Constraint Identification from STEP AP242 files for Automated Robotic Welding*

Shafi K. Mohammed[1a], Mathias H. Arbo[2], Lars Tingelstad[1]

Abstract— **This article proposes the use of STEP AP242 for identifying and extracting the relevant product data for the constraint-based programming of welding robots. Most of the product data is created during the design phase of its life cycle. This data can be reused in downstream processes by means of Digital Thread as part of Industry 4.0 practices. STEP AP242 is a neutral file exchange format that carries all the product data, including geometry and Product Manufacturing Information. This article discusses various types of constraints that can be derived from STEP AP242 files for robotic welding.**

I. Introduction

One of the earliest and most successful adoptions of robots in manufacturing is for welding. However, this is limited to large scale industries like automotive where the welding task is repetitive. In the case of small and medium industries where product variation is high, robotic welding is limited. This is because the changes in products need a change in the robot program, need highly skilled programmers, and are time consuming [1].

II. Robotic Programming

The limitations mentioned above can be overcome by constraint-based programming. In this approach, the constraint information can be extracted from the CAD files. Some of the frameworks which integrate CAD with constraint-based robotic programming are Autopass [2], Archimedes 2 [3], HighLap [4], iTaSC [5] and eTaSL/eTC [6].

Norberto Pires et al. [7], [1] presented a CAD interface for programming welding robots, where 3D CAD models of the workbench and the product are used to extract the geometric details and relative position of the product in the work environment. Other necessary information like the trajectories to be followed by the manipulator to complete the weld and welding parameters are added by a user. All this information is stored in the form of a DXF file and used to generate the robot program.

Shafi et al. [8] extracted constraint information from 3D CAD (STEP) files for task definition in eTaSL/eTC for automated robot programming for assembly operations.

*This work was supported by the Norwegian Research Council infrastructure project MANULAB: Norwegian Manufacturing Research Laboratory under grant 269898.

[1]Department of Mechanical and Industrial Engineering, NTNU, Norwegian University of Science and Technology, Trondheim, Norway

[2]Department of Engineering Cybernetics, NTNU, Norwegian University of Science and Technology, Trondheim, Norway

[a]Corresponding author. E–mail address: shafi.k.mohammed@ntnu.no (Shafi K. Mohammed)

III. Model Based Definition (MBD)

Traditionally, designers prepare 2D manufacturing drawings that are shared with the downstream operations. The necessary information is extracted and recreated manually from the manufacturing drawings. This manual intervention at the downstream operations can be avoided by adopting Model Based Definition (MBD) as part of a digital thread implementation. In MBD, the product manufacturing information (PMI) like critical dimensions, geometric dimensioning and tolerancing (GD&T), welding annotations, surface finish, and other needed information, are semantically added to the relevant features of the 3D CAD model [9]. The semantic attachment of the annotations to 3D CAD models increases the clarity and reduces confusion as in the understanding of ‘arrow side’ and ‘other side’ compared to a 2D manufacturing drawing. This PMI can be directly reused in many downstream processes.

Depending on the ease with which the parameters can be controlled to achieve a good quality weld, Norberto Pires et al. [1] classified them as follows:

- Primary inputs: These variables can be controlled during the welding process to achieve a good quality weld. Depending on the welding process, these can be voltage or welding speed.
- Secondary inputs: These parameters are fixed once the welding process is selected. In case of Gas Tungsten Arc Welding (GTAW), the secondary inputs will be shielding gas or filler material.
- Fixed inputs: These are the fixed parameters that can not be changed by the user. These depend on the product (geometry, material, etc.) and welding process selected.

Some of this information is already present in the 3D CAD model of the product like weld geometry. Most of the process parameters can be included in the MBD of the product as annotations which can later be used in the automatic programming of the welding robots.

IV. Identification and Extraction of Welding Constraints from STEP AP242 Files

The standard for the Exchange of Product Model Data (STEP) is a standard neutral file format, that enables the sharing of product information among various stakeholders. It is the ISO (International Standards Organization) standards 10303: Automation systems and integration — Product data representation and exchange. The application protocol AP242: Managed model-based 3D engineering deals with 3D semantic PMI. It replaced the two earlier application protocols *STEP AP203 – Configuration controlled 3D designs of mechanical parts and assemblies* and *STEP AP214 – Core data for automotive mechanical design processes*. The second edition of this application protocol (AP) was released early 2020 [10]. The PMI can be added to the 3D CAD model, as suggested in *ASME Y14.41–2019: Digital Product Definition Data Practices*.

For constraint-based programming, the presentation aspects of PMI are not relevant and only semantic elements are enough to extract the needed information.

The following STEP AP242 features can be used to extract the required welding information.

- Geometric Details: The geometric product details are readily available in the STEP file and can be used directly for identifying the various features and edges.
- Assembly Information: Product structure, relative positions of parts in the assembly, type of mating (like bolted joint, riveting, and welding) can be extracted from STEP AP242 files. The extraction of assembly information and its application in constraint-based programming for assembly tasks is presented by Shafi et al. [8].
- Critical Dimensions and Geometric Dimensioning and Tolerancing (GD&T): Critical part dimensions and GD&T are added to the 3D CAD model in the form of annotations. These can be used to extract the required information like part thickness and length, which can be used for defining the welding parameters.
- Welding Annotations: The second edition (Ed2) of STEP AP242, which was released in early 2020, supports welding annotations. STEP AP242 supports the welding annotations as per *AWS A.24 edition 2012 Standard Symbols for Welding, Brazing, and Nondestructive Examination* and *ISO 2553:2013 – Welding and allied processes – Symbolic representation on drawings – Welded joints*.
- Product Properties: Properties like product material and weight can be included in the STEP file and later used to automate the welding process selection or estimate the forces on manipulators during welding.
- Notes: Other process-related information can be added to the 3D CAD model as text annotation. These can include the voltage requirements or any other critical information that can be used to control the robot during the welding process.

V. Task Specification using the Constraint Information

The welding task is defined by converting the information extracted from STEP AP242 files into position, orientation, and motion constraints on the manipulator end-effector/tool Center Point (TCP). The brief description of various constraints on TCP is given below.

- Position: The position of TCP is determined by the geometry of the parts, their mating constraints, and the welding process. The welding process limits the minimum and maximum vertical distance of TCP from the weld surface (axis). The position of the weld can be found from critical dimensions and GD&T.
- Orientation: The orientation of the tool is expressed in the travel angle and work angle. These angles depend on the weld type and the geometry of the parts. This gives the tool three rotational degrees of freedom (DoF), one full DoF about the tool axis, and two DoFs limited by travel and work angles.
- Motion: The direction of motion is determined by the geometry and positioning of the parts. The velocity of motions is mainly dependent upon the welding process. The tool has two degrees of freedom in translation, one DoF along the weld axis and another limited translation along the vertical to weld axis.
- Weld Length: The length of weld and pitch (center-to-center distance) of welds can be extracted from welding symbols, which define the extent of tool motion.

VI. Conclusions

This paper has discussed the possibility of extracting constraint information from STEP AP242 files and use it for task specification for welding operations. All the relevant information for welding processes is identified and how this can be extracted from STEP AP242 files is explained. This will enhance the control of manipulator during welding process and improve the weld quality.

References

[1] J. Norberto Pires, Altino Loureiro, Gunnar Bolmsjo, *Welding Robots: Technology, System Issues and Applications*. Springer, 2006.

[2] L. I. Lieberman, M. A. Wesley, "AUTOPASS: An Automatic Programming System for Computer Controlled Mechanical Assembly," *IBM Journal of Research and Development*, vol. 21, no. 4, pp. 321–333, 1977.

[3] Stephen G. Kaufman, Randall H. Wilson, Rondall E. Jones, Terri L. Calton, "The Archimedes 2 Mechanical Assembly Planning System," *Proceedings of IEEE International Conference on Robotics and Automation*, vol. 4, pp. 3361–3368, 1996.

[4] U. Thomas, F. M. Wahl, "A System for Automatic Planning, Evaluation and Execution of Assembly Sequences for Industrial Robots," *Proceedings 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems*, vol. 3, pp. 1458–1464, 2001.

[5] Joris De Schutter, Tinne De Laet, Johan Rutgeerts, Wilm Decre, Ruben Smits, Erwin Aertbelien, Kasper Claes, Herman Bruyninckx, "Constraint-based task specification and estimation for sensor-based robot systems in the presence of geometric uncertainty," *International Journal of Robotic Research*, vol. 26, no. 5, pp. 433–455, 2007.

[6] Erwin Aertbelien, Joris De Schutter, "eTaSL/eTC: A constraint-based Task Specification Language and Robot Controller using Expression Graphs," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 1540–1546, 2014.

[7] J. Norberto Pires, T. Godinho, P. Ferreira, "CAD Interface for Automatic Robot Welding Programming," *Industrial Robot: An International Journal*, vol. 31, no. 1, pp. 71–76, 2004.

[8] Shafi K. Mohammed, Mathias H. Arbo, Lars Tingelstad, "Leveraging Model Based Definition and STEP AP242 in Task Specification for Robotic Assembly," *Procedia CIRP*, vol. Accepted, 2020. [Online]. Available: https://www.sciencedirect.com/journal/procedia-cirp

[9] J. B. Herron, *Re-Use Your CAD: The Model-Based CAD Handbook*. CreateSpace Independent Publishing Platform, 2013.

[10] ISO 10303-242:2020, "Industrial automation systems and integration — Product data representation and exchange - Part 242: Application protocol: Managed model-based 3D engineering," *International Organization for Standardization, Geneva, Switzerland*, 2020.