NSRP | National Shipbuilding Research Program

Tele-Welding Shipyard Prototype for Welding (and other) Applications (RA-2021-04)

NSRP Project Manager: Nick Laney (ATI)
NSRP Program Technical Representative: Ken Johnson (Vigor)

March 29, 2023
All Panel Meeting

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

Approved for Public Release; distribution is unlimited

Project Team

Newport News Shipbuilding

GENERAL DYNAMICS
Electric Boat

EWI®
We Manufacture Innovation

RTT
Robotic Technologies of Tennessee LLC

VISIBLE WELDING

Project Support

- RTT
  - Steve Canfield
  - Jamie Beard
- NNS
  - Elmer Dickens
  - Chris Cathis
  - Paul Hebert
  - Jon Sweeney
  - Brian Maher
  - Kurt Lang
- GDEB
  - Luke Bittner
  - Emily Tunila
  - Maks Valischenko
- VisibleWelding
  - Steve Edelson
- NSWCCD
  - Matt Sinfield
  - Jennifer Semple
  - Jim Thomas
- EWI
  - Connie Reichert
  - Paul Blomquist
  - Katie Hardin
  - Tim Moore
- Ingalls
  - John Walks
- Gullco
- Bug-O

Benefits to Tele-Welding in Shipyards

- Attacks the loss of skilled welders
- Transforms welding to a high-tech career
- Significantly reduces geographical impact on labor pool
- Isolates welders from the hazards of dangerous welding operations
- Empowers persons of all ages and limitations to be productive in manufacturing

Tele-Welding can increase arc-on time which can decrease production cost by an estimated 60%.

Tele-Welding is estimated to reduce welder training time by 50%.

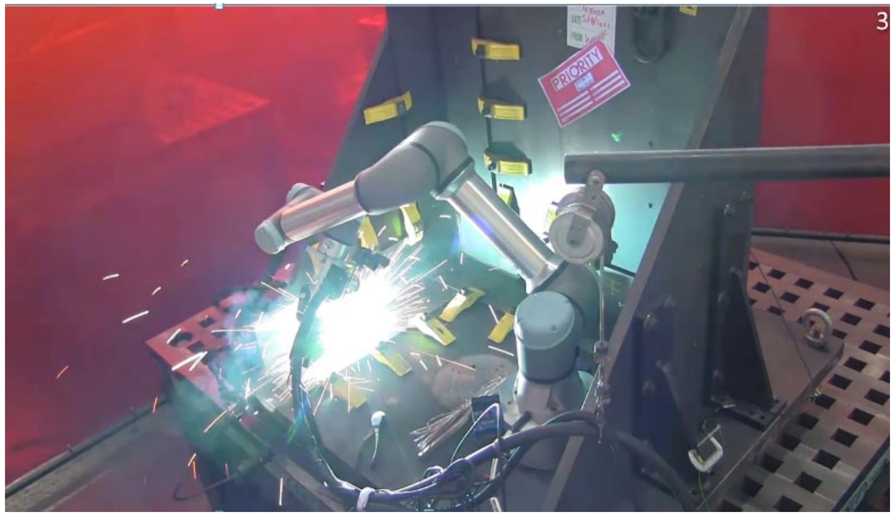
Tele-Manufacturing

- Remotely operating machinery or fabrication processes, while still in control of the process
  - Employs smart methods such as 3D digitizing of the remote environment to gather information to send to a remote worker
  - Uses smart tools such as haptic feedback devices to convey information to the worker who is remote from the fabrication process
  - Uses low-latency communication methods to livestream sound and video to the remote worker in real time

Phase 1 Completed 2021: Tele-Welding Project Successes

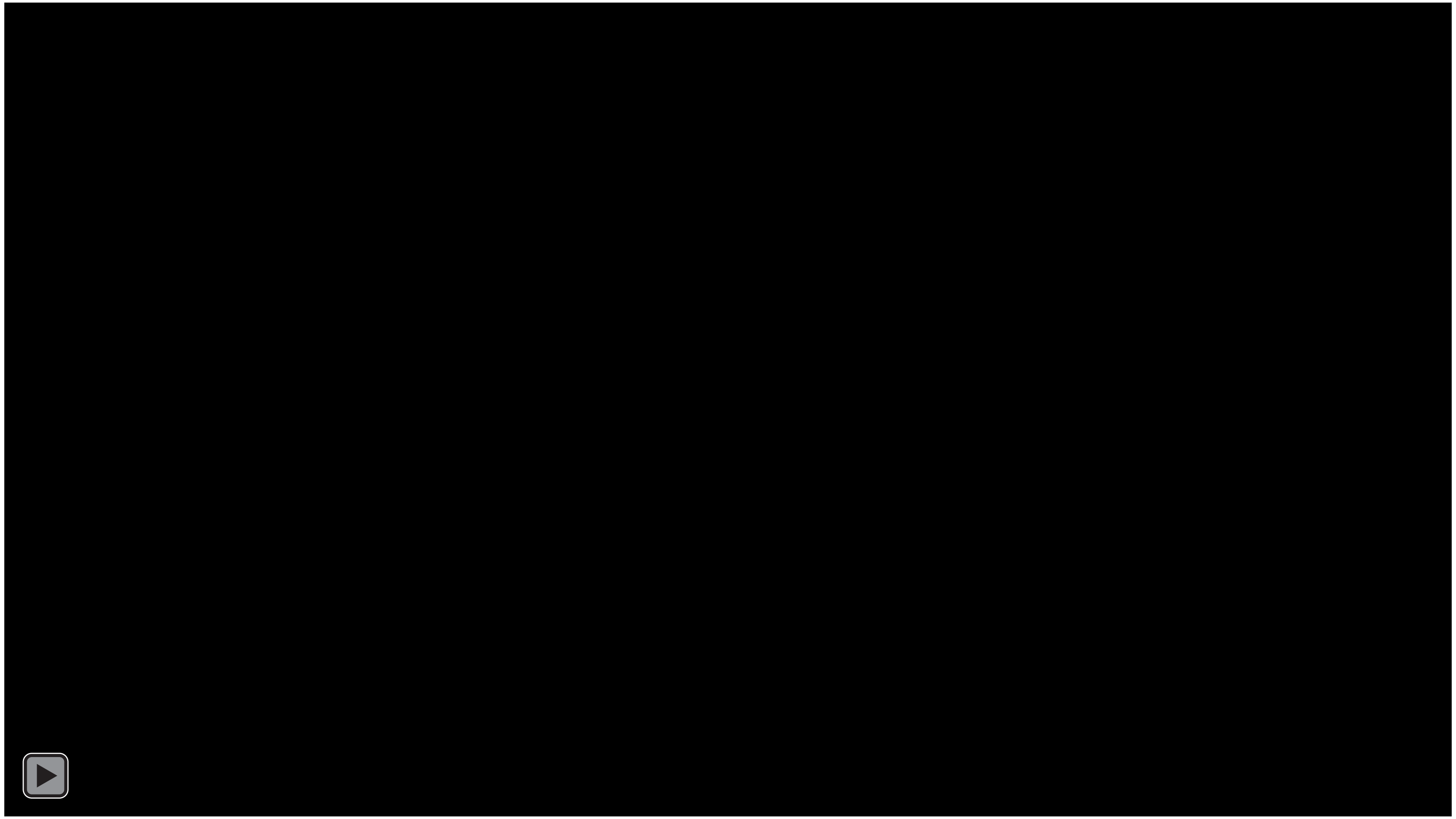
RA-2019-375-001

- Developed tele-welding technology that allows an operator to view a livestream of a remote welding process they are 100% controlling using a local desktop stylus device.
- Developed two tele-welding systems that allow workers to operate remote welding equipment, while using their own dexterity and decision making to perform GMAW welding.
- Engaged shipyard partners for assistance, feedback, testing, review and critique during development of the tele-welding technology.
- Demonstrated tele-welding at both partner shipyards, allowing many welders and shipyard personnel to experience tele-presence welding.



Demonstrations of Tele-Welding – Cobot Platform

Demonstration of Tele-Welding – Crawler Platform



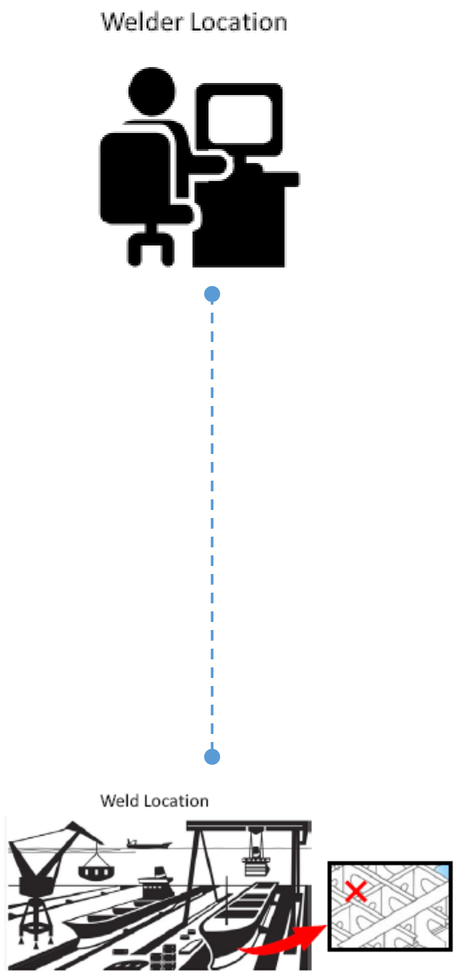
Shipyard Demonstrations of Tele-Welding

- GDEB Demonstration at Quonset Point, RI facility
  - May 2021
  - Cobot application in mock shipyard fixture 2G
  - EWI demonstrated to shipyard personnel
  - Shipyard welders and other personnel tele-welded
- NNS Demonstration at Newport News, VA facility
  - June 2021
  - Crawler application in 2G position on plate
  - RTT and EWI demonstrated to shipyard personnel
  - Shipyard welders and other personnel tele-welded

Tele-Welding Roadmap for Shipyard Applications

Phase	Description
Alpha-prototype 2019-2021 COMPLETED	At the end of RA-2019-375-001, two tele-welding Alpha prototypes were successfully demonstrated at EWI and in both partner shipyards, allowing shipyard welders the chance to experience tele-welding.
Beta-prototype 2022-2024	This current RA-2021-04 effort will provide a tele-welding Beta-prototype ready for repeated shipyard use. Lessons learned from use will be applied to allow an implementation-ready prototype.
Implementation 2024-2025	Integrator supports tele-welding platform during implementation.
Commercialization 2024 -2025	Commercial offering of tele-welding system.

RA-2021-04 Project Overview



Purpose

- Create a shipyard-ready Beta-prototype with a TRL of 6-7 and perform extensive testing in the shipyard.

General Objectives

- To empower the entire spectrum of shipyard welding personnel.
- To allow welding personnel access to technology and equipment enabling them to be fully productive welders, physically remote from the welding process, yet in full control of the equipment.

Benefits

- Shifts welding into a high tech, clean environment
- Lures next-generation workforce candidates, toward welding and manufacturing as a career choice
- Provides better view of the arc puddle than traditional welding helmet views
- Significantly reduces geographical impact on labor pool
- Allows personnel of diverse physical capability levels the ability to contribute to the workforce (i.e., disabled warfighters)

Business Case Impact

- Increased worker productivity
- Decreased cost of seeking, hiring, and training large numbers of local personnel to meet production
- Increased first-time quality rate as the most skilled welders can be deployed anywhere, virtually
- Reduced injury or illness by removing worker from hazardous location

Project Objectives

- Create and integrate a shipyard-ready Beta-prototype with TRL of 6-7
  - Refinement of the Alpha-prototype system will yield operational and performance improvements that will lead to identification of qualification and training issues that will be further applied to further improve the Beta system.
- Merge tele-welding sensors, real-time feedback methods, and shipyard welders' and operators' suggested changes into a commercially supported Beta-prototype.
- Identify classes or a selection of shipyard welds that can be welded remotely with the Beta-prototype system, using existing qualified procedures.
- Develop new, intelligent technologies including path recording capabilities to allow expert welder motions and parameters to be recorded for analytics.
- Maintain shipyard data security and integrity by operating within existing data integrity management protocols by tele-welding from within the shipyard.
- Develop the key requirements for a remote welding training course for experienced and new welders.

Year 1 Scope of Work (2022-2023)

- Review Results from RA-2019 Alpha-Prototype System and Shipyard Requirements for Operation of Remote Machinery
- Identify Technologies to be Updated or Newly Developed for the Beta-prototype
- Creation of the Beta-prototype System
- Test Remote Welder Performance Qualification

Review Alpha Prototype System (RA-2019)
Review Shipyard Requirements for Remote Operation

Year 1 Scope of Work (2022-2023)

Features and Categories: Review of Alpha Prototype

New Feature or Improve Feature	Comment/Feature **NNS Magnetic Crawler Tele-Welding System**	Must Have	Nice to Have
Travel Speed	Travel speed control.	X	
	Cruise control capability.	X	
	Display travel speed to user.	X	
Camera	Add a trailing camera.	X	
	Zoom function on camera.		X
	Increase resolution.	X	
	Increase image brightness.	X	

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.				

Shipyard Requirements for Tele-Controlled Technology

- Identify existing requirement that the shipyards might have with regard to operating remote machinery.
  - Remote machinery
  - Robotic vs. mechanized or semi-automatic
- Data integrity management protocols
  - Shipyard to provide or discuss data security procedures to determine the best way to communicate with the remote equipment.
    - Open communication to and from the internet will not be permitted.
    - IT can create a safe method to use an internal shipyard network in future projects.
    - Wired communication is preferred if cable lengths allow it, and Wi-Fi is permitted with engineering controls.

Cobot Definitions and Tech Pub 248

- Definitions
  - Automatic robotic – pre-programmed, push a button and it goes
  - Mechanized robotic – using robot to more torch, but has direct interaction with operator
- Tele-Weld
  - Won't be conventional mechanized, but also not fully automatic
  - Cobot is a "special" case.
- Tech Pub 248 Rev 1
  - Mechanized robotic welding - says can leverage level 1 semi/auto qualifications, but have to perform level 2 qualifications – NDT
  - Common interest from shipyards on cobot definitions

Evaluation of New Technologies

Year 1 Scope of Work (2022-2023)

Beta System Functionality Evaluation and Specification

- Evaluate the ability to include methods to account for welding process peripheral tasks.
- Combine list of suggested updates from Alpha-prototype shipyard evaluation (Task 2) with the new technologies identified in this task.
- Categorize the list of improvement updates, develop ranking based on increase in usefulness, technical difficulty to implement, and cost to implement.
- Select the technologies for further investigation and implementation onto the Beta system.
- Beta system must be designed to be durable and withstand shipyard use.

Technologies for Potential Inclusion onto Beta Prototype

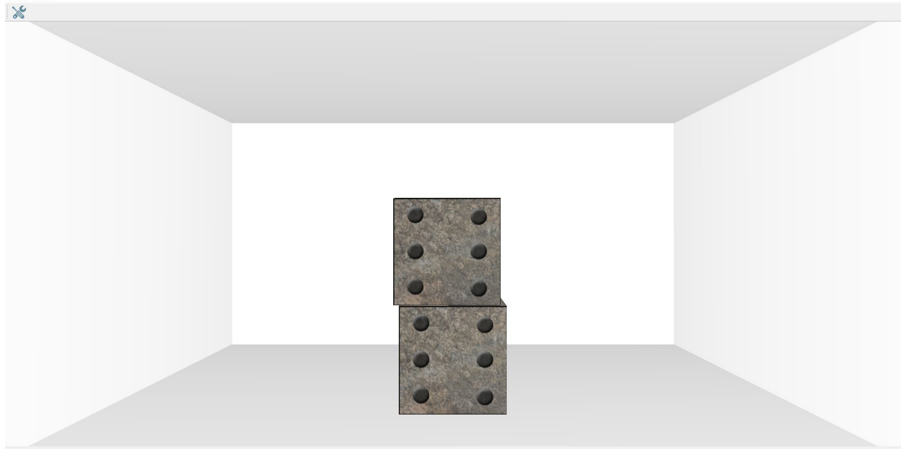
- Evaluating Technologies
  - VR/AR environment with haptic controller
  - Path memorization for master welder
  - Path superimposed for operator guidance
  - Visible Welding weld pool camera updates
  - Additional camera technologies
  - Sensors
    - Laser displacement
    - Temperature
  - Alternate controller devices (mouse, joystick)

Evaluated New VisibleWelding Camera

- Visible Welding provided a new camera system for evaluation.
  - Smaller size – less than half the original size
  - Ethernet communication instead of USB3 which allows for longer lengths between the camera and the PC or peripheral that will stream the video over the network.
  - Discussing options for features updates.

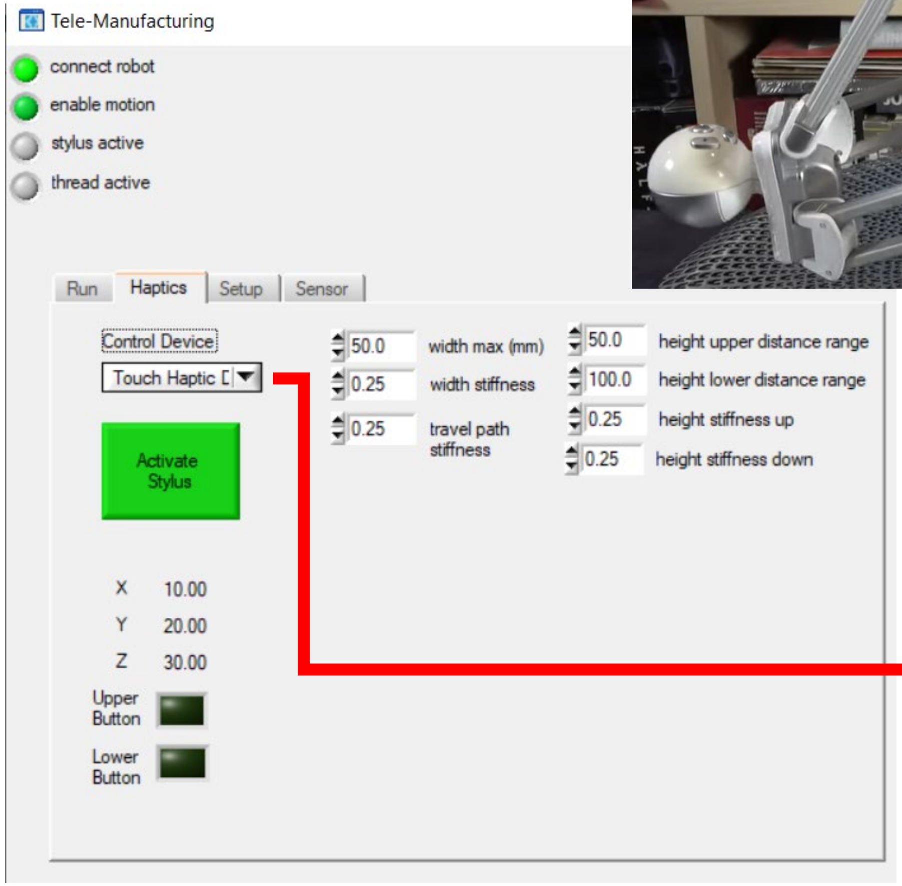
Evaluating New Technologies – AR/VR

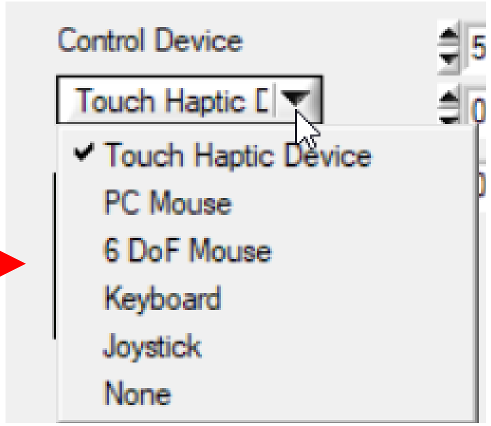
- Virtual Feedback
  - The existing 3DSystems stylus device has software features that allow you to create a virtual environment around the virtual stylus.
  - Project team is currently evaluating this technology for potential including onto Beta system.
  - Potential use will involve adding the real-time environmental feedback data into a virtual environment.



Evaluating New Technologies – Haptic

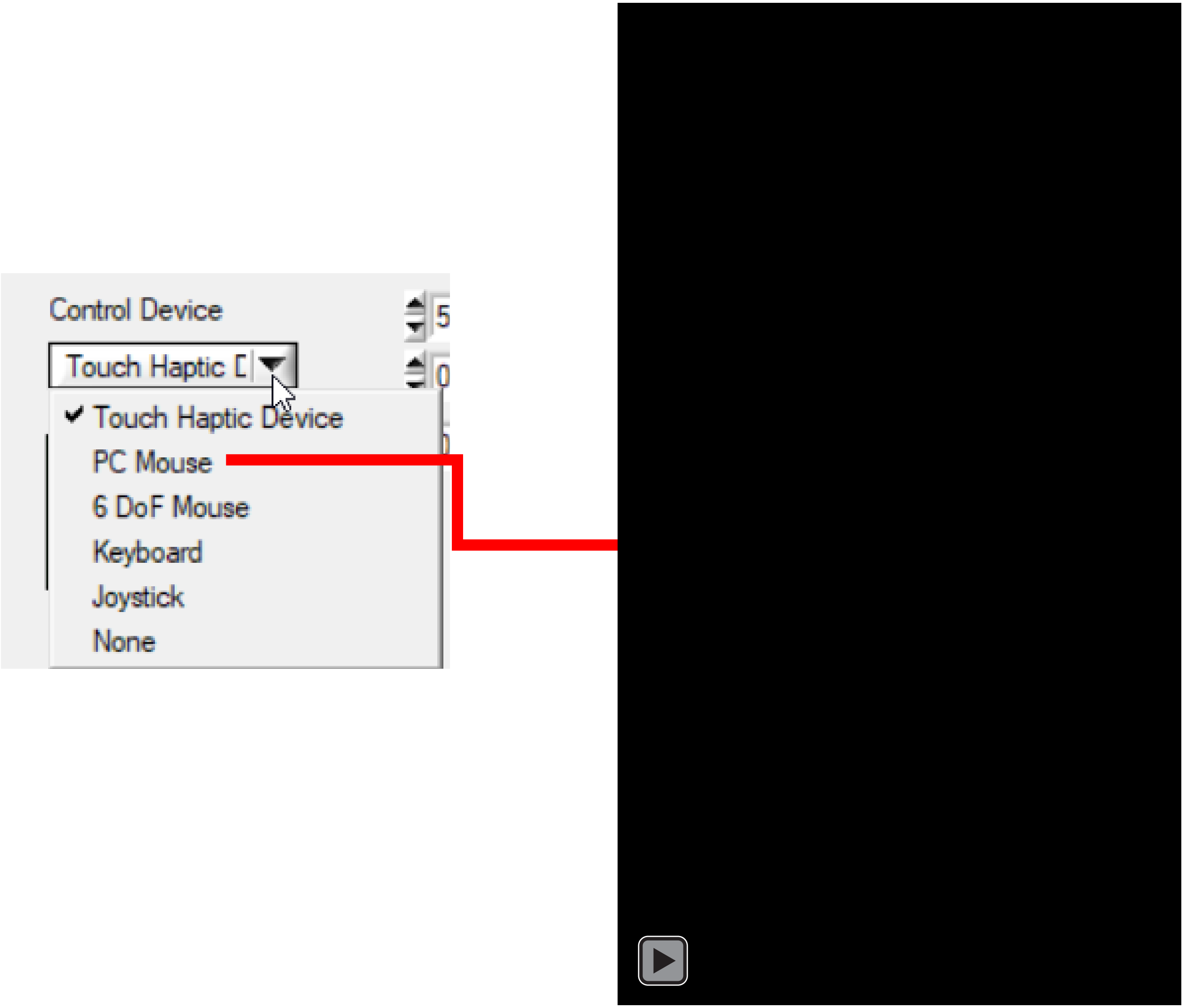
- Alternative control devices
  - Researched other commercially-available haptic stylus device that could be used to control the remote equipment.
- Non-haptic control devices
  - Evaluating non-haptic but more commonly-available devices such as PC mouse, keyboard.
  - Updating tele-welding software program to allow user to select which mouse functions or keyboard options control which robot axes or robot motion.





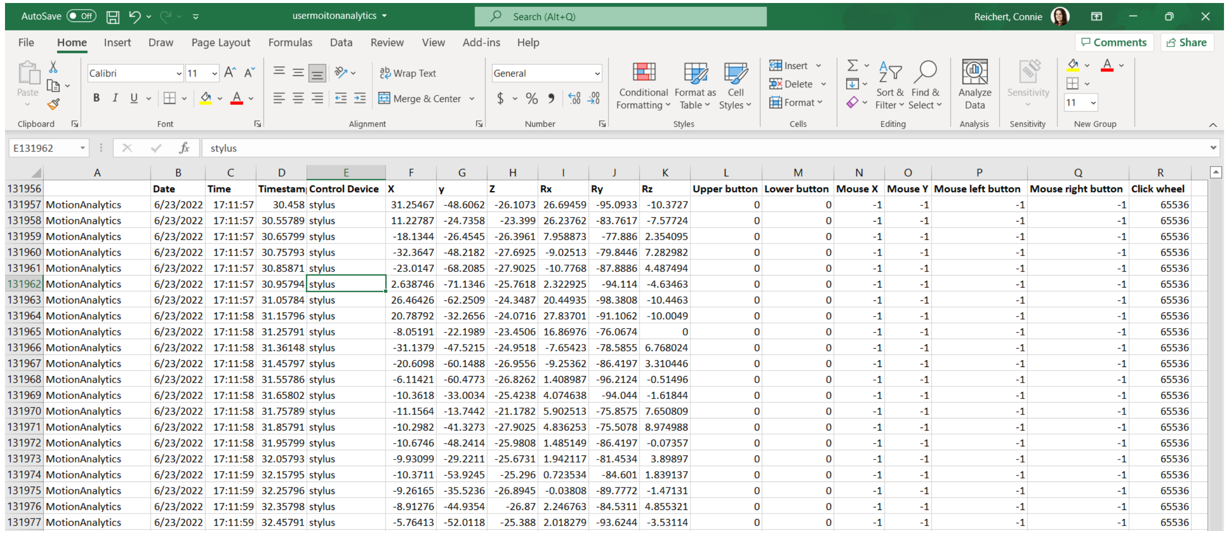
Evaluating New Technologies - PC Mouse

- Alternative control devices
  - Researched other commercially-available haptic stylus device that can be used to control the remote equipment.
- Non-haptic control devices
  - Evaluated a non-haptic but more commonly-available device – a PC mouse or track pad.
  - Updated tele-welding software program to allow user to select which mouse functions or keyboard options control which robot axes or robot motion.
  - Currently evaluating joystick control.

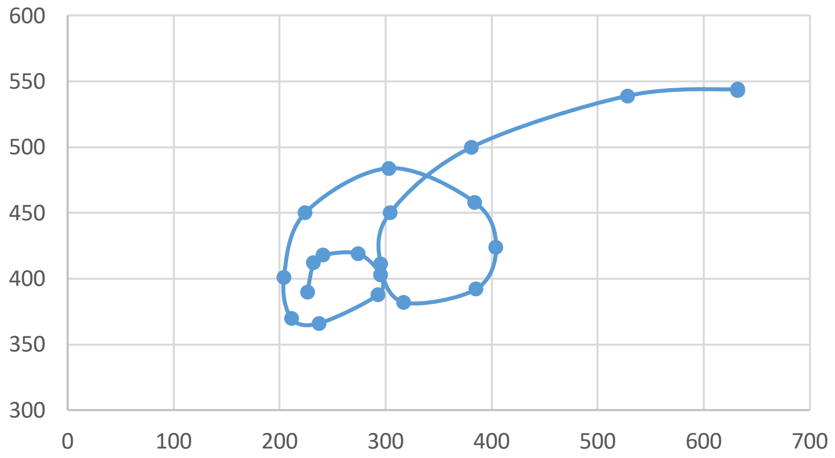


Evaluating New Technologies

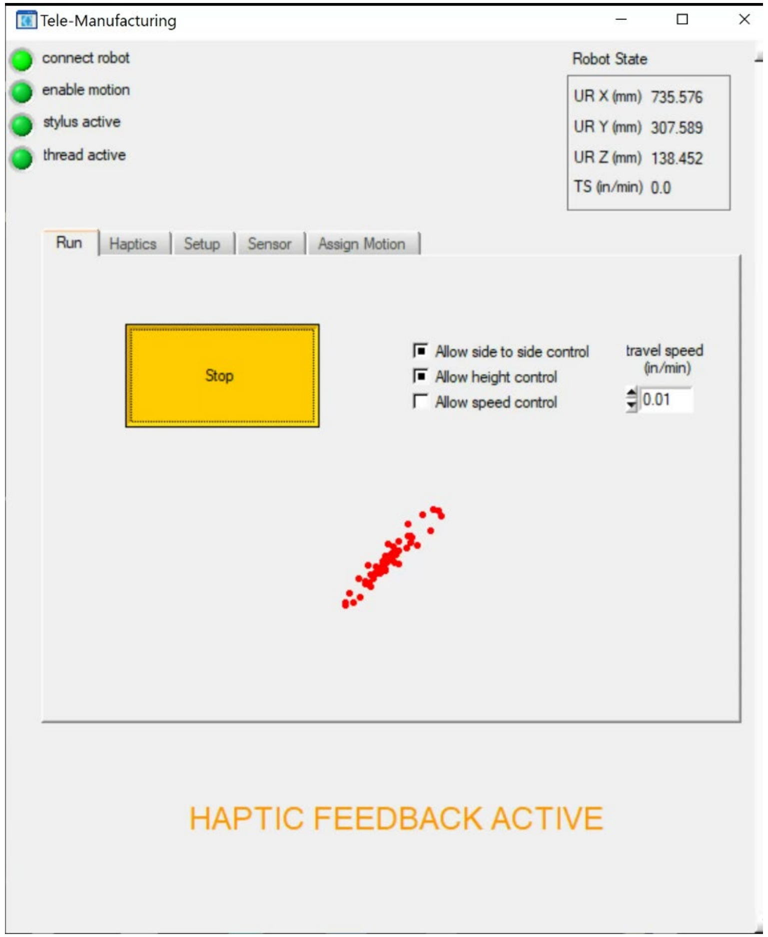
- Path Memorization for Analytics
  - Team is investigating recording of user motions from control device.
  - Tele-welding software records the user motions to a CSV file.
  - Future task will evaluate use of this data for potential example use:
    - Superimposed “path guidance suggestion”
    - Robot programming

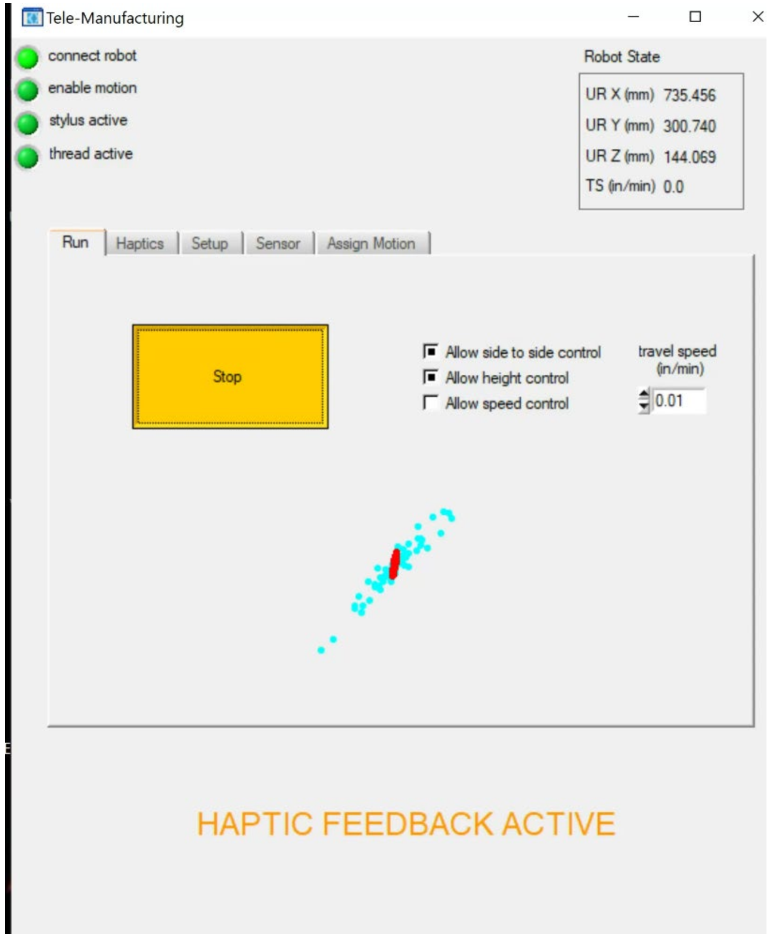


131956		Date	Time	Timestam	Control Device	X	y	Z	Rx	Ry	Rz	Upper button	Lower button	Mouse X	Mouse Y	Mouse left button	Mouse right button	Click wheel
131957	MotionAnalytics	6/23/2022	17:11:57	30.458	stylus	31.25467	-48.6062	-26.1073	26.69459	-95.0933	-10.3727	0	0	-1	-1	-1	-1	65536
131958	MotionAnalytics	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	-23.0147	-68.2085	-27.9025	-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	-9.93099	-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	-3.53114	0	0	-1	-1	-1	-1	65536



Original Path Superimposed on Screen for Subsequent Passes





Evaluating New Technologies - Damping

- Investigate if there is way to apply damping to user motions.
  - Prevent jittery movement from someone who might have less steady movement
  - Account for accidental “out-of-character” motions
  - Accidentally dropping the stylus
  - Unintentional abrupt change in motion
- Use data science to predict where user is likely to move.
  - Use previous “runs” of saved user motions to determine where to go
  - Use previous “runs” of saved user motions to help with haptics
  - Use previous “runs” of saved user motions to program next pass on the robot

Prototype System Design

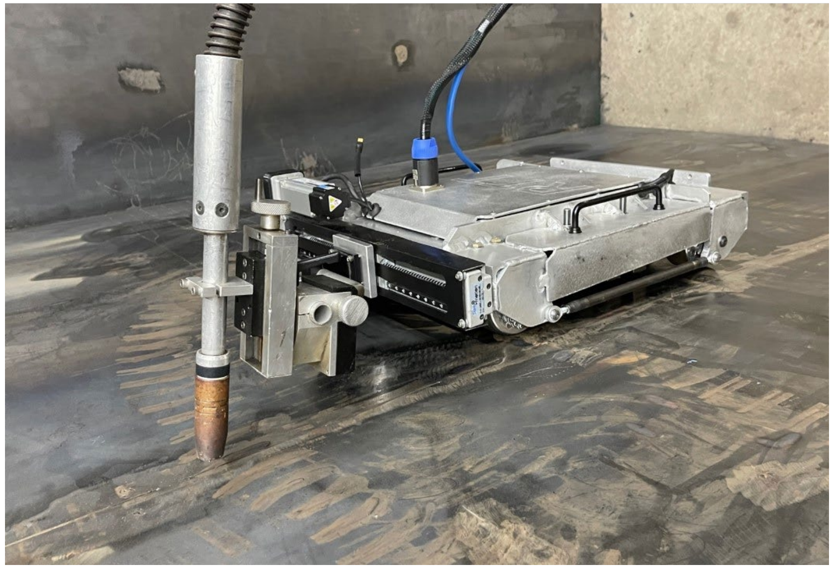
Year 1 Scope of Work (2022-2023)

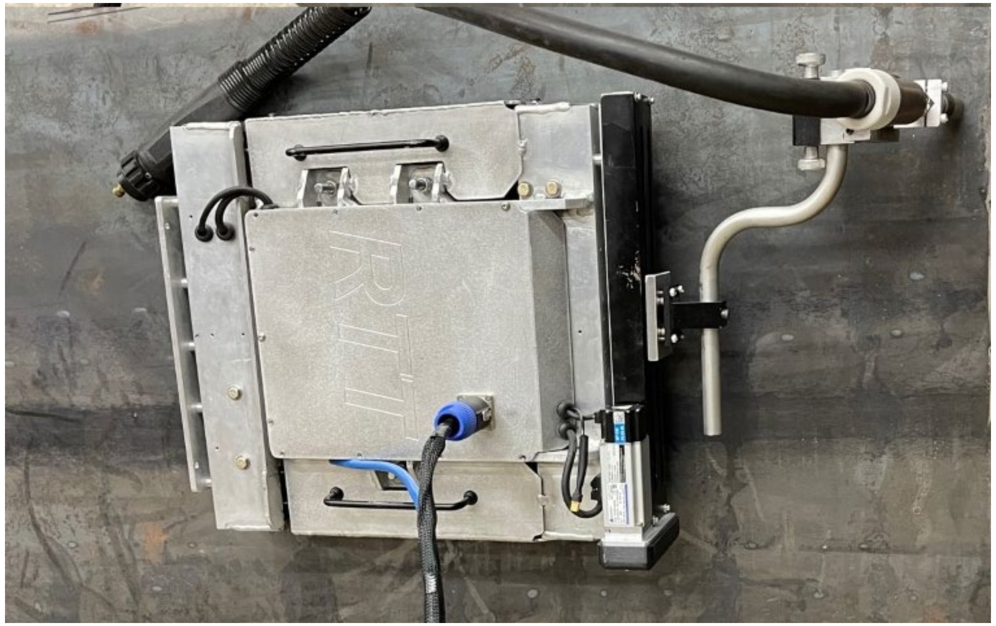
RA-21 Tele-Welding Beta Prototype System Design

- Develop tele-welding motion control technology using the Universal Robot (UR) cobot arm, independent of base platform selection
  - Cobot arm performs the tele-controlled motions and is mounted onto any crawler platform.
  - Crawler platform performs travel motion only, so it can be magnetic, track-based, etc.
  - Crawler platform's motion direction and speed may be coordinated with the cobot arm.
- Benefits
  - Potential for selection of any type of base or crawler platform to be used (magnetic, track-based, stationary clamp).
  - Makes use of the tele-welding control technology for cobot arms, already developed on RA-19.
  - UR offers four 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.

Magnetic Platform Option

- Switchable magnets, non-magnetic wheels, no tracks
- Onboard active guidance to ensure accurate heading (any heading from vertical to horizontal)
- Performed testing to show progress and capability
  - Extended length horizontal running to measure drift
  - Payload testing of 40 lbs.
  - Payload testing with 100 ft tether weight



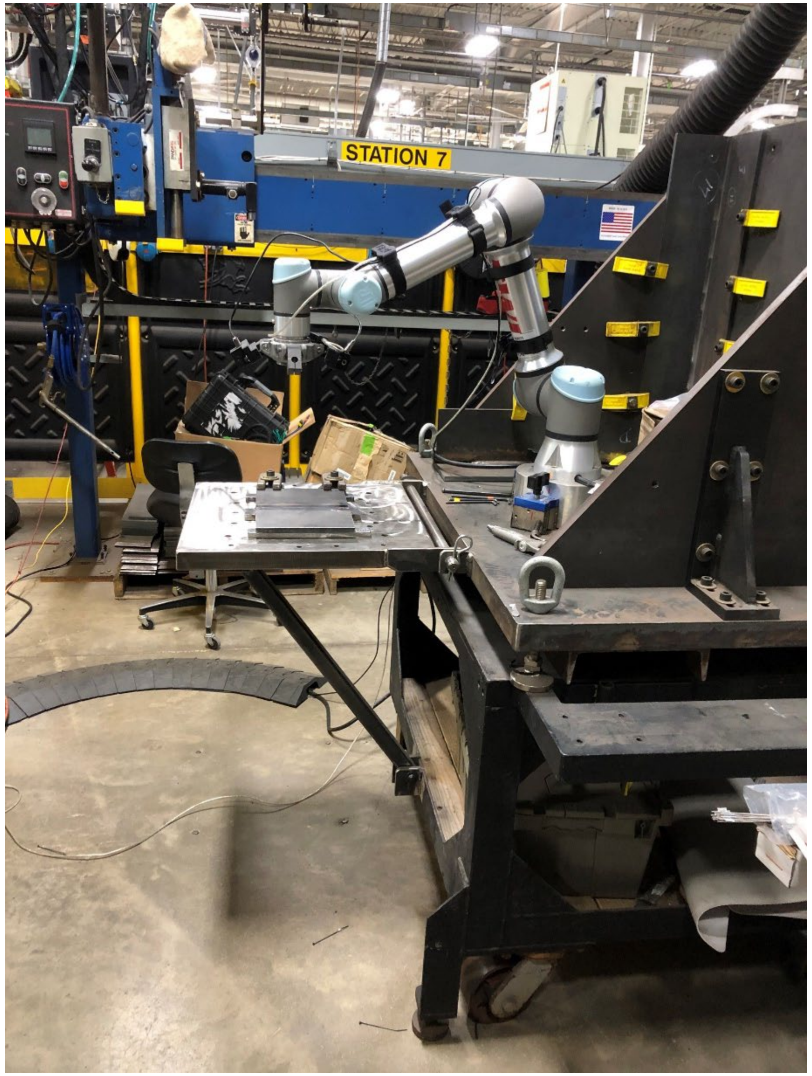


Track-based Platform Options

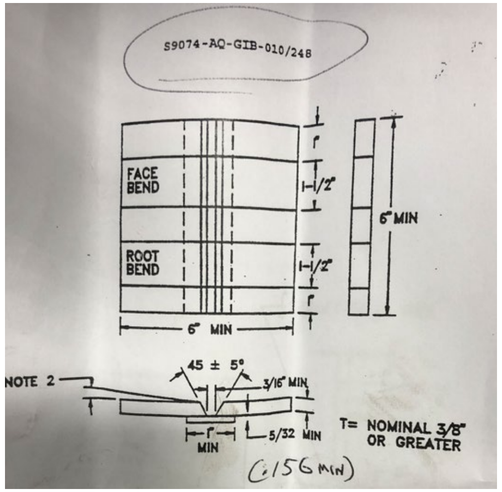
Test Tele-Welder Performance Qualification

Year 1 Scope of Work (2022-2023)

Weld Testing and Qualification Station



- Designed and fabricated remote welder testing station.
- Allows for the existing cobot to be remotely controlled by an operator for attempting welding qualification.
- Created test weld blanks as per Tech Pub 248 for 1G and 2F multi-pass weld tests.



Current Status:
Year 1 SOW Ends in July

Year 2 Scope of Work (2023-2024)
Begins in July

Year 2 Scope of Work Plan (2023-2024)

- Beta Prototype System Testing at Shipyard
- Sample Weld Qualification for Selected Joint and Tele-presence Welding
- Outline a Tele-welder Training Course, Containing Expected Skill Level Requirements for both New and Experienced Welders
- Identify a Range of Shipyard Processes that can be Potentially Tele-operated

Beta-prototype Testing at NNS

- Project team will deliver the Beta-prototype system to the shipyard, and train shipyard personnel to use the system on the selected non-production weld joint.
- NNS will use the system on non-production mockup joints to access the system performance, ease of use, and other factors.
- NNS will provide feedback to the project team via reporting and conference calls.
- Project team will visit the shipyard to observe how the Beta-prototype system is being used and to discuss views on tele-welding and the Beta-prototype system with end-users.
- Project team will review feedback and make suggested changes to the Beta-prototype system.

Tele-Welding Roadmap for Shipyard Applications

Alpha-prototype 2019-2021 COMPLETED	At the end of RA-2019-375-001, two tele-welding Alpha prototypes were successfully demonstrated at EWI and in both partner shipyards, allowing shipyard welders the chance to experience Tele-welding.
Beta-prototype 2022-2024	This current RA-2021-04 effort will provide a tele-welding Beta-prototype ready for repeated shipyard use. Lessons learned from use will be applied to allow an implementation-ready prototype.
Implementation 2024-2025	Integrator supports tele-welding platform during implementation
Commercialization 2024 -2025	Commercial offering of tele-welding system

Questions?