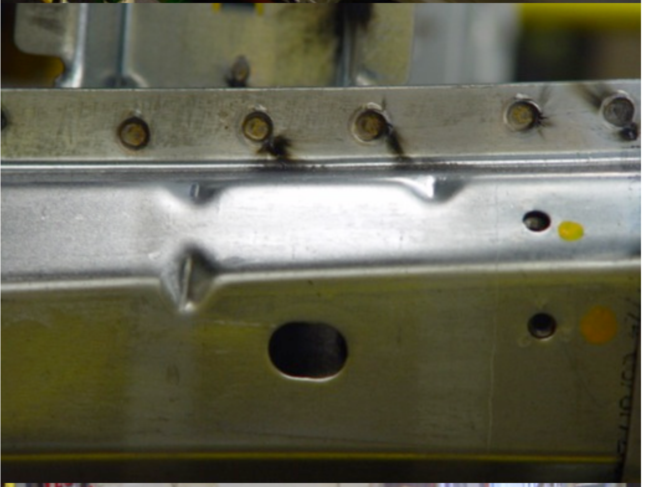

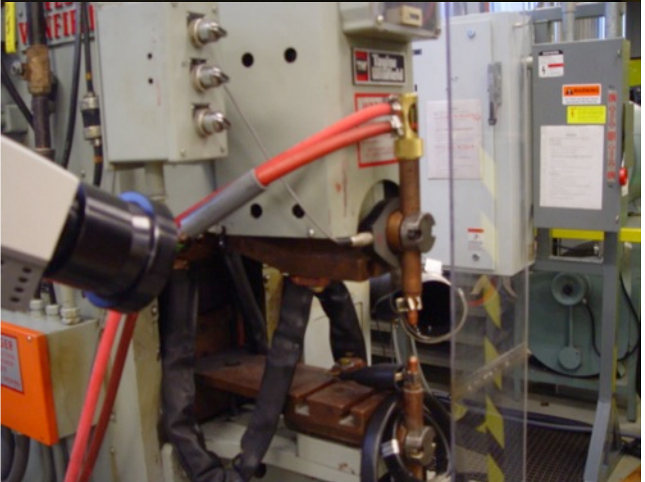

On-Line Weld NDE with IR Thermography

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Oak Ridge National Laboratory

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Project ID # LM054

Oak Ridge National Laboratory

Overview

Timeline

- Start: June, 2008
- End:
  - Phase I: June, 2010
  - Phase II: June, 2013
- Percent complete:
  - Phase I: 100%
  - Phase II: 90%

Budget

- Total project funding
  - DOE share: $1,297K
  - Industry in-kind share: $210K
- Funding for FY13: $0

Barriers

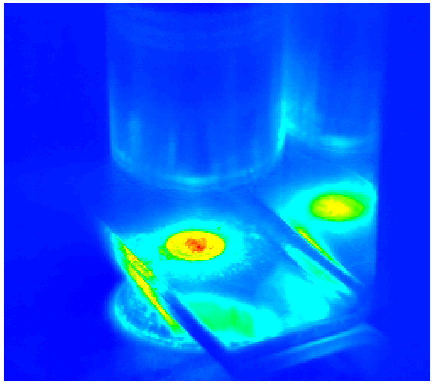
- Barriers addressed
  - Non-destructive techniques for the evaluation of the integrity of joints made with lightweight materials.

Partners

- Interactions / collaborations
  - Chrysler, Ford, and GM
  - ArcelorMittal
  - AET Integration Inc.
  - AMD NDE Steering Committee
  - A/SP Joining Team
- Project lead
  - Oak Ridge National Laboratory

Project Objective

- Develop an online non-destructive evaluation (NDE) technology for resistance spot weld (RSW) quality monitoring based on infrared (IR) thermography that can be adopted reliably and cost-effectively in high-volume auto production environment for weld quality assessment
  - An expert system including hardware and software
  - Capable for both **post-weld** and **real-time** on-line weld quality inspection
  - **Weld quality database** covering wide range of weld configurations (materials, thickness, coatings) common in auto-body structures



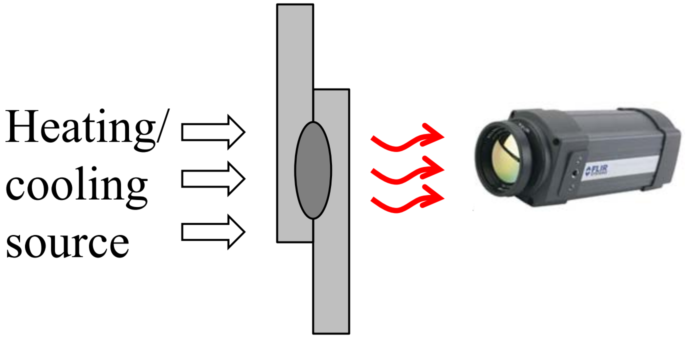
Relevance: Technology Gaps that This Project Addresses

- Today industry primarily relies on destructive testing of spot welds
  - Labor intensive, slow and expensive (rework and scraps)
  - Less effective for advanced high-strength steels, aluminum and other lightweight materials

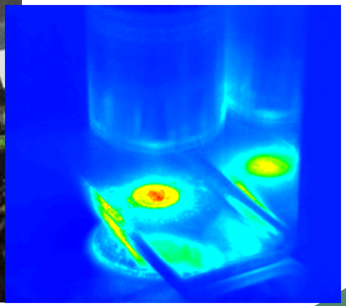
- The destructive evaluation of weld quality is based on statistics and random sampling of small portion of as-welded auto-bodies.
  - Impossible to inspect 100% of the welds
  - No efficient method to immediately send feedback to the production lines

Principles and Past Attempts on IR Thermography based RSW Inspection

- Postmortem NDE
  - Mostly limited to lab trials
  - Heating/cooling source
  - IR thermography is highly sensitive to surface condition and environment interference
    - Requiring painting of the weld surface (impractical in auto production line)
- Real-time NDE
  - Utilize the heat during welding
  - No successful attempts
- Advantages of IR:
  - Non-contact,
  - Non-intrusive,
  - Whole field imaging, and
  - Fast



Unknown & non-uniform surface condition (usually low emissivity)



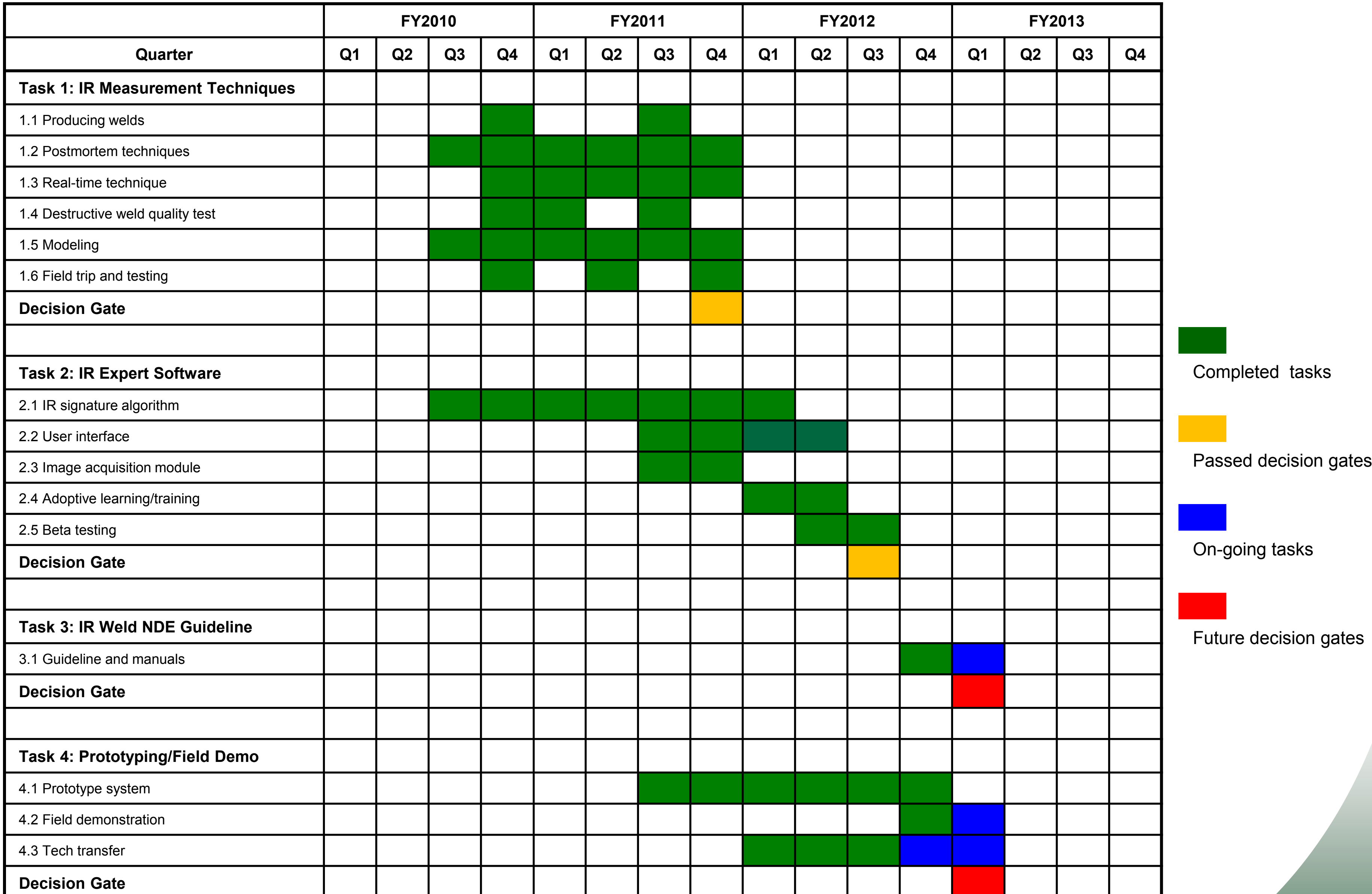
Project Approach/Strategy

- Phase I Concept Feasibility
  - Demonstrate the feasibility to detect various weld quality/defect attributes
    - Post-weld inspection must overcome critical shortcomings of past attempts
    - Real-time inspection as weld is being made (new approach)
- Phase II Technical Feasibility
  - Refine and optimize the robust IR image analysis algorithm that can provide quantitative measure of the quality and the level of defect (if any) of spot welds
  - Develop the cost-effective prototype system (hardware and software) operated in high-volume auto production environment
  - Develop a database covering wide range of weld configurations common in auto-body structures

Project Milestones

Month/Year	Milestone or Go/No-Go Decision
Jun-10	Demonstrate feasibility – detection of major weld quality Phase I Go/No-Go Decision (**Passed**)
Nov-10	Produce additional spot welds with different weld quality attributes for different steels, coating, thickness and stack-up configurations (**Completed**)
Feb-11	Modeling of post-mortem inspection to identify quantifiable IR thermal signatures and refine/optimize heating device and procedure (**Completed**)
Apr-11	Confirm the capability of low-cost IR camera (**Completed**)
Dec-11	Develop IR image acquisition module and analysis algorithms module for both real-time and post-weld inspection (**Initial versions completed**)
June-12	Development of expert software and prototype system including image acquisition, user interface, ability to adaptive learning and decision making (**Prototype system developed**)
Dec-12	Evaluate and improve system accuracy (**Completed** with expanded sets of welds)
Jan-13	IR weld NDE guideline (On-going)
June-13	Further improvement and field demo (On-going)

Phase II Tasks and Schedule



Project is expected to complete in 2nd quarter of FY2013 due to later start in third quarter of FY2010

Approach: Weld Quality Metrics

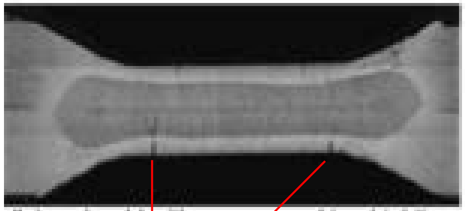
- Ranked by industry advisory committee in the order of importance (high to low)
  - Weld with no or minimal fusion
  - Cold or stuck weld
  - Weld nugget size
  - Weld expulsion and indentation
  - Weld cracks
  - Weld porosity

Most critical

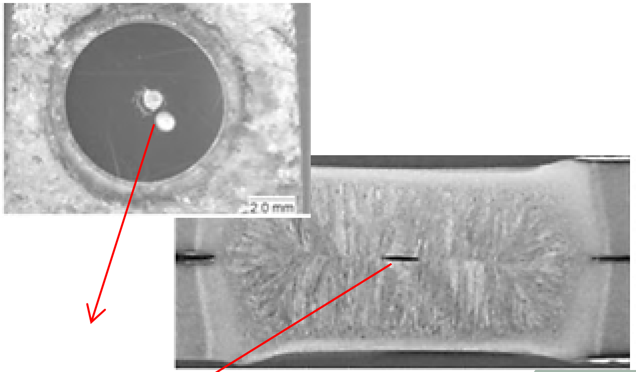
Less critical

Stuck weld (insufficient fusion)

Excessive indentation



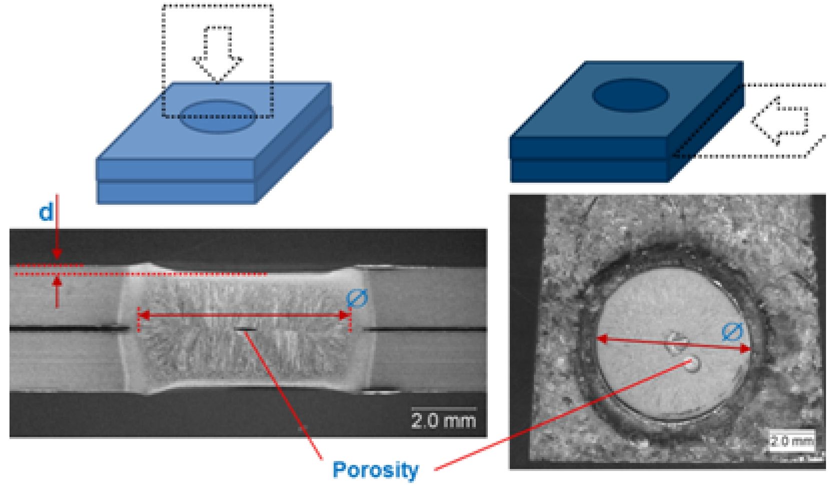
Cracks

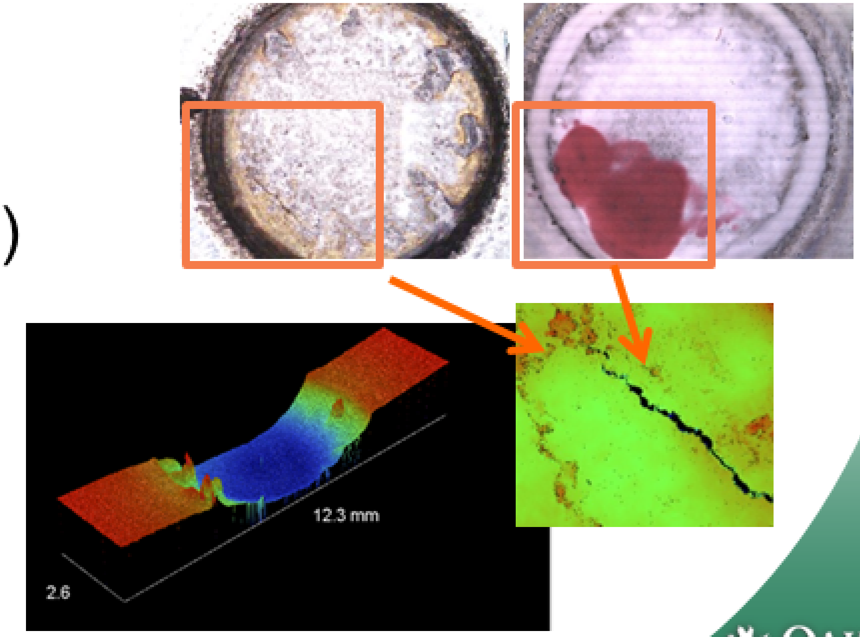


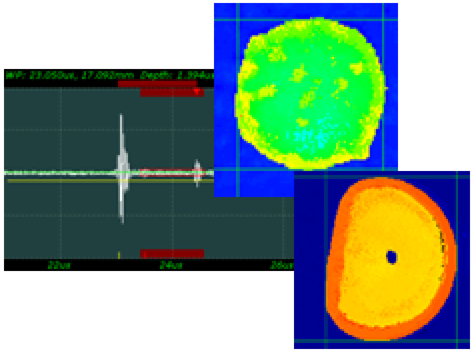
Porosity

Accomplishment: Destructive Examination of Weld Attributes

- Sectioning welds
  - Nugget size and shape
  - Porosity and expulsion
  - Surface indentation
- Dye penetrants
  - Surface cracking
- Surface micro-profiling
  - Surface indentation
  - Surface cracking
- Ultrasonic C-Scan (underwater)
  - Nugget and weld shape
  - Porosity

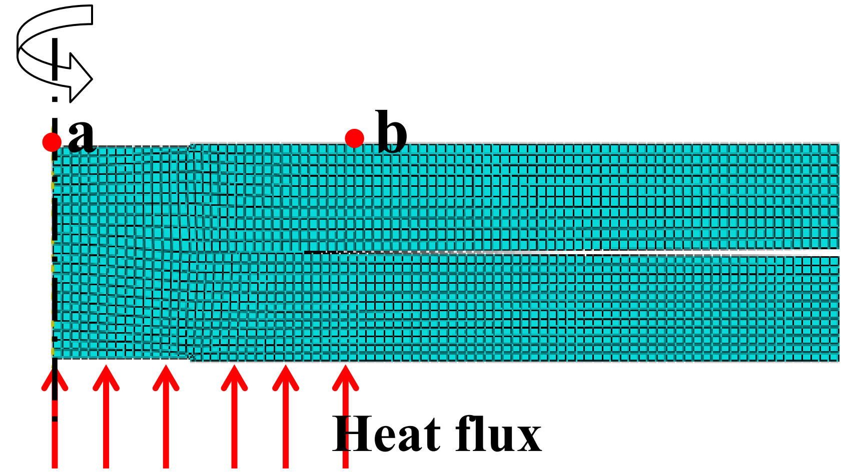


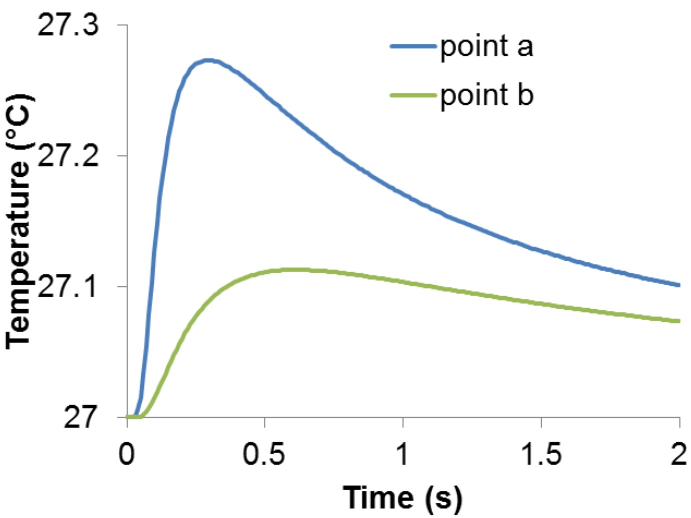


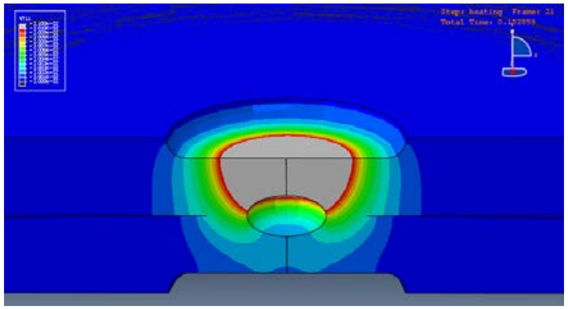


Accomplishment: Computer Modeling (Post-weld NDE)

- Assist development of IR signal analysis algorithms of post-weld IR NDE
  - Several types of thermal signatures have been identified and detection algorithms have been developed for weld quality analysis, which are insensitive to surface conditions
  - Optimize the heating and testing procedures and hardware arrangements







Weld with internal porosity

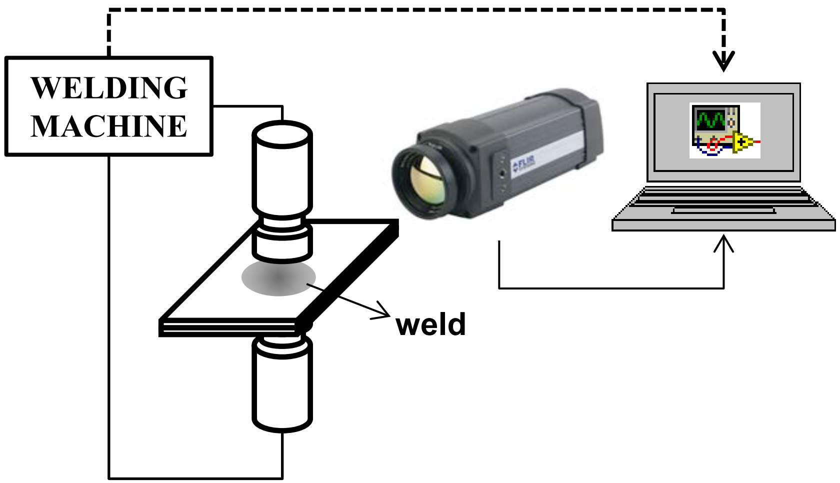
Accomplishment: Low-Cost Camera

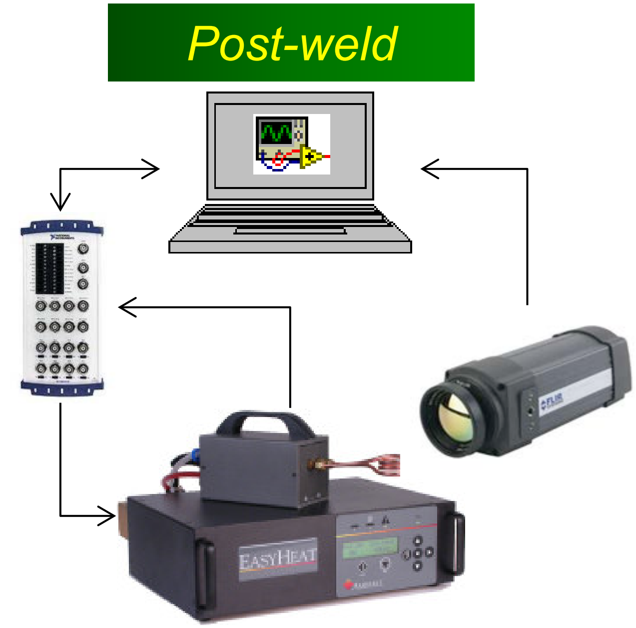
Phase I: Indigo Phoenix, $200K

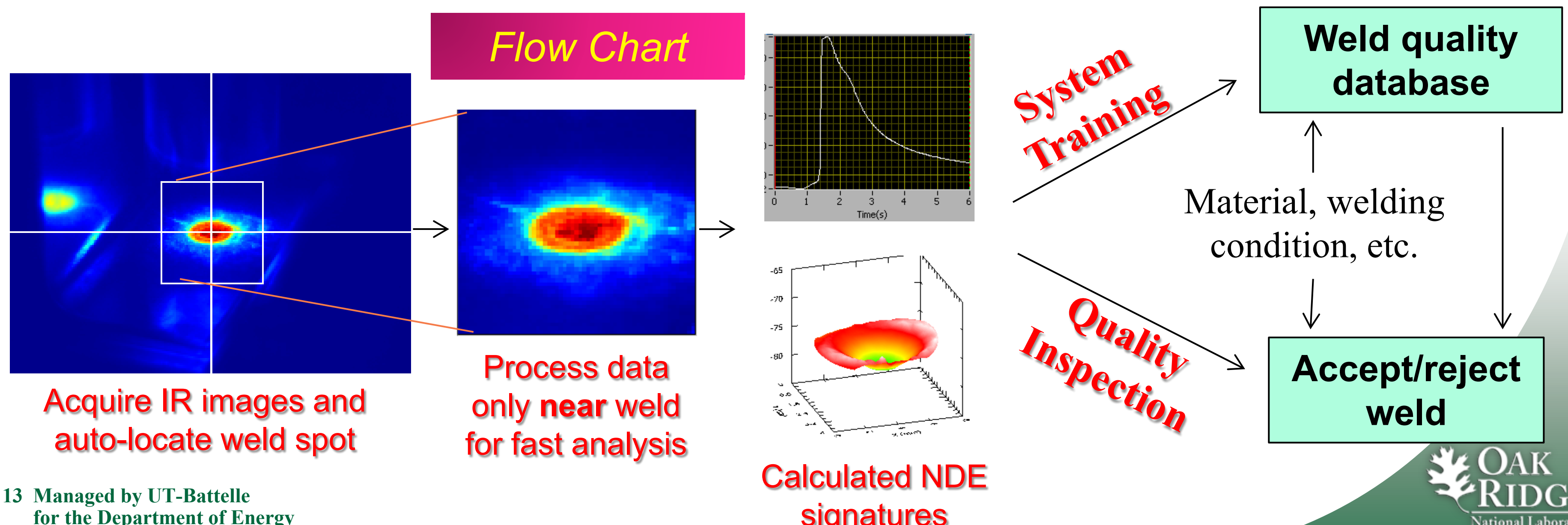
Phase II: FLIR A325, $20K

- Dual use: both real-time monitoring and post-mortem NDE
- Initial cost estimate of entire system: $30K-$35K
  - IR camera: $20K
  - Heating/cooling device: $8K
  - Computer and software: $2K
- Post-mortem and real-time benchmarking tests using Phase I welded samples confirmed the new camera has sufficient sensitivity and resolution

Accomplishment: Prototype Automated System Developed







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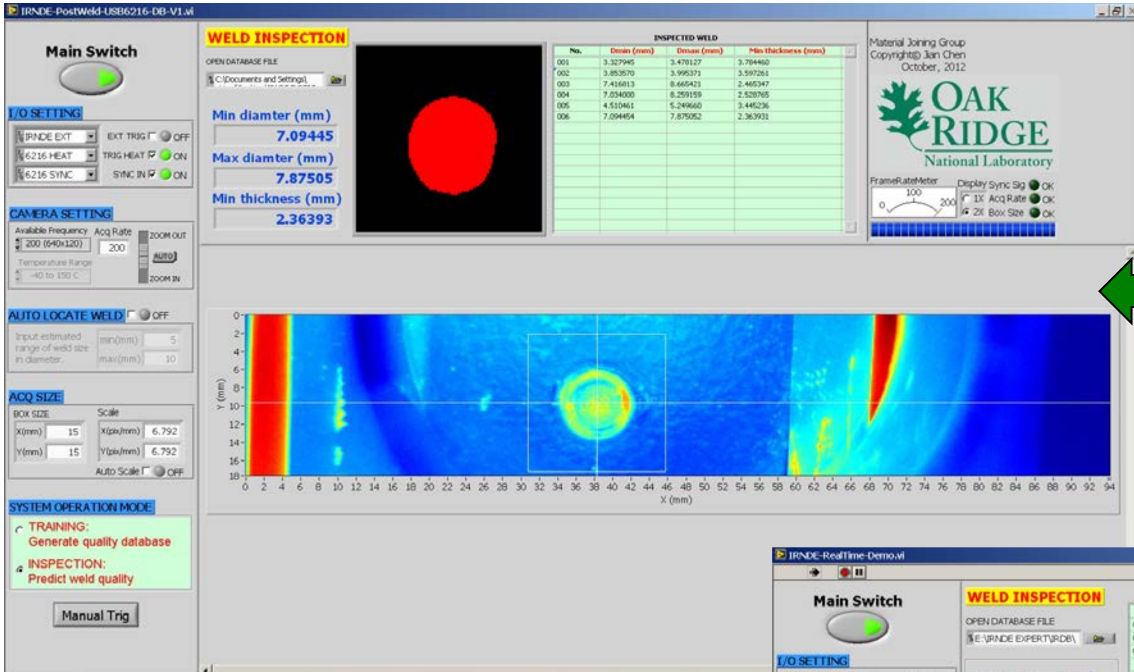
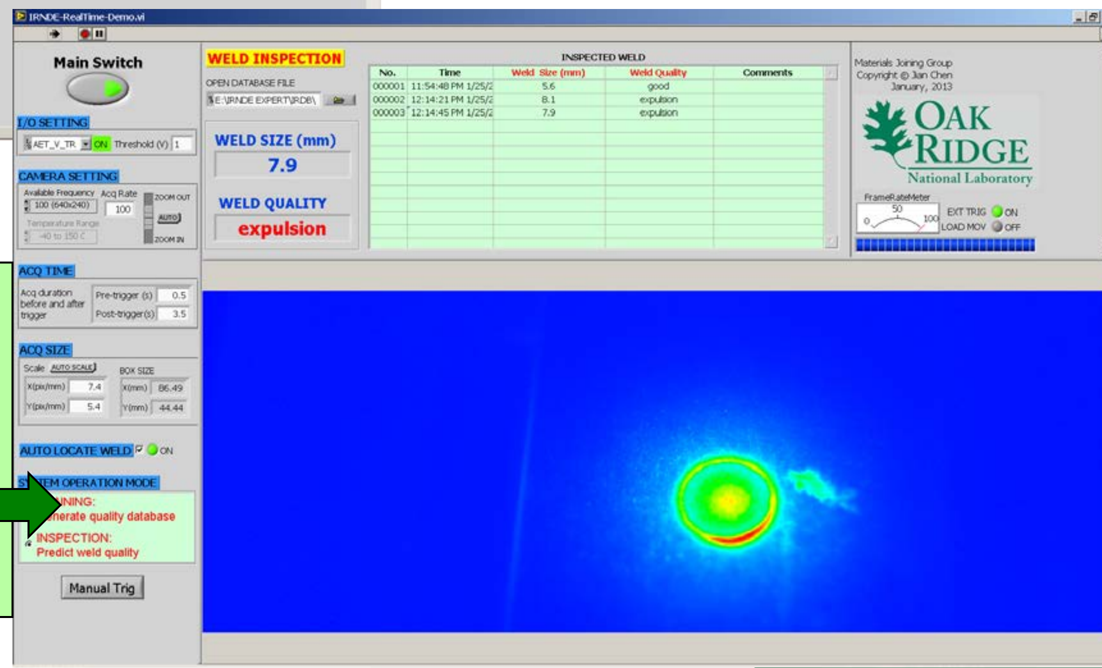
Accomplishment: Automated Weld Quality Analysis Software



Post-weld

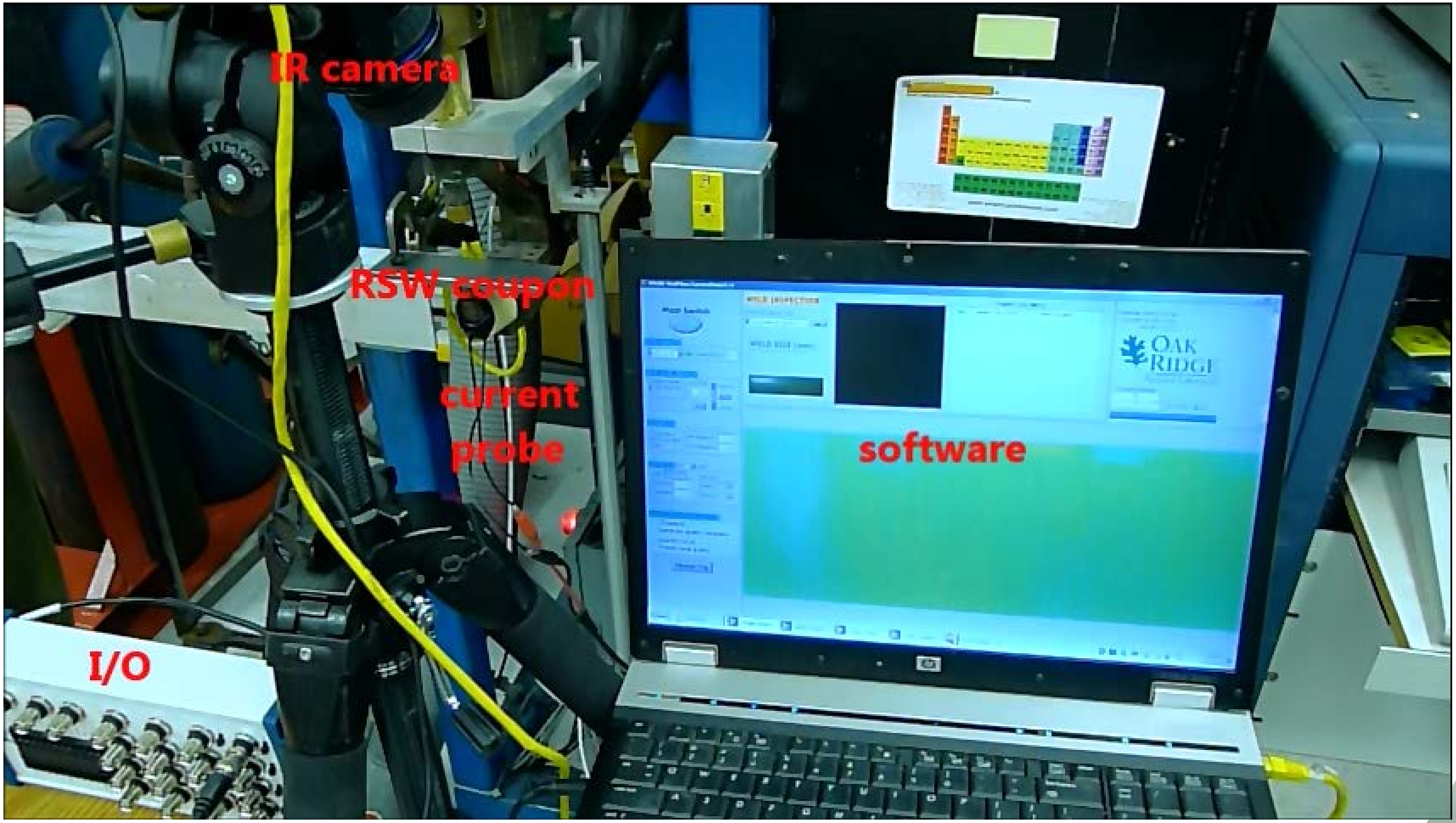
- Measurable weld attributes
  - Nugget size and shape
  - Cold/stick weld defect
  - Weld thickness/indentation
- Inspection time
  - ~3s



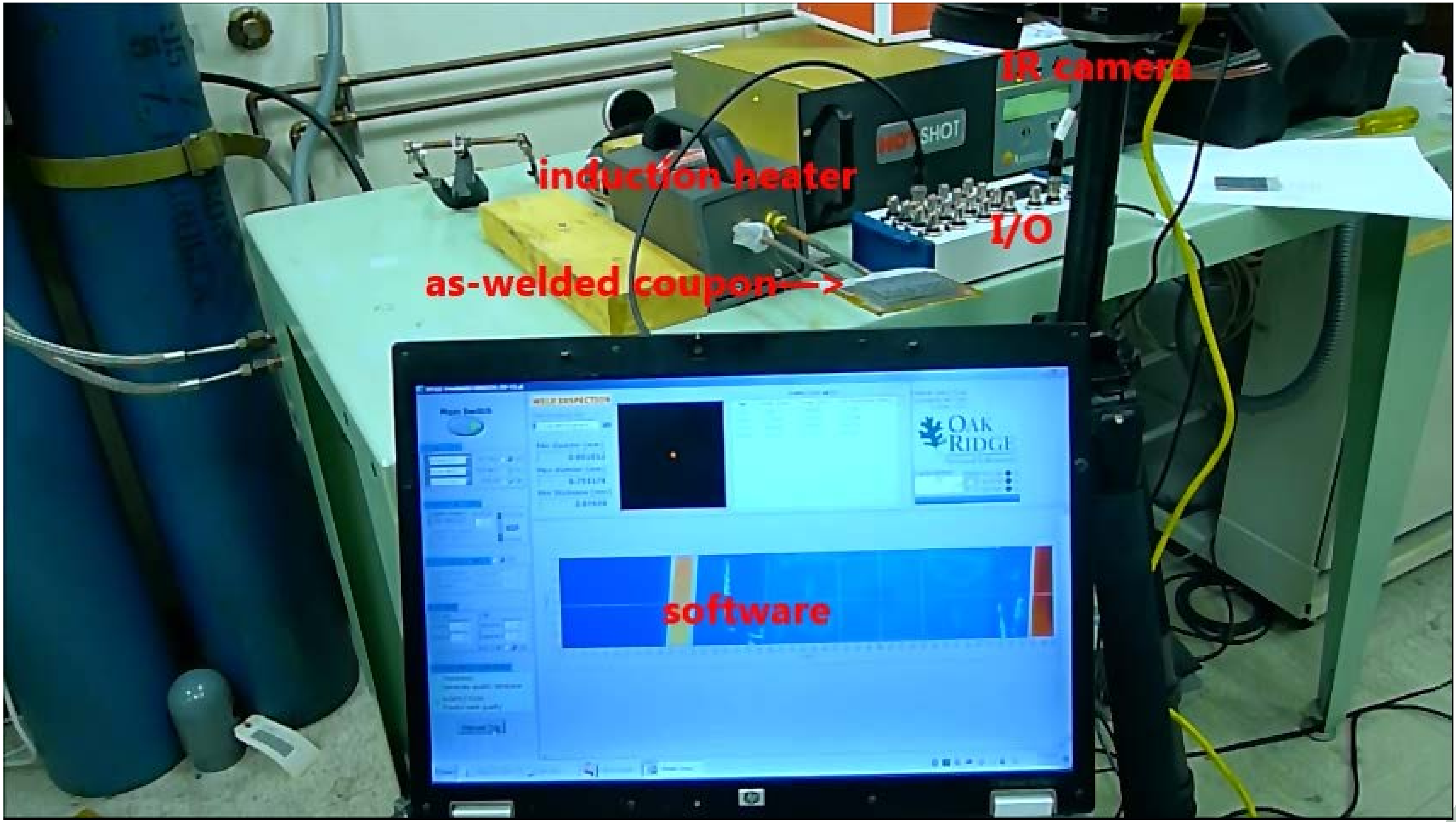
Real-time

- Measurable weld attributes
  - Nugget size
  - Cold/stick weld defect
  - Expulsion
- Inspection time
  - 1.5~2.5s

Real-time NDE System Operation Demonstration (Movie clip)



Post-weld NDE System Operation Demonstration (Movie clip)



Accomplishment: Prototype system has been tested using a large matrix of materials relevant to AHSS Intensive vehicle structure

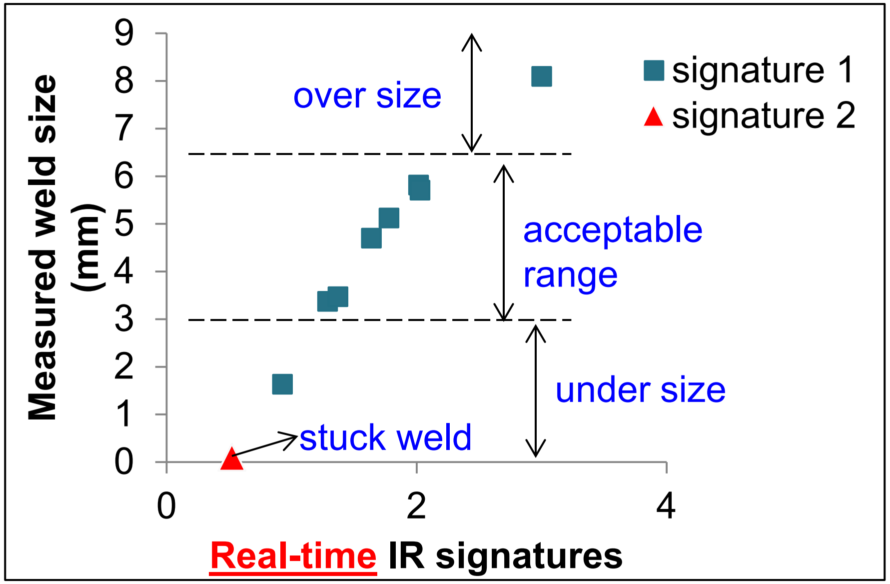
3T stack: varying steel grades, coating, thickness
• Boron bare 1.0mm • Boron bare 2.0mm • Boron bare 1.0mm
• Boron aluminized 1.0mm • Boron aluminized 2.0mm • Boron aluminized 1.0mm
• Boron bare 1.0mm • Boron aluminized 2.0mm • Boron bare 1.0mm
• Boron aluminized 1.0mm • Boron bare 2.0mm • Boron aluminized 1.0mm
• DP600 bare 1.2mm • DP600 bare 2.0mm • DP600 bare 1.2mm
• DP980 HDGA 1.0mm • DP980 HDGA 2.0mm • DP980 HDGA 1.0mm
• TRIP780 HDGA 1.0mm • TRIP780 HDGA 1.9mm • TRIP780 HDGA 1.0mm

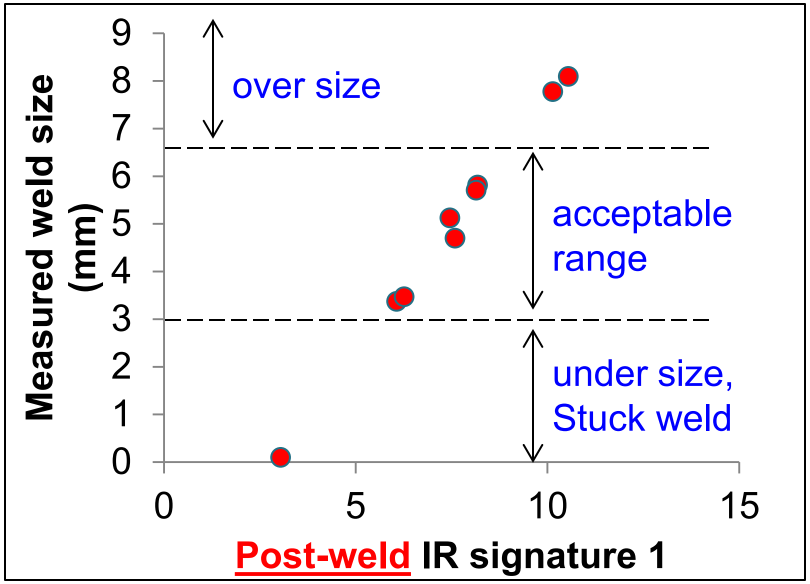
2T stack: varying steel grades, coating, thickness
• Boron bare 1.0mm • Boron bare 1.0mm
• Boron aluminized 1.0mm • Boron aluminized 1.0mm
• Boron bare 1.0mm • Boron aluminized 1.0mm
• Boron bare 1.0mm • Boron bare 2.0mm
• Boron aluminized 1.0mm • Boron aluminized 2.0mm
• Boron aluminized 1.0mm • Boron bare 2.0mm
• Boron bare 2.0mm • Boron bare 2.0mm
• Boron aluminized 2.0mm • Boron aluminized 2.0mm
• Boron bare 2.0mm • Boron aluminized 2.0mm

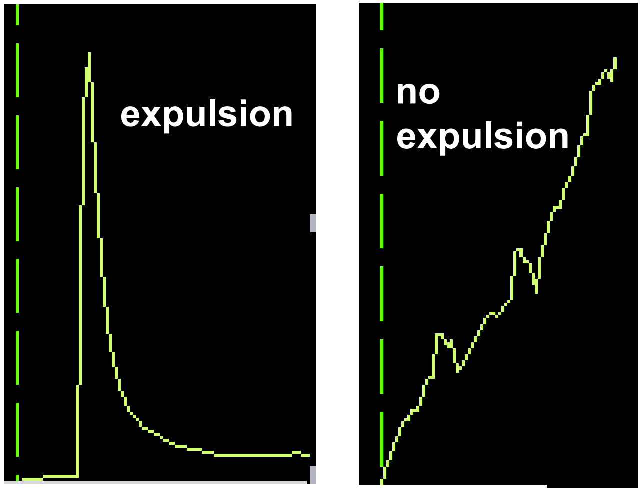
2T stack: varying steel grades, coating, thickness
• DP590 galvanized 1.2mm • DP590 galvanized 1.2mm
• DP590 galvanized 1.8mm • DP590 galvanized 1.8mm
• DP980 cold rolled 1.2mm • DP980 cold rolled 1.2mm
• DP980 cold rolled 1.2mm • DP980 cold rolled 2.0mm
• DP980 cold rolled 2.0mm • DP980 cold rolled 2.0mm

- *Each combination includes spot welds with varying attributes (i.e., nugget size, indentation & defects)*

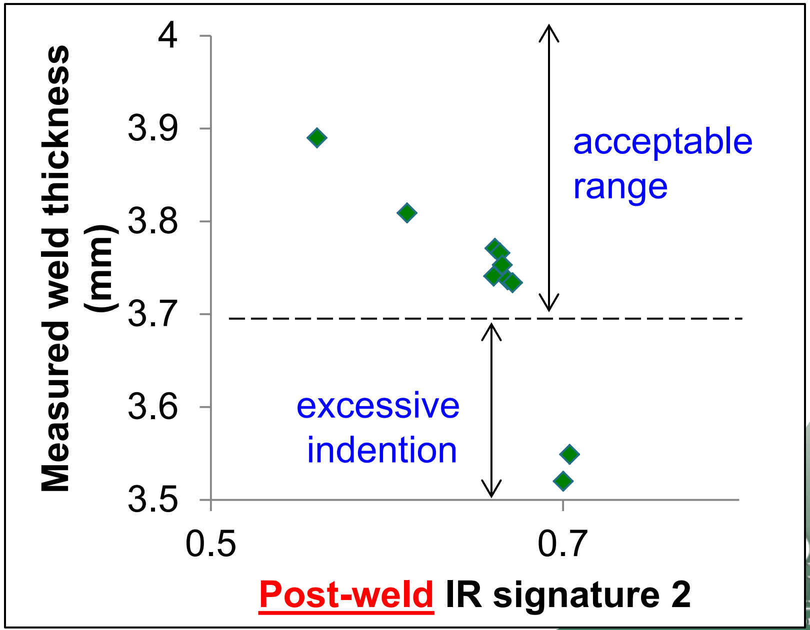
Accomplishment: Surface-insensitive Thermal Signatures vs. Weld Attributes



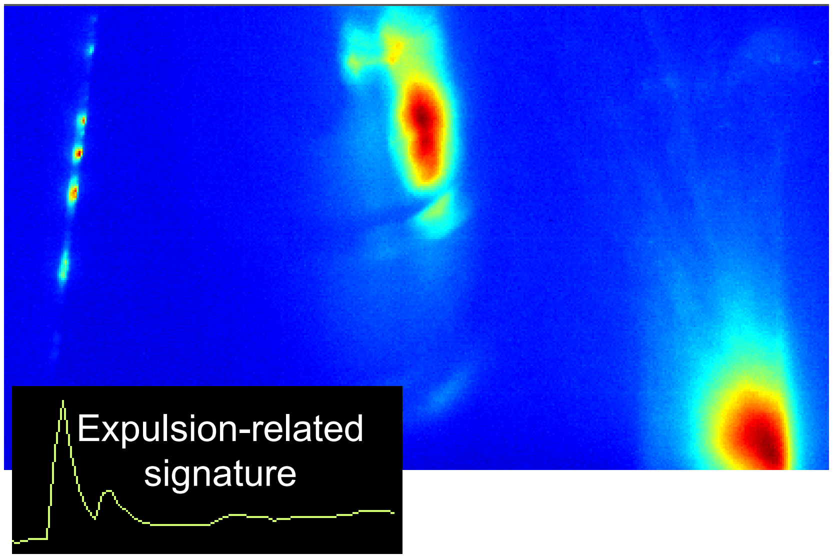




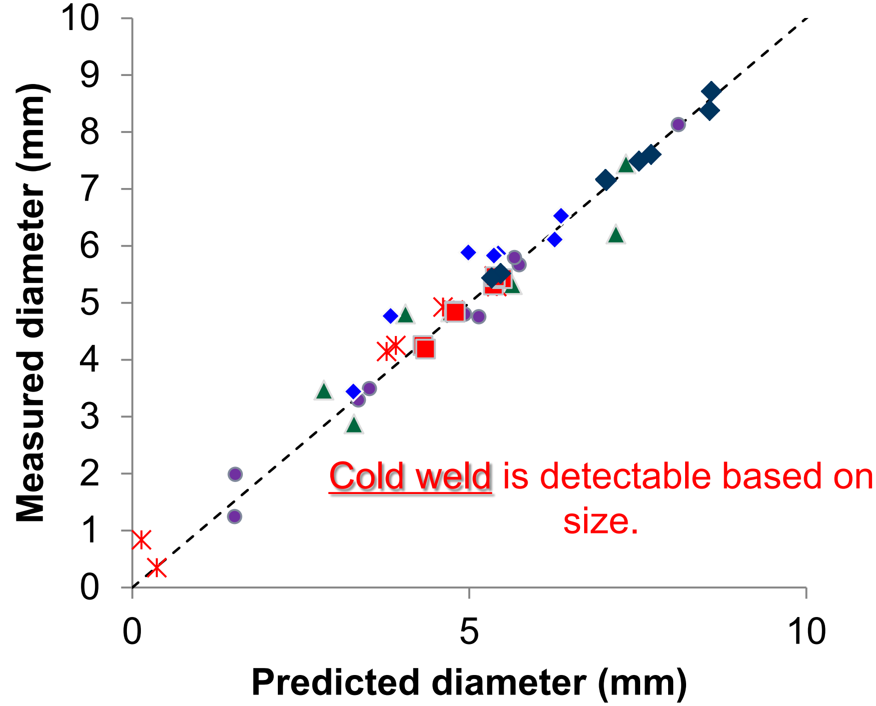
Real-time IR signature 3



Accomplishment: Weld Quality Prediction (Real-time)

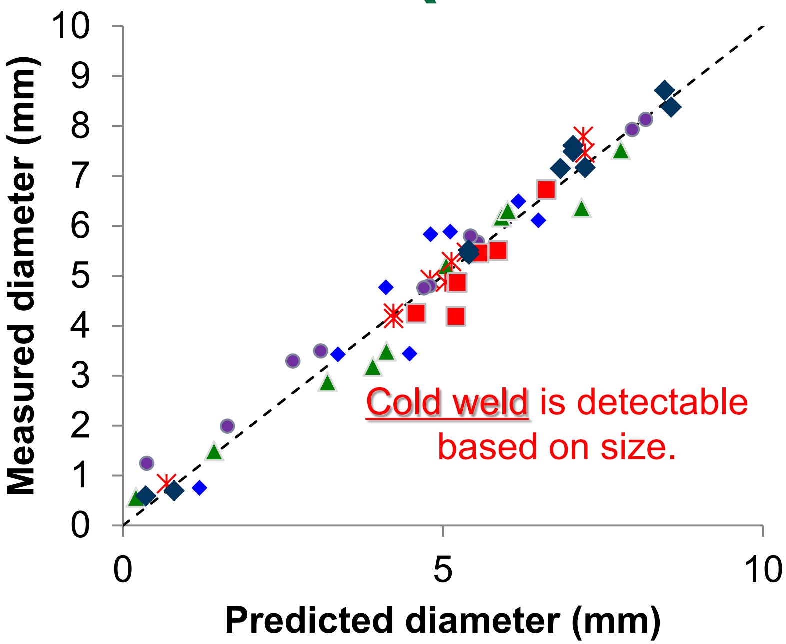


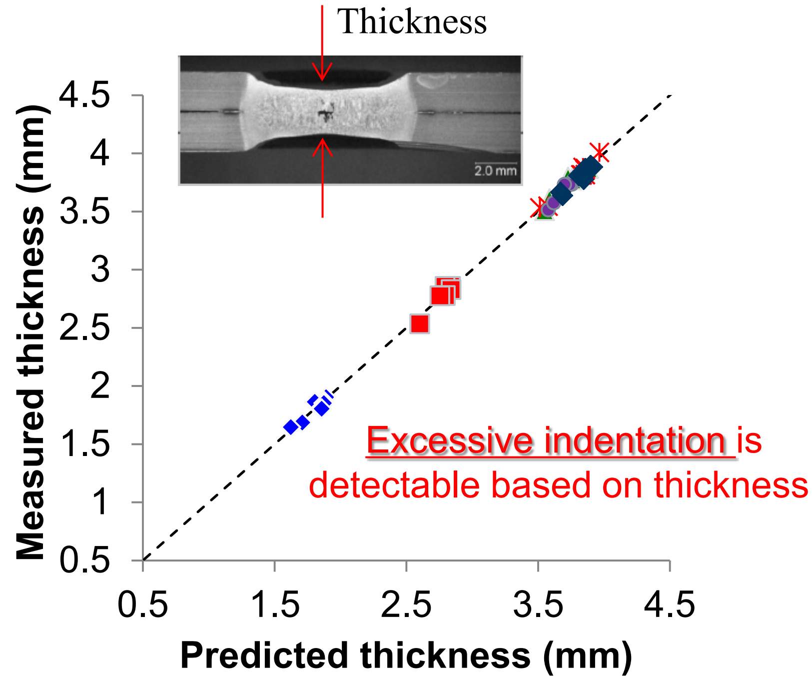
Severe expulsion is detectable based on the expulsion-related IR signature .

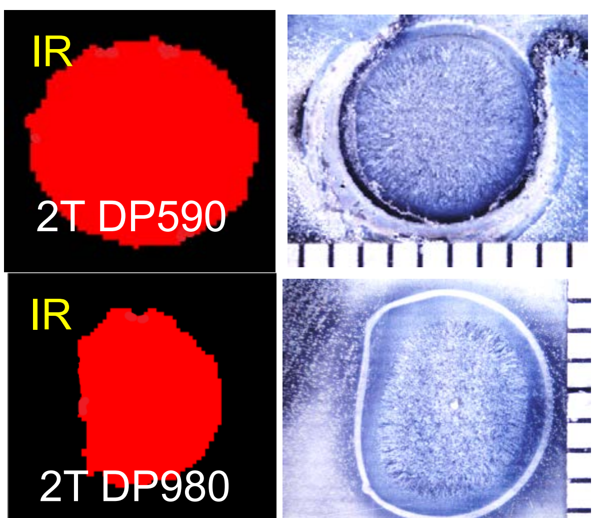


- *Results from a combination of*
  - *Materials*
  - *Plate thickness*
  - *Stack up configurations (2T/3T)*
  - *Surface coatings*

Accomplishment: Weld Quality Prediction (Post-Weld)







- *Results from a combination of*
  - *Materials*
  - *Plate thickness*
  - *Stack up configurations (2T/3T)*
  - *Surface coatings*

Collaboration and Industry Participation

- Extensively and closely worked with the industry stakeholders/end-users during R&D and system prototyping and testing
  - Support and cost-share from Ford, GM, Chrysler and ArcelorMittal
  - AMD NDE Steering Committee
  - A/SP Joining Team
  - Project technical advisory committee
    - M. Jones, W. Charron, and A. Wexler, Ford Motor
    - B. Carlson, D. Simon and, D. Hutchinson, General Motors
    - C. Schondelmayer, George Harmon and D.J. Zhou, Chrysler
    - S. Kelly and B. Yan, ArcelorMittal

Future Plan

- To complete the project
  - Beta test of the entire system at assembly line production environment
    - In discussion with OEMs for suitable testing sites.
  - Perform field demonstration.
  - Write guideline and user manual.
  - Seek industry partnership for technology transfer and eventual commercialization.
- Future opportunities
  - Apply to other materials and joining processes
    - Al Alloys (promising results have been obtained), and Mg alloys
    - Solid-state joining processes

Summary

- Successfully developed an IR-based spot weld NDE inspection prototype system capable for both real-time and post-weld on-line applications.
- Reliable detection of weld size, cold weld, expulsion, and surface indents with sufficient accuracy for various combination of materials, thickness, stack-up configuration and surface coating conditions.

Application	Measurable weld attributes	Inspection time
Real-time	• Nugget size and weld shape • Cold/stick weld defects • Expulsion	1.5~2.5s
Post-weld	• Nugget size • Cold/stick weld defects • Weld thickness/indentation	~3s