In-situ monitoring of processing defects and avenues for control/correction in laser-based metal additive manufacturing.

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Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D)
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AMSC Virtual Event on AM Standardization to Highlight Inspection/Monitoring to Meet Regulatory Requirements, January 7, 2021
• Department head within the Materials Science Division of the Applied Research Laboratory (ARL) & Associate Research Professor at Penn State.

• Graduate Faculty appointments with
  • Engineering Science and Mechanics Department,
  • Additive Manufacturing & Design (AMD) Graduate Program, &
  • Department of Mechanical Engineering.

• Worked in the field laser processing of metals for >13 years. Focus on laser-based AM of metals since 2012.
  • Earned PhD, from Penn State, in 2012. Thesis on *laser-sustained plasma and the role of plasma in carbon dioxide laser nitriding of titanium*.
  • As part of PhD, completed Post-Baccalaureate Program in Laser-Materials Processing.
  • >35 journal articles, >10 invention disclosures (>5 provision or current patents).

• In 2020, awarded the International Outstanding Young Researcher in Freeform and Additive Manufacturing (SFF FAME JR) Award.

Dr. Abdalla R Nassar
Who We Are

- Designated by DoD as a University-Affiliated Research Center (UARC)
- Maintain a strategic long-term relationship with DoD
- All U.S. Citizens (including students)
- Government Contractor within a University
- Regularly audited (financials, security, purchasing, contracts)
- Maintain timecards and detailed cost/schedule records on all projects
- Advised by Board comprising a mix of PSU and outside senior officials
Interest in sensing and control of PBFAM has grown nearly exponentially over past decade. However, is difficult to differentiate between hype and reality…
• Traditional process performance qualification requires a repetitive manufacturing process to achieve products that exhibit equivalent performance.
  • For example, a Welding Procedure Specification (WPS) for a specific weld type and alloy. (AWS C7.4, ASME Sec IX)
    • A Procedure Qualification Record (PQR or WPQR) is used to document the performed weld and record any required tests.

• Works only if all manufacturing functions, may be well defined….AM's greatest assets is also its greatest liability: Complexity is not so free…

• In-situ sensing offers the potential to
  • verify part quality,
  • accelerate process and part qualification, and
  • enable process control.
Roles of sensing

Subsystem Status
- Laser power
- Scanner error
- Optics temperature
- Oxygen level
- Gas flow speed

ISO/ASTM 52941, ISO/ASTM 52942

Process Monitoring (for quality & control)
- Photodiodes
- Pyrometers
- Spectrometers
- Acoustic sensors
- Layer imaging

ASTM WK62181

Process Monitoring (to elucidate physics)
- High-speed VIS imaging
- High-speed IR imaging
- X-ray imaging
- High-resolution topography

ASTM WK62181

Detector
Rotational Stage
Cone Beam
X-Ray Source

ISO/ASTM 52941,
ISO/ASTM 52942
Some definitions

**Sensor configuration**

- **Co-axial Configuration**
  - integrated within laser’s optical path

**Detector Type**

- **Single-point detector**: Integrates captured signal over its total field of view.
  - e.g., Photodiode, microphone

- **Array detector**: Captures signal using a 1D or 2D array such that signal is discretized in space.

*note: by this definition a spectrometer (which uses a 1-d array of pixels) is a single-point detector.*
Heterogeneous monitoring of DED

Coaxial Vis & IR Imaging

Illuminated Pool Imaging

Plume Imaging

Optical Emission Spectroscopy

Powder Flow Monitoring

Laser Ultrasonics
Heterogeneous monitoring of PBF

IR Imaging

Diffuse Field Ultrasonics

Layerwise Camera & Multi-spectral sensor

High-speed camera

Coaxial multi-spectral

Output Display

Computer Controller/DAQ

Build Plate Insulating Layer SMART Sensor

Housing

Spectrometer

Acoustic Sensor
Fundamental challenges are

• Wide range of time and length scales
• System interfacing & data acquisition
• Replication crisis (too many variables)
• Volume of data being generated
• Alignment/Registration uncertainty

Can standardization meet each of these challenges???


Computed Tomography (XCT) Data

Build Plan or STL

Register XCT Data

Identify Flaws/Features

Confirm Flaws/Features

Run Analysis

Time-series Data Synched to X,Y,Z

Register Data

Split Data into Parts

Rasterize Data

Extract Neighborhood

Build Plan or STL
Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D)

Our Capabilities

3D System DMP Factory 500
- 500 x 500 x 500 mm work envelop

Wire Arc Additive Manufacturing (WAAM)

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Thank You!
Questions?

Large-Scale DED
Calibrated IR Imaging
DED Sensing
DED Feedback Control
Optimized & Functional Designs
Feed-forward Control of PBFAM

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