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# Real Time Non-Destructive Evaluation During 3D Manufacturing of Metal Parts

Araz Yacoubian
President and CTO
Ler Technologies, Inc.
ayacoubian@lertechnologies.com

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# Need For NDE in 3D Metal Printing

- A non-destructive evaluation unit can be added to an existing additive manufacturing (AM) tool of direct metal laser sintering (DMLS).
- Provide real-time information about the part quality, and detecting flaws as they occur.
- The information provided by this unit is used to a) qualify the part as it is being made, b) to providing feedback to AM tool for correction, or to stop the process if the part will not meet the quality.
- Save time, energy and reduce material loss.
- Significant reduction in cost.
- Potentially higher quality 3D part due to advanced multi-modal optical inspection

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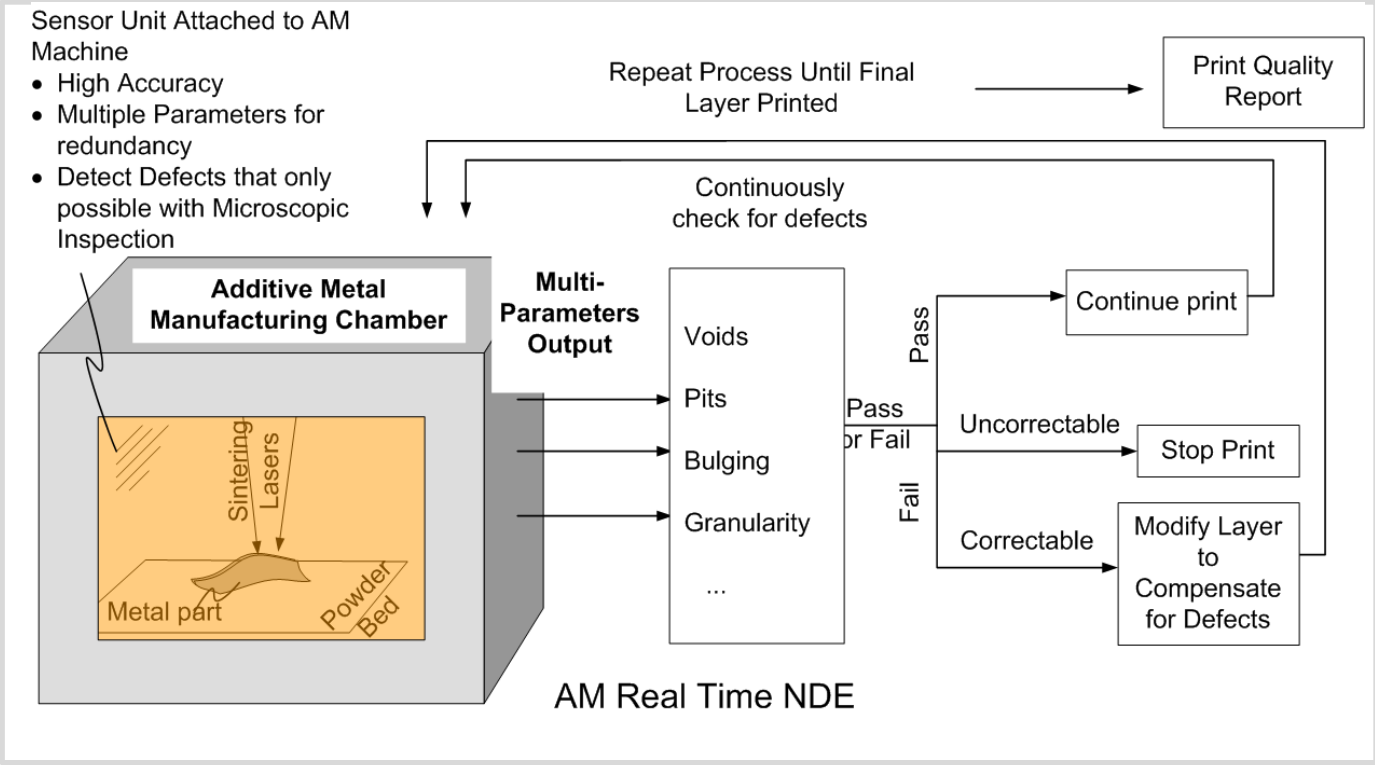
# Overview

- Use a combination of multi-parameter imaging techniques.
- Each of these modality detects different types of defects.
- The final outputs are combined to produce a defect map.
- Defects not seen by microscopic inspection can be detected by advanced optical methods

**Example of Defects Detected:**

- Voids
- Cracks
- Bulging
- Granularity Variation



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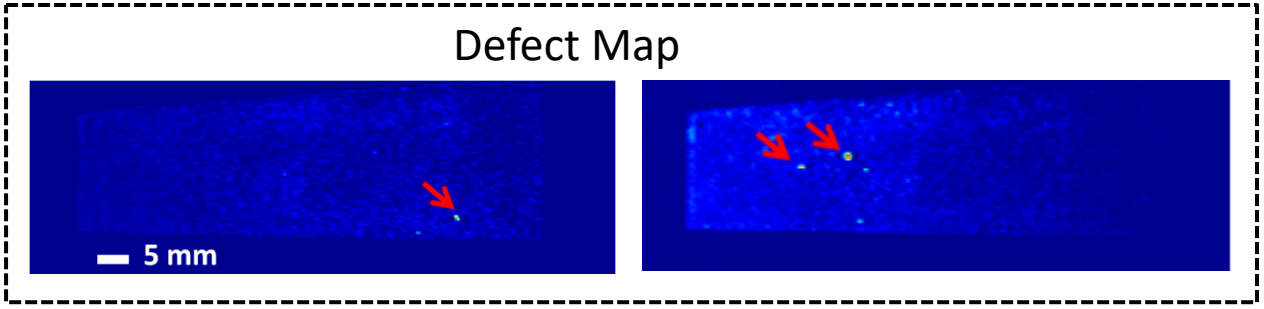
# Advantage of Multi-Parameter Detection Method

- Enables a robust real-time inspection method that ensures printed part quality.
- Provides measurement redundancy, maximizing likelihood of detecting defects that may otherwise be missed using a single parameter sensing approach.
- Avoids false readings.
- Each sensing technique sensitive to various types of defects, thus it covers a broad range of print quality issues.

Selectively Detect Various Defects



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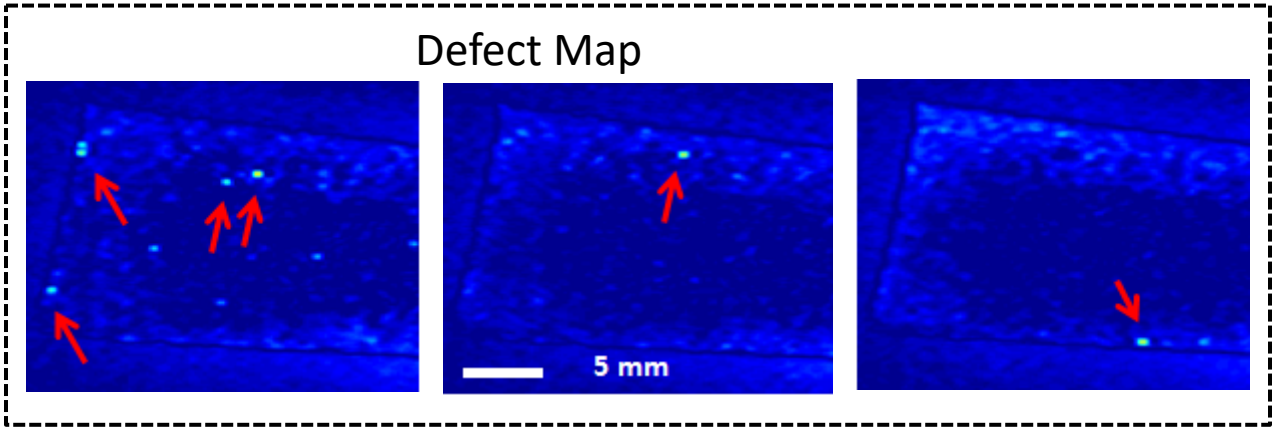
# Phase II Objectives

1. Design and fabricate pre-prototype with multiple sensing modalities.
2. Develop a portable prototype which is compatible with 3D metal printing machine by combining pre-prototype units of multiple sensing modalities into a single unit.
3. Demonstrated prototype performance by testing samples with defects and compare detected and actual defect values.

Selectively Defect Mapping



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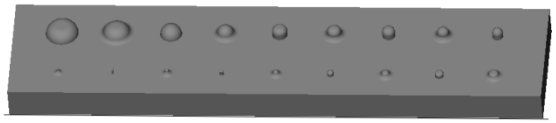
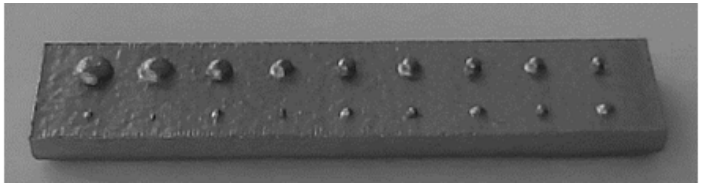
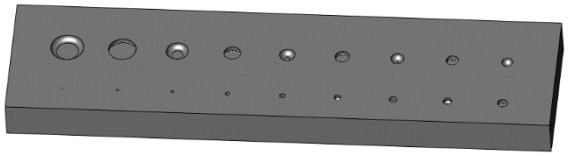
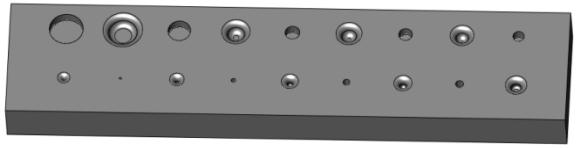
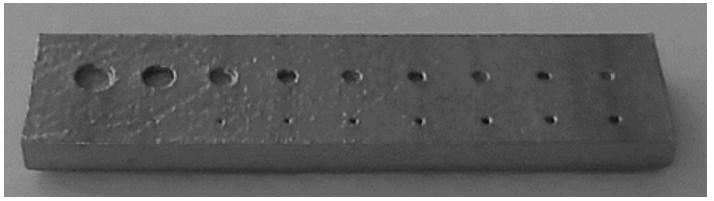
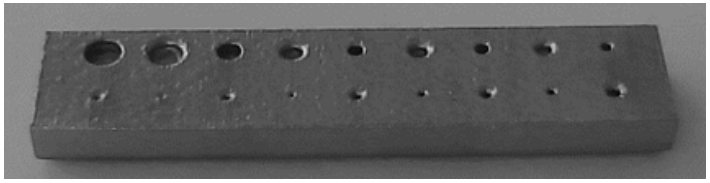
# DMLS Samples

| | 3D CAD Layout | DMLS Sample Photographs (Stainless Steel 316) |
|---|---|---|
| Bulging Sample: Varying Diameter and Shapes |  |  |
| Surface Void: Varying Diameters, Shapes and Depth |   |   |

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# Summary of Some of the Sensor Capabilities

| Type of Defect | Detection with This Method |
|---|---|
| Voids | √ |
| Bulging | √ |
| Improper melt | √ |
| Non-fused metal | √ |
| Dimensional Verification | √ |
| Surface quality/ finish/ roughness | √ |

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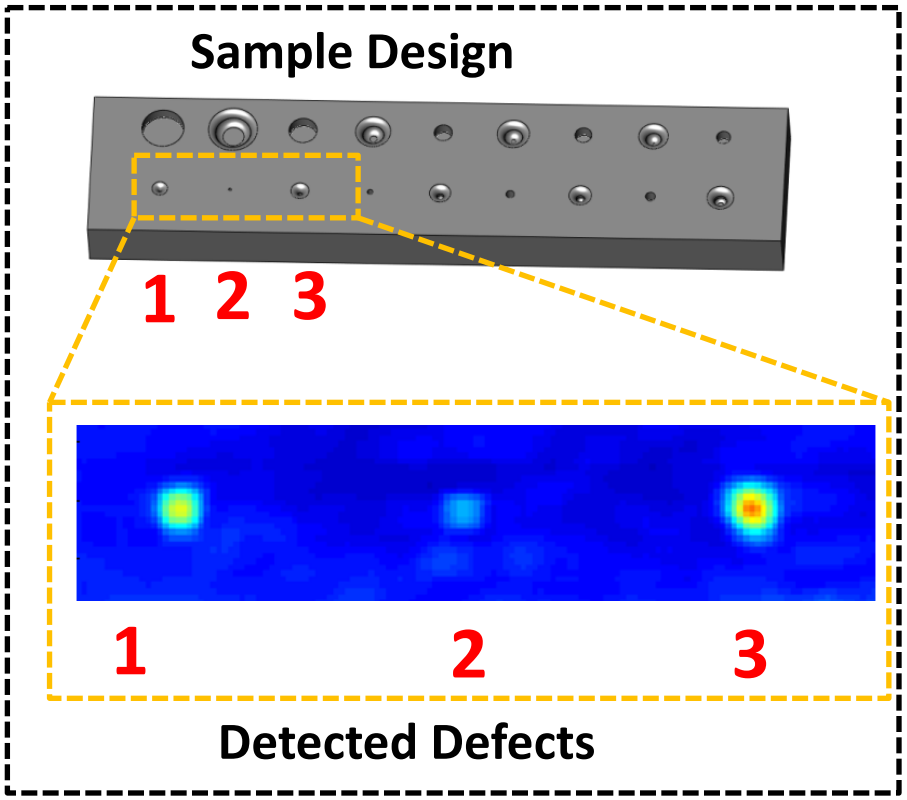
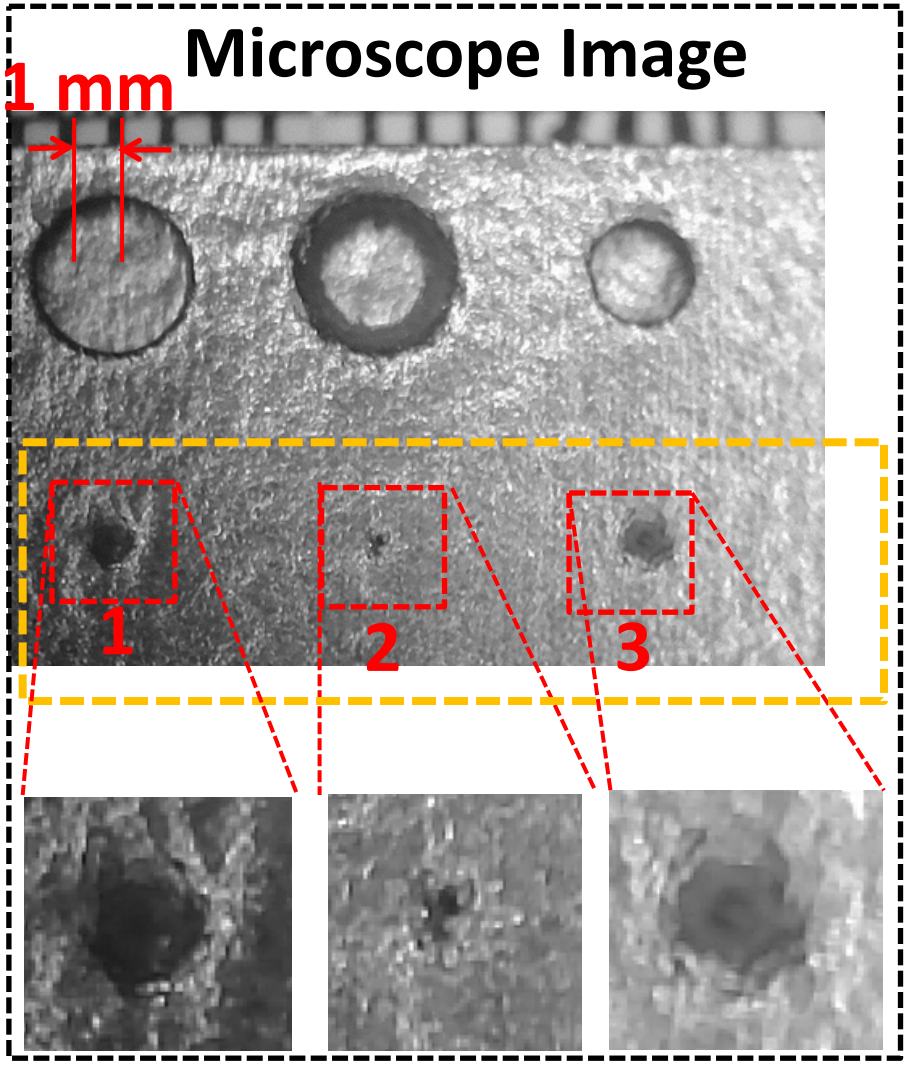
# Surface Void Detection




- Void depth ~ 1 mm
- Smallest detected voids barely visible under a microscope.

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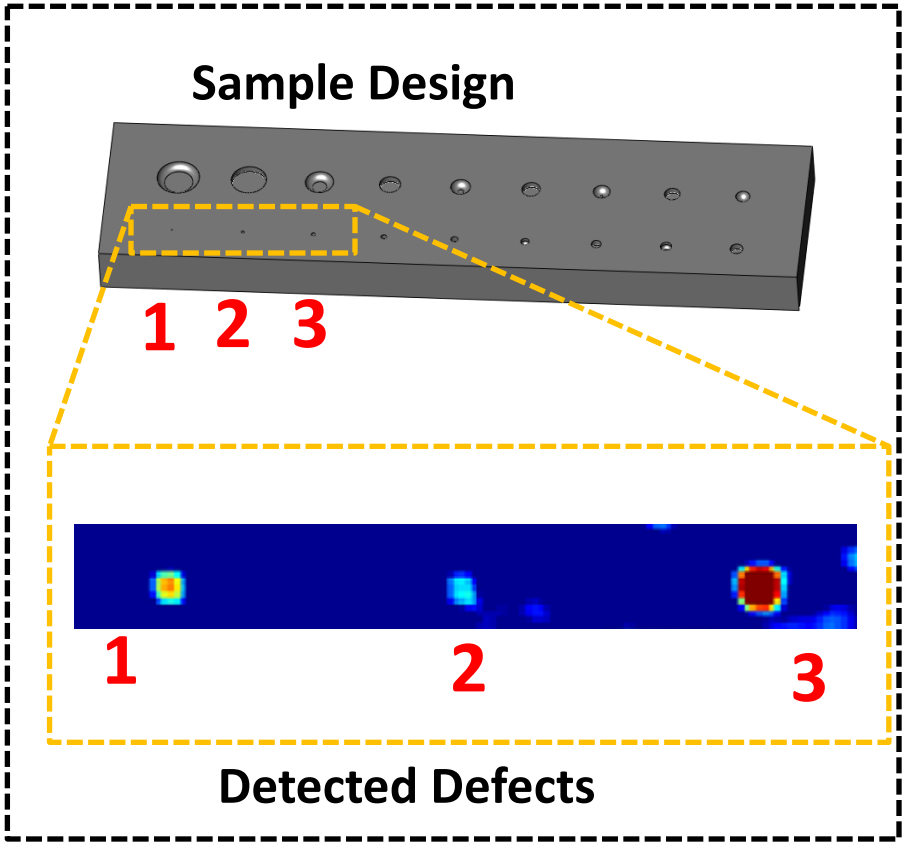
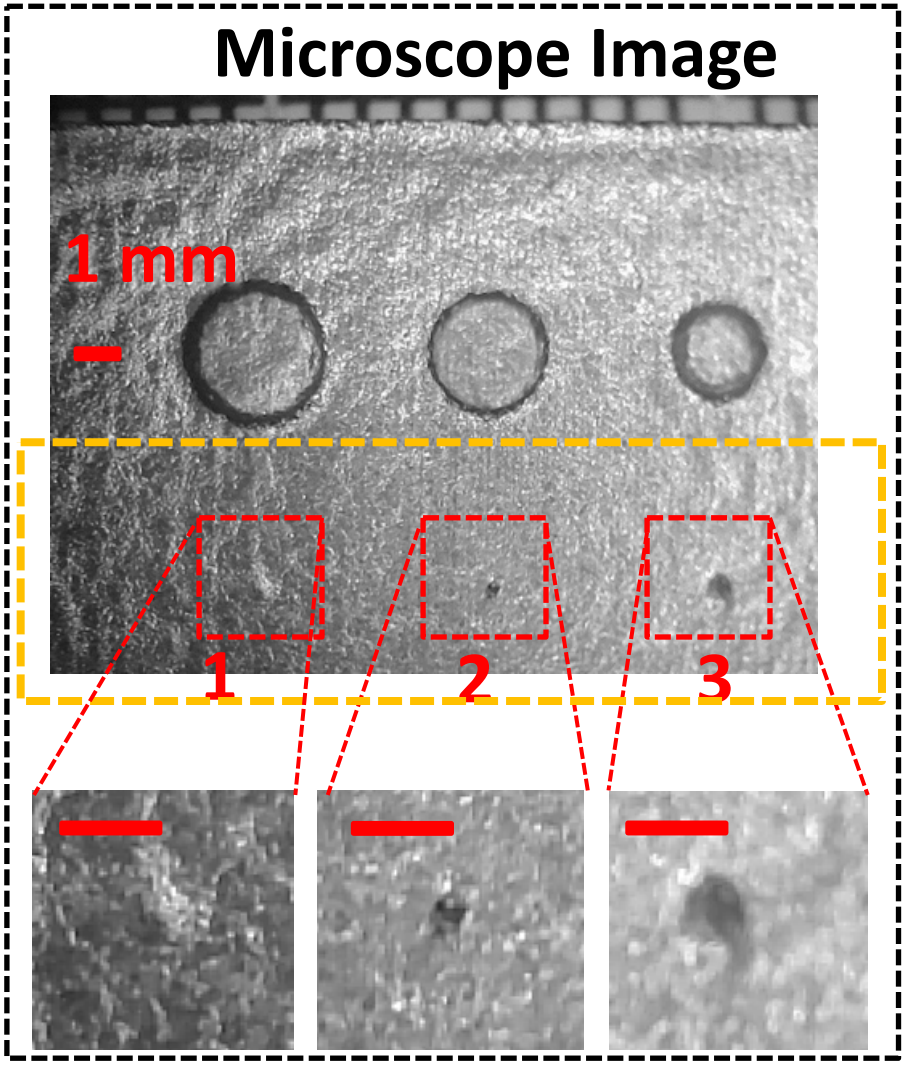
# Shallow Surface Void Detection




- Void depth 0.5 mm
- Smallest detected voids barely visible under a microscope.

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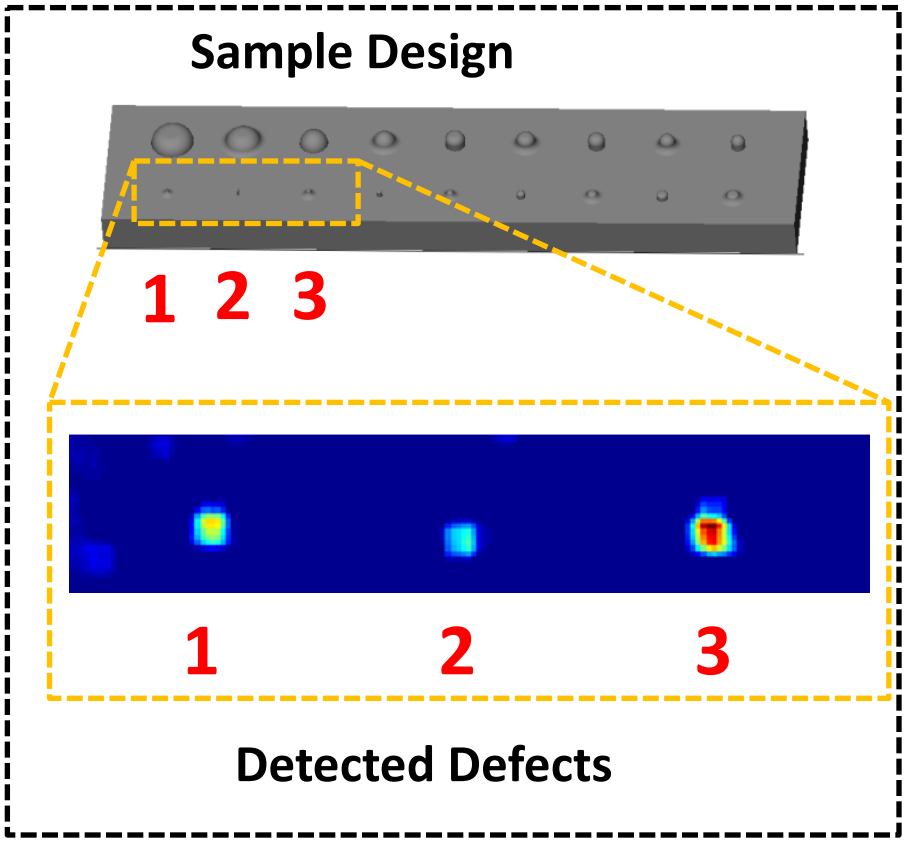
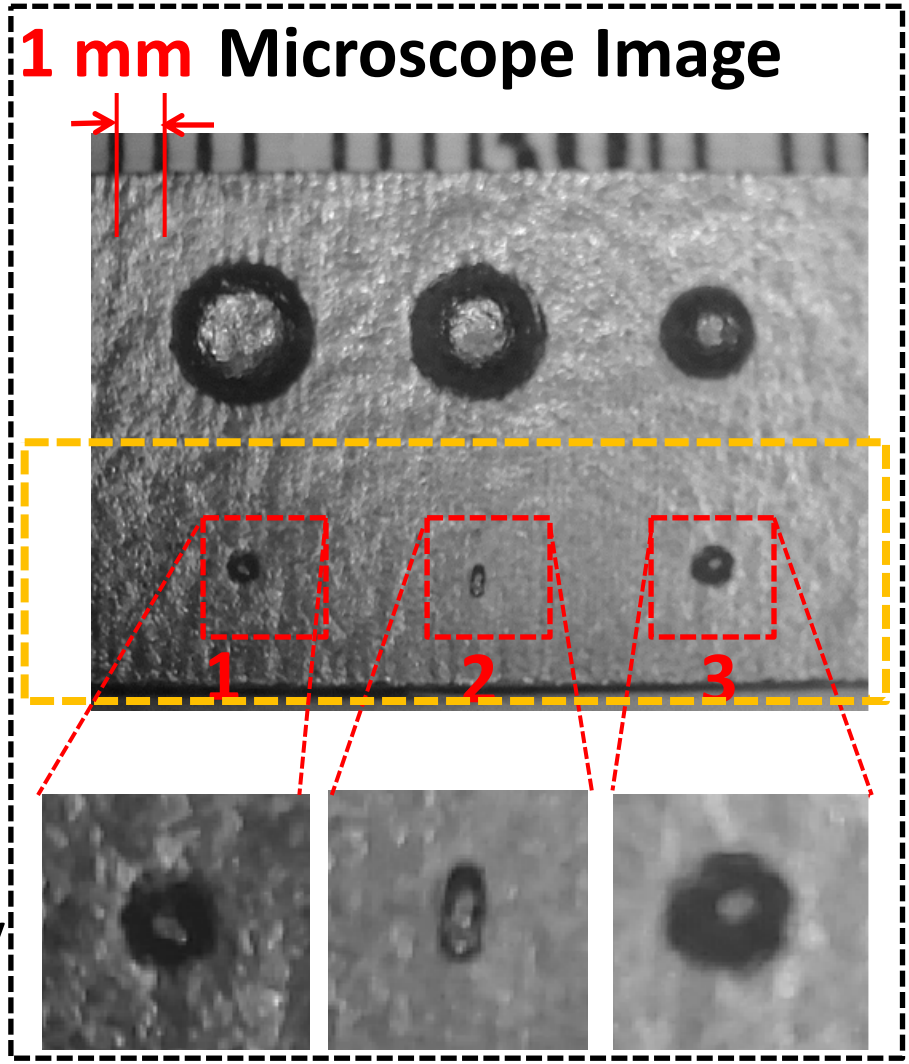
# Surface Bulging Detection




- Smallest detected bulging barely visible under a microscope.

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# Milestone Status

| Milestone/Objectives | Completion |
|---|---|
| 1. Design and fabricate samples using laser metal sintering to be used for NDE approach | Completed in Phase I |
| 2. Demonstrate feasibility of multi-parameter NDE approach using the fabricated sample with known defects.<br>a. Defects that were even difficult to detect with microscopy were detected<br>b. Demonstrated applicability to actual machine environment | Completed during Phase I |
| 3. Fabrication Table top pre-prototypes | Expected completion date on July, 2020. |
| 4. Complete portable prototype to a single unit | Expected completion date on February, 2021. |
| 5. Test and verify prototype performance by comparing actual and detected defect values | Expected completion date on July, 2021. |

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# Project Plan (Phase II)

| Tasks | Status |
|---|---|
| Design Real Time Monitoring Sensor System | Current work |
| Fabricate Table-top Pre-prototype | Current work |
| Design and Fabricate Samples for Testing | Planned |
| Test Samples with the Table-Top Prototype | Planned |
| Control electronics | Current work |
| Build a Portable Prototype Unit | Planned |
| Test Prototype Unit | Planned |
| Detection Verification | Planned |

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# Risk and Challenges

| Risk or Challenge | Solution or Mitigation Tools |
|---|---|
| **Accurately detect defect** | **Multi-parameter approach** |
| **False positives** | **Redundancy built-in to our approach** |
| **Ability to operate in machine environment** | **Combination of sensor design and proprietary algorithms to enable operation even in the most unforgiving environments.** |

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# Next Activities

| Tasks | Status |
|---|---|
| Design Real Time Monitoring Sensor System | Continue |
| Fabricate Table-top Pre-prototype | Continue |
| Design and Fabricate Samples for Testing | Next step |
| Test Samples with the Table-Top Prototype | Next step |
| Control electronics | Continue |
| Build a Portable Prototype Unit | Planned |
| Test Prototype Unit | Planned |
| Detection Verification | Planned |

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# Summary

- Phase I results demonstrated the feasibility NDE detection with multiple modality approach
- Sensor unit attached to DMLS machine enables:
  - real-time inspection
  - provides measurement redundancy
  - maximizes likelihood of detecting
- Enables real-time defect correction
- Reduces cost and significantly reduces post-fabrication inspection needs.