.

Assumptions

One shipyard welding school reports that it takes about six months to train a new hire to qualify for welding in the positions necessary. Some of this is classroom time for understanding materials and procedures, but most is learning the motor skills of physically welding.

For this putative training scenario, the six-month cycle costs $77,000 per welder at $75 per hour.

The percentage of the time that the arc is operating compared to the total time charged to the job is called the operator factor (OF).

Welders performing manual semi-automatic welding typically have an OF of 12.5% — or the arc is on approximately one hour in an eight-hour day.

Initial ROI provided in the summary proposal was based on the cost of the both tele-welding projects, RA-2019 which was completed in 2021, and this current RA-2021-04 to be completed in March 2024.

The updated ROI provided in this report is also based on the cost of both RA-2019 and RA-2021-04 projects, which total $1.7 million in Navy funding.

Equation

Navy ROI = Cost Reduction −Navy Investment/Navy Investment

Investment

The investment funding provided by the Navy is based on the cost of both RA-2019 and RA-2021-04 projects, which total $1.7 million in Navy funding. No implementation costs are assumed to be chargeable to the Navy and are not included in the Navy investment. Implementation costs that will be borne solely by the shipyards are not included in the calculated ROI.

The EROM in the Research Announcement Summary Proposal

The original ROI at the start of the project was based on two metrics including savings on training cost per welder and savings from a reduction in labor cost when tele-welding instead of traditional manual welding. This also included the addition of a welder aide/setup helper who would be needed to setup equipment at the welding location. Table 6 in the image below shows the original metrics:

Table 6. Original ROI Metrics

Metric	"As-Is" Baseline	Project Goal Tele-Welding	Delta	% Change (+/-)	Tracking & Reporting Plan
Training cost per welder	$77,000	$50,000	$27,000	-35%	Compare to typical weld school training time
Production Labor: cost of one welder hour at 12.5% OF vice Tele-welder + set-up helper per hour at 40% OF MANUAL WELDER	$600	$234.38	$365.63	-61%	Compare to typical manual welder productivity on similar jobs **Savings from Higher Operator Factor (includes set-up helper)**

Estimated ROI

First, the cost savings of training is estimated to be $27,000 per tele-welding operator. In conversations with one shipyard welding school, it takes about six months to train a new hire to qualify for welding in the positions necessary. Some of this is classroom time for understanding materials and procedures, but most is learning the motor skills and building the almost automatic responses that welders need to make minor changes as the weld bead progresses with hand motion and inherent "shake" from fatigue or "muscle weariness." The tele-welding operator will need the hand-eye coordination to run the system but will need less training time due to the remotely operated equipment carrying the weight of the torch and leads, as well as damping out erratic human motions and having a better view of the welding process provided by specialty cameras. For this putative training scenario, the six-month cycle costs $77,000 per welder at $75 per hour. Of that, $54,180 is spent solely on mastery of physical skills. Given the nature of the device and looking at the success of such devices in surgical operations, a 50% reduction in that portion of training time is conservatively achievable. This generates a savings of $27,000 per welder trained.

Training 20 tele-welding operators will cost ~$1.0 million.

For an estimate of implementation cost in the case of the semi-automatic replacement, the estimated total government investment in the program is less than $1.7 million (RA19 + RA 21-04). If 20 units were deployed, an annual savings of approximately $10.8 million can be achieved. The 20 units would cost around $85,000 each (due to economies of scale), for a total of $1.7 million. Training cost of $0.54 million is added.

ROI = (Savings – project cost) / project cost

Project cost in this case is ($1.7 million +$1.7 million + $1.0 million) = $4.4 million

ROI = (10.8 – 4.4 / 4.4) = 1.45

Certainly, the greatest benefit will be in the replacement of the manual semi-automatic welding process with tele-welding operators. The replacement of mechanized tractors is still useful and will benefit by attracting workers that look forward to the high-tech aspect, but the opportunity for other workers who are "locked out" due to minor injuries or age-related limitations has a very high value.

Also, note that the implementation of 20 units does not have to take place at one shipyard to achieve the savings. It may be smaller quantities over several yards, especially when higher-cost manual scenarios are discovered in which the savings will be greater due to issues such as high preheat in confined areas for which personnel may be allowed to work for shorter periods to avoid heat exhaustion or other situations.

The EROM in the “End of Phase 1” Report

During Phase 1, the project team updated the ROI by adding another metric to the cost savings by a decrease in production labor. The new calculation of the predicted decrease in production labor cost accounts for the change in labor between a mechanized welder and the tele-welder. A mechanized welder is described as a welder who has experience operating the Gullco tractor system, which has been included in the tele-welding beta prototype.

Due to the change in the proposed tractor system, existing mechanized shipyard equipment will be used for the tractor instead of a new system.

- The shipyard already has experience using the Gullco tractor equipment, reducing the labor that would have been required in learning how to operate and deploy a new mechanized crawler or tractor.
- Enhancing the existing equipment by adding tele-control techniques onto it provides a quicker realization of the increased arc-on time as less time is needed for setup and training.
- A new metric is detailed to compare the mechanized welder’s production labor to a tele-welder’s production labor prediction.

The three metrics for cost savings that have been calculated are shown in Table 7 below.

Table 7. Cost-Saving Metrics

Metric	“As-Is” Baseline	Project Goal Tele-Welding	Delta	% Change (+/-)	Tracking & Reporting Plan
Training cost per welder	$77,000	$50,000	$27,000	-35%	Compare to typical weld school training time
Production Labor: cost of one welder hour at 12.5% OF vice Tele-welder + set-up helper per hour at 40% OF MANUAL WELDER	$600	$234.38	$365.63	-61%	Compare to typical manual welder productivity on similar jobs **Savings from Higher Operator Factor (includes set-up helper)**
Production Labor: cost of one mechanized tractor operator welder hour at 25% OF vice Tele-welding tractor at 40% OF MECHANIZED WELDER	$300	$188	$112	-37%	Compare to typical mechanized tractor welder productivity on similar jobs

The number of welders to be used has decreased from 20 to 10. The following are estimates of the saving in training cost for 10 welders for Metric 1 training:

1. Ten welders × $77,000 = $770,000 in yearly savings on training.
2. Of the ten welders, six are estimated to be manual welders who will now be tele-welders. The following is the estimate of savings in production cost for Metric 2: manual welder to tele-welder:
    - $365.63 savings per hour multiplied by 8 hours = $2,925 savings per day
    - $2,925 savings per day multiplied by 1500 hours = $4,387,440 savings per year
    - Six welders multiplied by $4,387,440 per year = $26,324,640 savings per year

3. Of the ten welders, four are estimated to be mechanized welders who will now be mechanized tele-welders. The following is the estimate of savings in production cost for Metric 3: mechanized welder to mechanized tele-welder:
    - $112 savings per hour multiplied by 8 hours = $896 savings per day
    - $896 savings per day multiplied by 1300 hours = $1,164,800 per year
    - Four welders multiplied by $1,164,800 per year = $4,659,200.00 savings per year
4. Total reduction in cost for all three metrics is $31,253,840.00 per year.
5. Using the equation in Section 3, the ROI is:

$$\text{Navy ROI} = \frac{\text{Cost Reduction} - \text{Navy Investment}}{\text{Navy Investment}} = \frac{\$31.3\text{M} - \$1.7\text{M}}{\$1.7\text{ million}} = \$17.4\text{ M/year}$$

The five-year ROI for the Navy is estimated to be $87 million.

Discussion

There were two variables that changed during the course of this estimation and that includes the addition of Metric 3 and the reduction in welders to be trained. The addition of Metric 3 provides an additional way to reduce cost by converting a mechanized welder operator into a mechanized tele-welder operator. The number of welders to be hired was reduced from 20 to 10 to accommodate shipyard estimates. See Appendix F for ROI calculations.

Deliverables: The deliverable for this task was this final report including recommended next steps.

APPENDIX A

PROJECT RESULTS SUMMARY

PROJECT SUMMARY REPORT

Tele-Welding- Remote Operation of Shipyard Welding (and other) Equipment

March 21, 2024

Task Order Agreement 2019-375-006

EWI Project No. 59030GTH

Submitted to:

Nicholas Laney
ATI Project Manager
Nicholas.laney@ati.org

EWI Contact:

Connie LaMorte
Principal Engineer, Automation Group
614.688.5247
creichert@ewi.org

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NSRP
NATIONAL SHIPBUILDING RESEARCH PROGRAM
Taking Shipbuilding and Repair to the Next Level
Proudly Celebrating 50 Years of Innovation

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EXECUTIVE OVERVIEW

The overarching goal for this technology area was to create a method for workers to get exposure, gain confidence, and guide future efforts in remote-controlled manufacturing technologies. The project team, consisting of EWI, Robotic Technologies of Tennessee LLC (RTT), Visible Welding, Huntington Ingalls Industries – Newport News Shipbuilding (HII-NNS), and General Dynamics Electric Boat (GDEB), successfully developed and demonstrated an Alpha-prototype tele-welding system during RA-2019-375-001 completed in 2021. Based on the success of the 2019-375-001 alpha-prototype system, the project team proposed to convert the alpha-prototype design into a shipyard-rugged, beta-prototype system.

The goal of this 2019-375-006 project was to further develop a shipyard-ready beta-prototype with a Technology Readiness Level (TRL) of 6-7 and perform extensive testing in the shipyard.

This effort focused on refinements that decreased mechanical complexity of the alpha-prototype, and improved overall capabilities of the system, with the goal of increasing the welder's desire to use the system.

The beta-prototype system focused on remotely welding selected shipyard non-production weld joints. The system was evaluated at HII-NNS shipyard over a two-month time frame while users exchanged feedback with the project team. At the conclusion of this project, the beta-prototype was ready for shipyard implementation and commercialization.

CONTACT INFORMATION

EWI Technical POC: Connie LaMorte, creichert@ewi.org, 614.688.5247

COLLABORATORS

GDEB provided guidance in system functionality description, portable system design, and project. NNS provided guidance in system functionality description, portable system design, welding joint information, and detail. GDEB also supported tele-welding equipment demonstrations in its shipyard. RTT provided portable base motion platform design and robotic arm assistance, evaluation of motion platform selection, and project support. VisibleWelding provided updates to the welding pool camera system, guidance on integration with the tele-welding technology, and technology transfer. Gullco joined the project team in Year 2 and provided automated, tractor-based motion platform and support.

DESCRIPTION OF METHODOLOGY

The project team further developed the tele-welding technology into a beta-prototype system that allows workers to operate welding equipment from a remote location. Shipyard partners identified a welding application that would benefit from tele-presence welding and that would be used for demonstration of the tele-welding technology. The first year of this project involved reviewing feedback and suggestions from demonstrations with the alpha-prototype system at both shipyards. Next, the project team evaluated new technologies that could be integrated into a beta prototype design, evaluated the benefits to each technology and then ranked and voted on the new beta system features. Several options for motion platforms were evaluated including a magnetic, robotic crawler, a cobot arm, and a mechanized track-based motion platform. The project team developed a functionality specification document that detailed the required functionality of the beta-prototype system. The beta prototype was designed to use a cobot arm for the tele-controlled motion and a mobile platform to transport the cobot arm. A Gullco automated motion platform was selected for the mobile base and the UR cobot arm was mounted onto the Gullco platform. Temperature sensors, upgraded camera features, motion damping, AR/VR environments, path guidance, and path memorization were new features evaluated or integrated into the beta-prototype system.

The project team evaluated a joystick option for the user manipulation device and a PC mouse. The haptic feedback stylus device used on the alpha system remained the default option to allow the user to manipulate the remote equipment. The stylus device was programmed to provide a haptic response to the user, to indicate weld joint sidewalls and other obstacles. The control system software program was updated to communicate with all the peripheral devices and an updated user interface enabled starting and ending the welding process, along with a livestream of the video and sound. Three persons with varied welding experience were trained to use the beta-prototype system and then attempted to pass a weld qualification of a multi-pass weld joint. A sample tele-welding training course was developed. The updated beta prototype tele-welding system was demonstrated at EWI, and shipyard welders were able to test and attempt welding in 1G or 2G positions. The system was delivered to NNS shipyard for testing and evaluation of the technology. Shipyard welders and personnel were able to tele-weld on the representative weld joint application and provided feedback on the technology during the testing period. The tele-welding systems received overwhelmingly positive responses from shipyard welders of all experience levels. The tele-welding system was used to weld the selected shipyard joint and passed visual testing and dye penetrant testing. The tele-welding system was able to completely weld the shipyard joint without any changes while following the WPS. The project team evaluated other shipyard operations and determined that carbon arc gouging and grinding would be good candidates to be considered for tele-operation.

RESOURCES NEEDED

The outcome of this project is a fielded tele-operational, beta prototype tele-welding system, tested and used by shipyard partner personnel in the shipyard environment. The beta prototype tele-welding system is ready for implementation. A follow-on project could include operator training, the addition of other shipyard operations that could be tele-operated using the same hardware or technology, and investigation of other welding applications that could be converted to tele-operation with this system. Additional mobile base platforms can be used to accommodate the tractor or magnetic mobile platforms that may be in use at other shipyards.

EVALUATION AND ANALYSIS METHODS

Monthly project meetings were conducted to ensure the project was meeting anticipated goals. The overall project objective and approach and goals, deliverables, and responsibilities for each partner were reviewed at each project meeting. Adjustments required to the task plan, or the task deliverable time frame were communicated to the team, evaluated, and then agreed upon by the project team. The program manager monitored project financial health and technical progress monthly and communicated to the task lead per each task. The success of the project is analyzed by delivery of the physical prototype to the shipyard, the ability of shipyard welders to independently create welds using the system, and feedback collected during the independent evaluation of the system at the shipyard and during demonstrations.

TIME ESTIMATE

The system can be used as delivered on a Gullco track-based motion platform, can be attached to another mobile platform, or can be mounted stationary. The system can be used immediately on the selected welding applications or other similar weld joints in 1G and 2G positions. The shipyard will need to conduct necessary/appropriate steps for the qualification of the beta prototype for production work. Customization of the beta system for shipyard-specific welding applications, incorporating feedback received during this project is recommended for tele-welding technology and formal introduction into the shipyard following the tele-welding roadmap provided in this report.

LIMITATIONS OR CONSTRAINTS

The requirements of operator training, testing, qualification for use in relevant environments, and weld process monitoring will be required for all shipyards. The shipyard will need to conduct necessary/appropriate steps for the qualification of the beta prototype for production work. All size shipyards making new or repair fabrication welding could apply tele-welding to at least some welding applications.

MAJOR IMPACTS ON SHIPYARD

This technology has not yet been implemented into the shipyard. The tele-welding technology roadmap indicates implementation and commercialization can occur in concert at the completion of this project and successful shipyard evaluation of the beta-prototype system.

COST BENEFIT ANALYSIS/ROI

The original ROI at the start of the project was based on two metrics: savings on training cost per welder and savings from a reduction in labor cost when tele-welding instead of traditional manual welding. This also included the addition of a welder aide/set-up helper who would be needed to set up equipment at the welding location. The project team updated the ROI by adding another metric to the cost savings by a decrease in production labor. The new calculation of the predicted decrease in production labor cost accounts for the change in labor between a mechanized welder and the tele-welder. The cost savings of training is estimated to be $27,000 per tele-welding operator. The cost savings per production hour of a manual welder is estimated to be 61%. The cost savings per production hour for a mechanized welder is estimated to be 37%.

EVALUATION AND ANALYSIS METHODS

This technology has not yet been implemented into the shipyard. The tele-welding technology roadmap indicates implementation and commercialization can occur in concert at the completion of this project and successful shipyard evaluation of the beta -prototype system.

LESSONS LEARNED

This technology has not yet been implemented into the shipyard. The tele-welding technology roadmap indicates implementation and commercialization can occur in concert at the completion of this project and successful shipyard evaluation of the beta -prototype system.

TECHNOLOGY TRANSFER

This technology has not yet been implemented into the shipyard. The tele-welding technology roadmap indicates implementation and commercialization can occur in concert at the completion of this project and successful shipyard evaluation of the beta -prototype system.

IMPLEMENTATION

To develop an integration plan, a roadmap for the implementation of a tele-welding system into the shipyard was developed. Figure 53 shows the draft of the roadmap for tele-welding technology. The outcomes from this project yields a fielded tele-operational, beta prototype tele-welding system, tested and used by shipyard partner personnel. This beta prototype tele-welding technical system is ready for implementation. The shipyard will need to conduct necessary/appropriate steps for the qualification of the beta prototype for production work.

APPENDIX B

ALPHA TELE-WELDING SYSTEM EVALUATIONS

Task 2 – GDEB Comment Evaluation of Alpha Tele-welding System Rate

New Feature or Improve Feature	Comment/Feature GDEB Robotic Arm Tele-Welding System	Must Have	Nice to Have	Not Needed	Rank Top 5
Camera view	Increase screen size or use a separate monitor.				
	Increase image resolution.				
	Adjustable camera angle.				
Camera angle	Add a puddle view angle or allow angles for different joint types.				
Camera zoom	Allow an operator-controlled zoom function.				
Depth perception of camera	Demonstrate how close torch is from material or part surface.				
	Tie distance to plate/part to force feedback felt on stylus device.				
	Indicate distance of travel from or with respect to start point.				
	Add color or indication on screen (green, red, etc.) for where torch is in relation to plate/part.				
Weld travel direction	Make this application specific (default setting for weld direction push/pull).				
	Add more flexibility in the system for travel direction.				

New Feature or Improve Feature	**Comment/Feature** **GDEB Robotic Arm Tele-Welding System**	**Must Have**	**Nice to Have**	**Not Needed**	**Rank Top 5**
Speed control	Include option for slower or faster speed change.				
	Put an upper and lower bound on travel speed.				
Operator Feedback/Audio	Zero latency/lag in arc sound, if remote.				
Operator adjustment	Accommodate the different type of welders: Body type, welding style, welding inside and outside of the sub.				
	Allow for a combination of preset and variable functionalities.				
	Have a good default setup that can be immediately used but can also be adjusted.				
Wire management/torch tending	Have a robot home position to get back to the same spot (to ease manual torch management procedures).				
	Include an automatic wire snipper capability.				
Memory buttons	Make a setup/config memory button for each user.				

Task 2 – NNS Comment Evaluation of Alpha Tele-welding System Rate

New Feature or Improve Feature	**Comment/Feature** **NNS Magnetic Crawler Tele-Welding System**	**Must Have**	**Nice to Have**	**Not Needed**	**Rank Top 5**
Travel Speed	Travel speed control.				
	Cruise control capability.				
	Display travel speed to user.				
Camera	Add a trailing camera.				
	Zoom function on camera.				
	Increase resolution.				
	Increase image brightness.				
Monitor Display/Operator View	Add a scale on monitor screen to judge size/length.				
	Heads-up display option.				
	Heat input calculation.				
	Arc voltage and amperage displayed.				
	Alarms for out of tolerance/etc.				
Control/Communication	Wireless.				
	Wired.				

New Feature or Improve Feature	Comment/Feature **NNS Magnetic Crawler Tele-Welding System**	Must Have	Nice to Have	Not Needed	Rank Top 5
Crawler Functionality/Performance	Track-based system or at least as an option instead of magnetic.				
	Home position/maintenance position for weld wire tending.				
	Wire feeder location near torch (onboard or on mobile cart).				
	No drift in travel position/path.				
	Torch angle control.				
Crawler Sensors	Obstruction sensors (Lidar, camera, collision).				
	Seam Tracking.				
Stylus and Stylus control	Control by stylus (instead of by pendant).				
	Set and lock out stylus control of individual axes. "Set and forget."				
	Free form travel direction control. Operator can move forward or backward travel direction at any time.				
	Push on/push off button functionality for the stylus button so that the operator does not have to hold button in for the entire weld.				

New Feature or Improve Feature	Comment/Feature NNS Magnetic Crawler Tele-Welding System	Must Have	Nice to Have	Not Needed	Rank Top 5
Arc Control	Hot start functionality.				
	Clean restart – no crater left to fill.				
	Automate arc start/arc end functions.				
	Delays for arc start and stop.				
	Arc on/off by Stylus button.				
Safety	Dead-man switch.				
	Safety tether.				

APPENDIX C

TRAINING OUTLINES

Task 12 - Training Outline for the Experienced Welder

Task 12 - TRAINING OUTLINE FOR THE EX

(Click on icon to access file.)

Task 12 - Training Outline for the Non Experienced Welder

Task 12 - TRAINING OUTLINE FOR THE NC

(Click on icon to access file.)

APPENDIX D

TECHNOLOGY TRANSFER AND IMPLEMENTATION PLAN (TTIP)

2019-375-006 (EWI 59030GTH) TTIP_Rev_

(Click icon to access report.)

APPENDIX E

OPERATOR OUTLINE FOR TELE-WELDING 1G AND COMMENTS ON WELDING

1G OUTLINE FOR TELEWELD.

Base Metal: HY-80 Material Thickness: 2.00 inch

Joint Design: Double-V-Groove Groove angle: 20-degree Ceramic Used: Yes,
Root Opening: 1/16inch Root Face: 1/8-inch

Filler Metal: Lincoln Super Arc LA-100 Diameter: 1/16” Ceramic Used: Yes

Preheat: 150F/175F Interpass: 150F/250F

Power Source: Miller Continum 500

Wire Feeder: Miller Continum Single Feeder

Torch: Tregaskiss Tough Gun CA3 Water Cooled: Yes

Gullco: Yes (travel speed set at 14IPM)

Torch Gas Cup Size: 5/8” and 3/4" Bore.

Gas: 95% Argon – 5% CO2 Gas Flow Rate: 40 CFH (Gas Turbine Flow Meter used to check gas at nozzle)

Heat Input: Min: N/A Max:45 (kg /in)

Parameters: 300amp/27.5volt checked with Arc Agent and WFS taken from front panel of Miller Continum. Program 2 on Miller Continum.

Transfer Mode: Spray

Contact Tip to Work Distance: 1/2” – 3/4"

Gas Cup Distance: 1/2” – 3/4"

Tele weld setup

When lining up camera, the view on the monitor doesn’t have to match the way the part is positioned on the fixture but be sure to know which side (mark plate) is which while welding. This seemed to have a better view on the toe lines of the weld in different positions, especially 2G. I will also move the monitor to give me a better angle of the weld toes lines.

The actual travel speed will be set on the Gullco and the weld length on the Tele program.

The weld torch will be programmed to start in the same spot each time and you will use the work angle button to position the wire in the weld joint. You will have enough movement on the Stylist to move the torch to the side of the bevel you are welding and If the Stylist feels like it will have a difficult time getting to the bevel you may have to make another starting point. I welded with the stylist with full width of movement side to side and when I placed the two outside weld passes for the cap, I would tighten up the width to keep me from going too far over into the baseplate and this is an easy adjustment that takes no time to set.

The arrow keys on the keyboard will be used to control the correct amperage while watching the camera that is positioned on the Millers WFS window. When using these buttons, I position the keyboard so that I am comfortable while using the arrow keys. The arrow keys are a big plus that was added to tele-weld.

1G OUTLINE FOR TELEWELD CONTINUED.

Material Prep

HY80 plates were machined to correct bevel and the width of each plate measured 10 inches and the length of each plate measured 12 inches.

There will be a side 1 and side 2 and after four layers on side 1 the plate will be flipped to side 2 and the ceramic will be removed and will be back gouged to clean weld metal from side 1 and will be ground to remove all the gouge marks are smooth and then will use PT to verify there are no defects or LOF before continuing to weld side 2.

Lincoln DC 1000 used for gouging with an amperage around 400 - 500 and using a Lincoln 3/8" carbon electrode.

Once plate has been through PT welding will start on side 2 and flipping to side 1 after pass 17. Side 1 will be finished out after this flip and will flip back to side 2 to complete. PT was performed 03/11/2024 and pictures taken and showed no indications.

NOTES:

PT showed the back of weld to be clean with no defects after gouge. When starting side 2 had to modify nozzle to reach into the weld joint. Nozzle was squeezed enough to fit into weld joint but still tight in the root area along sidewalls. First half of plate welded like it should've and the last half really had a problem with arc blow and gouge into the clean gouge area causing this area to be manually repaired with E8018, 1/8", SMAW at 125 amps. Made repair passes until had a nice foundation to work from. I started counting passes with pass 3 to pass 17 and will flip to side 1. The root area will have areas that will show in RT along with other areas as the fill passes inside 2. I flipped the plate end to end so that the start will be alternated, and this did help with arc blow. The tele weld system worked fine but the root area was tight along with the arc blow causing problems but as the weld came up in the weld joint and with the correct nozzle, welding went well and was able to continue back-to-back with the weld passes after power brush the weld joint. The root area with 1G or 2G will be difficult for the tele weld to fit down into the weld joint to achieve proper ESO and be able to use a slight oscillation to help with the toe lines there would need to be another task to develop a solid root and hot pass but with some work and correct nozzle this could be achieved. The tele weld system did a great job once the weld joint began to fill and good foundation to work from and was able to use the correct nozzle and also to have more work area for ESO and side to side motion. Plate will be flipped back to side 1 and start with pass 8 and will weld until weld joint is filled to proper weld height. Side one showed areas where the root pass on side two blew through in areas and the same repair procedure that was used on side 2 will be used on side 1. The remaining passes 8 through 20 had no issues while welding and as mentioned before the plate was alternated end to end and this did help with the arc blow and keeping the ends built up. Passes 17 through 20 which is the cap passes were hard to see and didn't matter if the lens was clean or not and could have been fume or the light on top of the plate, but this was really the only problem I had.

Side one will have VT done to Mil-STD-2035, Class 1 and I don't see any problem with the weld being accepted. I know there are areas in the weld that will be REJECTED using RT and with the cap having reinforcement on both sides will put our tube at max thickness and make anything in the weld hard to tell where the indication is at in the weld.

The welding parameters that the shipyard had sent to EWI were used.

Average Amp: 324

Average Voltage: 27.8

Average Weld Duration: 49.1

Weld Length: 10inch

Preheat Temperature: 150F / Interpass Temperature: 225F.

Average Heat input: 44.1Kj/in

21 Passes/9 Layers Side1/ Weld Sequence: Page 5

All passes were recorded while welding with Tele-weld starting 03/12/2024, 03/13/2024, 03/14/2024, 03/15/2024. Videos can be viewed at the Tele station for the weld passes.

JIM HANSEN will be doing the VT.

VT, SIDE 1: RT: NONE

After the completion of side 1 the plate was flipped to side 2 to finish the remaining passes starting with pass 18 thru 26 and nothing changed far as parameters and same techniques used as side 1. Plate welded good no issues to report.

Average Amp: 325

Average Voltage: 27.7

Average Weld Duration:49.1

Weld Length: 10 inches

Preheat Temperature: 150F / Interpass Temperature: 225F.

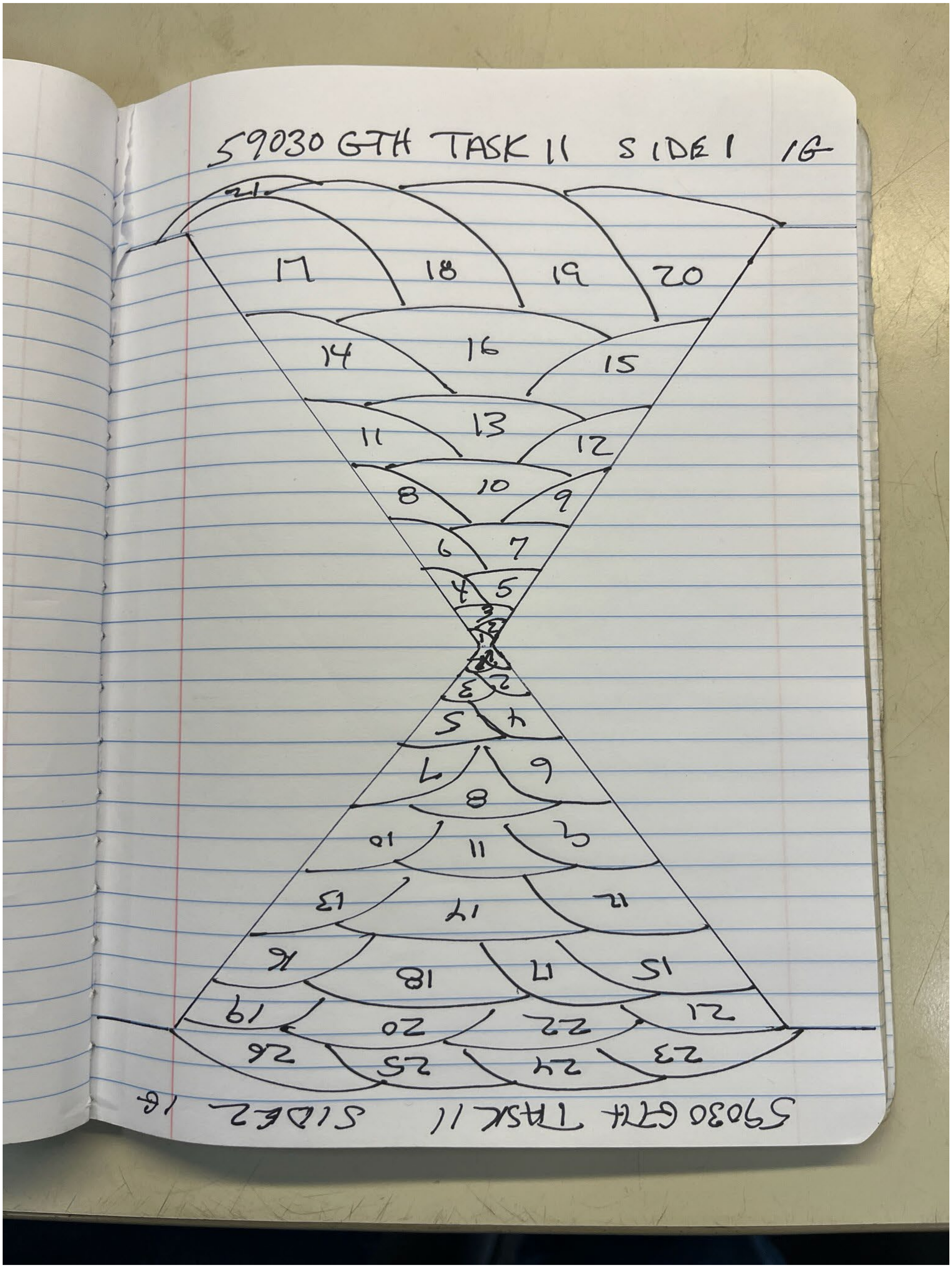
Average Heat input: 44.21Kj/in

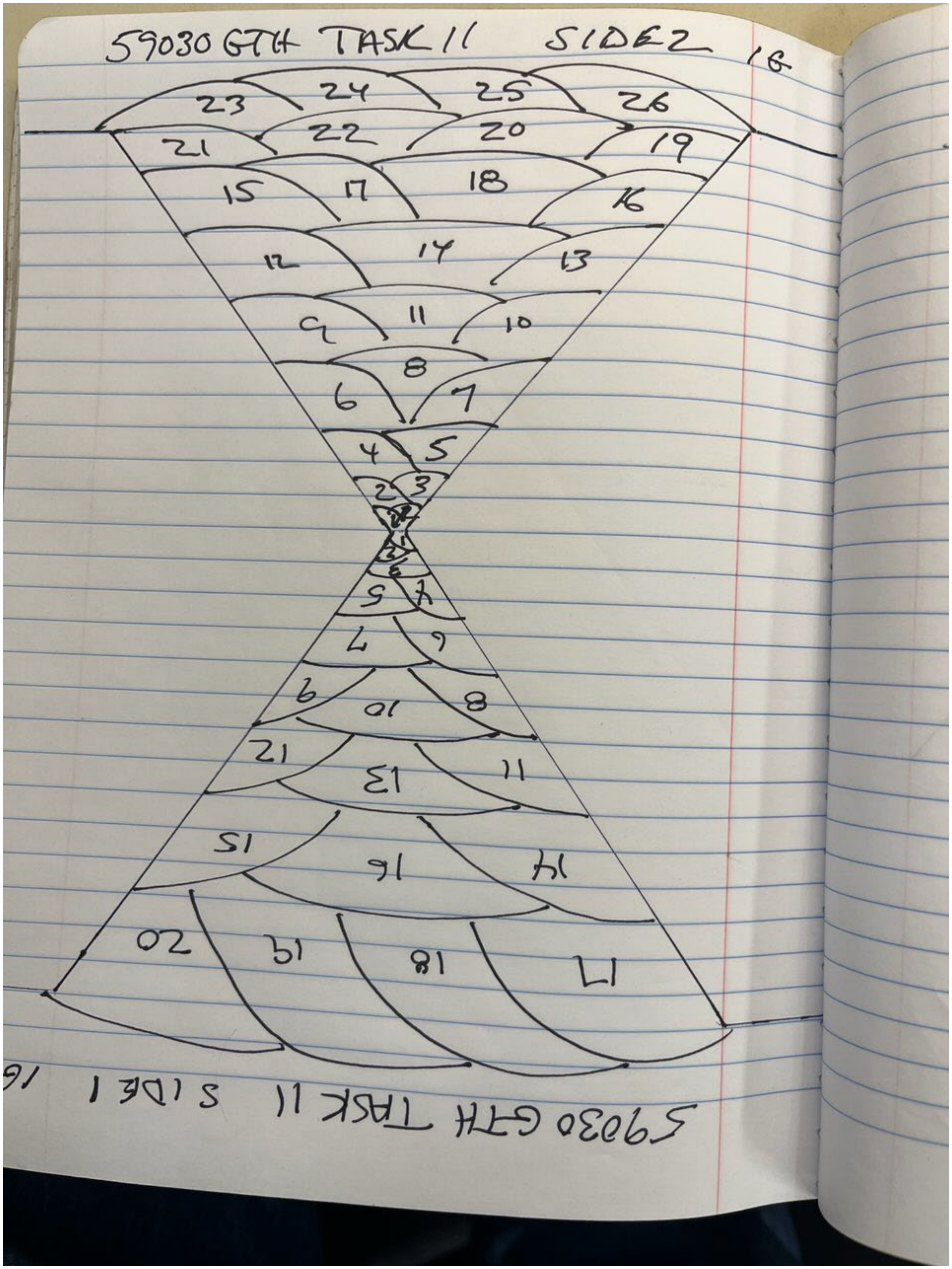
26 Passes/9 Layers Side 2/ Weld Sequence: Page 6

JIM HANSEN will be doing the VT.

VT, SIDE 2: RT: NONE

All passes were recorded while welding with Tele-weld starting 03/12/2024, 03/13/2024, 03/14/2024, 03/15/2024.


59030 GTH TASK 11 SIDE 1 1G
59030 GTH TASK 11 SIDE 2 1G


59030 GTH TASK 11 SIDE 2 16
59030 GTH TASK 11 SIDE 1 16

APPENDIX F

ROI CALCULATIONS

Basis for Cost Reduction

CATEGORY	Baseline	Tele-Welding
Training cost per welder	$77,000	$50,000
Production Labor: MANUAL WELDER cost of one hour	$600	$234
Production Labor: MECHANIZED WELDER cost of one hour	$300	$188

Calculated ROI

Savings	Savings per day	Days of use per year	Yearly savings per welder	Number of welders	Cost reduction per year	Navy Investment	1-year ROI	5-yr ROI
$27,000				10	$270,000.00	$1,699,471	-0.84	
$366	$2,925	1,500	$4,387,440	6	$26,324,640.00	$1,699,471	14.49	
$112	$896	1,300	$1,164,800	4	$4,659,200.00	$1,699,471	1.74	
				Composite	$31,253,840.00	$1,699,471	17.39	86.95