PennState Applied Research Laboratory

Multifunctional Automated Repair System (MARS)

Sea, Air and Space
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Materials Science Division

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Introduction

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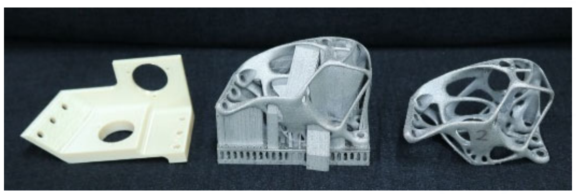
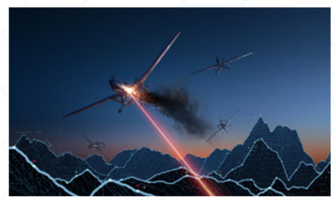
- The Material Science Division performs applied and fundamental research in developing and implementing processes and high-performance materials for a wide spectrum applications in aerospace, marine and land based systems.
- Develop long term strategic partnerships to develop, validate and implement technologies that support the mission of the DoD and the US industrial base.

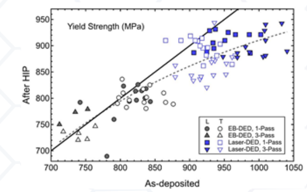
Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D)
Develop and implement directed energy processes for metal deposition
Dr. Ted Reutzel

Advanced Metals, Ceramic and Coatings Processing
Develop materials and materials processes for extreme environments
Dr. Doug Wolfe

Materials Evaluation and Engineering
Characterization of AM materials for qualification and model validation
Dr. Jay Keist



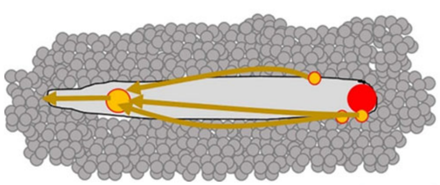


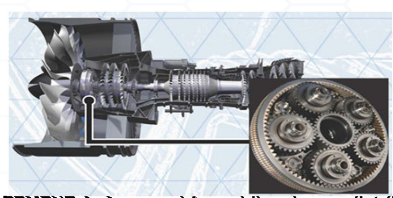


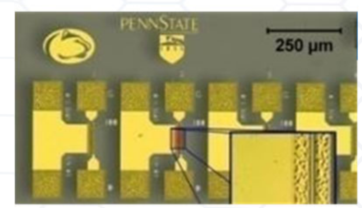
Process Physics, Analytics, and Engineering
Develop advanced processes, materials and components using process monitoring control systems, and analysis methods
Dr. Abdalla Nassar

Drivetrain Technology Center
Performing Research in Gear Technology for DoD and Industry
Aaron Isaacson
aci101@arl.psu.edu

Electronic Materials and Devices
Develop materials and materials processes for electronic and electromagnetic applications
Dr. David Snyder







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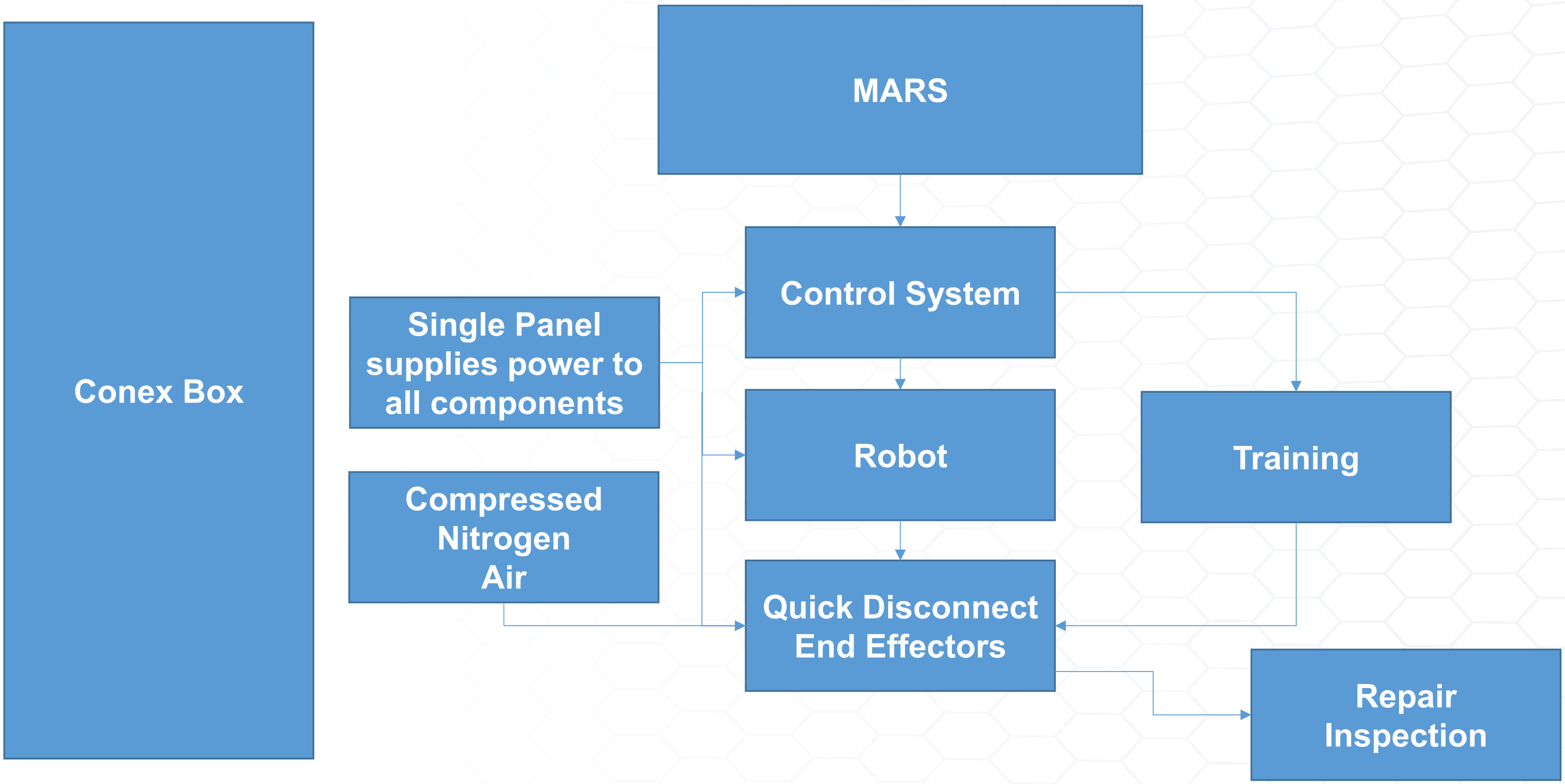
Multifunctional Automated Repair System (MARS)

The Multipurpose End Effector system provides an automated, turn-key, fully portable preparation, repair, and inspection capability for emergent facilities including forward operating bases, ships, and shipyards. The system is configurable for a variety of repair applications from in-theatre battle damage repair to shipyard maintenance.

Benefits:

- Iterative fielding demonstrations allow for incorporation of feedback from end users during system design
- User interface with built-in video tutorials and augmented reality for quick and effective training and fielding
- Speed and agility in implementation
- Technology maturation for all end effector technologies and robot systems
- Forward-deployable in a variety of locations and applications
- Easy-to-use, self-contained prep and repair capability

System Overview



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Multifunctional Automated Repair System (MARS)

Requirements:

- Portable
  - Complete system fits in a Conex container
  - Components meet man-portable requirements
  - Pass through a submarine hatch
- Modular
  - Capable of performing several different functions
  - Easily expandable/reconfigurable
  - Repair system can be used on different robots
- User-friendly
- Training modules
- Affordable
- Upgradeable

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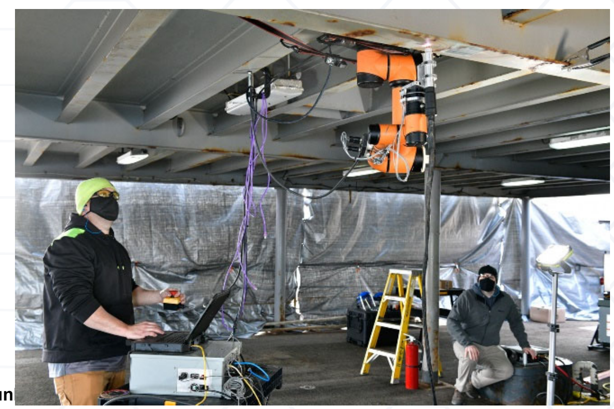
MARS Development

- Performing iterative fielding demonstrations during development to incorporate end user feedback in system design
- MARS Demonstration #1 completed aboard the Self Defense Test Ship (SDTS) at the Naval Surface Warfare Center Port Hueneme Division in March 2021
  - Deploy in operations that remove personnel from hazardous areas
  - Additional lessons learned:
    - Software and hardware modifications identified in addition to potential use cases (flight decks, tanks, etc.)
    - Sailors will use system in unintended and creative ways
    - System portability and cable management are critical
    - Ship power/grounding considerations; scarcity of utilities at prep/repair locations
    - Environmental (heat, cold, humidity, rain, seawater, sand, etc.) considerations
    - Press release: https://www.dvidshub.net/news/396206/navy-debuts-future-state-technology-automate-maintenance-ships

Sailors Operating MARS

Navy Civilians Operating MARS

MARS Plasmablast on a Ceiling



Control System

- Software communicates with robot to control motion and receive coordinate information
- Dynamic surface detection allows user to identify two points and the robot automatically follows the surface and defines repair area
- Xbox Controller – for easy use
- Automatic end-effector detection
- Each end-effector has process parameters pre-programmed
- Training module available for each end-effector
    - User can select any end-effector
    - Can add immersive environment
- Can be used on different robots

Robot and Magnetic Mobile Base

Robot Technologies of Tennessee

Equipment overview:

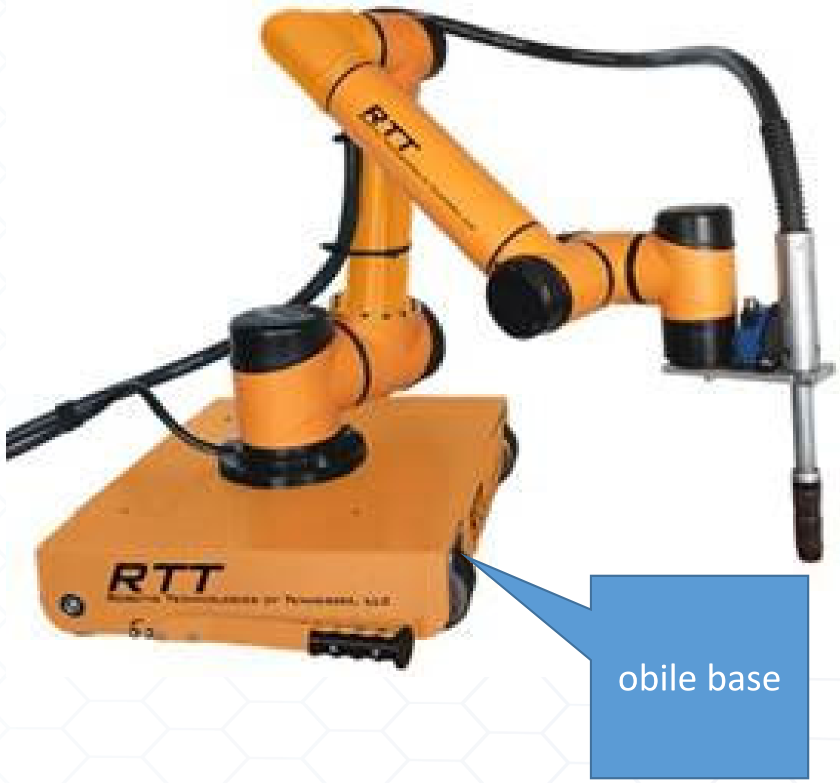
- **Six axis robot for manipulation of repair tools**
- **Mobile base allows in-place repairs and access to confined locations**
- **Quick change interface enables rapid end effector changes**
- **5 kg load capability**

Power Requirements:

- **110 VAC**
- **Battery Powered**

Status:

- **RTT robot control has been modified**
- **Looking at portable magnetic bases**



Robot with Track Base

Telerob – Telemax Hybrid

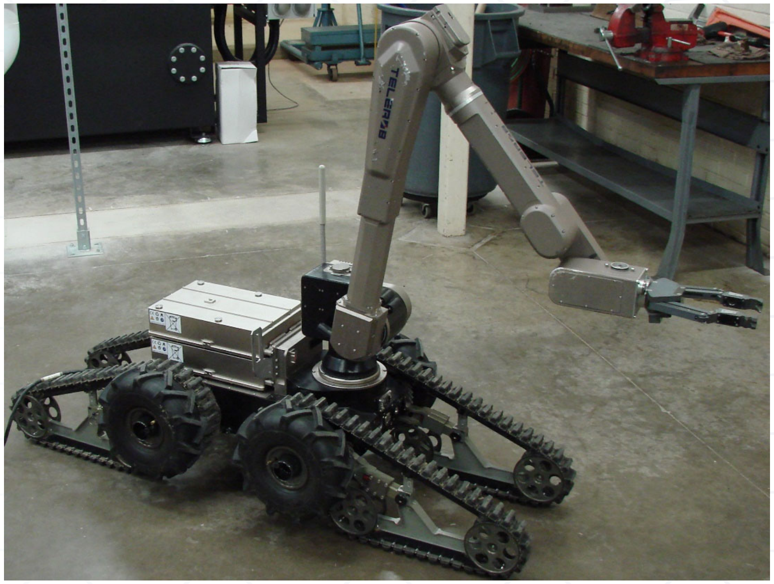
- Trackbase width 15.7 in
- Total weight 195 lbs
- Arm weight 65 lbs
- Battery weight 20 lbs
- Six axis robot for manipulation of repair tools
- Tracked system
- 82 lbs with 18in 30lbs at 60”
- Quick change interface enables rapid end effector changes
- Interfaces with PSU software
- Tethered or remote control

Utilities required:

- 5 hrs run time per batteries
- 2 batteries for system

Status:

- PSU/ARL has Telebor robot



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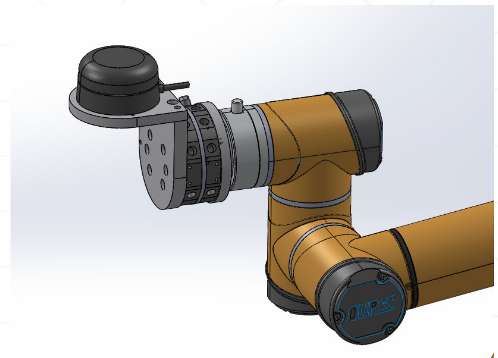
End-Effectors

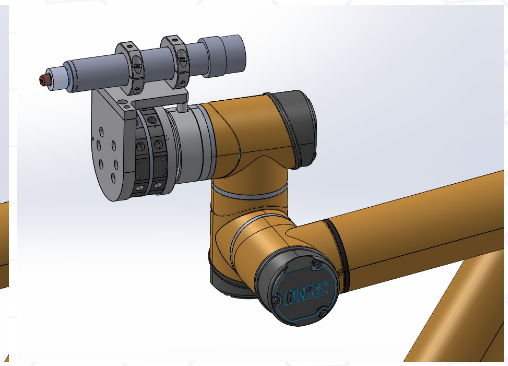
- **Surface Definition/Inspection**
  - **HD Video**
  - **LIDAR**
  - **Dynamic Surface Following**
- **Surface Preparation**
  - **Grit Blast**
  - **Plasmablast**
  - **Laser Ablation**
  - **Grinder/wire wheel**
- **Metal Deposition**
  - **Cold Spray**
  - **Laser**
  - **Wire arc**
- **Inspection**
  - **Ultrasonic**
  - **Eddy Current**
  - **HD Video**
  - **IR Camera**
  - **Gas Sensors**

1. Camera

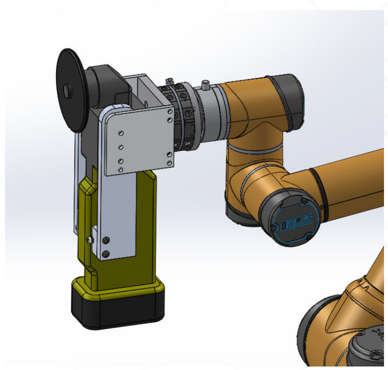
2. LIDAR Scanner



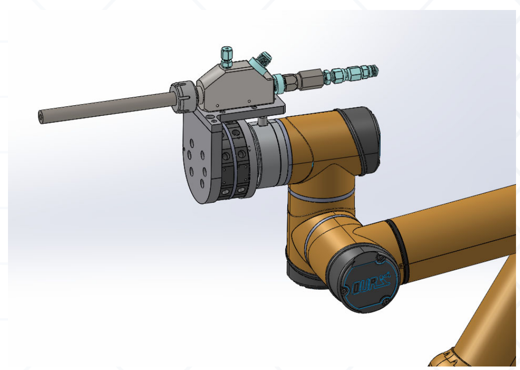
3. Plasma Blast



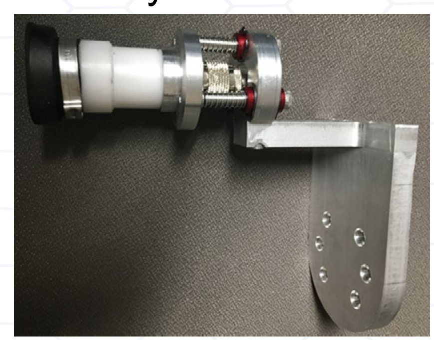
4. Grinder



5. Cold Spray



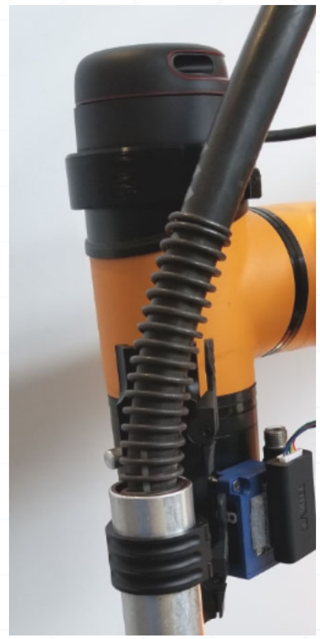
6. Ultrasonic / Eddy Current

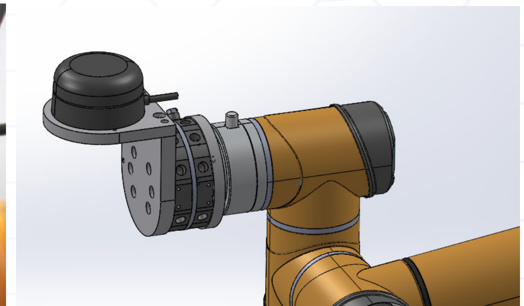


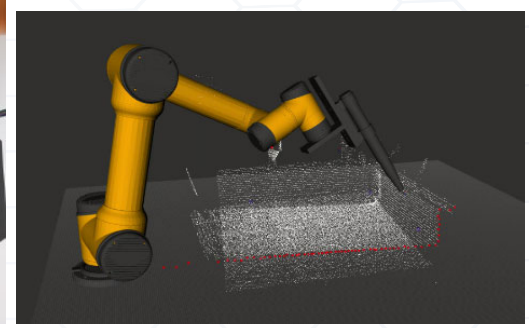
High Definition Video/LIDAR Scanner

Equipment:

- **LIDAR scanner generates point cloud map of workspace for robot path planning**
- **LIDAR scanner mounted to robot**
- **High definition video**







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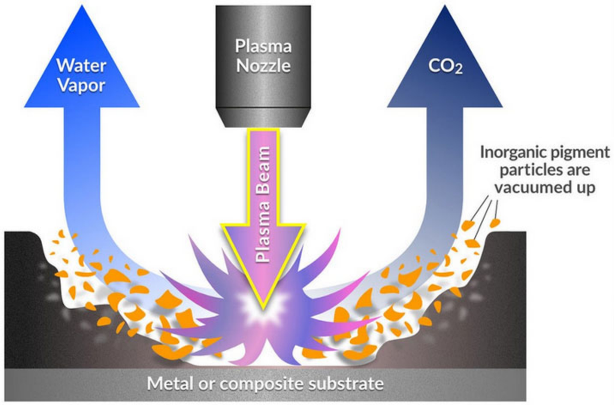
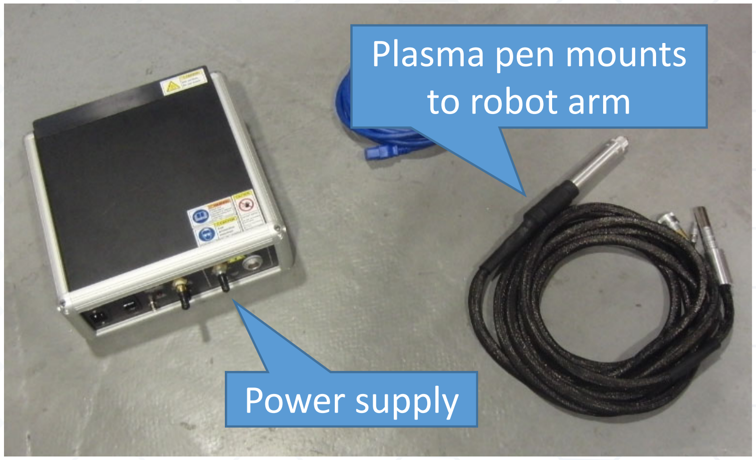
Plasma Blast

Equipment overview:
- **Removes coatings without the use of abrasive media or chemicals**
- **Supplied by Atmospheric Plasma Solutions**

Utilities required:
- **Compressed air**
- **240VAC power**



https://apsplasma.com/coating-removal/

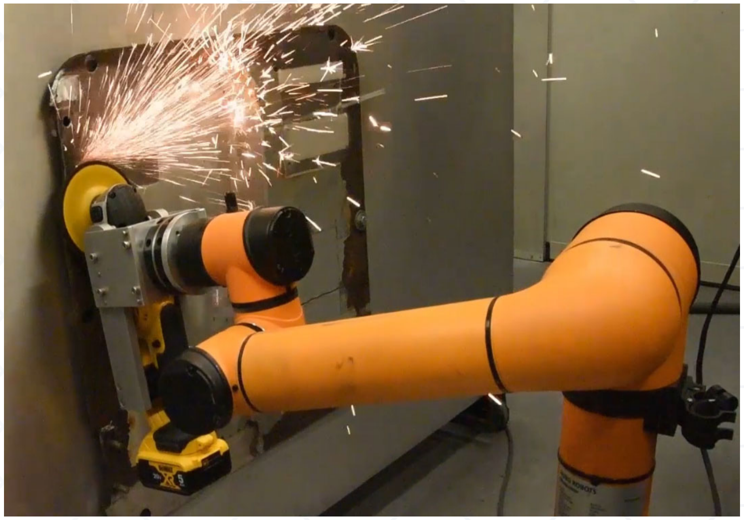


Grinder

Equipment overview:
- Grinder used for additional surface preparation before cold spray
- Uses COTS grinder modified to be actuated with robot wrist motion
- Supplied by GI^2 Technologies
- Designing new grinder system with compliant mount

Utilities required:
- None – powered by 24V battery

Grinder End Effector



Cold Spray

Equipment overview:
- Dragon Fly
  - Meets man-portable requirements
- Raptor
  - Shop
  - Dockside

Utilities / supporting hardware required:
- 480VAC 3-phase power Compressed nitrogen
- Portable glovebox / spray enclosure - in design/fabrication
- Portable dust collector – available
- Powder storage and disposal
- Characterization equipment

VRC Dragon Fly

VRC Raptor

Ultrasonic / Eddy Current Inspection

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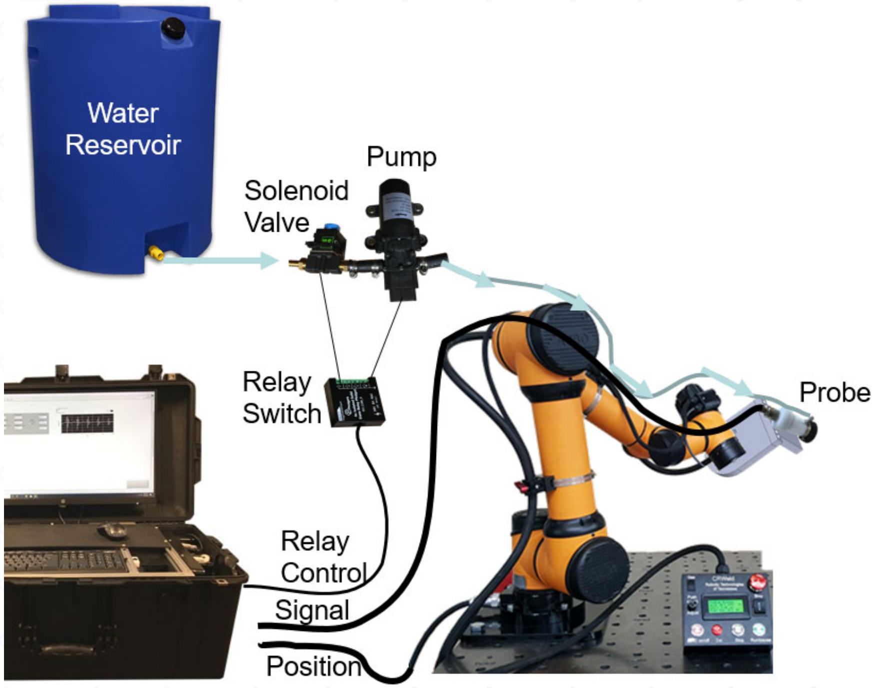
Equipment overview:

- Ultrasonic and eddy current inspection PSU/ARL partnering with Box Elder Innovations

Utilities required:

- 110VAC
- Water reservoir (TBD if this will be necessary)



Ultrasonic / Eddy Current Inspection

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Equipment Transport

- **All repair equipment and supporting hardware needs to fit in 20’ shipping container (Conex box)**
- **Preliminary layout shown**
- **Size constraints need to be considered in equipment design**
- **Nitrogen generator**
- **Air Compressor**

Status:

- **PSU/ARL to work with SEA BOX to determine scope and lead time of container modifications**

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Additional Cold Spray Activity

Helium Recovery System Operational August 2021

ONR Solid State Structural Repair (S3R)

Training for NAVSEA

- **In-class**
- **Hands-on**
- **Raptor**
- **Dragon Fly**

SPEE3D – Lightspeed for casting replacement

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Cold Spray Technology Transition Time Line

Cold Spray Facility Implementation

- Jan 2019 – Shipyard Implementation Starts
- Jun 2020 Norfolk performs first repair
  - 12 different repair performed
- Pearl Harbor system operational
- USMC Albany, GA system operational
- Portsmouth has Raptor System
- System Planned Puget Sound system in FY22
- Mar 2021 Shipboard Mobile Automated Repair System (MARS) Demonstration
- Jun 2021 Cold Spray Pop-up Cell Norfolk VA, government leased, contractor operated
- Sep 2021 Pop-up Cell Port Orchard, WA
- Dec 2021 Shipboard Cold Spray Repair

Process & Procedures

- Jun 2019 – Uniform Industrial Process Instruction (UIPI) –allows repair approval at shipyard
- Qualified Spray Procedures for each repair can be used by certified facility
- Mar 2021 ARL/PSU develops Navy approved training for operator certification
- Mar 2021 ARL/PSU develops standard procedures for QSP testing
- Aug 2020 ARL/PSU certified NAVSEA Cold Spray Facility
- Jul 2021 VRC certified

Funding

- Total ManTech Funding for Cold Spray Technology -$ 4M
- Leveraged Funding – OSD/Army, Marine -$11.8M
- Estimated Cost Avoidance $50M-$100M
- ONR Solid State Structural Repair (3SR) -$1.1M
- Additional Funding for Cold Spray
- FY19 NNDA Congressional Budget for “support of the development of advanced additive technologies for the sustainment of Navy assets, including cold spray.” $15.6M
- ARL/PSU received $3M

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Acknowledgements & Questions

NAVSEA
- Janice Bryant
- Jeff Campbell

Shipyards
- NNSY
- PHNSY
- PSNDY
- PNSY

NSWCs
Marines
NAVAIR
VRC