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DMDII
a UI LABS Collaboration
DIGITIZING AMERICAN MANUFACTURING

DMDII PROJECT CLOSE OUT SUMMARY

PROJECT TITLE: DMDII 14-07-03: INTELLIGENT, ADAPTIVE FIXTURING FOR MACHINING OF HIGH VALUE LARGE CASTINGS AND FABRICATED ASSEMBLIES

SPONSORSHIP DISCLAIMER STATEMENT: This project was completed under the Cooperative Agreement W31P4Q-14-2-0001, between U.S. Army - Army Contracting Command - Redstone and UI LABS on behalf of the Digital Manufacturing and Design Innovation Institute. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of the Army.

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I. EXECUTIVE SUMMARY

The major motivation of this project was to develop a set of methods and software enabler (IAMFix®) to reduce the setup time for machining of large castings and fabrications and to virtually eliminate scrapping any of these high value parts. Castings can be of various grades, each of which can have its own set of tolerances. In addition, distortion of the castings can occur during solidification. After casting, the components must be machined in order to meet the tolerance requirements of the part. Setting up large castings for machining is time consuming, sometimes requiring more time than machining itself, and errors in setup can result in scrapping large and expensive parts.

II. GENERAL PROJECT INFORMATION

	Description	
Project Name	***Intelligent, Adaptive Fixturing for Machining of High Value Large Castings and Fabricated Assemblies***	
Project Description	*A tool to significantly reduce the time and cost required to set up large castings and fabricated assemblies for machining operations*	
Technology Developed	*Software*	**Program:** *Advanced Vehicle Make* **Thrust Area:** *Intelligent Machining*
Project Lead	*PDA, LLC*	**Principal Investigator:** *Jiten Shah* - info@pda-llc.com
Other Project Participants	*Arizona State University* *American Foundry Society* *Steel Founders Society of America*	**DMDII Program Manager:** *Michael Howard* Michael.howard@uilabs.org
Project Funding	*Federal Funds $176,815.00* *Cost Share $192,932.00* *Total $369,747.00*	**Project Start Date:** *8/1/2015* **Project End Date:** *08/31/2016*
Technology Readiness Level	*Beginning TRL: 4* *Ending TRL: 6 - Demonstrated the IAMFix® framework and AutoFix® software in a relevant manufacturing environment.*	

a. Project Background

DMDII-14-07 Plug-and-Play Toolkit for Geometric-Adaptive Machining

Project Call Release Date	*9/23/2014*
Project Call Goal	*Plug-and-Play Toolkit for Geometric-adaptive Machining" (to be referred to as Technology) - is to develop a generic and effortlessly portable "plug-and-play" hardware and software toolkit that addresses industrywide problems related to efficient machining, machine setup and fixturing. The developed solutions shall utilize geometric-adaptive tool path modifications that reflect the actual geometric features of the workpiece/assembly, its actual location on the machine and the machine's workspace, while being independent of machine configuration and controller platforms. They shall also address a wide-range of problems including, for example, machining of large castings and composites, repair of turbine blade airfoils, machine setup, robotic assembly, etc. and provide physical Technology demonstration*

b. Project Goal Statement

Development of a set of methods, framework and software to predict distortion and reduce the setup time for machining of large castings, such as complex cored valve bodies, locomotive truck frame, military vehicle components, and to virtually eliminate scrapping any of these high value parts. The software is used to determine the range of adjustments on the fixture datums to obtain the desired tolerances on the finished machined part from scanned point clouds for each cast piece of the demo article.

c. Specific Industry Problem or Challenge being addressed by the Project

Complex cored sand castings and fabrications have piece to piece dimensional variability, which is inherent to the manufacturing process. Especially, low volume manufacturing doesn't permit to estimate statistically the variability pattern in a production environment and requires high skilled operator to manually compute for every piece and find the best orientation after loading into the machining fixture for the first few operations where, as-cast surface with variability are referenced. This results into an extensive set up time and impacts overall machining cycle time and costs, occasionally producing scrap or rework.

d. How was the Problem addressed

Casting dimensional variability was captured digitally using white light scanner point cloud data for multiple castings, which were analyzed successfully with PDA-ASU co-developed AutoFix enabler. ASU applied two of its novel technologies to the point cloud to determine kinematic transformation between displacements at the physical adjustment devices on the fixture. These technologies are the normative feature fitting library (nFF) and multivariate models of manufacturing variations (T-Maps). AutoFix provided the adjustments required for every serial number and the adjustments were than manually applied to the specially designed and fabricated adaptive machining fixture and castings were machined successfully.

e. Summary of Project Outcomes

The project software ('ASU-AutoFix®') is able to predict distortion through casting process simulation and modeling, and determine the positions of the to-be-machined surfaces by scanning the critical surfaces of the casting. This data is used to determine the fixture locations required for the part to be machined to the correct tolerances. The fixture used is adaptive, so that the actual points of contact between the fixture and the part can be adjusted based on the outputs of the tool. The project incorporated critical dimensional tolerances per the casting industry standard, such as ISO 8062 into base 3D Model of rough casting with nominal dimensions.

Set up time reduction for initial machining operations:

PDA has machined over 600 pieces of these valve bodies in the past for the customer and spent an average 20 min of the set up time for each piece for the first set of machining operations using as-cast surface, due to dimensional variability. Time measurements were taken, with a few videos to assess the set up time with IAMFix® implementation and was found to be 2 min average.

Scrap due to mis-machining:

In one test article, the valve body front face was ground off excessively, resulting in inadequate machining stock, which was predetermined using AutoFix, as it predicted an unfeasible solution. In the past, a machinist would have not have been able to determine this before completing the boring operation and preparing to mill the top face, which would have resulted in a scrapped part and wastage of the machining operation up to that point.

Rework due to mis-machining:

Some alloys, like steel and some grades of aluminum, can be easily weld repaired. If the valve body is made out of wieldable alloy, one would have welded the top face and build up material such that it has sufficient machining stock and the valve body could have been salvaged. This would save the cost associated with the shipping of the castings to the machining house and the cost associated with the boring operation and set up time.

f. Final Project Deliverables

- A software enabler tool called 'ASU-AutoFix®' and the process map
- A set of instructional manuals on how to use the tool with examples
- Demonstration article related data:
  i. Fixture adjustment values for the 1st operation
  ii. Rough casting and finished casting Scanned STEP files for every article
  iii. Performance improvement metrics with set up times, scrap and rework if any

III. KPI's + METRICS

Metric	Goal	Results	Validation Method
Set up time for the initial machining operations	80% reduction in set up time with IAMFix	Achieved	Comparison to valve-body baseline setup time from previous fabrications completed by PDA for the customer
Scrap due to mis-machining, estimated to be 1-2 % in low volume	Estimated scrap 0% with the use of IAMFix	Achieved	Ability of tool to determine whether adequate machining stock is present prior to machining operations
Re-work due to mis-machining, estimated to be 1-2% in low volume	Estimated scrap 0% with the use of IAMFix	Achieved	Ability of tool to determine whether adequate machining stock is present prior to machining operations

IV. INDUSTRY IMPACT + POTENTIAL

a. Impact to the specific market the project was addressing and size of that market

IAMfix significantly reduces the set up time for machining raw castings and fabrications with piece to piece dimensional variability and virtually eliminates scrap and rework due to mis-machining and non-machinable parts. IAMFix with AutoFix produced 80% reduction in the set up time for the first few operations which utilize as-cast target surfaces. During the demonstration, a few castings, which would have resulted into the scrap and rework, were captured ahead of loading into the machining fixture.

b. How this could be used in other industries

Although the current project has successfully demonstrated this technology and software for machining of one design for aluminum sand-castings, the very same technology is applicable to other materials (iron, steel) and to large welded assemblies, such as hulls of military assault vehicles. In addition to metal casting and fabrication, the technology can be applicable for any custom molded process including polymeric composite, FRP and forgings.

c. Next Steps based on other use potential

AutoFix in its current form is limited to the valve body type shape and machining operations with limited feature recognition but can be expanded to allow other types of feature recognitions for more real world practical complex shapes.

PDA envisions future efforts to automate the AutoFix outputs directly into the CNC machining operation and/or automated adaptive machining fixture with PLCs for each target movement. Casting metrological certification against as-cast tolerances can also be automated with a digital thread, which was demonstrated using conventional manual interpretations. Leveraging STEP AP242 recently developed in a DMDII-funded project would also benefit IAMFix framework with complete data exchange and shall be explored further.

V. ACCESSING THE TECHNOLOGY

a. Background Intellectual Property

DMDII Members will need the following Software Tools to utilize 'ASU-AutoFix®':

- ACIS and InterOp – Spatial
- Visual Studio – Microsoft
- CREO – PTCA

b. Technical and System Requirements

The following are system requirements needed to run the software:

- Core I5 processor, or better
- 4 GB of Ram, or better

The following test configurations were completed – note different configurations might not work:

- Visual studio 2012
- ACIS geometric kernel 25 and 26
- Windows 7

VI. ADDITIONAL COLLABORATION OPPORTUNITIES

The Principal Investigator is interested in further collaborating with other DMDII members in the following ways:

PDA is very interested and strongly recommends its participation into the various ongoing DMDII-funded projects, where it can leverage lessons learned from this project and add a substantial value; for example the ones led by Caterpillar, Rolls Royce and John Deere.

☐ Case studies to further test technology

☐ Further develop technology outcomes (advance TRL)

☐ Utilize DMDII Partner Innovation Projects platform

☐ Commercialization partner

☐ Venture funding

☐ Develop application for the Digital Manufacturing Commons

☐ Other _____