Model-based Visualization for Resistance Spot Welded Assembly Design

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Design + Process = Model-based visualization
Resistance Spot Welding (RSW)

- Resistance spot welding (RSW)
  - Contacting metal surfaces joined by the heat obtained from resistance to electric current (Jeffus, 2002).

- Contacting point of two metal pieces create weld pool, which is called the spot or nugget.

RSW Impacts

- Design parameters of the work pieces along with RSW process parameters → influences over the shape of the nugget width.
- Process parameters (e.g., electric current, welding time, welding force, etc.) → cause the variation of nugget width.
- Original equipment manufacturers (OEM) carries out numerous tests to design a new weldment (assembly design) → these tests are costly and time consuming.
- Various efforts are made to simulate and predict the nugget width.
Concept of Data-driven Design

- CAD System
- Ontology (spatiotemporal, welding)
- Rules
- Ontological Framework
- Knowledge Base
- Data Driven Design Feedback
- Process Flow
- Flow of Information
Model Based Engineering and Assembly Design

- MBE to utilize the data model (e.g. CAD data) and to enhance the machine interpretability
  - Reduce the human intervention and enhance the accuracies.
- In manufacturing, CAD used for human understanding only.
  - Not only do humans to understand the model, but software applications have to “understand” the model as well.
- Machine needs to understand the product’s assembly/mating/joining information properly to enhance the machine readability, to reduce the human effort, and to enhance the efficiency.
Design and Visualization

- Effective visualization - a powerful way to convey a concept, design intent, or idea in a globally distributed environment.

- 3D visualization - a way to represent the concepts in a more understandable manner.
  - X3DOM - 3D visualization in a globally distributed environment.

- Effective visualization for RSW weldability analysis with the welded assembly design is very limited.

- Focuses incorporating the 3D design data with the welding process data to represent the process data in a more intuitive way.
Formal Assembly Design Model

- Mereotopology to express the product’s part to part assembly relationships.
- Discrete mereotopology (DM) (Randell et al. 2013) utilized to formally represent the product’s assembly relationships and static and dynamic behaviors.

\[ xPy := \forall z (zOx \rightarrow zPy) \]
Objectives

- **Model-based visualization framework** to integrate RSW weldability knowledge with assembly models
- **Knowledge-based semantic weldability prediction method** has been developed to effectively predict the weldability of RSW processes, while reducing the data inconsistency effects.
Model-Based Visualization and Integration Framework

System 1: Design Database

System 2: Decision rules
- CART Algorithm
- Welding process & response parameter database

System 3: STM ontology

System 4: RSW ontology & SWRL rules
- Predicted nugget width

System 5: Visualization Module
- Design
- Assembly
- Process
- Response

Mapping Integration
Part 1: Integration of Design Database with STM Ontology

- Design database - the parametric and assembly information
- CAD systems and design database.
- STM (SpatioTemporal Mereotopology) ontology
  - Relevant spatial and temporal design and assembly knowledge.
STM Ontology - Concept Map

New concept
Kim et al. (2008)
PRONOIA-1 (2011)
PRONOIA-2 (2015)
STM Ontology

Geometric design and assembly classes and sub-classes
Part 2: Rule Extraction and SWRL Generation

- Classification and Regression Tree (CART) algorithm
  - To extract the decision rules and converted them into SWRL rules
- System predicting the response parameter (i.e., nugget width) based on the given design and process parameters
## Parameters in RSW Quality Dataset

<table>
<thead>
<tr>
<th>Feature types</th>
<th>Geometric Parameters</th>
<th>Design Parameters</th>
<th>Process Parameters</th>
<th>Response Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td></td>
<td>Material Thickness (mm)</td>
<td>Weld force (lbs)</td>
<td>Nugget width (mm)</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td></td>
<td>Coating-EG</td>
<td>Minimum button</td>
<td></td>
</tr>
<tr>
<td>Height (mm)</td>
<td></td>
<td>(Electrogalvanized)</td>
<td>Diameter of stack-up (mm)</td>
<td></td>
</tr>
<tr>
<td>Radius (mm)</td>
<td></td>
<td>Coating-HDG</td>
<td>Weld current (kA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coating weight (gm/m2)</td>
<td>Weld time (ms)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface class</td>
<td>Weld time cycle</td>
<td></td>
</tr>
</tbody>
</table>
Regression Model for Analyzing Welding Dataset

\[ Y_p = \bar{r}(X_t) = [r(X_t, \lambda, D)] \]

- \( Y_p \): Final predicted value.
- \( \bar{r} \): Average regression function.
- \( X_t \): Observation from test set.
- \( \lambda \): Random parameter of partition.
- \( D \): Total data.
Building Ontology

Top – Down Approach

Bottom – Up Approach
RSW Ontology Concept Map

- **Weld nugget expansion**
- **Joint Parameters**
  - Shape of weld nugget
  - Weld nugget width
  - Weld nugget penetration

- **Response Parameter**
  - Thickness
  - Material
  - Coating weight
  - Surface class
  - Coating-EG (Electro galvanized)

- **Design Parameter**
  - Minimum button diameter of stack-up
  - Weld Time Cycle
  - Squeeze Time
  - Hold Time
  - Weld Current
  - Weld force

- **Machine Parameters**
  - Part

- **Properties Parameters**
If Weld Time Cycles is greater than 19.5 (unit) (consider right side of the branch) AND Nugget 1 Meets Min Width is true AND Current is greater than 8.95 (unit) AND Current is less than 13.205 (unit) THEN Nugget Width will be 7.951 (unit)
## SWRL Rule Conversion

<table>
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<tr>
<th>Rule</th>
<th>Test cases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Decision rule</strong></td>
<td>If Weld Time Cycles is greater than 19.5 (unit) (consider right side of the branch) AND Nugget 1 Meets Min Width is true AND Current is greater than 8.95 (unit) AND Current is less than 13.205 (unit) THEN Nugget Width will be 7.951 (unit)</td>
</tr>
<tr>
<td><strong>SWRL rule</strong></td>
<td>weld_time_cycles(?x, ?y) ^ swrlb:greaterThanOrEqual(?y, 19.5) ^ Nugget_1_meets_min_width(?x, true) ^ weld_current(?x, ?z) ^ swrlb:lessThan(?z, 13.205) ^ swrlb:greaterThanOrEqual(?z, 8.95) -&gt; nugget_width(?x, 7.951)</td>
</tr>
</tbody>
</table>
Part 3: Mapping, Integration, and Visualization

- **X3DOM** visualizes 3D contents along with their relevant information.
- **Schema mapping** enables the seamless data transfer among the systems.
- System 3 (STM ontology: geometric and assembly knowledge) and 4 (RSW ontology: welding process and response knowledge) mapped with system 5 (X3DOM).
- MATLAB is utilized to parse the ontologies (STM and RSW) to extract the mapped information for the X3DOM.
- X3DOM can visualize the welding process, response and geometric information.
RSW Assembly Design Viewer

- Visualize the welded and non-welded assembly.
- Capable of showing the stages of joining and the interrelationships between the mated or unmated parts.
- Two basic parts.
  - Visualization interface.
    - X3DOM works as a HTML-based visualization interface; traditional browser is utilized for the visualization.
    - MATLAB is utilized to convey the necessary information from the ontologies to the X3DOM.
  - Protégé to develop the ontologies.
  - Display information of the visualized 3D object.
To understand the joining/welding process properly, it is important to visualize the models before/after welding.

Visualizer can show the interrelationships between mated and unmated parts before/after welding.
Demonstration - Case 2

- Process, response, design and assembly information visualized before/after welding
- Predicted nugget sizes and displayed.
Summary

- Combines the geometric design database with the RSW process database and using the data predicts and visualizes weld quality
- **Data-driven and model-driven visualization** for RSW weldability knowledge
- CAD environment used as a design database and then the design database integrated with the STM ontology to extract the design and assembly knowledge
- STM ontology captures the spatial entity of a weldment
- Welded assembly design and process information taken to the RSW ontology from the welding database
- Decision rules extracted from the welding datasets and converted into semantic rules for the machine interpretability and easy information transfer
- **Design, process, and weldability information visualized** for redesign if needed
- Ongoing works
  - Data driven assembly modeler
  - Work on more complex geometry
  - Temporal entities for dynamic welding process
References


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Thank you