Sensor Integration into Industrial Metal 3D Printing & In-house Powder Spreader Equipment

Introduction

Powder Bed Fusion (PBF) is an advanced **Additive Manufacturing** (AM) technology. The advanced development has enabled wide uptake of commercial applications of for the production of high-value products that are not technically feasible with traditionally manufacturing processes.

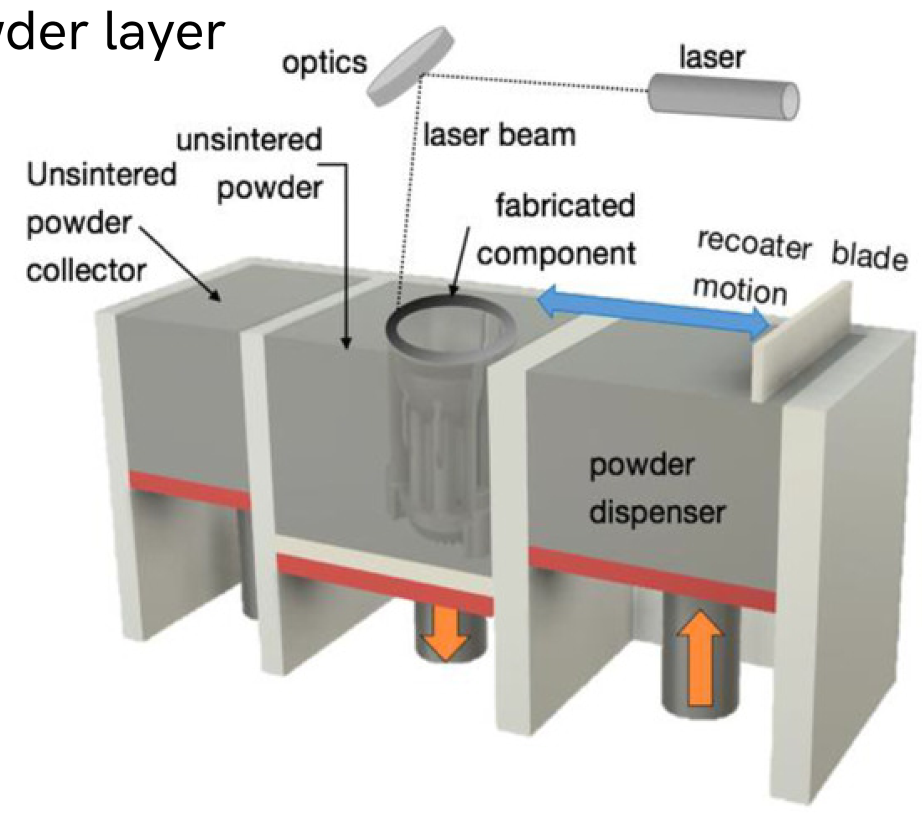
EOS M 290

Industry Applications:

- Aerospace components (brackets, nozzles for jet engines) - Rolls Royce
- Efficient energy storage systems (heat exchanges, cold plates for Electric Vehicles)

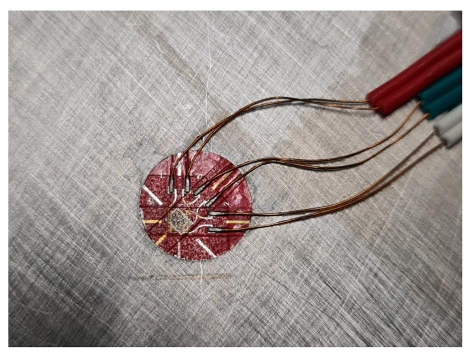
Working Principle - Building a part layer by layer

1. Apply a layer of powder
2. Selectively melting the powder using a laser light
3. Lower platform by the respective thickness of the layer
4. Applying a new powder layer

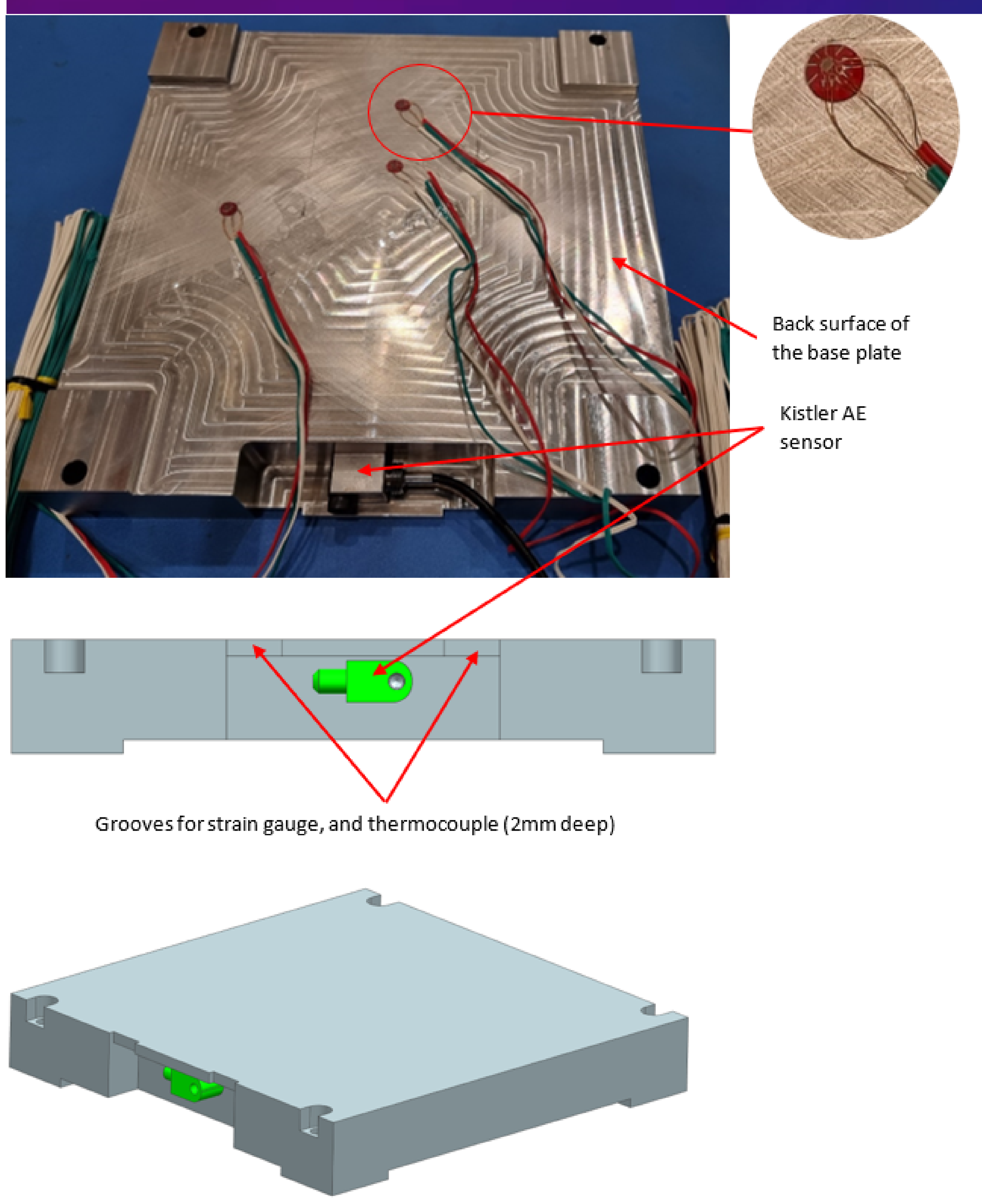


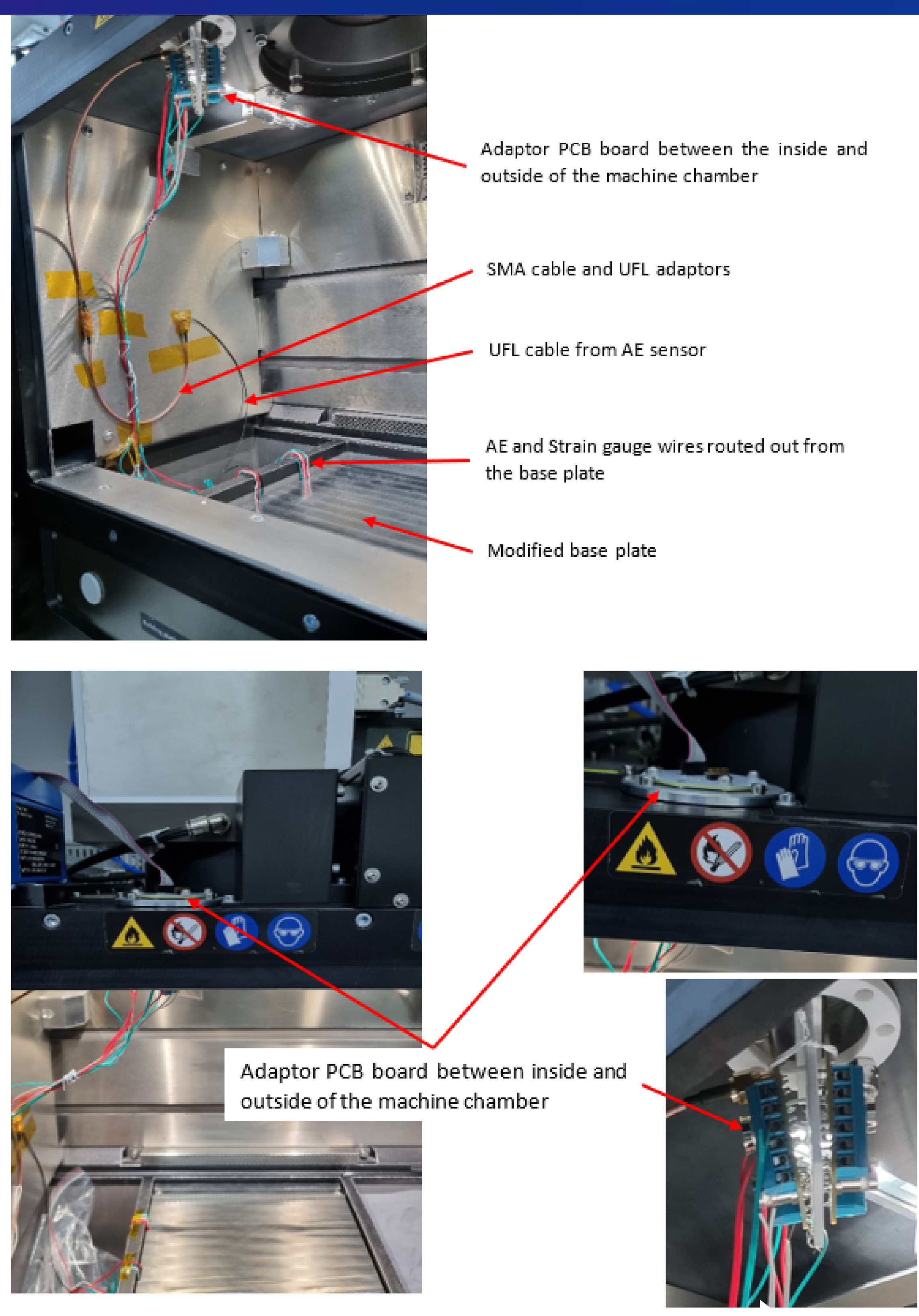
Feasibility Study - Investigate the practicality of sensor integration into the baseplate of the metal 3D powder-based machines for process monitoring

Strengths	Additive manufacturing has the ability to manufacture extremely complex parts with very high accuracy and strength using various material groups. In recent years, additive manufacturing has become one of the most demanding and fast-growing technologies in the domain of Industry 4.0.	
Weaknesses	3D printed parts are susceptible to faults and failures which mainly occur during the printing process as the result of various printing parameters, temperature variations, thermal stresses, porosity etc. Lack of reliable in-line process monitoring and condition monitoring of the printed parts to assist quality assurance slows down the fast industrialization of additive manufacturing	
Opportunities & Outcomes	Since metal 3D printing is a layer by layer-based part manufacturing method, monitoring the quality of each layer is crucial to provide a "qualify-as-you-build" quality assurance.	
	Early detection of faults in layers allows 1. Implementation of preventive measure 2. Neutralize advancement of faults into subsequent layers. Process monitoring of metal 3D printing is achievable via sensor integration and data collection and analysis of the printing process. Once a proactive maintenance method is established, next stages of process monitoring such as predictive maintenance and in-line feedback process control methods can be implemented.	E.g. Changing process parameters to find defects in the powder quality. INCREASE sustainability aspects (material and energy efficiency)

Sensors Used	
Strain Gauge (Type FRAB-1-350-11)	Kistler 8152C Acoustic Emission (100KHz to 900 kHz)
	
To measure...	
Strain Thermal-induced residual stresses	Stress wave Delaminating part from the build plate
Working Principle	
Warpage of baseplate from shrinkage of solidifying 3D part	Stress build-up from large temperature gradients

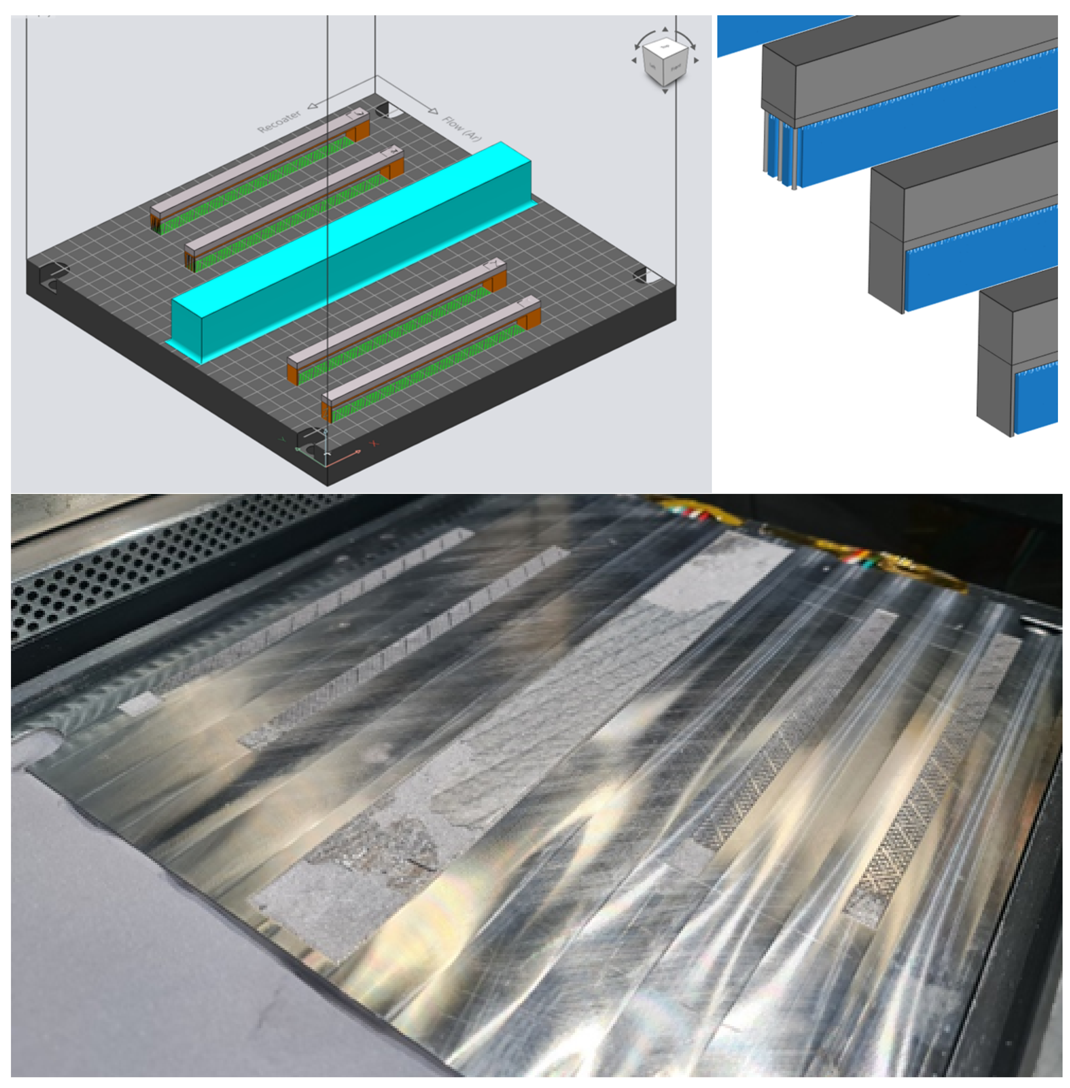
• Approach for Incorporating Sensors





• Print Design Approach

Geometries that have a high tendency to delaminate & crack are those that will have significant warpage (from large cross-sectional areas) and with thin support structures.



Aftermath of the print (AlSi10Mg powder on steel base plate at a height of 0.48mm)

The difference in materials caused the first few layers to have a low adherence to the base plate and to delaminate early. This was exacerbated by the curvature and surface roughness of the modified steel plate, where the surface has an inverted bowl shape, being taller in the center by 50µm compared to the corners. This gave rise to a greater chance of delamination in the early stages of printing.

Student: Clement TOH
Supervisors: Dr. Choon Seng CHEW (School) & Dr. Zheng Jie TAN (Company)

Advanced Remanufacturing and Technology Centre ARTC
SP Singapore Polytechnic

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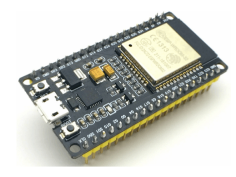
• Project 2: M5Stack FIRE IoT Development

Objective: To monitor and view the signal tower status of the EOS M 290 remotely with a M5Stack FIRE IoT device

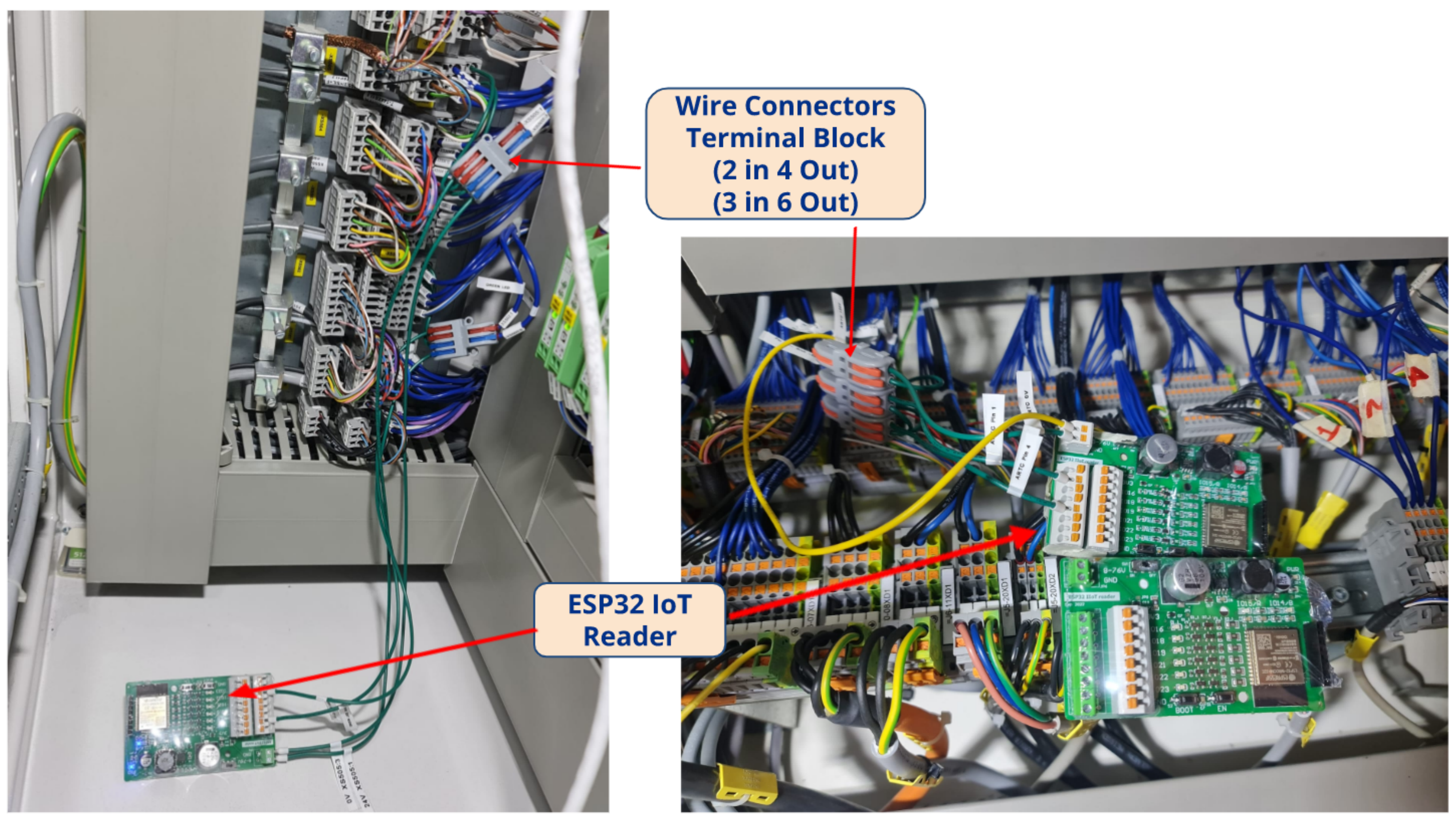
The M5 stack is an industrial internet of things (IIoT) device that can collect data from a 3D printer, such as temperature, humidity, or in the scenario, the machine status, and send it to a remote location for analysis.

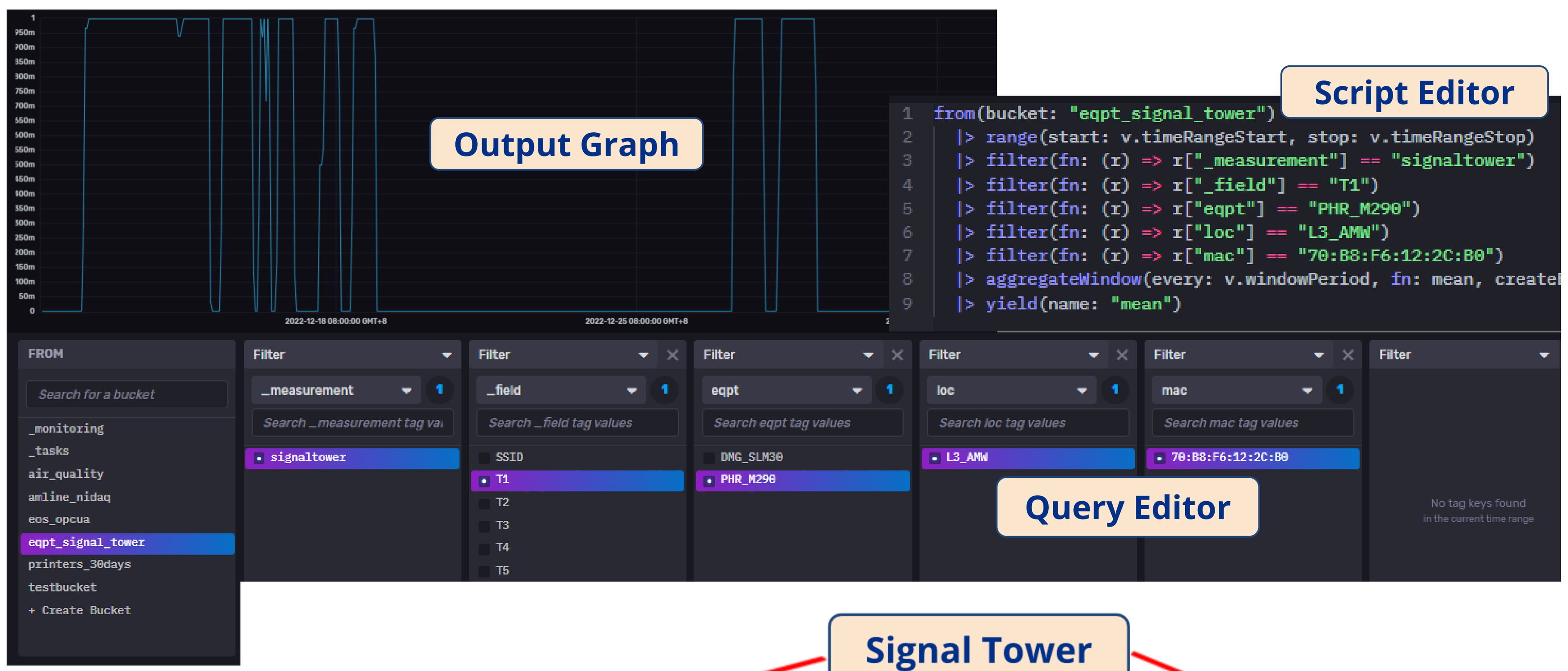
The M5 stack FIRE device is a modular, stackable, scalable, and portable device powered by an ESP-32 core.



✅ Open source, low cost, full function, and easy for developers to handle new product development.

The steps will cover the connection of the M5 stack to an EOS M 290 3D printer. It performs functions from collecting data via influxdata time series database and developing code for the M5 stack using C++ on the Platform.io IDE.





1. **Connect IoT device to EOS M 290 machine**
2. **Collect data via**
3. **IoT Development By Using C++ on VS Code (Platform.io IDE)**
4. **Upload to M5 Stack FIRE**

Operating well, M5 Stack FIRE

Issues occur, M5Stack FIRE

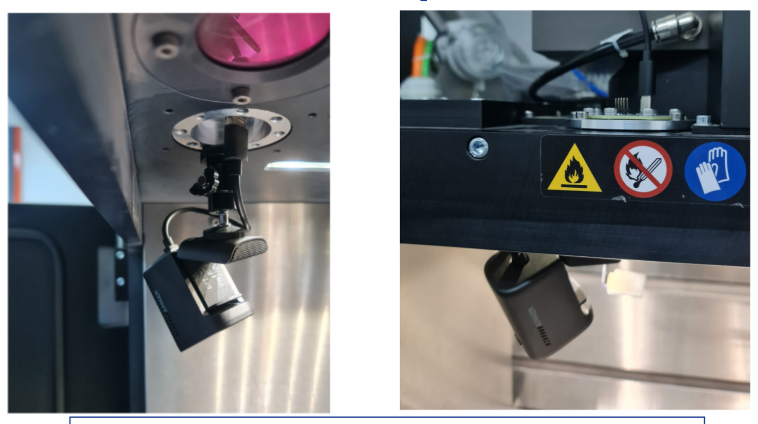
• Project 3: Webcam Streaming in EOS M 290 Chamber

Objective: To implement a real-time video streaming system to monitor the laser powder bed fusion process in an industrial setting.

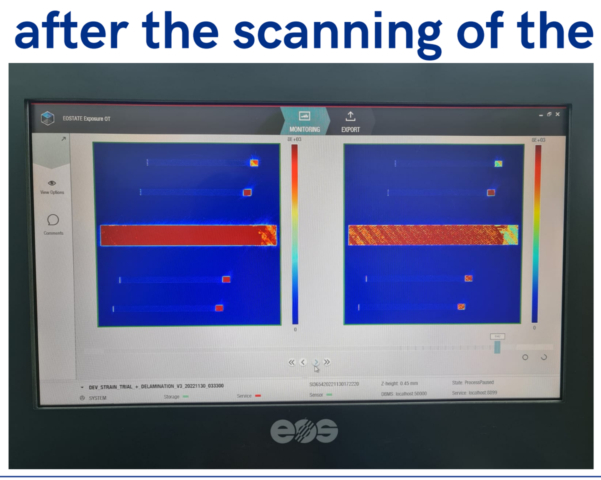
Purpose: To provide in-process monitoring during the scanning as well as sweeping of the recoater blade initiates the purpose of the Webcam Stream. Current solutions involves the documentation of the process before and after the scanning of the powder bed.

Several considerations considered:

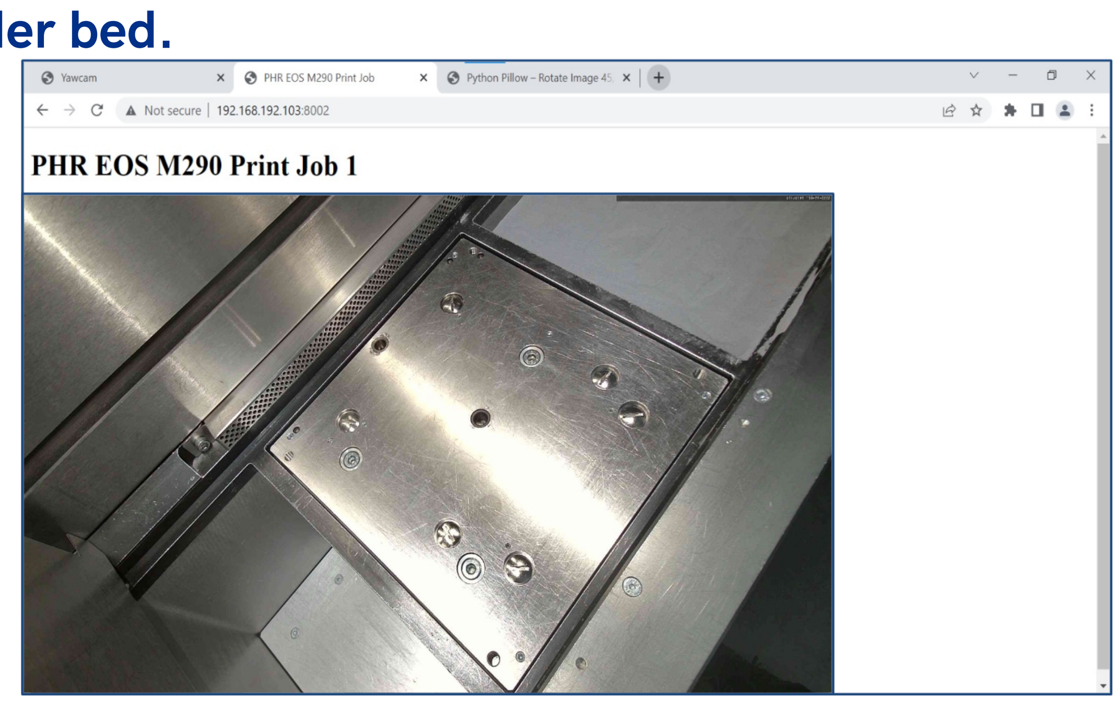
- Spatial
- Safety
- Network
- Hardware
- Software
- Preservation of printer chassis



```
<!DOCTYPE html>
<html lang="en">
    <head>
        <link rel="stylesheet" href="style.css">
        <meta charset="UTF-8">
        <title>PHR EOS M290 Print Job</title>
    </head>
<div class="center">
        <p><h1>PHR EOS M290 Print Job 1</h1></p>
        <img
src="http://192.168.192.103:8081/video.mjpg?q=30&fps=33&id=0.290069155791
2334&r=1667816092915"
            width="940" height="528.75" angle="90"/>
</div>
</html>
```

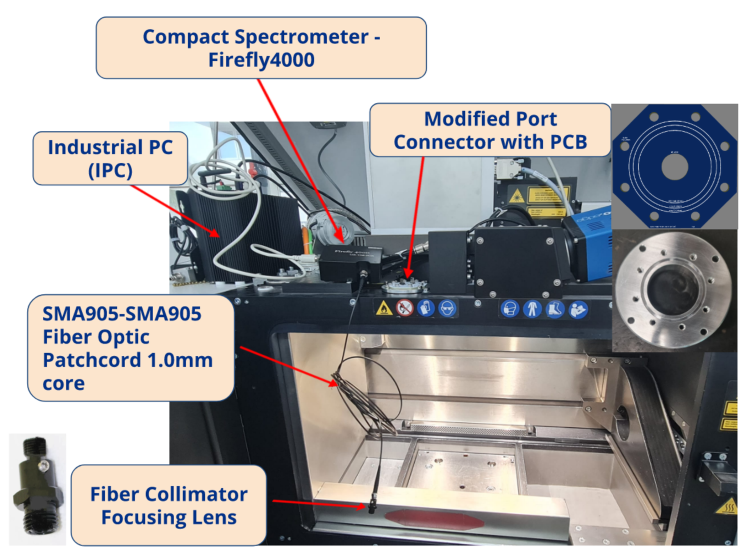


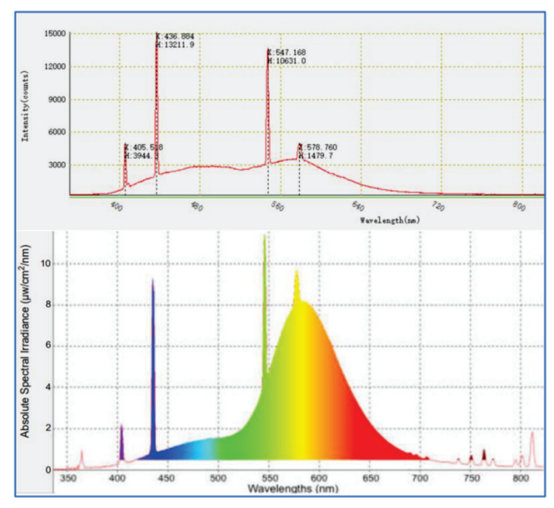
```
import http.server
import socketserver

PORT = 8002
class MyHttpRequestHandler(http.server.SimpleHTTPRequestHandler):
    def do_GET(self):
        self.path = 'index.html'
        return http.server.SimpleHTTPRequestHandler.do_GET(self)

Handler = MyHttpRequestHandler

with socketserver.TCPServer(("192.168.192.103", PORT), Handler) as httpd:
    print("Http Server Serving at port", PORT)
    httpd.serve_forever()
```



• Project 4: Spectrometer Integration and Development

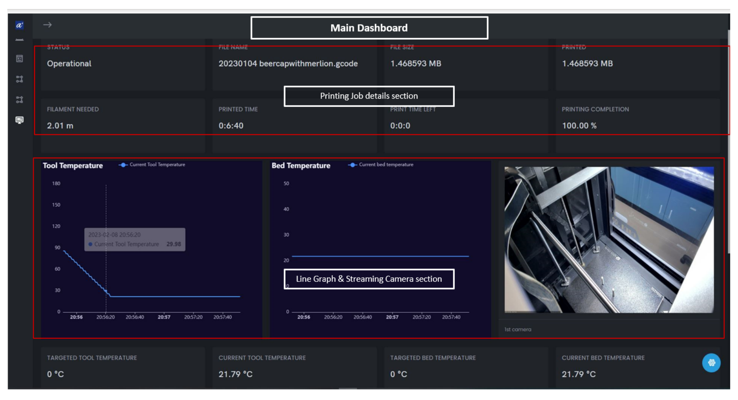
This project supports an upcoming grant program on powder reuse. It will evaluate how the elemental composition of the powder can be determined by the optical spectrum from its plasma emission when the powder is excited by a laser. Plasma emission is governed by the set of discrete energy levels present in a chemical system and varies from material to material, and also ought to be influenced by slight changes in the chemical properties of the feedstock powder. This work involves design aspects to extract spectroscopic spectra in-situ from live prints. Subsequently, the optical spectrum will be compared with other traditional ex-situ spectroscopic techniques, such as EDS, XRF or ICP-OES, to determine if spectroscopy-based in-situ monitoring would be useful for quality assurance in metal AM processes.





• Current Projects

- Supply Chain Control Tower – 3D Printing for Slow Movers (McKinsey & Company)
- ARTC 2023 Bi-Annual Technical Meeting (BTM) - Presentations & demonstrations for Core Research Project (CRP) Advanced Condition Monitoring and Spreadability Assessment of Powder Bed Device
- Further mechanical integration of sensors on EOS M 290 for machine learning via data acquisition (NI-DAQ) (Optical Emission Spectroscopy, Vibration Sensor, Acoustic Emission Sensor, Thermal Imaging Camera)



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