NASA SBIR 2020 Phase I Solicitation

Z4.04 Real Time Defect Detection, Identification and Correction in Wire-Feed Additive Manufacturing Processes

Lead Center: LaRC

Participating Center(s): MSFC

Technology Area: TA12 Materials, Structures, Mechanical Systems and Manufacturing

Scope Title

Development of Real Time Defect Detection, Identification and Correction in Wire-Feed Additive Manufacturing Processes

Scope Description

Additive Manufacturing (AM) (also referred to here as 3D printing) offers the ability to build light-weight components that are optimally suited for use in aerospace applications. Significant strides have been made in the development of AM with 3D printed components now being part of active aircraft and spacecraft[1,2,3]. While the use of AM has enabled non-traditional designs and decreased part counts, full inspection of each component is typically required post-build to determine fitness for the final application. Complex geometries, rough as-built surface finishes, and porosity can hinder inspection. If 100% inspection is not possible, proof test logic or some other method of proving fitness for use must be applied[4]. Defects that occur can force a complete reprint. The ultimate promise of AM is to enable on-demand production of customized unique components. For utility in space applications, printed parts have to be fully functional with zero to minimal post processing. Ideally, parts need to be built with acceptable form, fit, and function the first time, with sufficient documentation to allow direct entry into service. To enable the full realization of the potential of 3D printing, a capability for closed loop control of the process that integrates *in situ* monitoring, real-time defect detection and identification, & print parameter modification is required.

Wire-feed or extrusion type AM, with its relative simplicity, wide range of feedstocks and build volume flexibility is a popular 3D printing technique that is well suited to space applications [6]. Fused Filament Fabrication (FFF) and Electron Beam Free Form Fabrication (EBF[3]) are useful examples of wire-feed processes to illustrate the limitations placed on AM by presently available design and process control tools. After designing an object using 3D modeling software, the geometry is passed to a slicing and tool path planning code, which generates the list of instructions needed by the printing hardware. Once received by the printer, no further modifications or corrections can be made, and the process continues to completion.

Proposals are invited to advance the manufacturing technology by incorporating an *in situ* defect detection and correction capability into wire-feed or extrusion type metallic, plastic or composite AM.

In Phase I, contractors should prove the feasibility of integrating sensor feedback with appropriate software tools and computation resources to be able to detect defects during fabrication of parts with complex geometries, evaluating the potential impact of the defects to the part performance and the correction of those defects. Solutions sought include the software that can be integrated into the 3D printing workflow, hardware requirements to run that software for real-time data processing and sensors capable of operating in the build environment to provide data also in real time. The proposed approach should be demonstrable at least on the coupon scale for shapes such as circles or boxes.

Phase II, should demonstrate the feasibility of Phase I concepts to arrive at closed loop solutions to build parts in which information on the processing generated from gathering and analyzing sensor data is used for the prediction of part performance, unique to each individual part, as it is being built. Incorporation of defect correction during fabrication, rather than requiring a print to be scrapped and restarted should be demonstrated on sample parts.

References

1. https://www.ge.com/additive/blog/new-manufacturing-milestone-30000-additive-fuel-nozzles [GE Additive news release – “New manufacturing milestone: 30,000 additive fuel nozzles”]
2. https://www.spacex.com/press/2014/05/27/spacex-completes-qualification-testing-superdraco-thruster [SpaceX news release - “SPACEX COMPLETES QUALIFICATION TESTING OF SUPERDRACO THRUSTER”]
3. https://www.rocketlabusa.com/news/updates/rocket-lab-celebrates-100th-rutherford-engine-build/[Rocket Lab News release -"Rocket Lab Celebrates 100th Rutherford Engine Build"]
4. https://www.nasa.gov/sites/default/files/atoms/files/msfcstd3716baseline.pdf [MSFC Technical Standard EM20 "Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals" - MSFC-STD-3716]
5. https://www.thefabricator.com/additivereport/blog/wire-feed-3d-printing-grows-in-popularity [the Additive Report- "Wire-feed 3D printing grows in popularity"]
6. https://www.ibm.com/blogs/internet-of-things/iot-3d-printing-quality-manufacturing/[IBM Internet of Things blog – “Why quality is the obstacle to mass adoption of 3D printing”]
7. https://cdn.eos.info/839090ec135565bc/b6a6ac17dca9/EOS_Whitepaper_Monito... [Lukas Fuchs, Christopher Eischer, EOS GmbH Whitepaper - “In-process monitoring systems for metal additive manufacturing”]
8. https://www.engineering.com/AdvancedManufacturing/ArticleID/19416/The-Importance-of-Closed-Loop-Control-in-Directed-Energy-Deposition-Additive-Manufacturing.aspx [Isaac Maw engineering.com – “The Importance of Closed-Loop Control in Directed Energy Deposition Additive Manufacturing”]
9. https://www.mdpi.com/2076-3417/9/4/787 [Shassere et al.,- "Correlation of Microstructure and Mechanical Properties of Metal Big Area Additive Manufacturing", Applied Sciences, 9, 2019 (4) 787.]

Expected TRL or TRL range at completion of the project: 2 to 3

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

Desired Deliverables Description

In Phase I, concept studies documenting the feasibility of incorporating sensor data feedback and appropriate software tools and computation resources to be used to detect defects during fabrication of parts with complex geometries, evaluating the potential impact of the defects on the performance of the parts and the correction of those defects.

Phase II, scale demonstration of a printer with closed loop control that incorporates defect detection, identification and correction during fabrication. The complexity of defects that are detected and corrected as well as the size of the parts should demonstrate the challenges that would come up in full-scale use of the control processes. Printed part sizes should be at least 10 cm per side for cubes with detectable defects down to the mm scale or smaller. The defects should have a demonstrable effect on the part performance, such as a decrease in mechanical properties that is then corrected for by the process.

State of the Art and Critical Gaps

Additive Manufacturing is seeing rapidly expanding applications in many areas including in aerospace. Despite this growth in AM, fulling its full potential has always been limited by quality control issues and certification of the manufactured parts as each component that is built is unique[6]. Some work has begun to add defect detection and correction to powder based manufacturing processes such as Direct Metal Laser Sintering (DMLS)[7,8] and wire-feed AM[9]. There has however not been the requisite advance in ensuring that defect detection and identification is coupled with the real-time correction of those defects and ensuring final performance of the manufacture part in a particular application.

Gap: Real-time defect detection, identification and correction in AM processes, which would ensure the performance of the as-printed parts without relying on post production inspection processes, with parts built with acceptable form, fit, and function the first time, with sufficient documentation to allow direct entry into service has not been demonstrated.

Relevance / Science Traceability

This topic fits under STMD (Space Technology Mission Directorate). It supports Advanced Manufacturing of Lightweight Structures. Enhancing quality control in AM opens up its use in many industrial applications as well as for NASA use. In particular, in-space use of AM in future Gateway, Lunar and Mars exploration missions will require that parts that are produced are ready for use as-produced since there will be limitations in availability of material for re-printing as well as crew time and equipment for post-printing inspection.