Vision-Based Defect Segmentation and Geometric Measurement for Real-Time Quality Monitoring in Friction Stir Welding

Present by

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MAXBATT – Battery Production, Products and Systems

- Scope and objective
  - MAXBATT focuses on sustainable battery production and competence development in West Sweden and Sweden in general.
- Objective
  - The project aims to strengthen Swedish industry and research in the rapidly growing international battery market. The objective is to create a national center for battery production where academia and industry can collaborate on research, innovation, and technology development for battery-powered products and systems.
- Partners
  - Högskolan Väst
  - Chalmers University of Technology
  - University of Skövde
- Financing
  - Region Västra Götaland (VGR)
- Project duration
  - 2025 – 2027

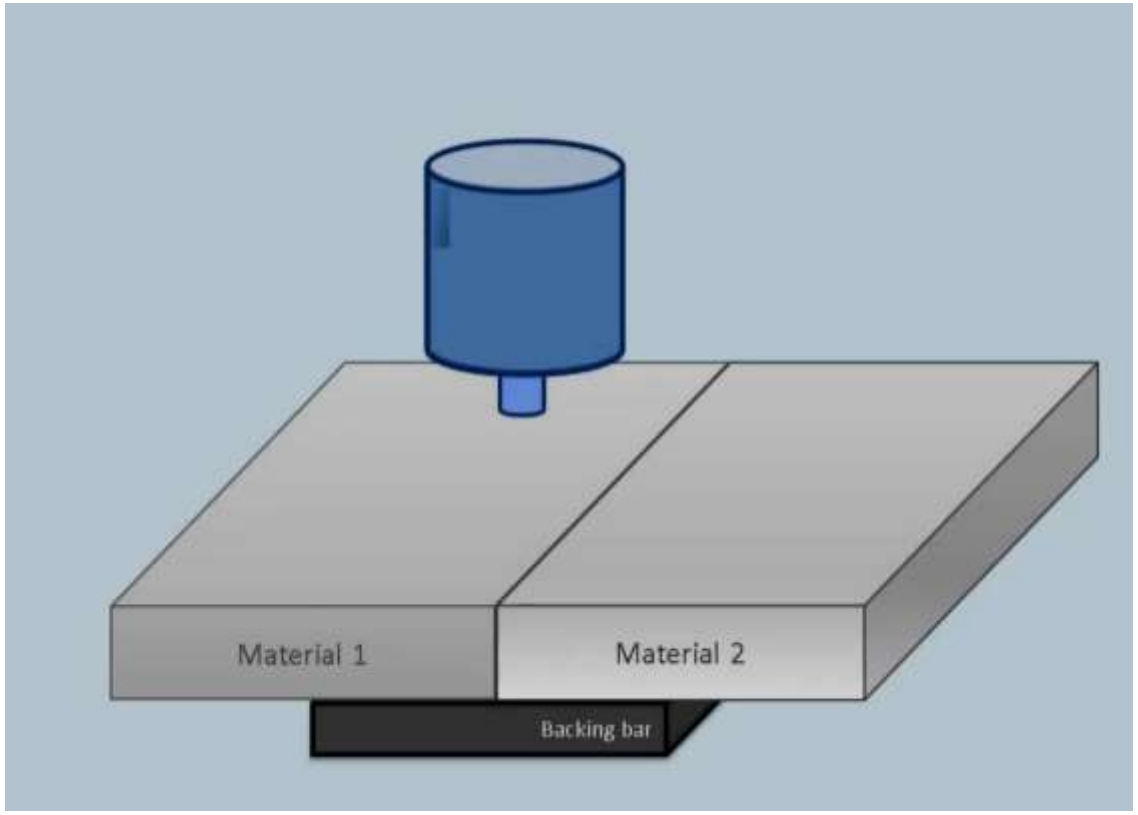
COMEJOIN – Novel Sustainable Joining Technique for Metal and Composite's Structure

- Scope and objective
  - COMEJOIN focuses on developing a green and sustainable joining technique using Friction Stir Welding (FSW) for high-strength aluminium materials used in airframe structures.
- Objective
  - The project aims to reduce the use of mechanical fasteners and screws by replacing conventional joining methods with lightweight, robust, and cost-efficient FSW solutions. Another important objective is to develop an online process monitoring and control system to ensure strong and reliable weld joints.
- Partners
  - Högskolan Väst
  - SAAB
  - DOF Tools AB
- Financing
  - Vinnova
- Project duration
  - 2025 – 2028

Outline

- Background
- Current challenges
- Plans
- Results
- Remaining challenges

Friction Stir Welding

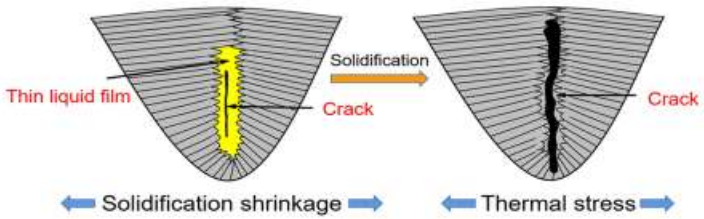


- Solid state process
- Eliminate solidification defects
  - ❑ crack
  - ❑ porosity
- Eliminate coarser microstructure

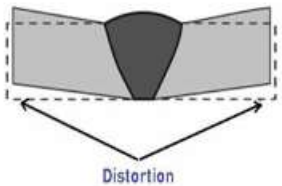
Sustainability benefits of FSW

Comparison with conventional fusion welding process

No melting



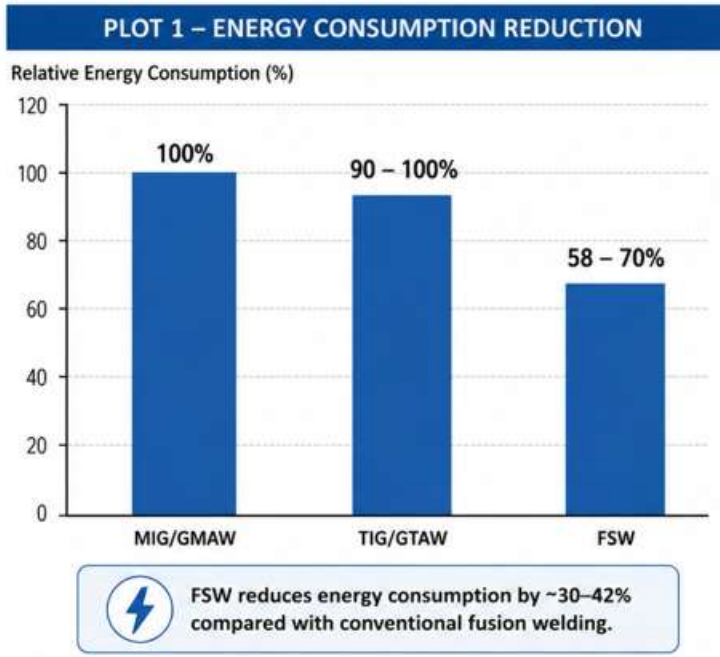
The solidification crack of the 6XXX series Al alloy

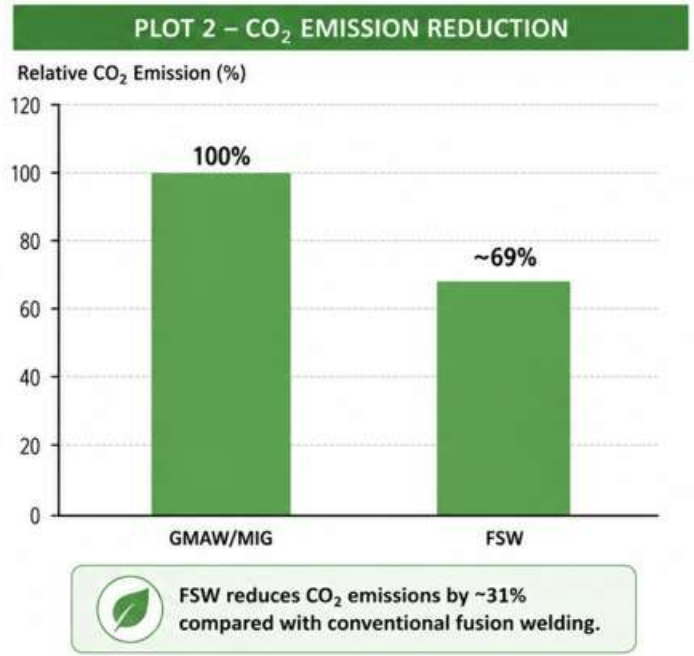


Low distortion and minimal emission

No shielding gas for most of the materials or filler materials needed

Manufacturing Process	Typical Rejection Rate (%)
Conventional welding (MIG/TIG)	3–7%
FSW	<1% to 2%
Casting or stamping defects	2–6%



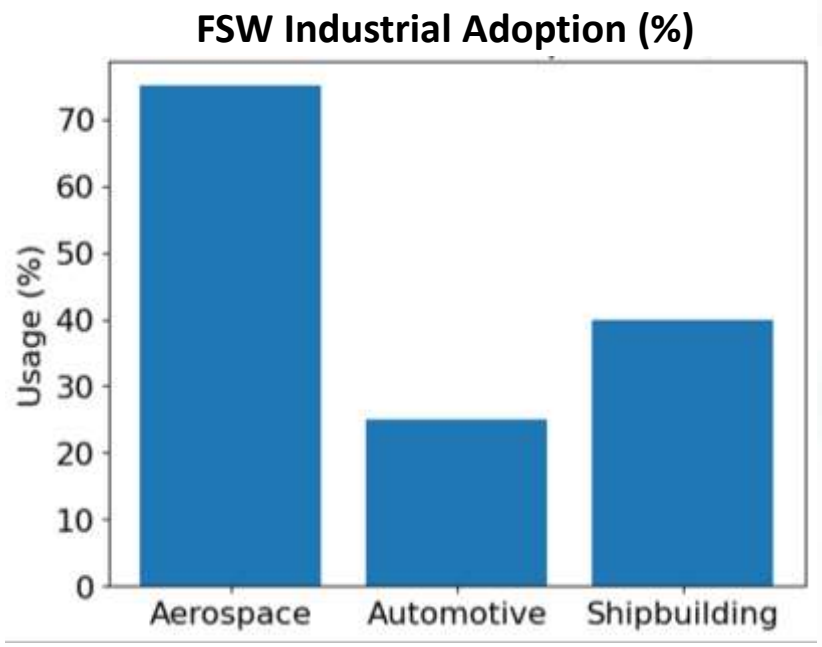


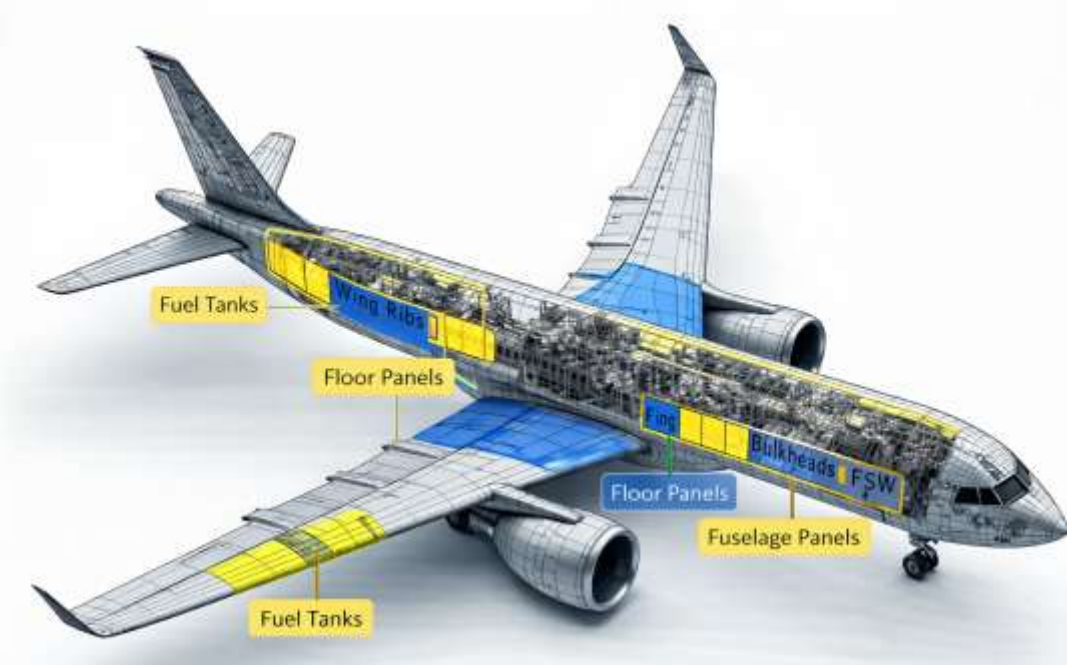
Values are normalized with conventional fusion welding (MIG/GMAW) = 100%

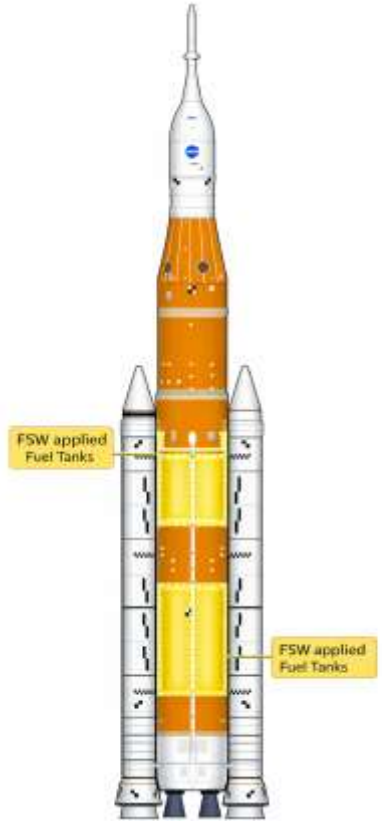
[2] Shrivastava, A., et al., Environmental and economic assessment of friction stir welding for aluminum alloys, CIRP Journal of Manufacturing Science and Technology, 2015, 8, 1-10.
[3] TWI - Friction Stir Welding of Aluminium Alloys, Technical Report, TWI Ltd., UK.
[4] Magudeeswaran, G., et al., Sustainability assessment of welding strategies in transportation manufacturing, Sustainability, 2023, 15(11), 8650.

Key Takeaway:
FSW is more sustainable joining process due to lower energy consumption , reduced CO_2 emission, no filler materials and no shielding gas requirement

Industrial application

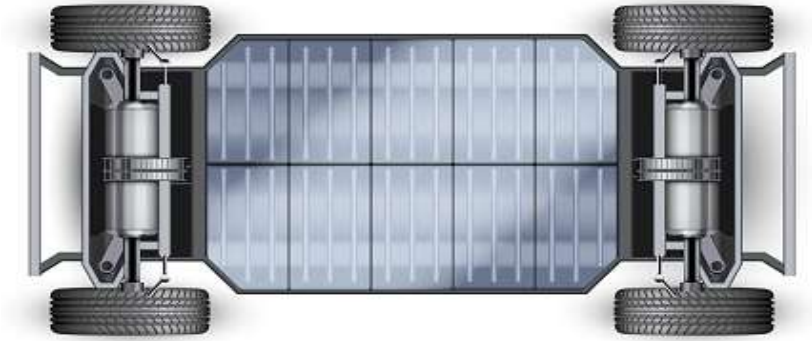






Pefered manufacturing liquid hydrogen and oxygen fuel tanks for space launchers (e.g., NASA's Artemis SLS rocket and SpaceX's Falcon Heavy) because it creates leak-proof, high-strength joints.

Automobile body frame



Battery tray on EV cars

[5] TWI, [6] NASA, Space Launch System (SLS) Manufacturing Overview, NASA, 2020, [7] SpaceX, Falcon 9 User Guide, Space Exploration Technologies Corp., 2021.

Challenges

Process Challenges:

- Sensitive to parameters (force, rpm, Travel speed)
- Narrow process window

Quality Issues:

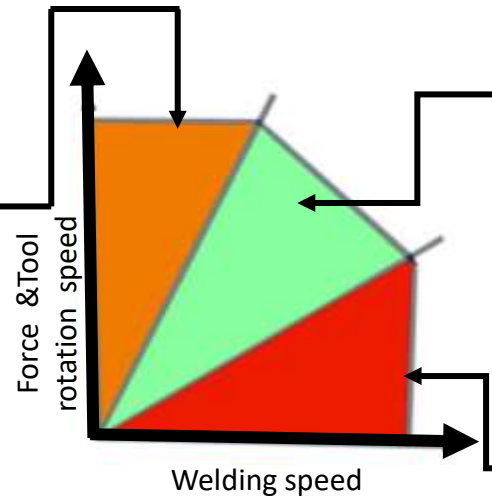
- Surface defects (flash, roughness, voids)

Industrial Limitation:

- No real-time quality prediction
- Trial-and-error parameter selection

Hot Weld (over stirring)

- High heat generation
- The material rotates more under the shoulder than in the weld bottom
- Possible defects: Wormhole-like defects (nugget collapse) due to unstable flow



Stable Conditions:

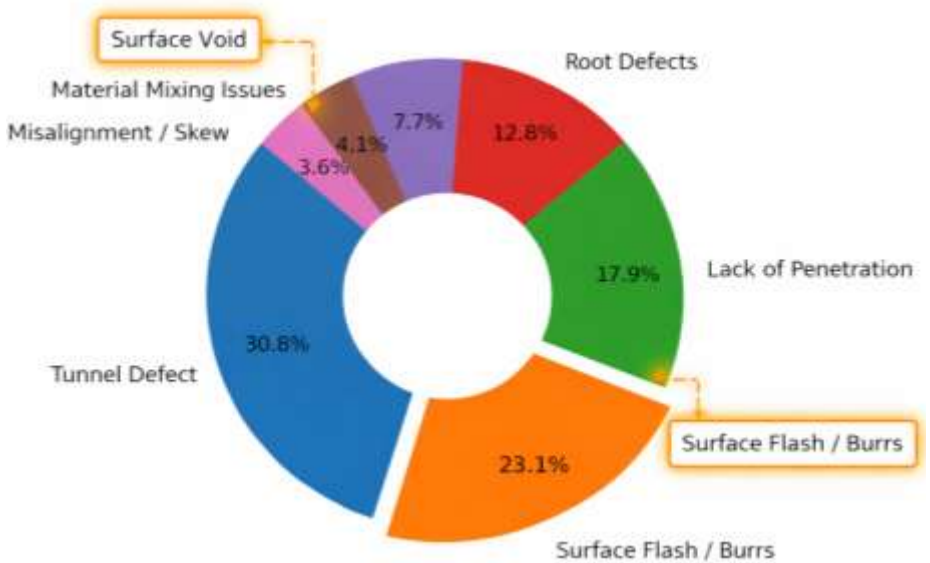
- The boundary layer maintains a stable, controlled material flow
- A sound and defects-free weld

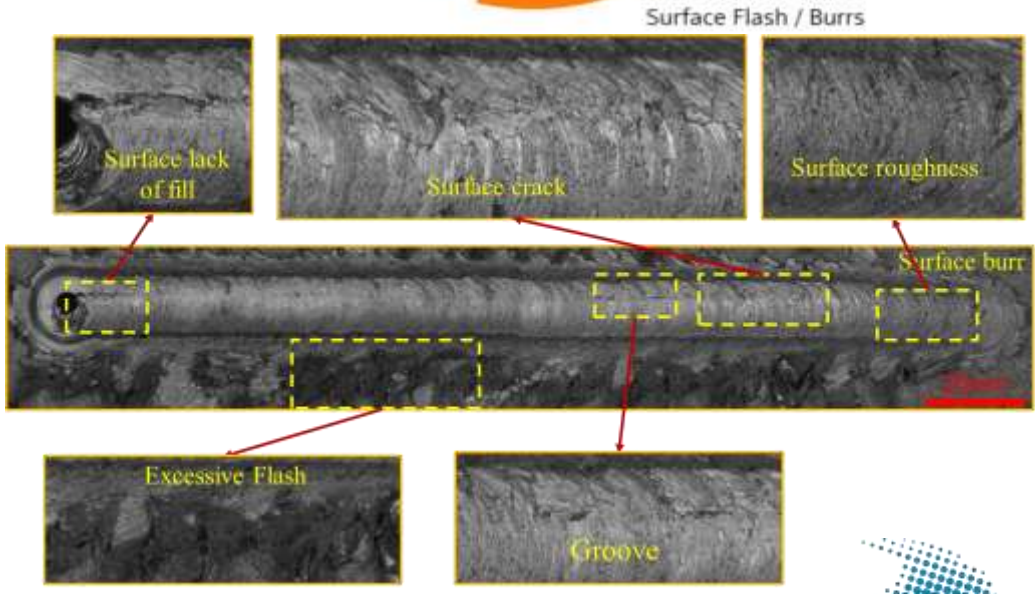
Cold Weld:

- Lack of material feeding at the weld bottom
- Leads to weak joints and defects

Correlation between process parameters with material flow and defect formations

FSW Defect Distribution





AI-Based Real-Time Monitoring Framework for FSW

Proposed Strategy to Overcome the Challenges

KEY CHALLENGES

NARROW PROCESS WINDOW
FSW is sensitive to parameter variation (force, rpm, travel speed).

DEFECT FORMATION
Defects such as lack of penetration, voids, flash, and surface irregularities occur.

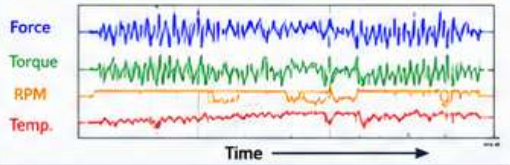
NO REAL-TIME QUALITY PREDICTION
Conventional methods are offline, time-consuming and costly.

HIGH INSPECTION COST AND TIME
Manual inspection and post-weld testing lead to higher cost and delays.

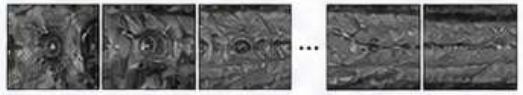
PROPOSED AI-BASED REAL-TIME MONITORING FRAMEWORK

1. **FSW PROCESS**
Aluminum plates joined using Friction Stir Welding.

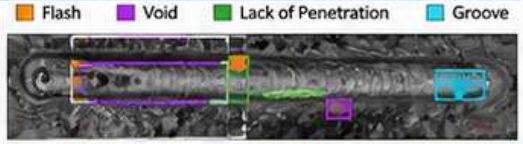
2. **DATA ACQUISITION**
HDR Camera + Process Sensors (Force, RPM, Torque, Temperature) with high-speed synchronized acquisition.



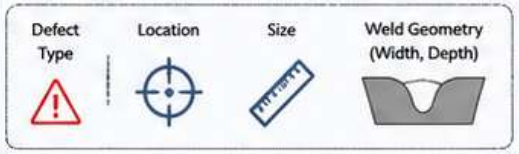
3. **FRAME SYNCHRONIZATION & PREPROCESSING**
Sensor–vision data alignment and data preprocessing for robust analysis.



4. **AI-BASED SEGMENTATION MODEL (YOLOv8-seg)**
Detects and segments defects and weld features in real time.

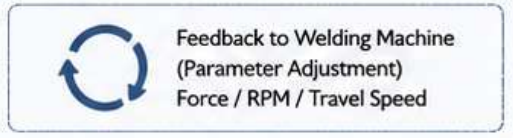


5. **DEFECT DETECTION + WELD GEOMETRY EXTRACTION**
Identifies defect type, location, size and extracts key weld geometry.



6. **REAL-TIME QUALITY PREDICTION & DECISION SUPPORT**
Outputs quality index and alerts for immediate action.

7. **FUTURE CLOSED-LOOP CONTROL**
Real-time feedback to adjust process parameters and ensure consistent weld quality.



INDUSTRIAL BENEFITS

REAL-TIME MONITORING
Instant defect detection and quality assessment during welding.

EARLY DEFECT DETECTION
Detects defects at early stage and prevents propagation.

REDUCED REJECTION RATE
Improved first-pass yield and higher weld quality consistency.

REDUCED INSPECTION COST & TIME
Minimizes manual inspection and post-weld testing.

SUSTAINABLE MANUFACTURING
Lower rework, less material waste, and reduced energy consumption.

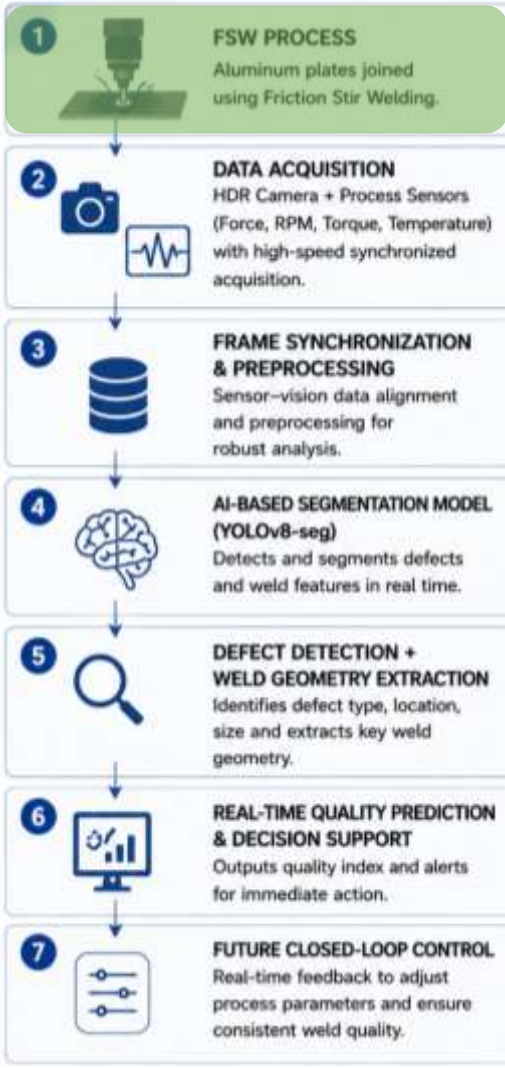
DATA-DRIVEN PROCESS OPTIMIZATION
Enables continuous improvement and knowledge generation.

Experimental setup

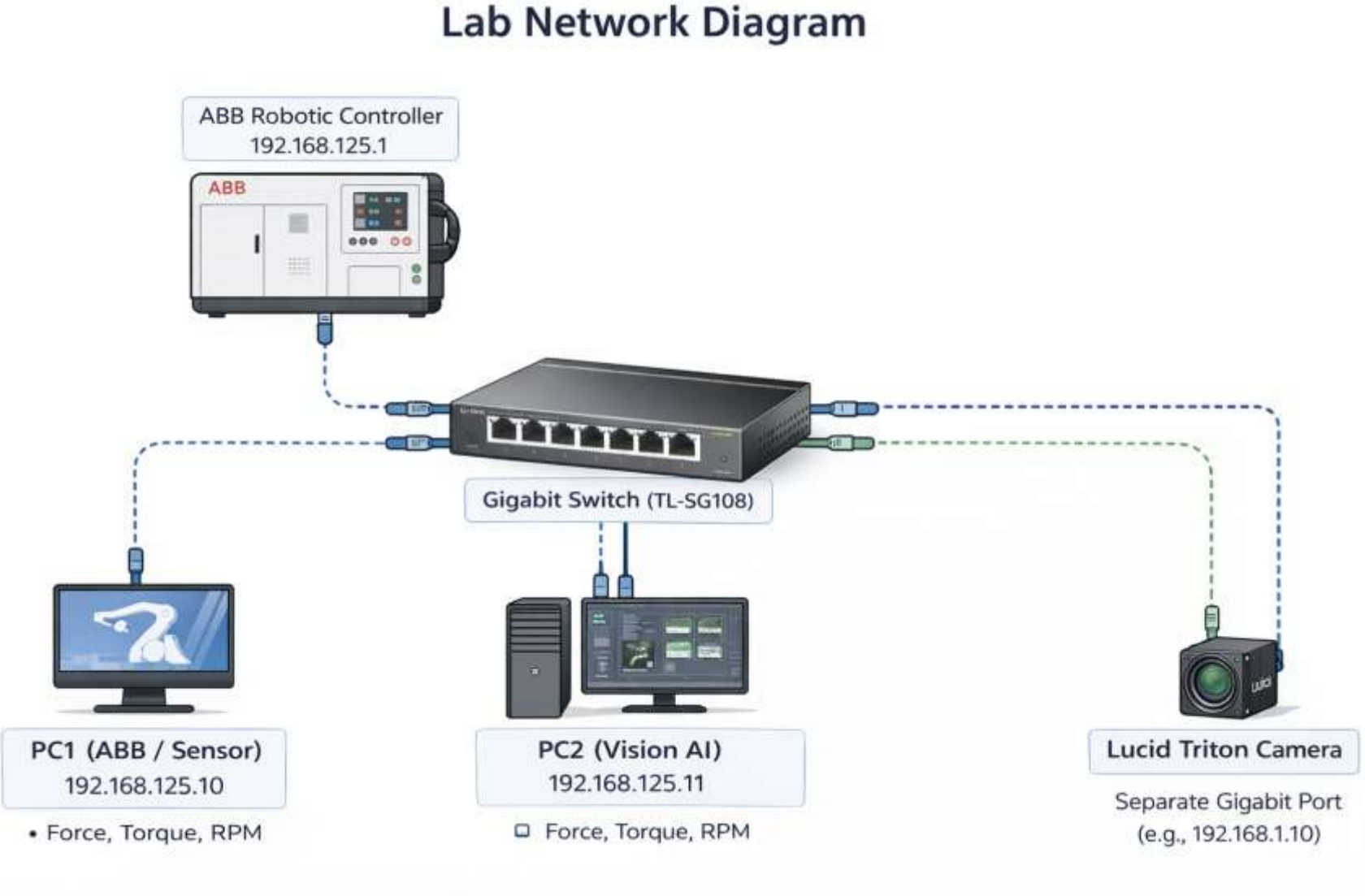
Force, torque sensor, RPM

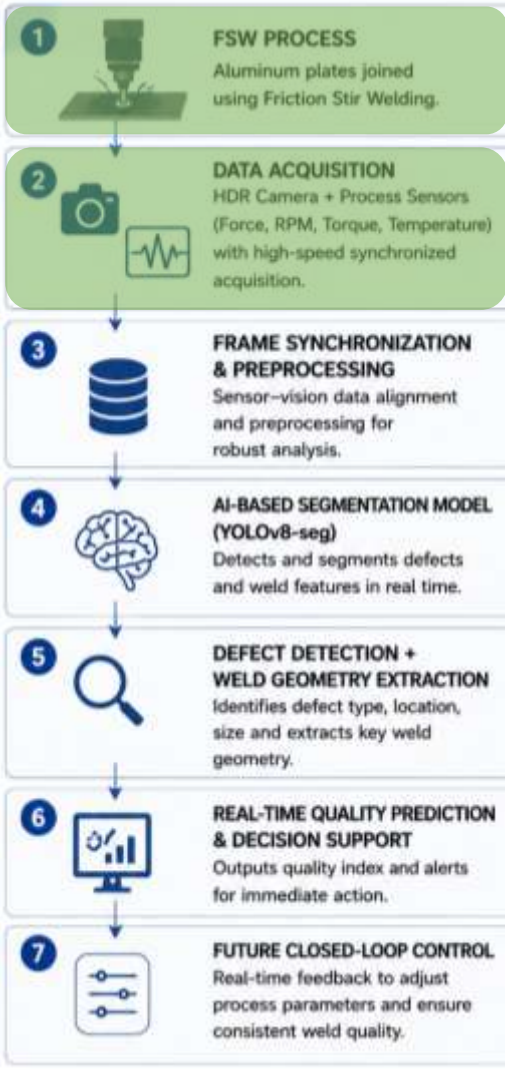
Vision Sensor TRI054-CC
- High speed imaging
- Weld surface observation
- Real time video acquisition

Setup Overview

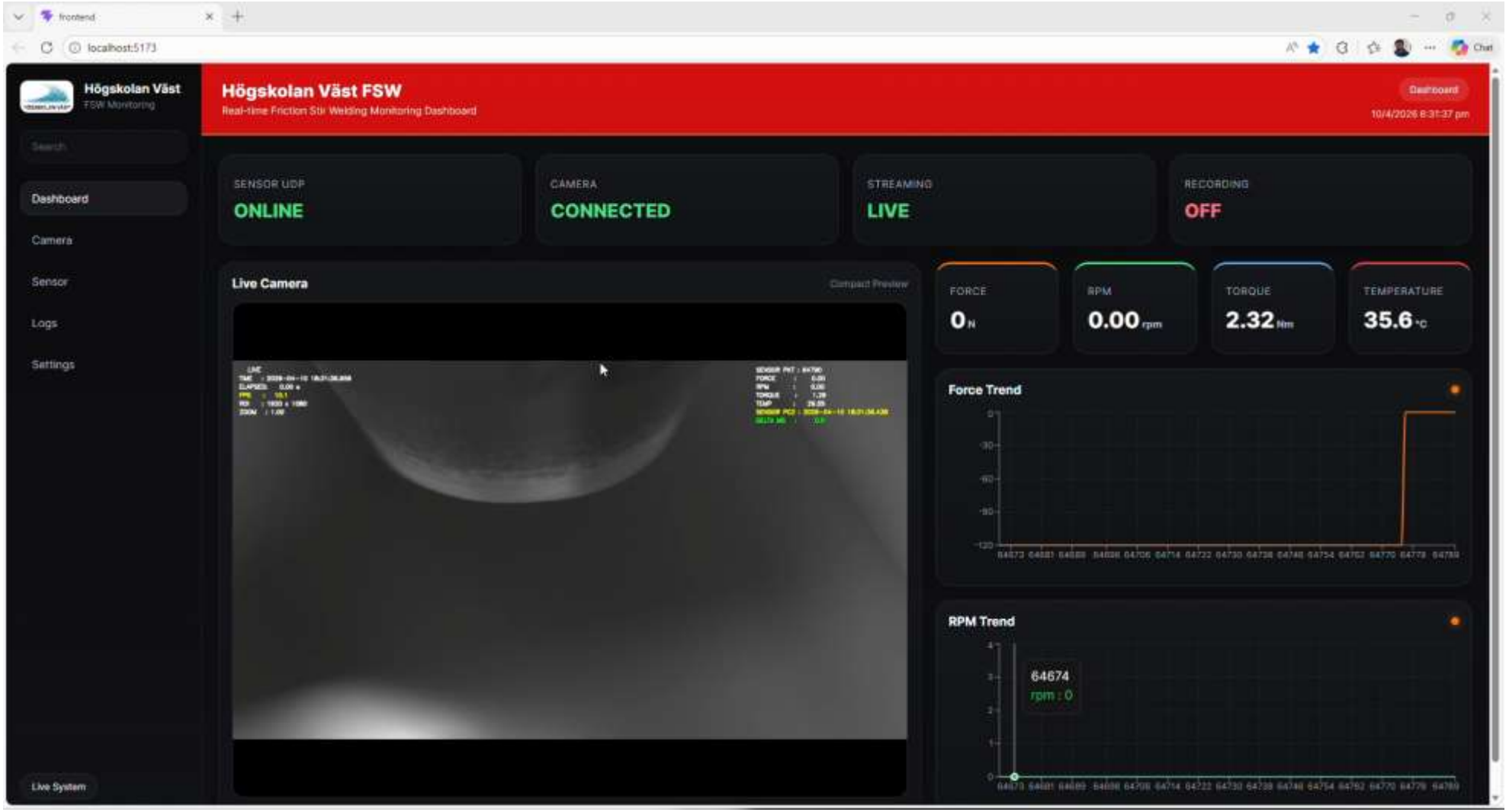


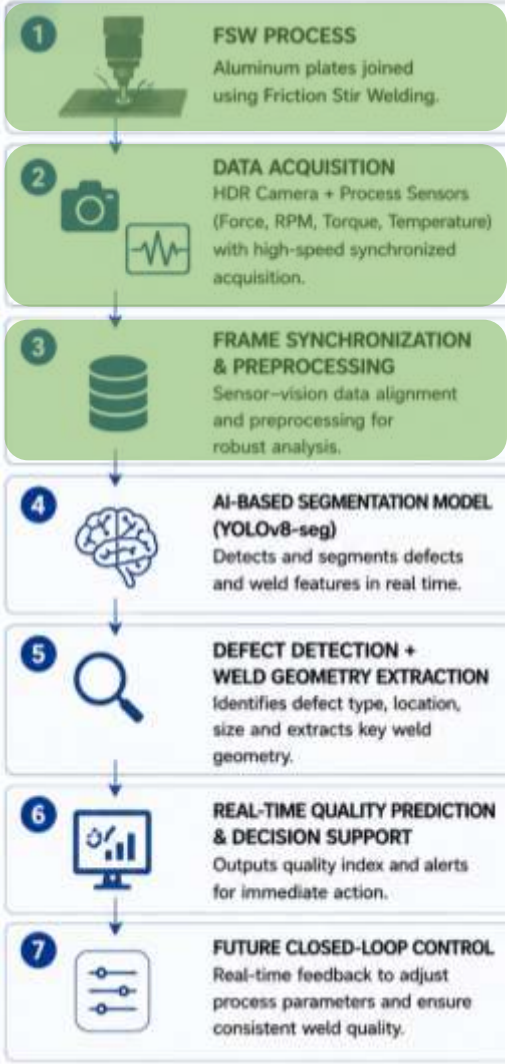
Integration of sensors





Real time monitoring system - Dashboard

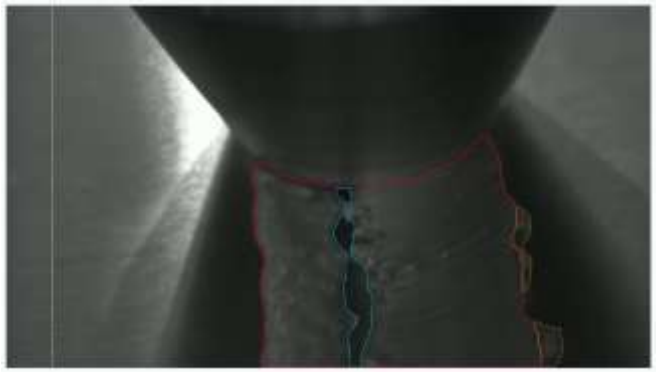




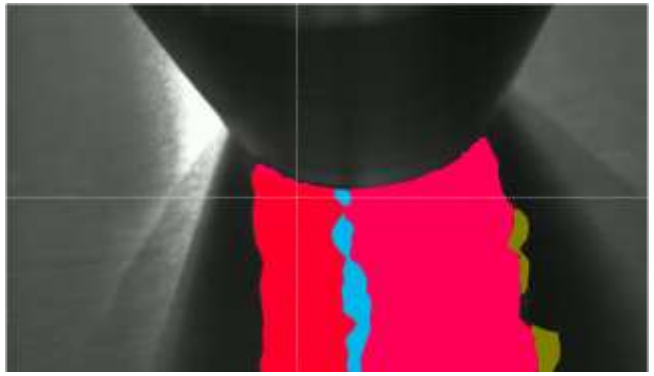
Key features

- ✓ Synchronized multi—sensor data acquisition
- ✓ Real time process monitoring
- ✓ Support closed –loop optimization

AI-based segmentation model



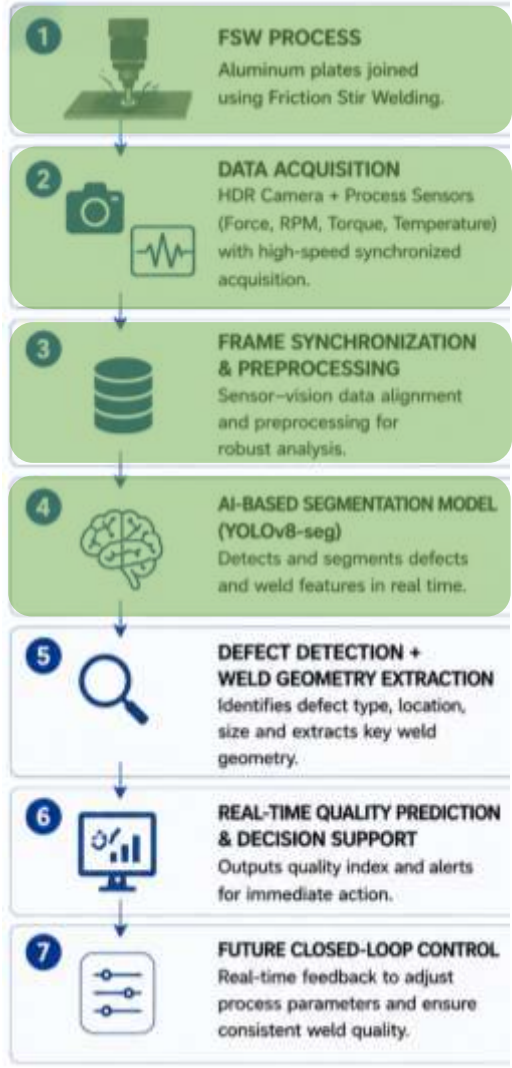
Annotation (Roboflow)



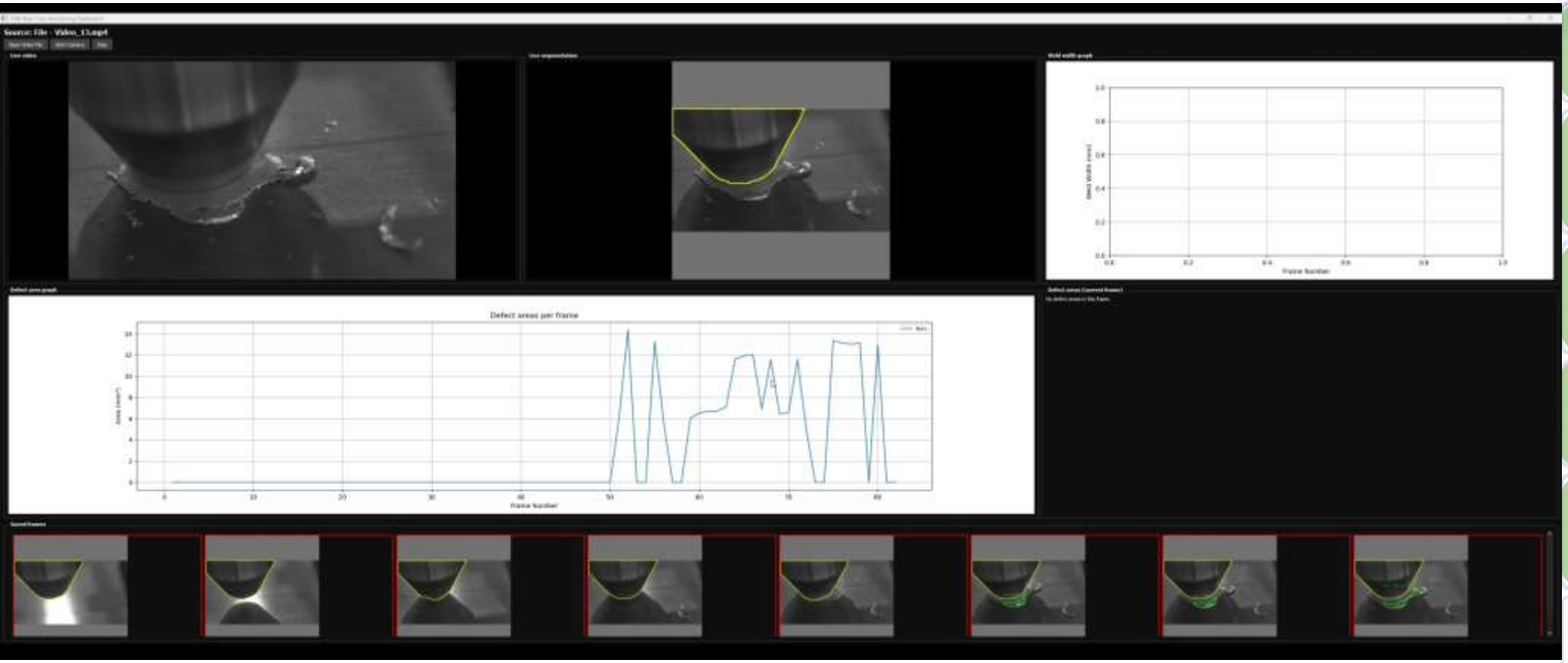
Key features

- ✓ Real time multi class defect detection and segmentation
- ✓ 30 Frames per seconds

AI-based defect segmentation model



Defect segmentation + Weld geometry extraction



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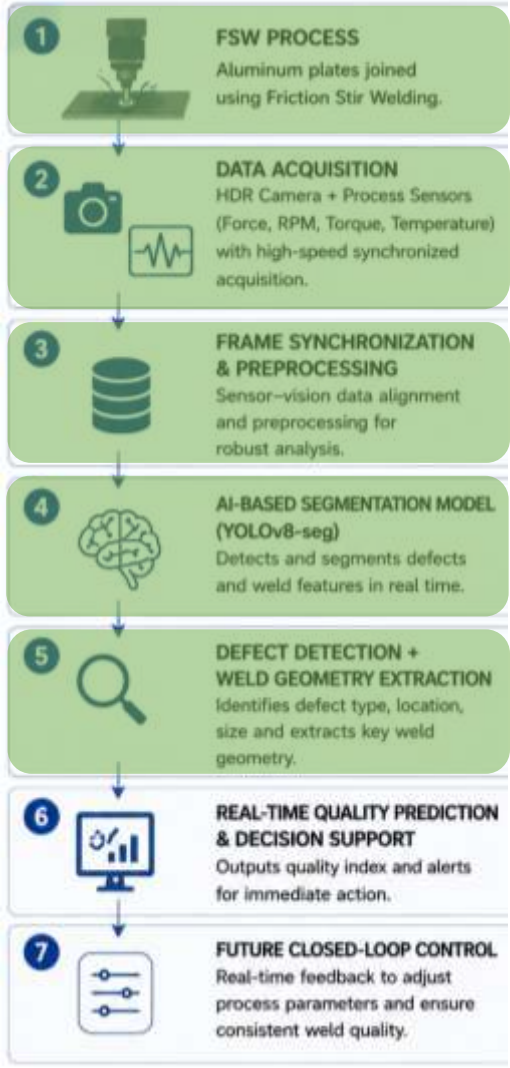
Loganathan N, Andersson J, Patel V. Machine vision defect segmentation and geometric measurement for real time quality monitoring in friction stir welding. J Manuf Syst 2026;85:175–92. https://doi.org/10.1016/j.jmsy.2026.01.007.

Conclusion

Proposed AI-based Monitoring framework successfully Demonstrated:

- Real-time surface defect segmentation for Friction Stir Welding
- Simultaneous weld geometry extraction and quality assessment
- Robust monitoring under industrial welding conditions using HDR imaging
- High segmentation performance with lightweight YOLOv8n-seg architecture
- Real-time inference capability (~25 FPS) suitable for shop-floor deployment
- Reliable geometric measurement with sub-millimeter accuracy
- Potential to reduce manual inspection, rejection rate, and production cost
- Strong potential for sustainable and intelligent manufacturing applications



Future Directions

Technical Improvements

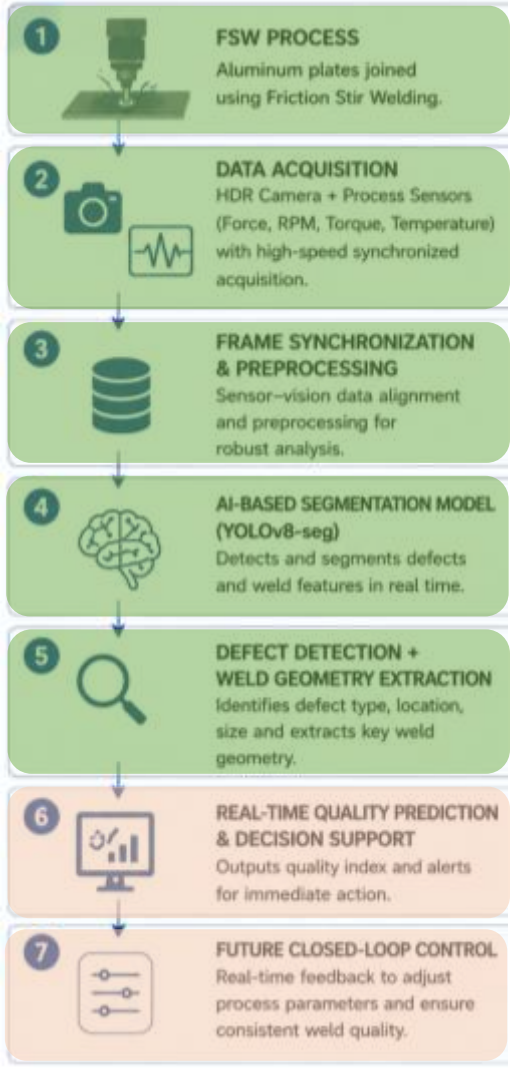
- Multi-sensor fusion using force, torque, RPM, and temperature signals
- Development of temporal AI models (LSTM/GRU/Transformer) for defect prediction
- Adaptive process parameter optimization using AI feedback

Industrial Deployment

- Real-time closed-loop process control
- Edge-AI deployment for low-latency monitoring
- Large-scale industrial validation under different materials and welding conditions
- Integration with Industry 4.0 and digital manufacturing systems

Long-Term Vision

- Autonomous intelligent FSW system with self-correcting capability
- Predictive quality monitoring and smart manufacturing analytics
- Sustainable manufacturing through reduced waste, rework, and energy consumption



Thank You All