



# Process Control For Wire-Arc Additive Manufacturing

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A close-up photograph of a wire-arc additive manufacturing process. A metal wire is being fed into a torch, creating a molten pool that builds up a series of overlapping layers of metal. The process is taking place on a metal substrate, and the resulting structure is a series of interconnected, layered metal parts.

# Process Control For Wire-Arc Additive Manufacturing

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# Content

**1 Concept of WAAM**

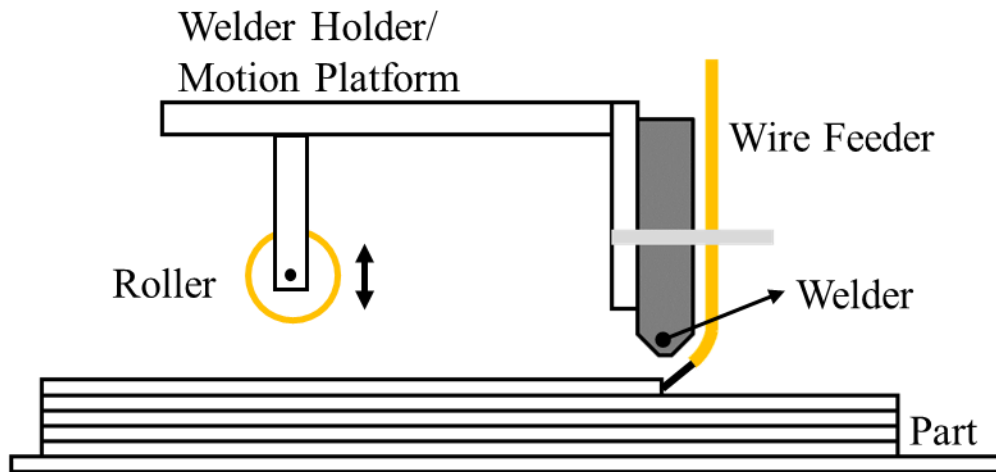
**2 Challenges to WAAM**

**3 Rolling Assisted Wire Feed Direct Deposition**

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# 1 Concept of WAAM



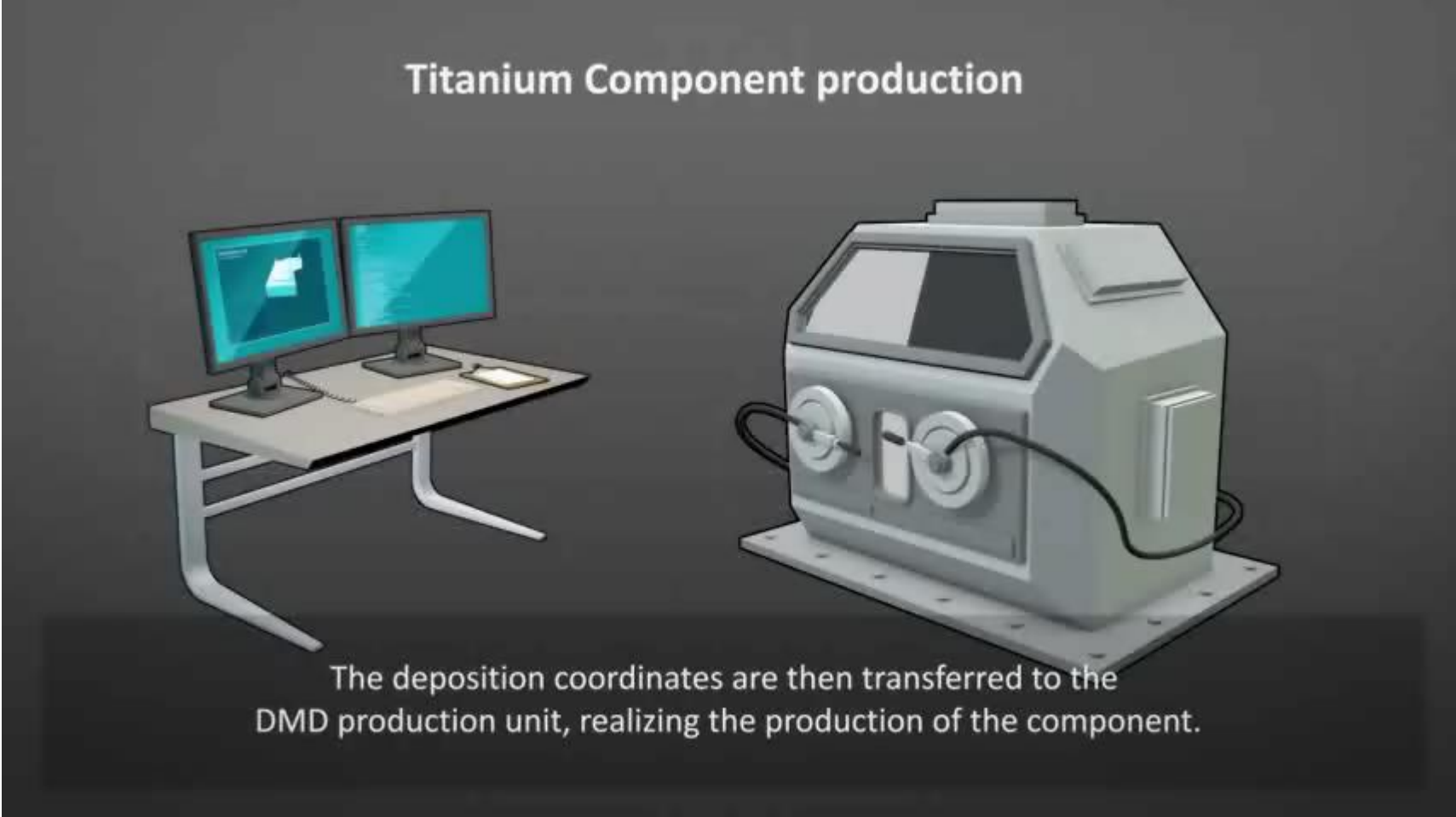
Schematic of WAAM process



WAAM depositing process

- **WAAM** is a arc-based Additive Manufacturing technique.
- **WAAM** can build large part with low cost.
- **WAAM** can achieve high energy efficiency.

# 1 Concept of WAAM



Source: <http://www.norsktitanium.com/>

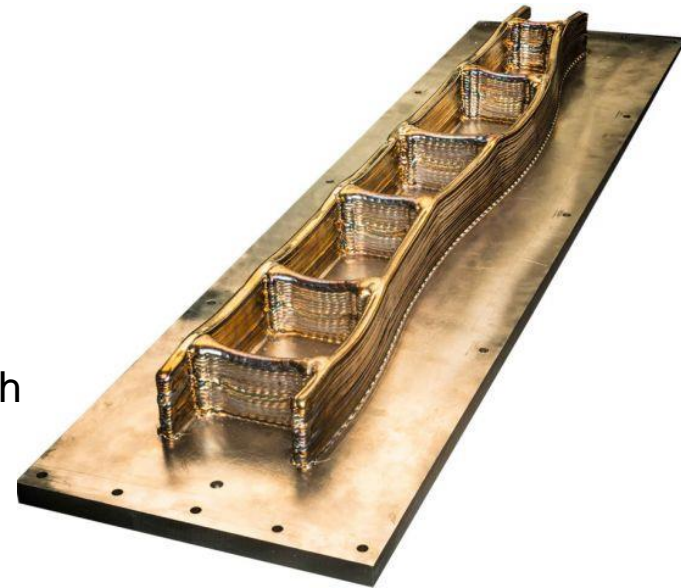
## 2 Challenges to WAAM

Distortion & Residual Stress are an challenges in WAAM

Shrinkage and uneven cooling rate are the main reasons for distortion and residual stress

Too many factors are involved in the WAAM process, such as welding voltage, welding current, feeding speed, ambient temperature, protecting gas flow rate, etc.

Still lack of systematic metrology method for WAAM

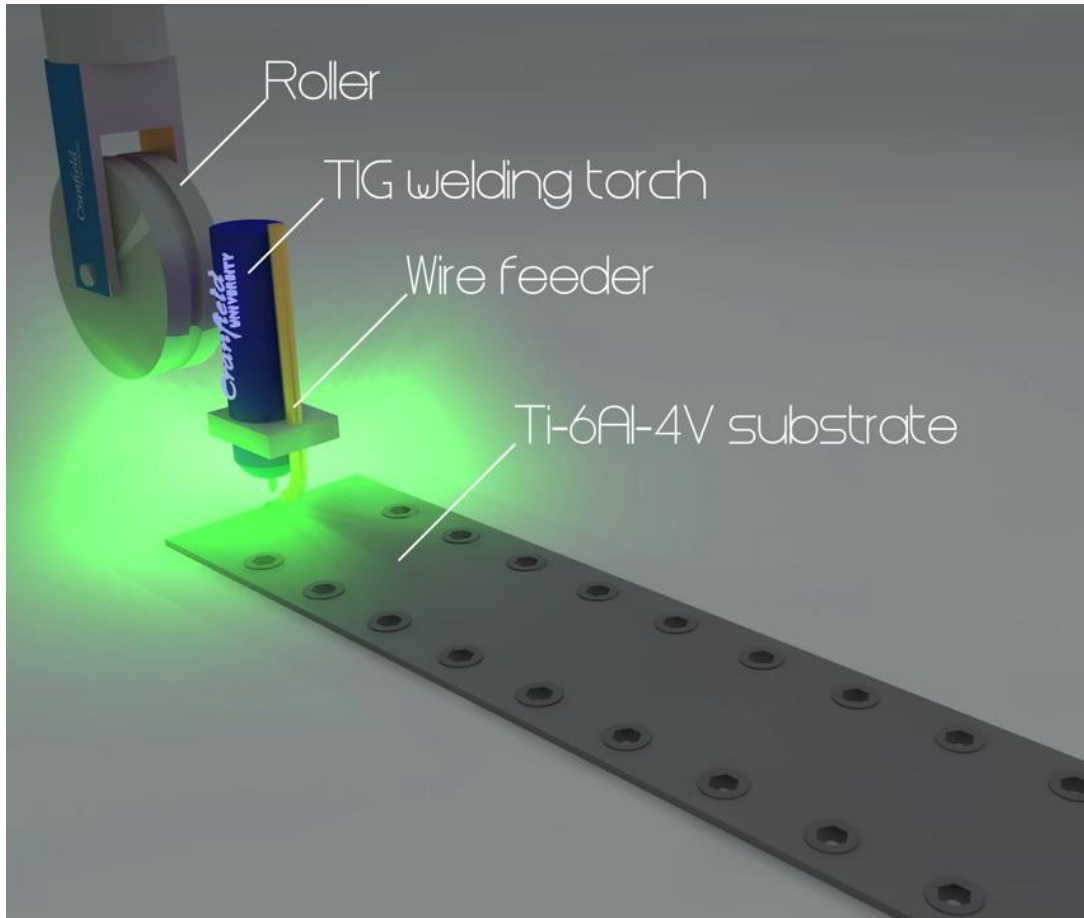


Aeroengine near net-shape part



WAAM produced part tilts up due to the residual stress

### 3 RAWFEED - Concept

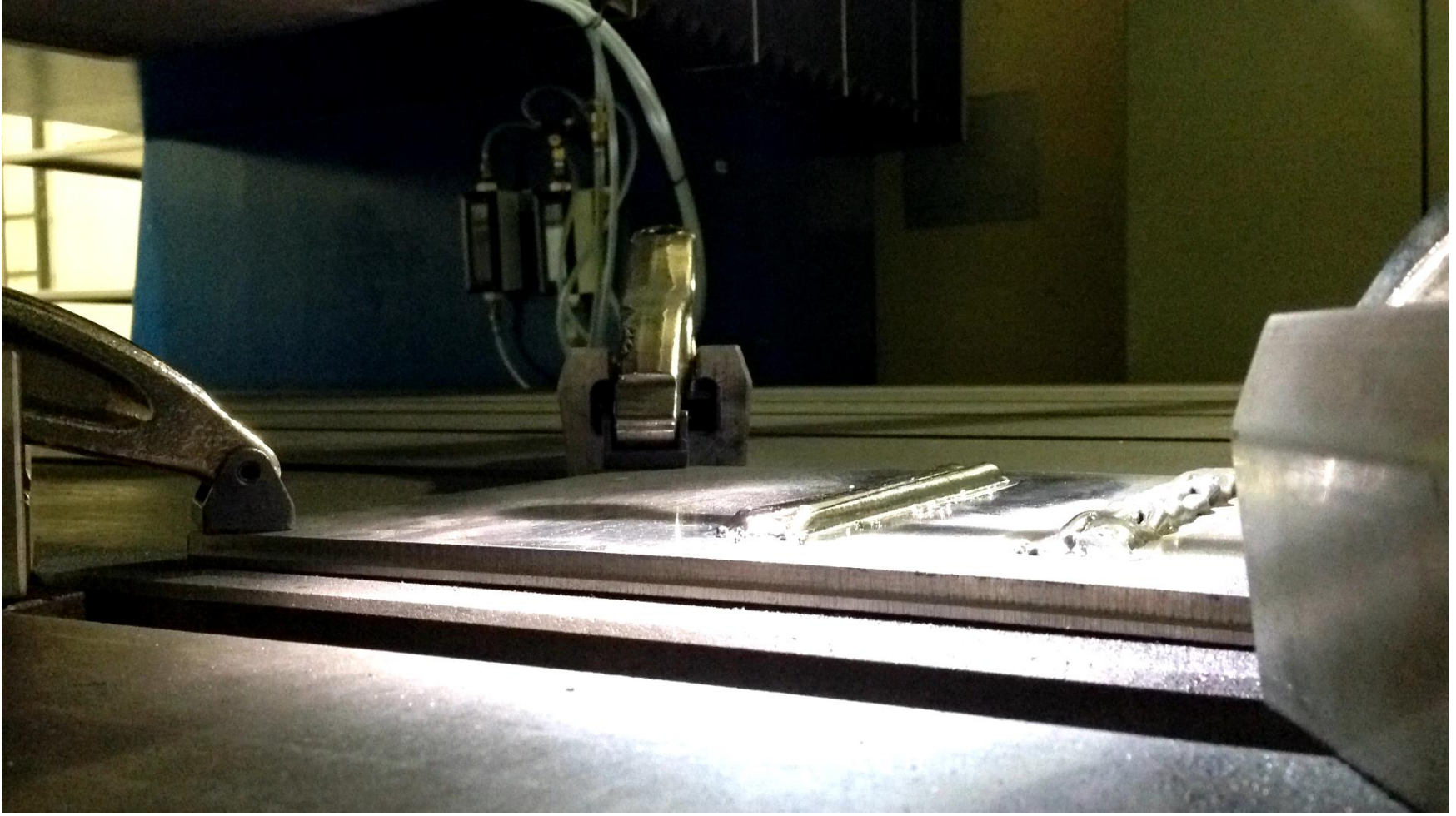


Video Source: Cranfield University

- **ROLLING** every layer after it was deposited to improve the microstructure and the mechanical property of the material
- This method has been proved to be effectively reduced 30% ~ 50% distortion.

Ref: Colegrove, P. a., *et al.* (2013).  
*Journal of Materials Processing*

3 RAWFEED - Demo





### 3 RAWFEED - Platform

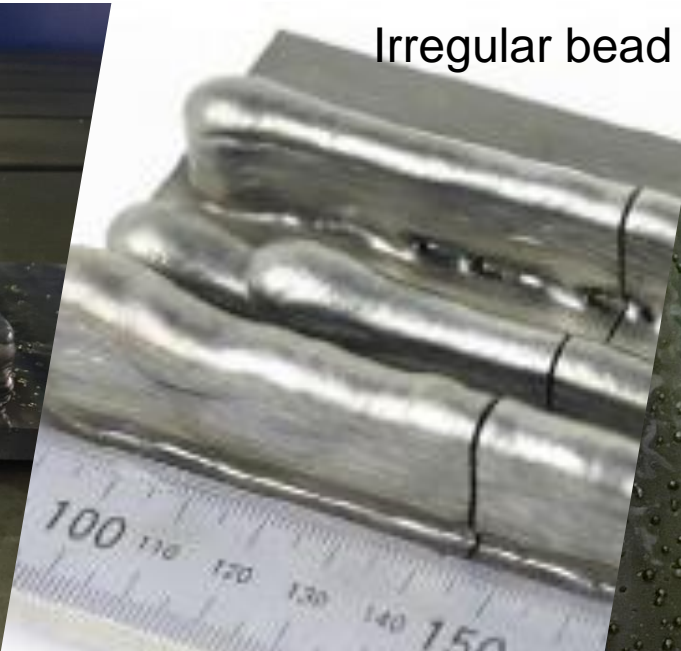


## 4 Multi-Sensor System – Requirements

Real-time monitoring system to monitor:

- **Shape** to provide feedback for rolling system
- **Heat** to avoid excess heat input/output which may cause distortion
- **Oxygen level** to prevent part from oxidation

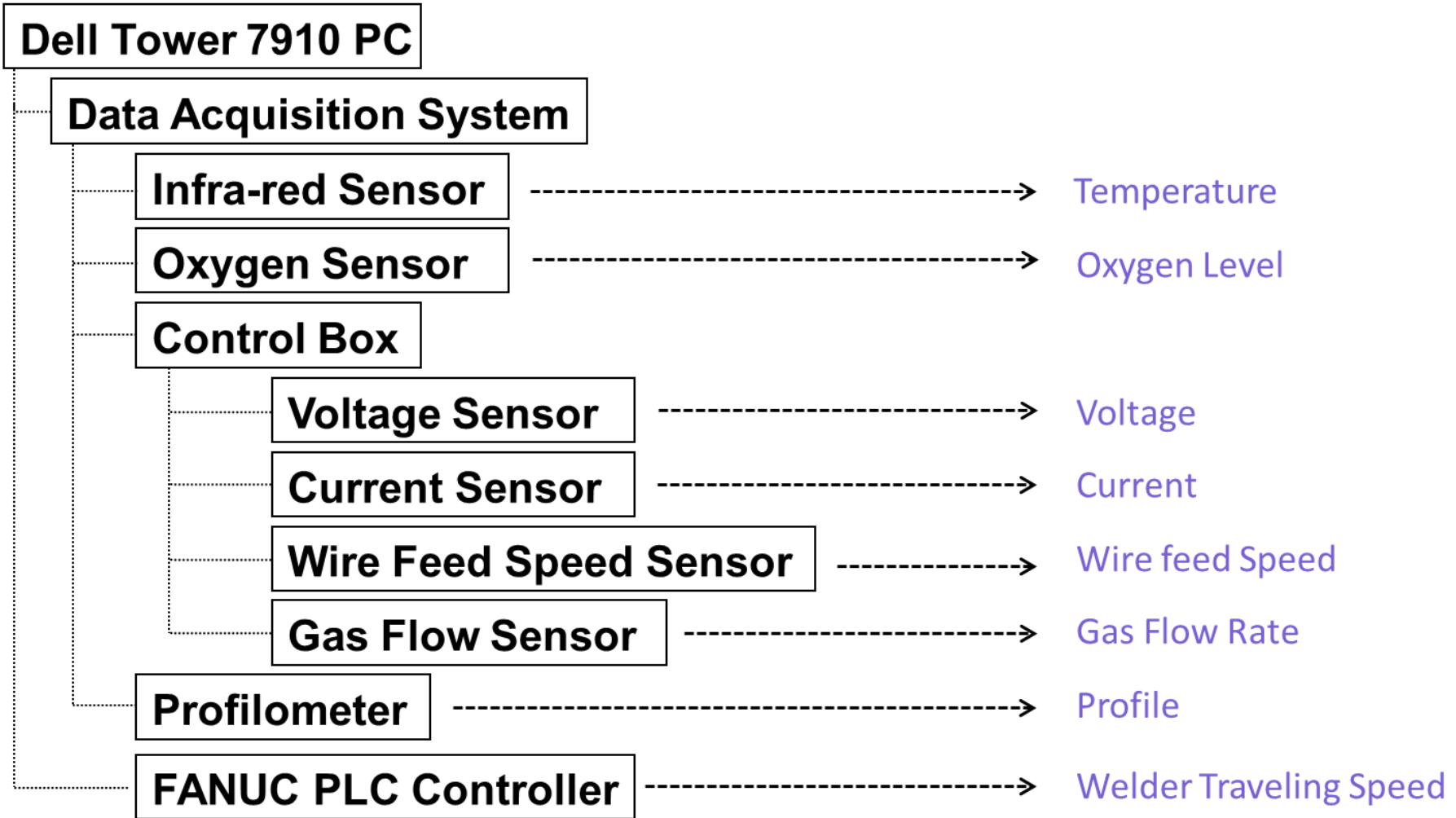
# 4 Multi-Sensor Framework – Aims



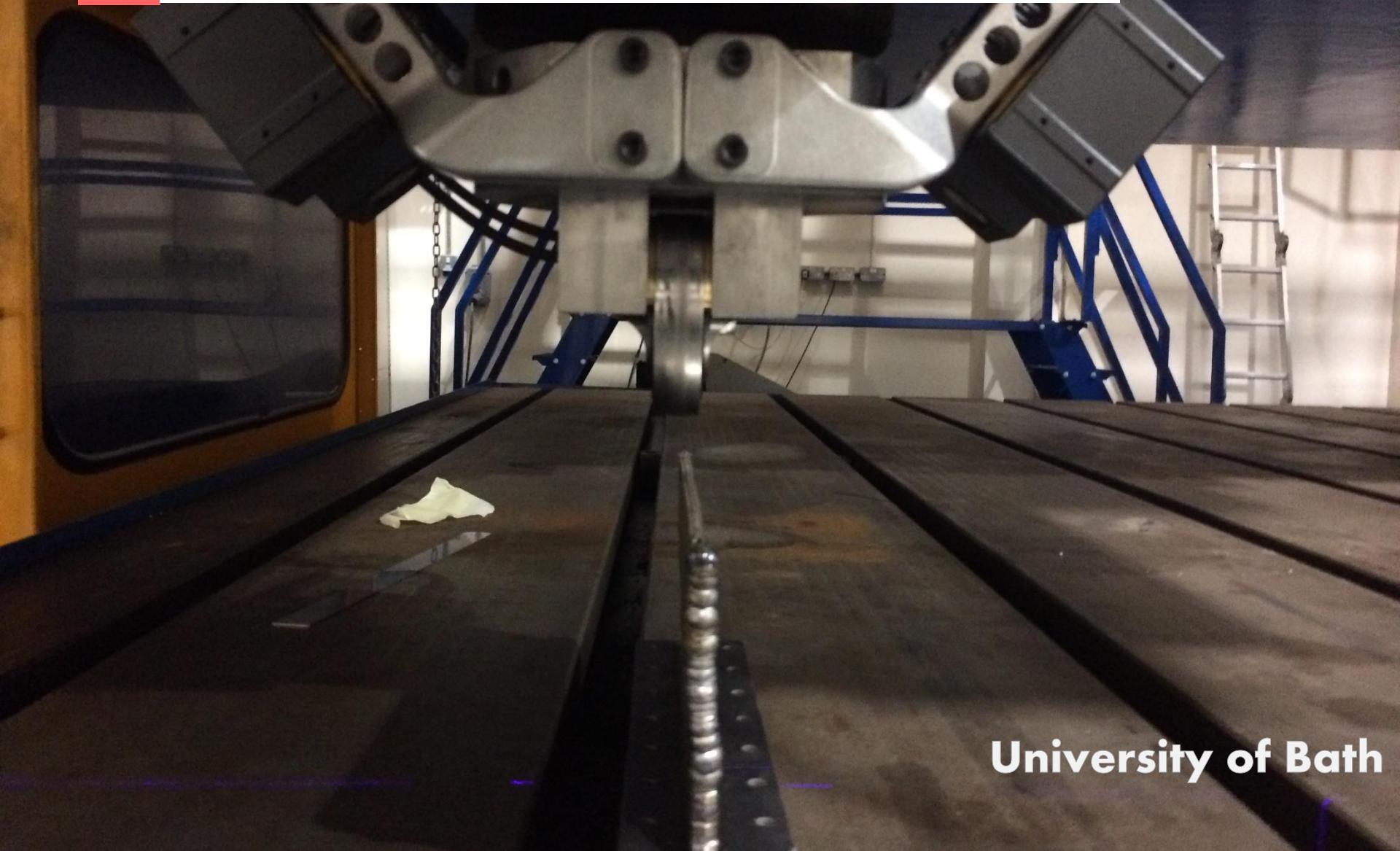
## Factors monitored:

- 1 Oxygen Level
- 2 Gas Flow Rate
- 3 Current
- 4 Voltage
- 5 Temperature
- 6 Profile
- 7 Wire Feed Speed (WFS)
- 8 Welder Travel speed

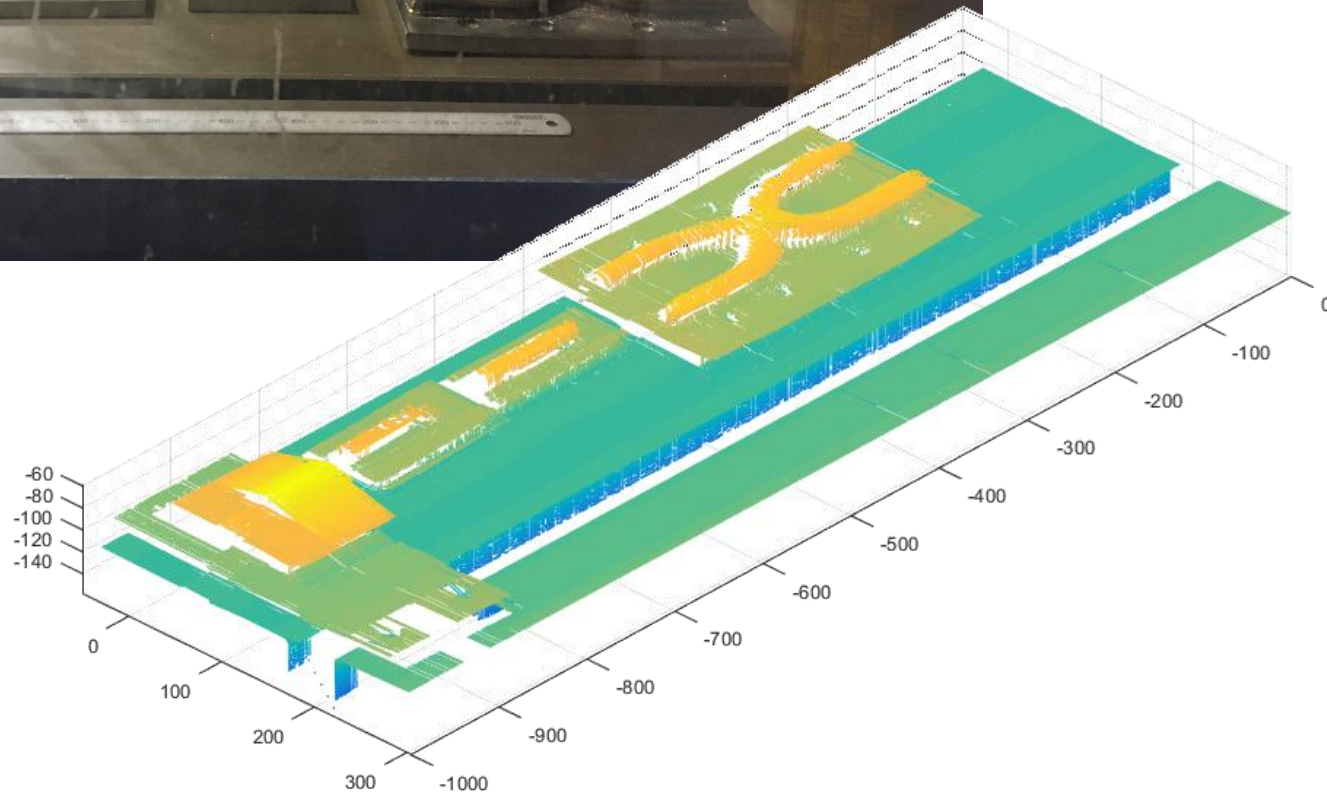
# 4 Multi-Sensor Framework – System Topology



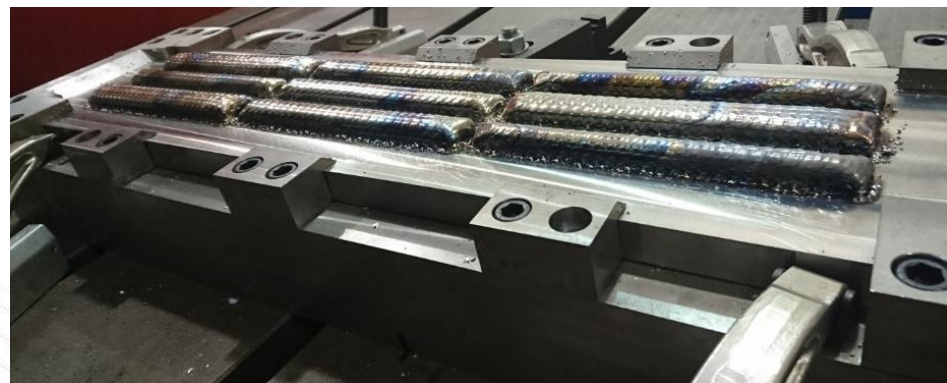
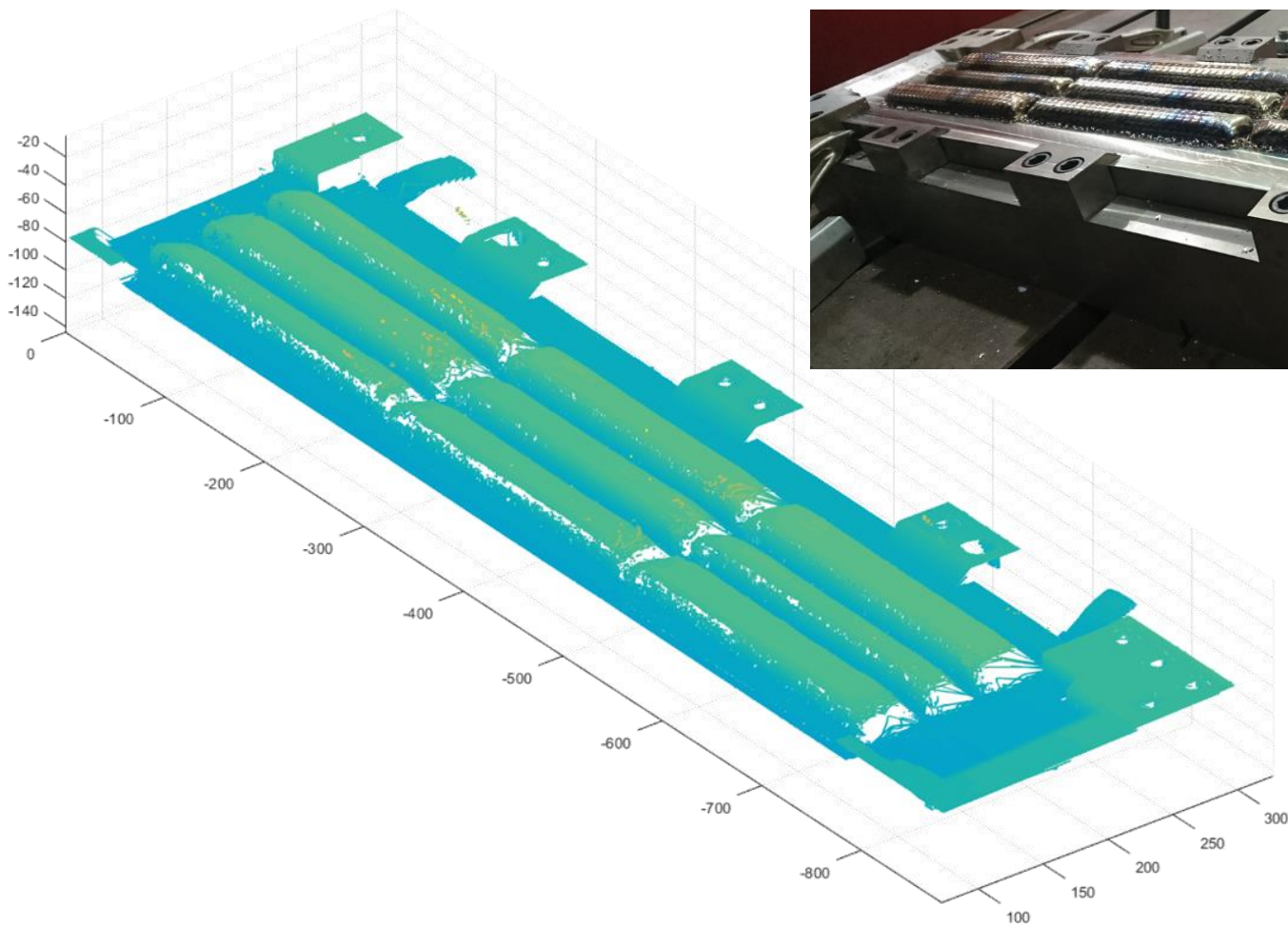
## 4 Realization of Multi-sensor System



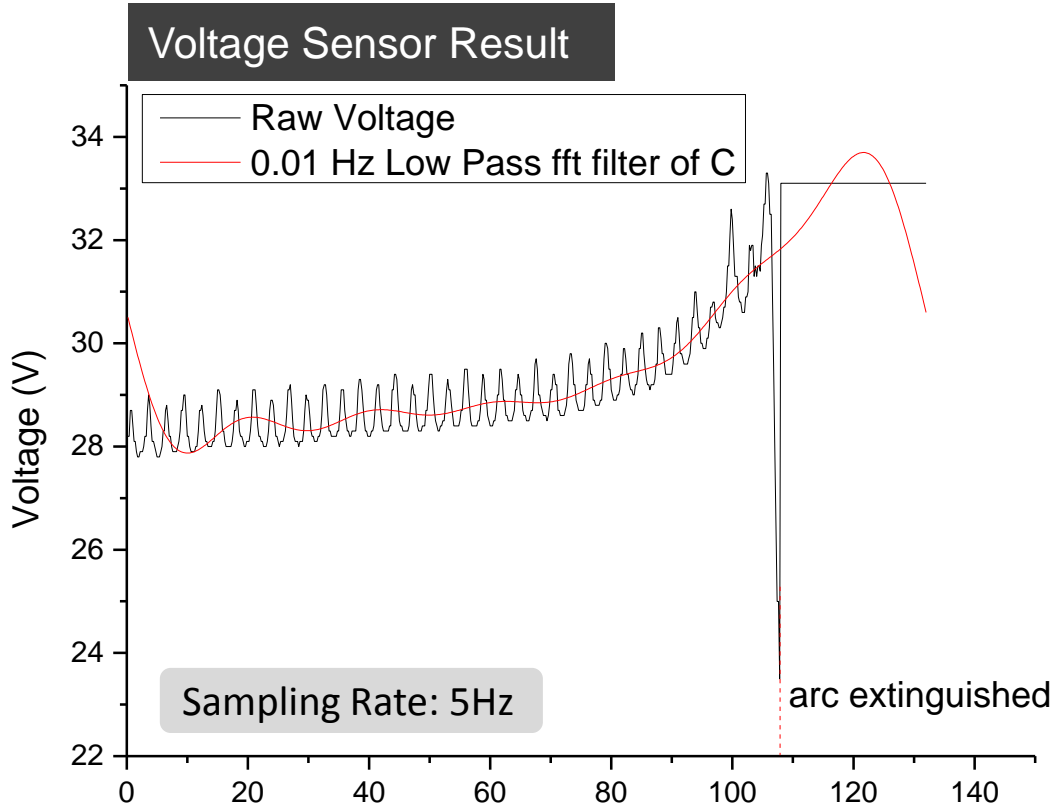
# 4 Multi-Sensor System – Laser Scanner



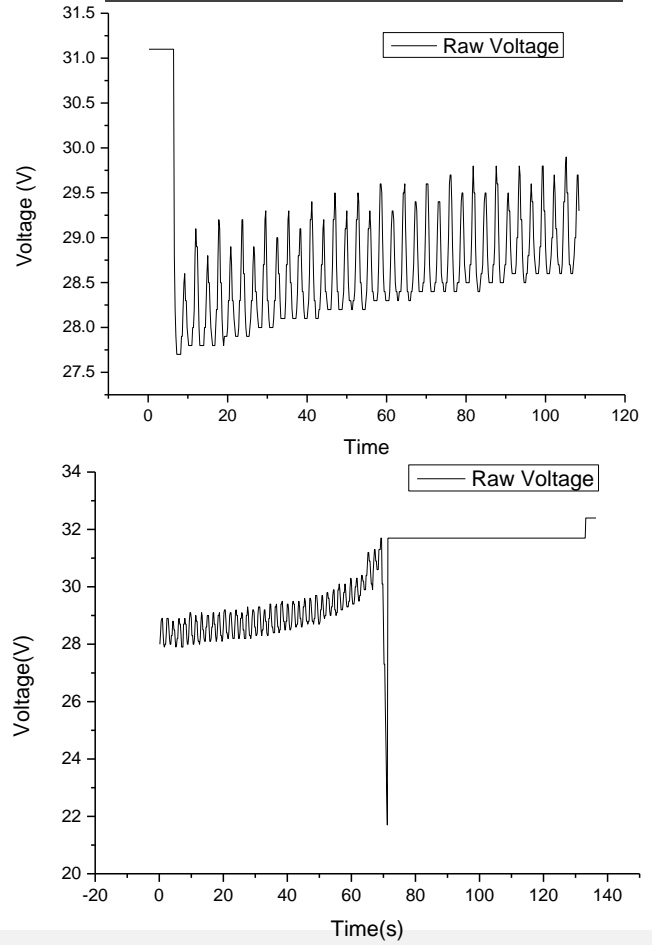
# 4 Multi-Sensor System – Laser Scanner Result



# 4 Voltage Sensor



## Another two voltage result

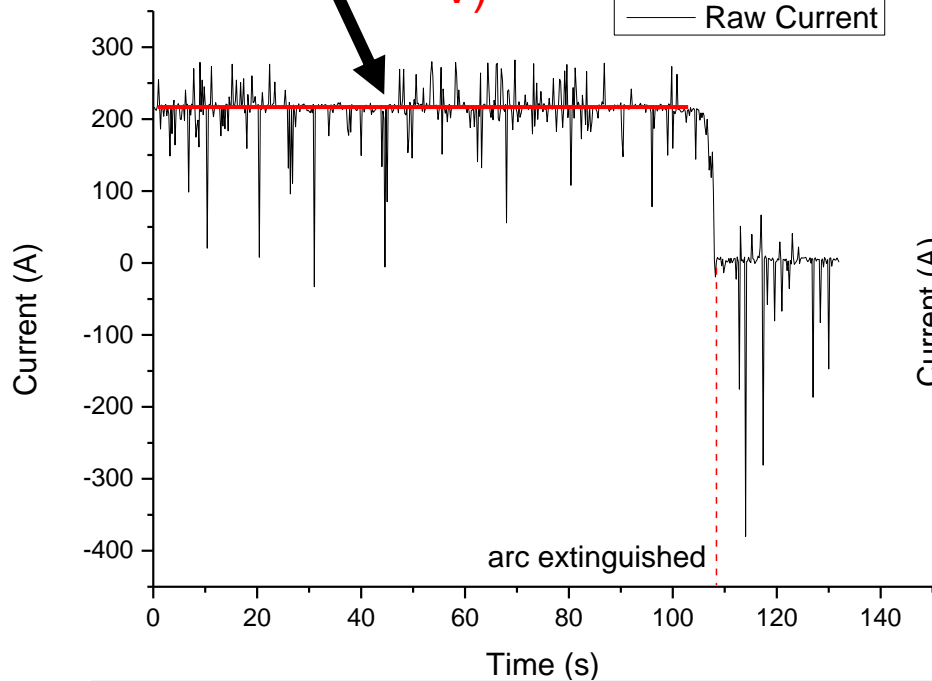


**Voltage Signal fluctuated within a small range.**  
 The reason is under investigation.  
 It might be due to the continuous periodic metal wire melting and dropping

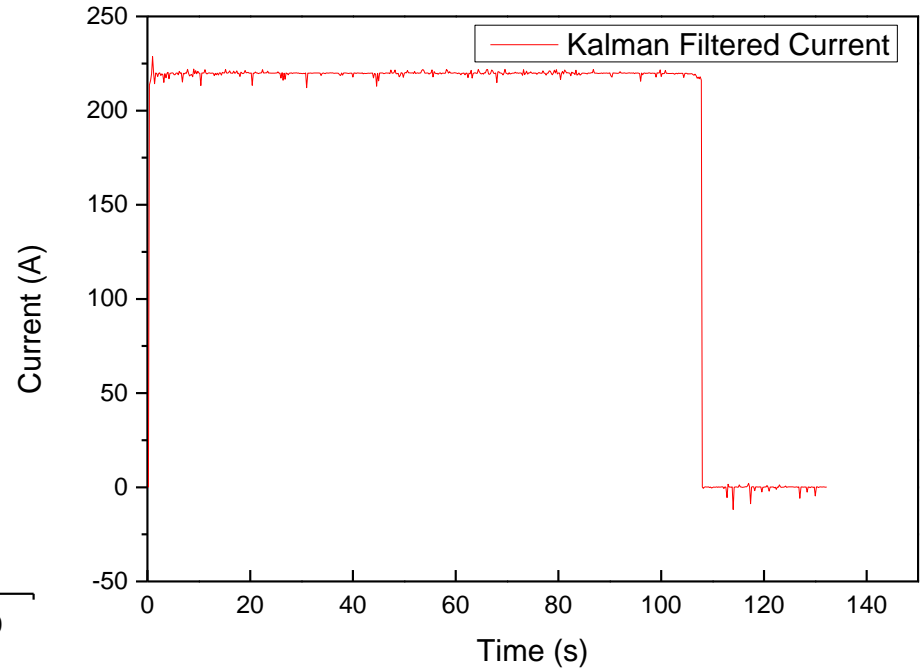


# 4 Current Sensor

Approximate Trend (About 220 V)

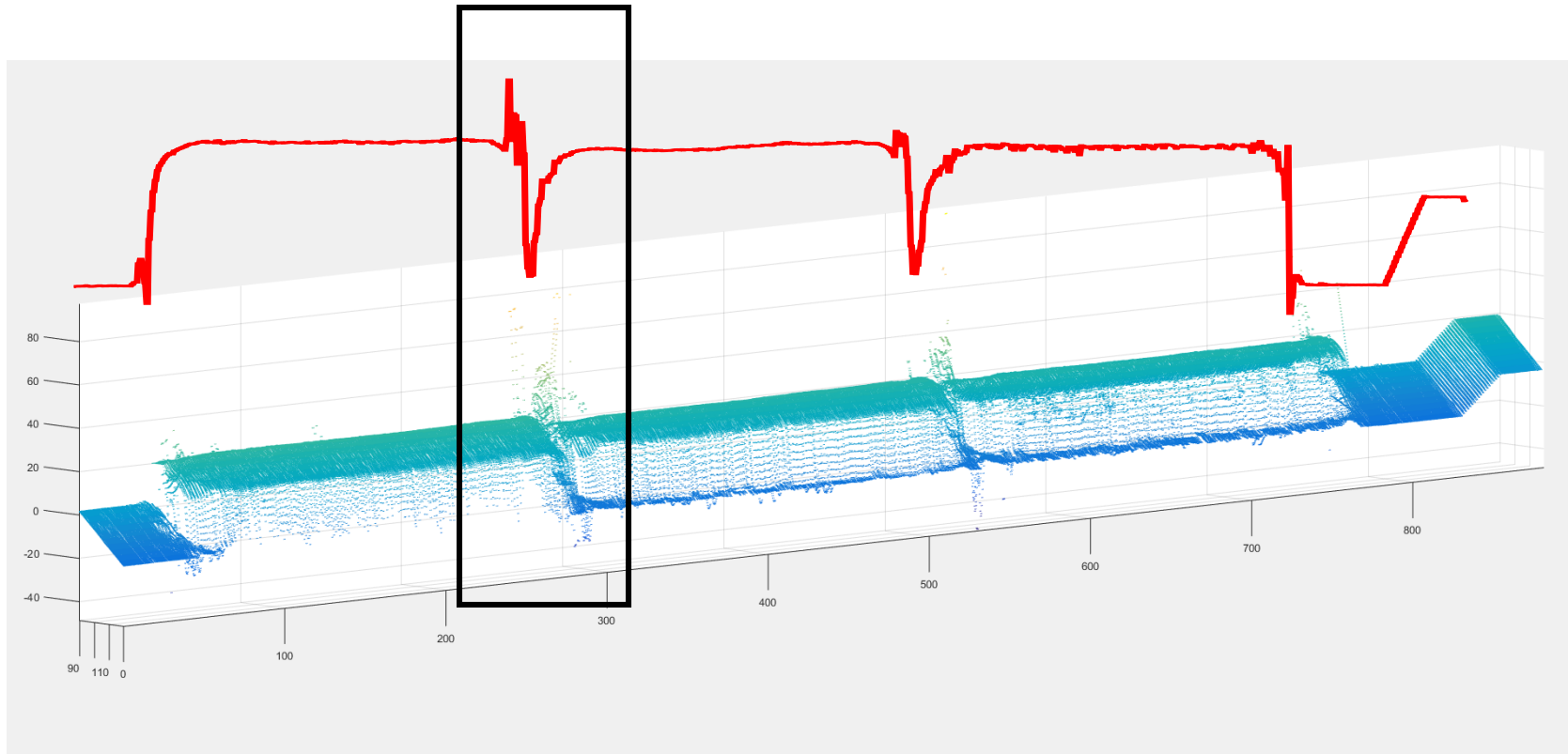


Kalman Filtered Current



The signal data distribution roughly conforms to the Normal Distribution, and the noise might be able to be eliminated by Kalman Filter

# 4 Average Height Variation along Y axis



# 4 Realization of the System – Structure

## Environment Monitoring Sub-system

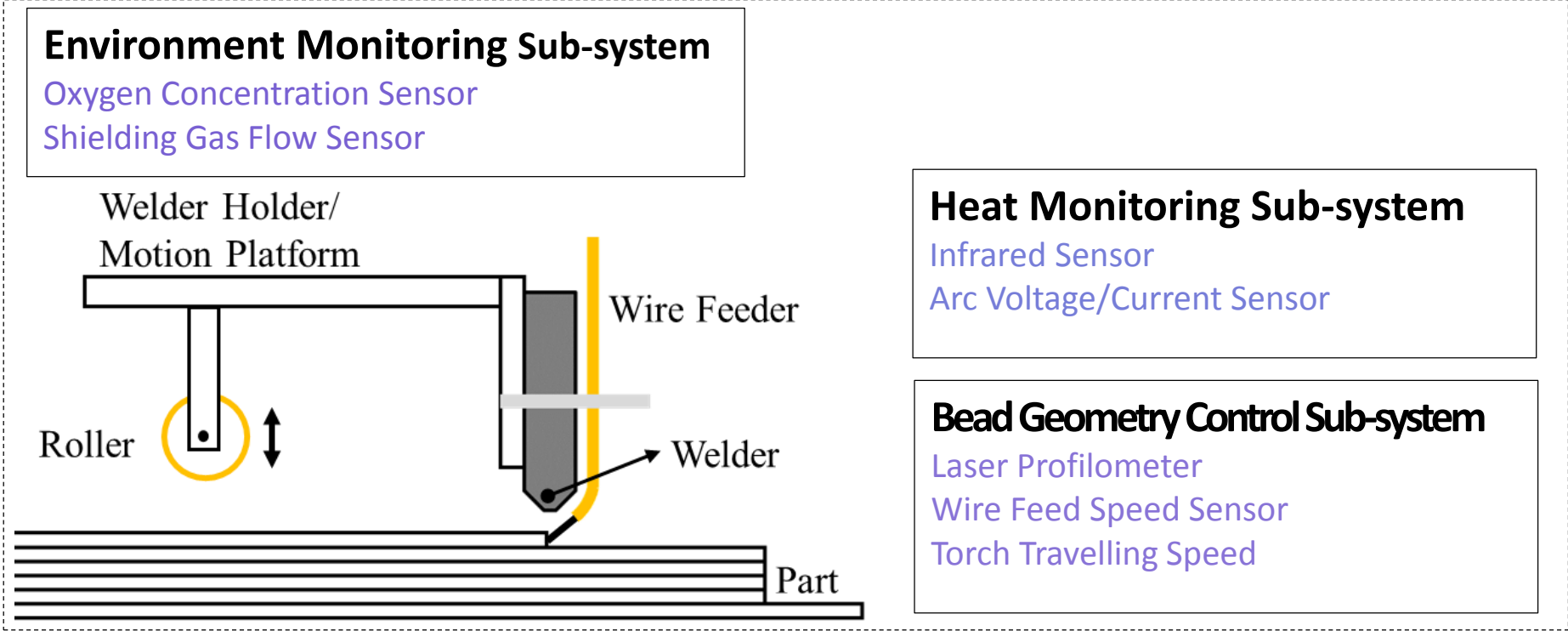
- Oxygen Concentration Sensor
- Shielding Gas Flow Sensor

## Heat Monitoring Sub-system

- Infrared Sensor
- Arc Voltage/Current Sensor

## Bead Geometry Control Sub-system

- Laser Profilometer
- Wire Feed Speed Sensor
- Torch Travelling Speed



## 5 Conclusions

- The main problems in the WAAM process have been analysed and a novel integrated monitoring solution proposed.
- A multi-sensor system has been built to monitor the WAAM process.
- The specified system shows that for a WAAM machine with an integrated rolling process to be monitored and controlled, a wide range of sensors needs to be configured and used.

# Any Questions?