Weld Panel Meeting 2024

"Toward Automated Weld Path Planning for Cobots in Cluttered environments"

Presented By:

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Overview of Concept

- High Mobility Cobots in Ship Manufacturing
- Brief overview of Cobots
- Applications
- Sensors
- Overview of Process
- Results
- Demonstrations

High Mobility CoBots in Ship Manufacturing

Portable CoBot

1) **Operator places HMMR on stiffener and switches mag-locks**
2) **Robot scans and welds stiffener and gusset on either side**
3) **Operator releases mag-locks, slides HMMR to the next stiffener**
4) **Repeat**

CoBot Integrating with Positioner

CoBot: A definition

CoBot – Collaborative roBot

Robot intended for direct human interaction with shared space or proximity (IFR)

- **Traditional robotics – separate robots from human contact during operation (safety)**
- **Cobots – achieve safety through weight, materials, geometry, sensing, controls**

Recent development (1997 patent) stemming from GM robotics center and University research

Four Levels of Collaboration between worker and cobot (IFR)		
Coexistence	Work side by side (no protective barrier)	
Sequential Collaboration	Share the workspace	
Cooperation	Work on the same part, at the same time	
Responsive Collaboration	Cobot responds to worker	

Cobot companies - timeline

- **Cobotics (late 1990's) - Automotive assembly**
- **Kuka cobot – 2004 (LBR series)**
- **Universal Robotics (2008)**
- **Rethink Robotics – (2011) Baxter**
- **Yasakawa (Motoman, 2013)**
- **AUBO robotics (2014, Smokie Robotics)**
- **FANUC (2015) CR series**
- **ABB (2015) YuMi**
- **Welding Examples**
  - ➢ **Fabtech 2018 – 2 welding cobots**
  - ➢ **Fabtech 2023 - 20+?**

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RTT

Ex Scientia Tridens, '83

Comparing robot specifications: Collaborative Vs. Traditional

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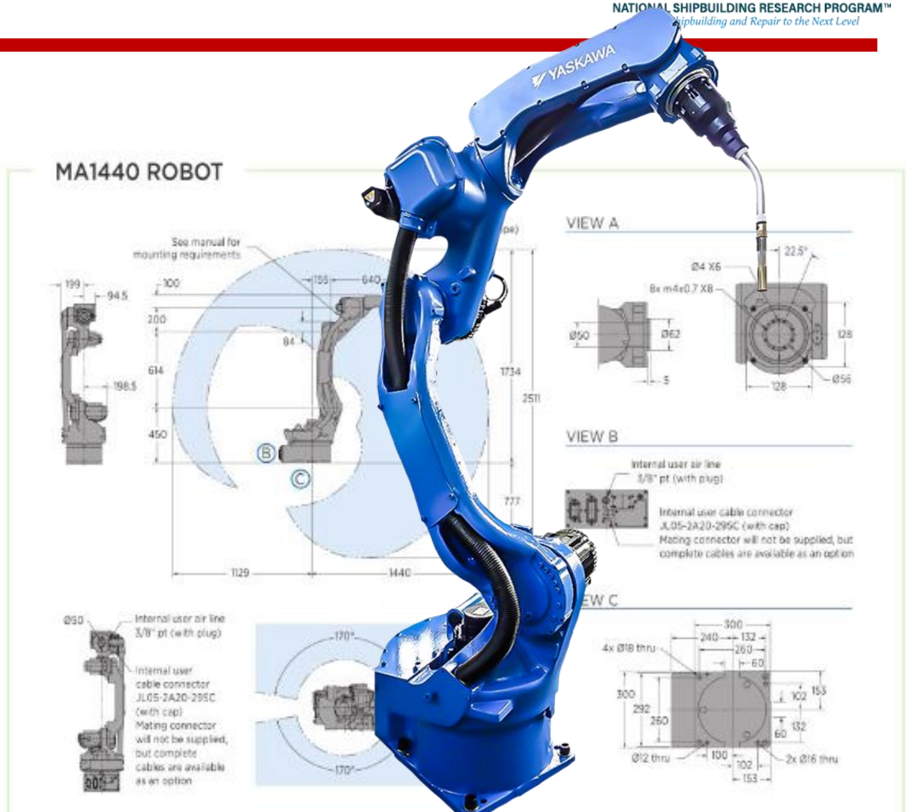
UR10 Technical specifications

Item no. 110110

6-axis robot arm with a working radius of 1300 mm / 51.2 in

Weight:	28.9 kg / 63.7 lbs
Payload:	10 kg / 22 lbs
Reach:	1300 mm / 51.2 in
Joint ranges:	+/- 360°
Speed:	Base and Shoulder: 120°/s. Elbow, Wrist 1, Wrist 2, Wrist 3: 180°/s. Tool: Typical 1 m/s. / 39.4 in/s.
Repeatability:	+/- 0.1 mm / +/- 0.0039 in (4 mils)
Footprint:	Ø190 mm / 7.5 in
Degrees of freedom:	6 rotating joints
Control box size (WxHxD):	475 mm x 423 mm x 268 mm / 18.7 x 16.7 x 10.6 in

MA1440 ROBOT



All dimensions are metric (mm) and for reference only.
Request detailed drawings for all design/engineering requirements.

SPECIFICATIONS

Axes	Maximum motion range [°]	Maximum speed [°/sec.]	Allowable moment [N•m]	Allowable moment of inertia [kg•m²]
S	±170	230	-	-
L	+155/-90	200	-	-
U	+240/-175	230	-	-
R	±150	430	10.5	0.28
B	+90/-135	430	10.5	0.28
T	±210	630	3.2	0.06

Controlled axes	6
Maximum payload [kg]	6
Repeatability [mm]	±0.08
Horizontal reach [mm]	1,440
Vertical reach [mm]	2,511
Temperature [°C]	0 to +45
Humidity [%]	20 - 80
Weight [kg]	130
Power rating [kVA]	1.5
Internal I/O cable (feeder control)	18 conductors
Internal gas line	(1) 3/8" connection

Similar payload and reach, 29 vs. 130kg arm mass

Cobot Theory, Standards and guidelines

- ISO 10218-1/2:2011 Safety Requirements for Industrial Robots
- ISO/TS 15066:2016 Robots and robotics devices – Collaborative robots
- Subject to Quasi-static and transient effects
- Bounds on mass, speed control, and torque sensing

Operational impacts on cobot design

- **Weight/mass**
- **Speed**
- **Accuracy**
- **Stiffness**
- **Exterior shell**

Cobot features

- **Real-time force sensing**
- **Speed-limiting**
- **Defined working boundaries**

Portable Cobot applications:

HMMR (Cobot on mobile platform)

Man-Portable cobot systems

Integration with track/positioners

8

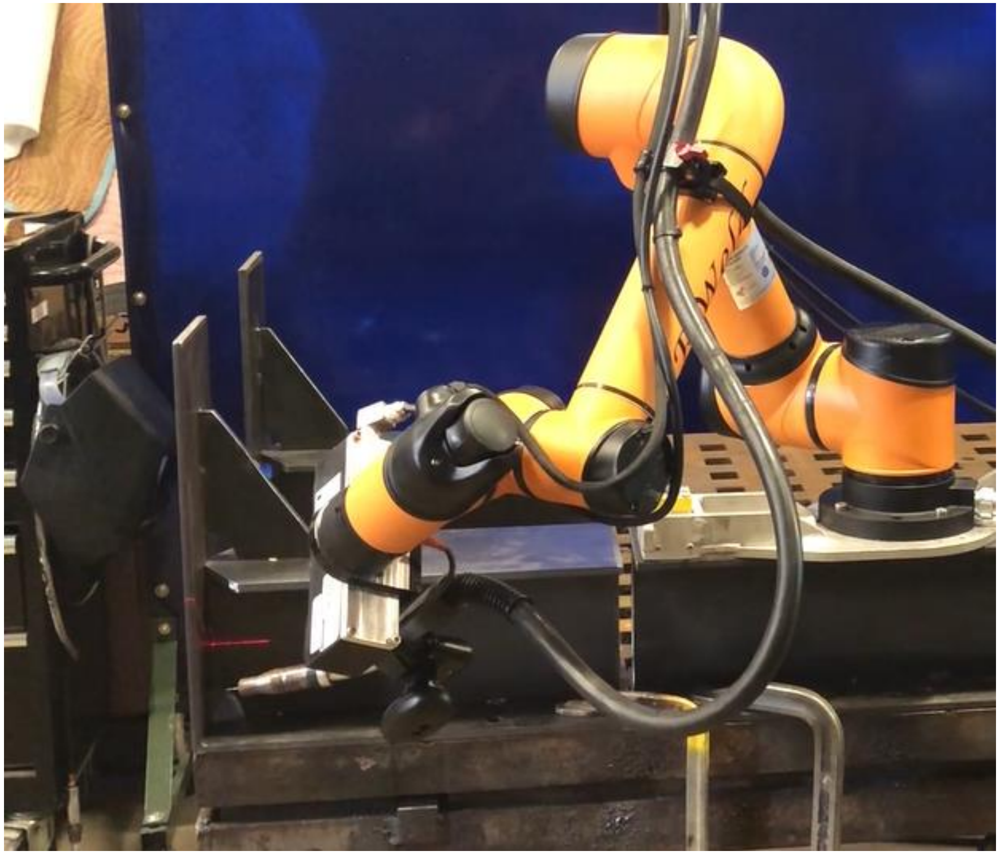
Cobot Workspace Sensing to Aid Portability

- **Considering three sensing strategies to aid portable welding**
  - **Structured-light**
  - **Lidar scanning**
  - **Depth Camera**

Laser Line Scanning

Laser-line or Structured Light Scanning

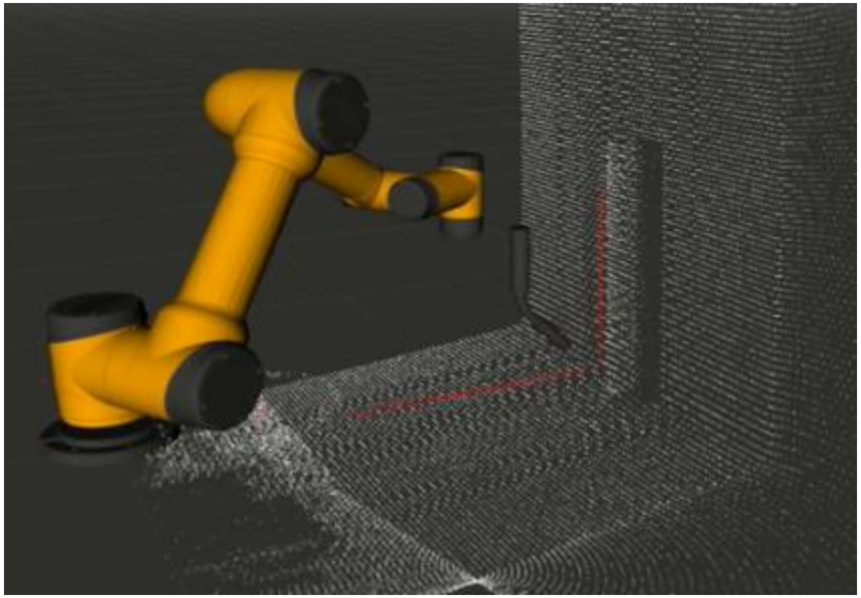
- **High resolution scan of the work seam**
- **High resolution (sub mm)**
- **Small viewable space**
- **Speed depends on workspace motion**
- **Application – requires prior knowledge of the workpiece**



Scanning with Lidar

Scanning Lidar

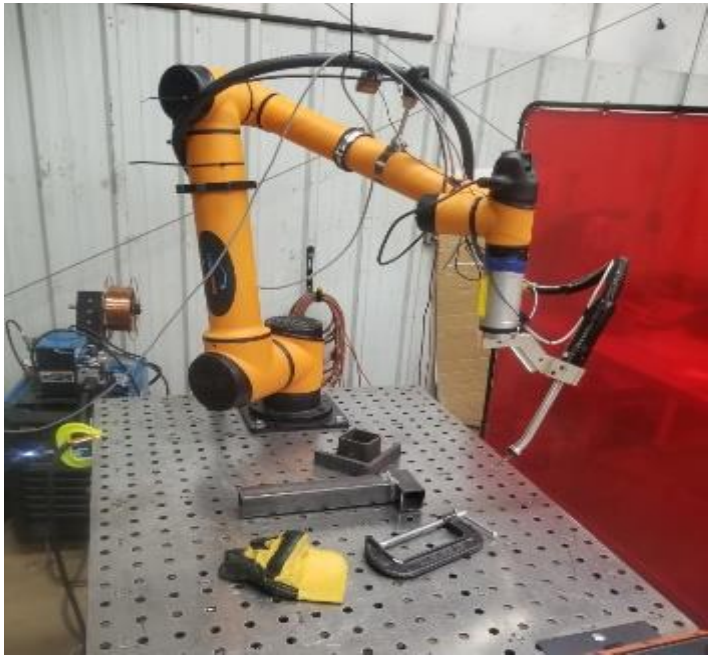
- Combine 2D laser scan with Arm Kinematics to create 3D point Cloud
- Large viewable space
- Medium Resolution (1-2 cm)
- Speed depends on Scanning motion

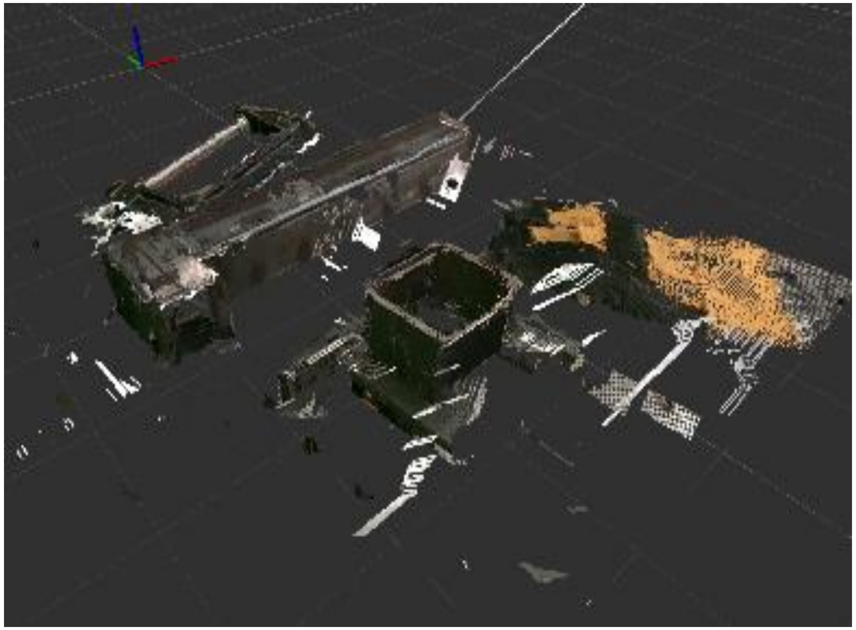


RGBD (Depth) Camera

Depth Camera

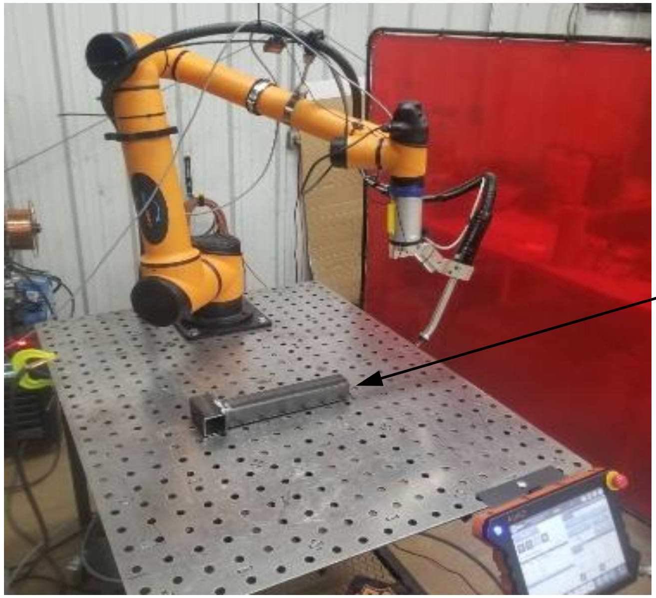
- RGB data with Point Cloud data
- Large viewable space
- Lower Resolution (1-5 cm)
- 3D data with each image

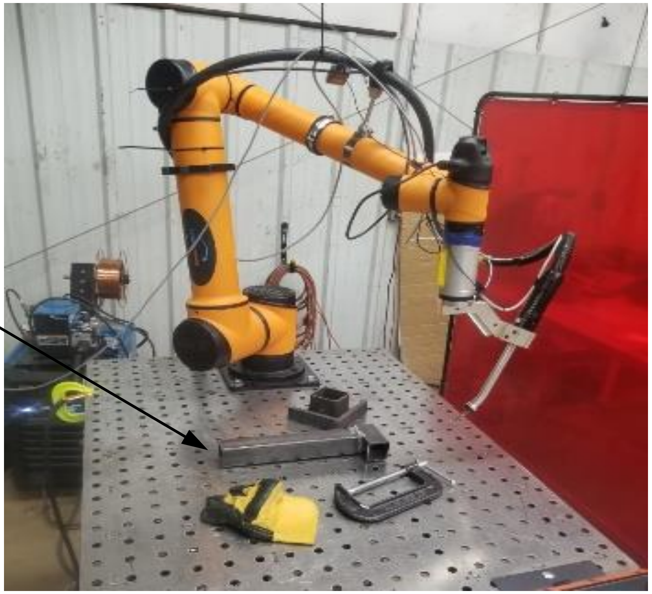




Example Use: Automated Weld Path in cluttered environment

- One-time training: Part and Path
- Future Operations on Part in arbitrary orientations
- Initial work has fixed Cobot, moving parts
- Intended work – fixed parts, moving Cobot

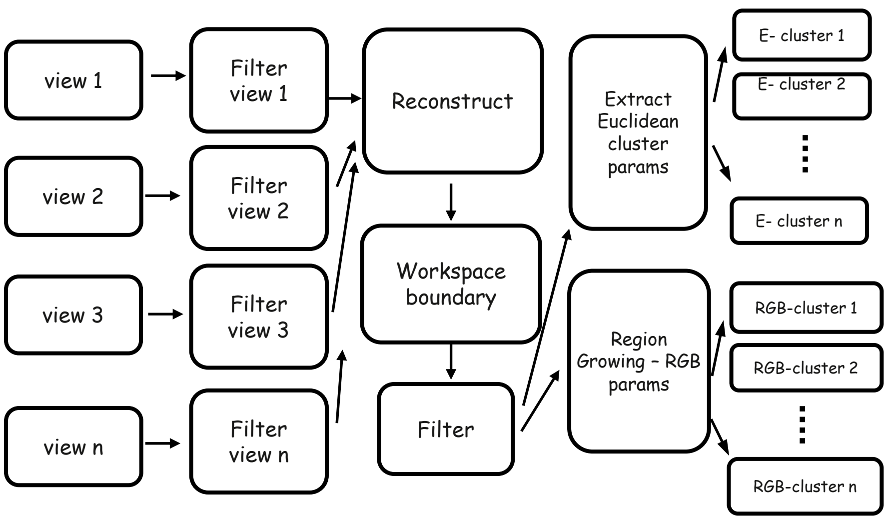




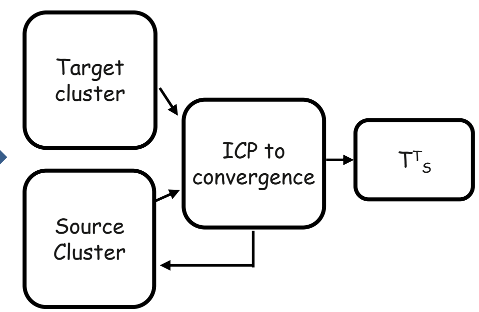
Workpiece

Process

- **Workspace sensing and clustering**
- **Cluster Matching**
- **ICP**
- **Job transformation**
- **Touch-point sensing / Real-time seam tracking**



$$Min(g);\quad g = \Big[\left(V_{target} - V_i\right)^2 + \left(\frac{\lambda_{max,target}}{\lambda_{min,target}} - \frac{\lambda_{max,i}}{\lambda_{min,i}}\right)^2 + \left(R_{target,j} - R_{i,j}\right)^2 + \left(G_{target,j} - G_{i,j}\right)^2 + \left(B_{target,j} - B_{i,j}\right)^2$$



14

Reconstruction, Filters

- **Reconstruct Image from 4 views**

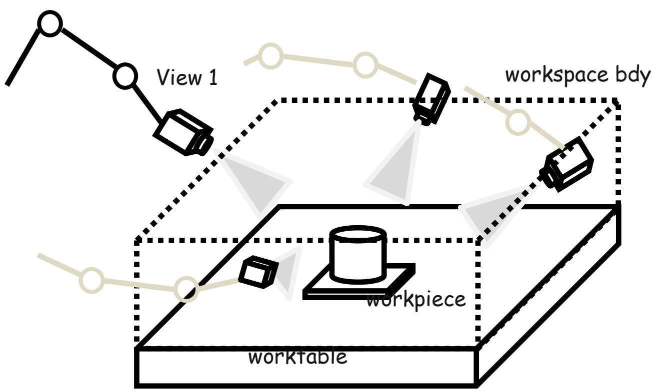
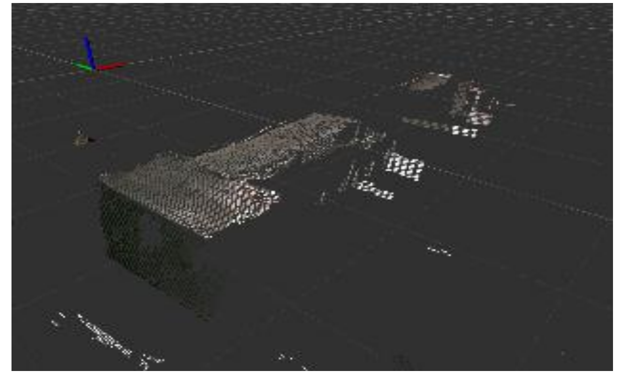
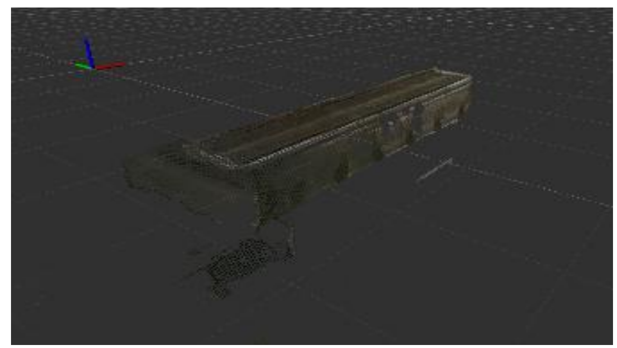
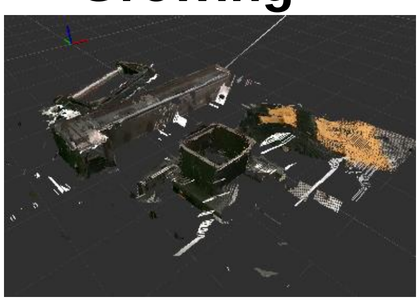


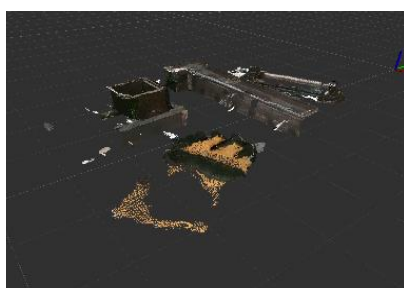
Figure 6: views of workspace





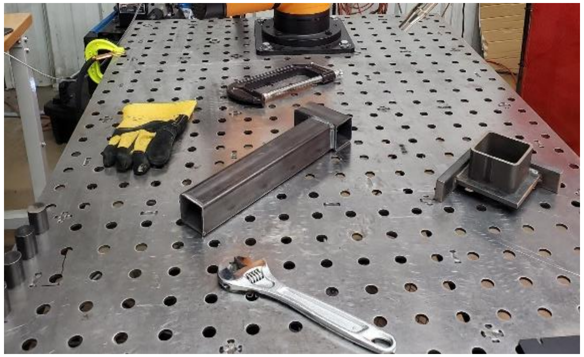
- **Filters: Stochastic + Region Growing**



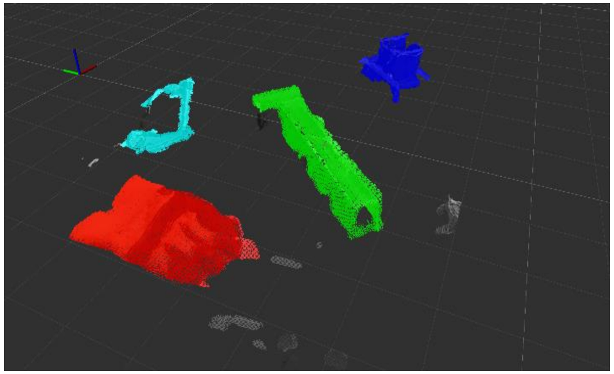


Clustering: Euclidean + Color

- Cluster to Isolate Components in Workspace
- Compare Clusters to identify Workpiece

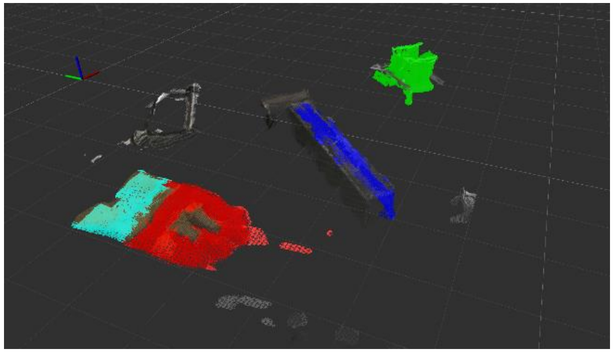


Workspace



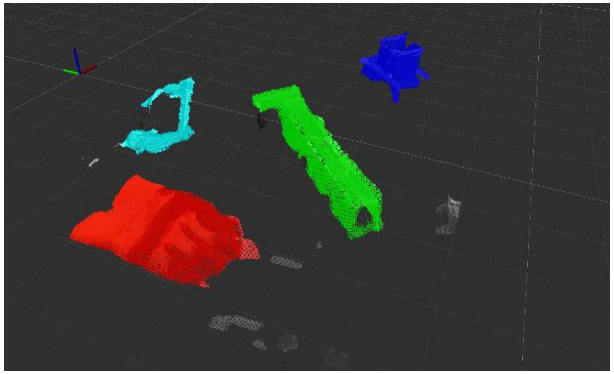
Euclidean Clusters

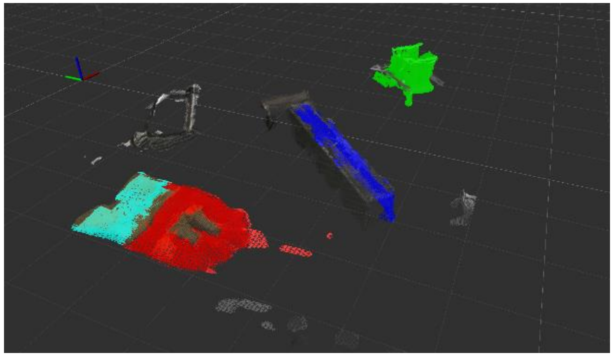
Color-Based Clusters

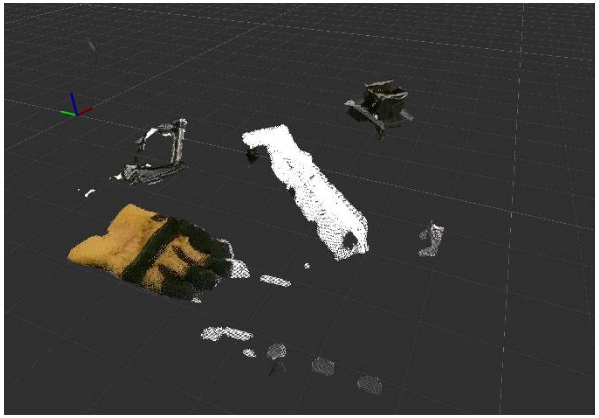


Match Clusters with Target

- **Compare parts (clusters) found in workspace with target (from training)**



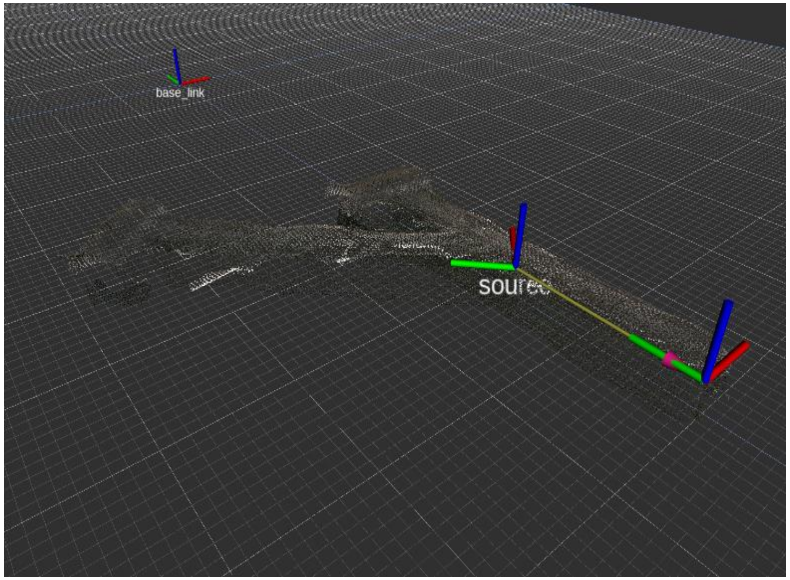




Selected workpiece (white)

Registration through ICP

- Use Target and Source Cluster to find Transformation
- Apply transformation to trained Weld path
- Resolution 1-2 cm
- Use Touch-point sensing for corrective shift to weld path
- Touch point sensing trained using workpiece geometry



Sample Problems for Portability

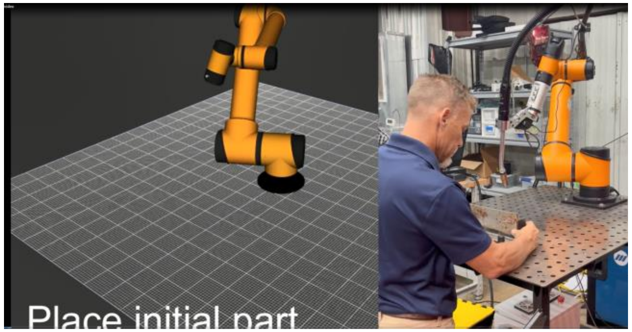
1) **Increase the range of opportunities for mechanized welding through a lightweight, portable (or mobile) robot**
2) **First, apply to general fillet weld types**
   1) **2F (Horizontal)**
   2) **3F (Vertical)**
   3) **4F (Overhead)**
3) **Second, apply to specific jobs (welds joining stiffeners to deckplate, bulkhead intersections)**

Motivating problem:

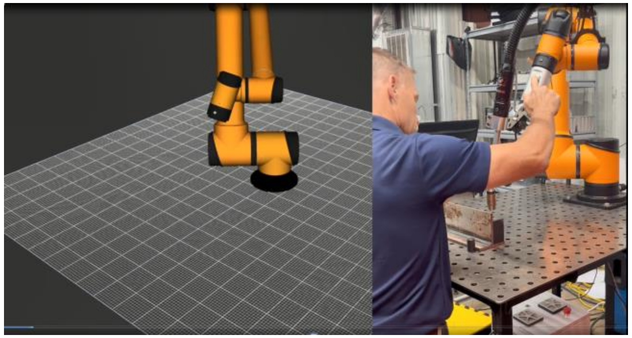
Demonstration

User teaches one part (robot learns from first part)

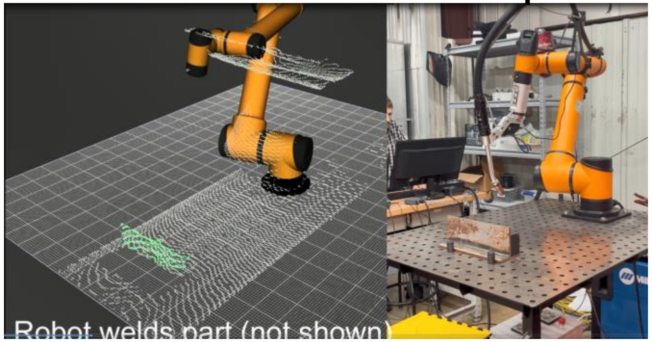
Place initial part



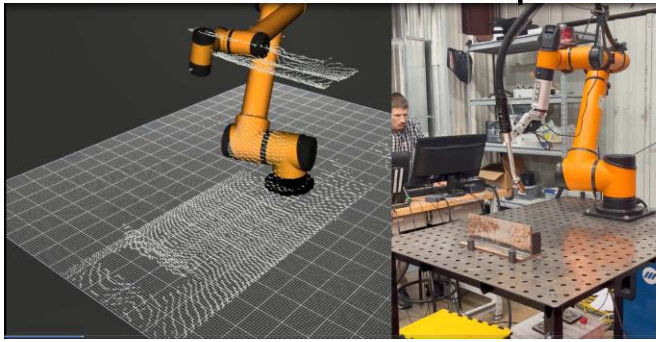
Teach weld on initial part



Robot learns initial part



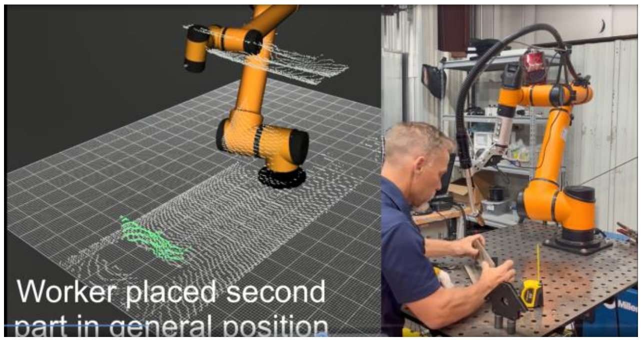
Robot scans initial part



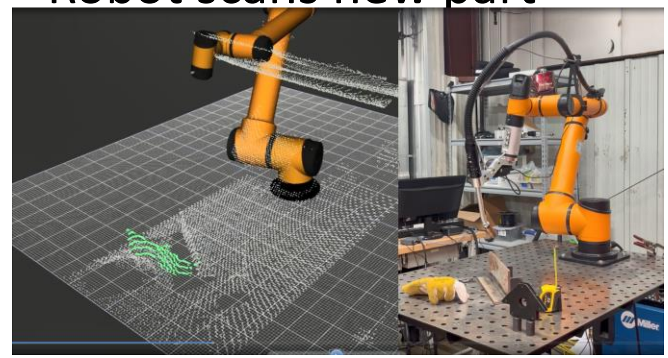
Demonstration

Robot automatically finds and welds new part

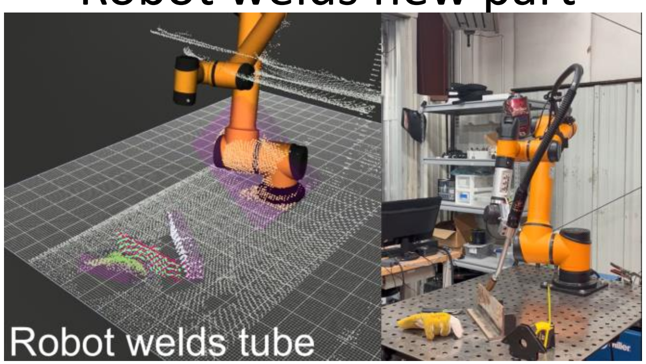
Arbitrarily place a new part



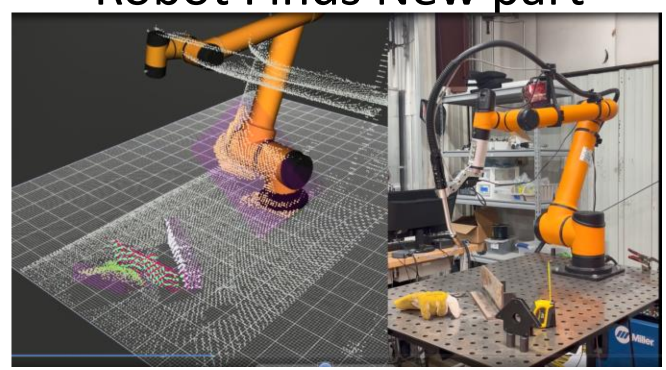
Robot scans new part



Robot welds new part



Robot Finds New part



- https://www.dropbox.com/scl/fi/sn3hqxq4dg38cyzootdux/final-video.mp4?rlkey=q9wpvcghwxc74jhegg4evynbx&dl=0

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Demonstration of HMMR Hardware

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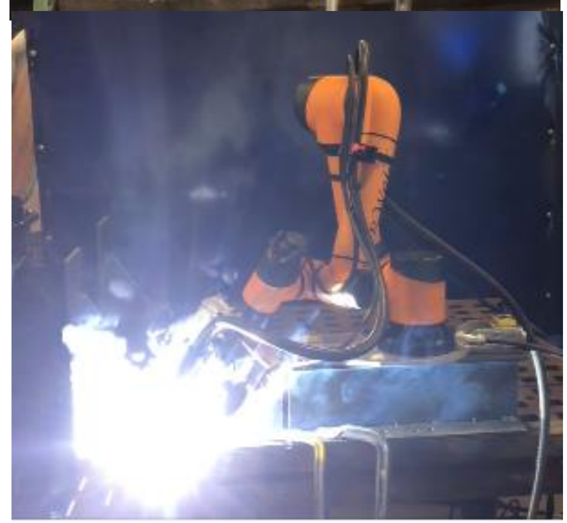

https://vimeo.com/528391072/171c0faace

Questions