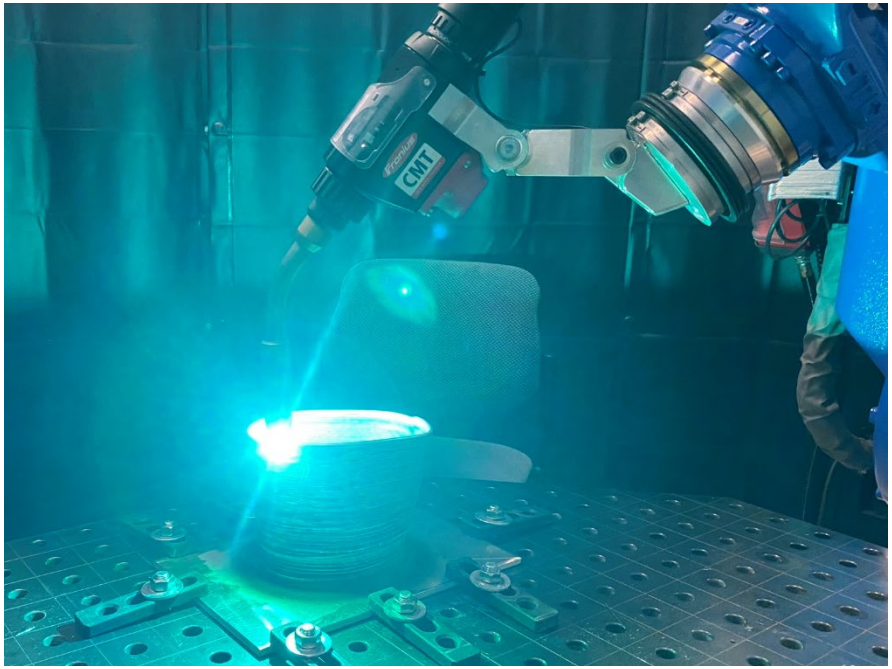
DEVELOPMENT OF A DATA SYNCHRONIZATION ALGORITHM AND VISUALIZATION FOR MULTI-STREAM DATA IN WAAM PROCESSES

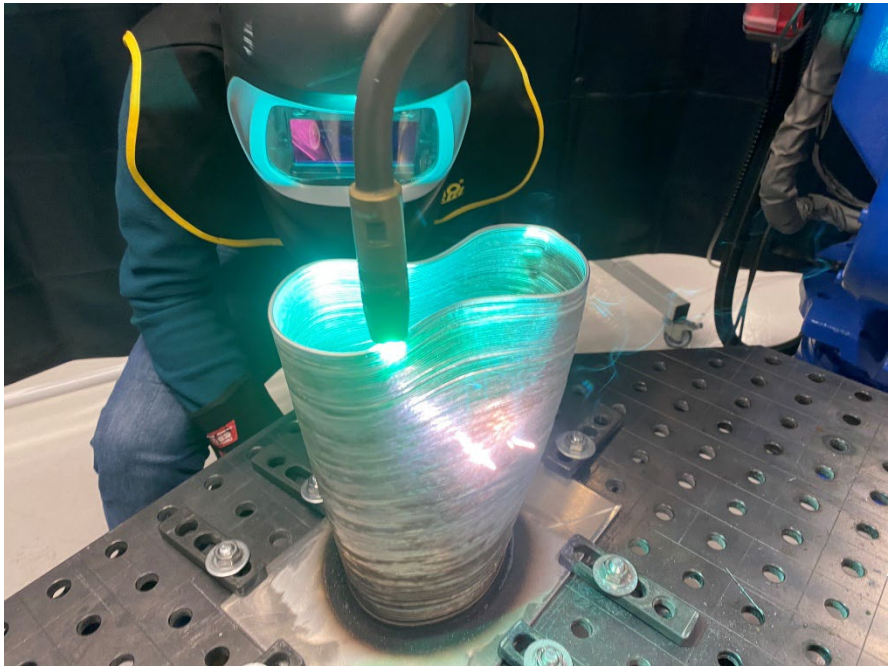
KOPILS SERGEJS

Transport and Telecommunication Institute

Wire Arc Additive Manufacturing (WAAM) TSI AdditiveLab

WAAM Process





Outline

- Introduction to WAAM Process
- Objectives of the Study
- Description of Multi-Stream Data Types
- Data Structure and Relationships
- Synchronization Algorithm
- Visualization of Synchronized Data
- Conclusions
- Acknowledgements

Objectives

- Develop a **synchronization algorithm** for multi-stream data (initial, process, spatial) in the WAAM process.
- Ensure accurate **temporal and spatial alignment** between initial data, process parameters, and laser measurements.
- **Visualize** the **results** of synchronization in a form suitable for analyzing the quality and stability of the printing process.

Data Types

Initial Data

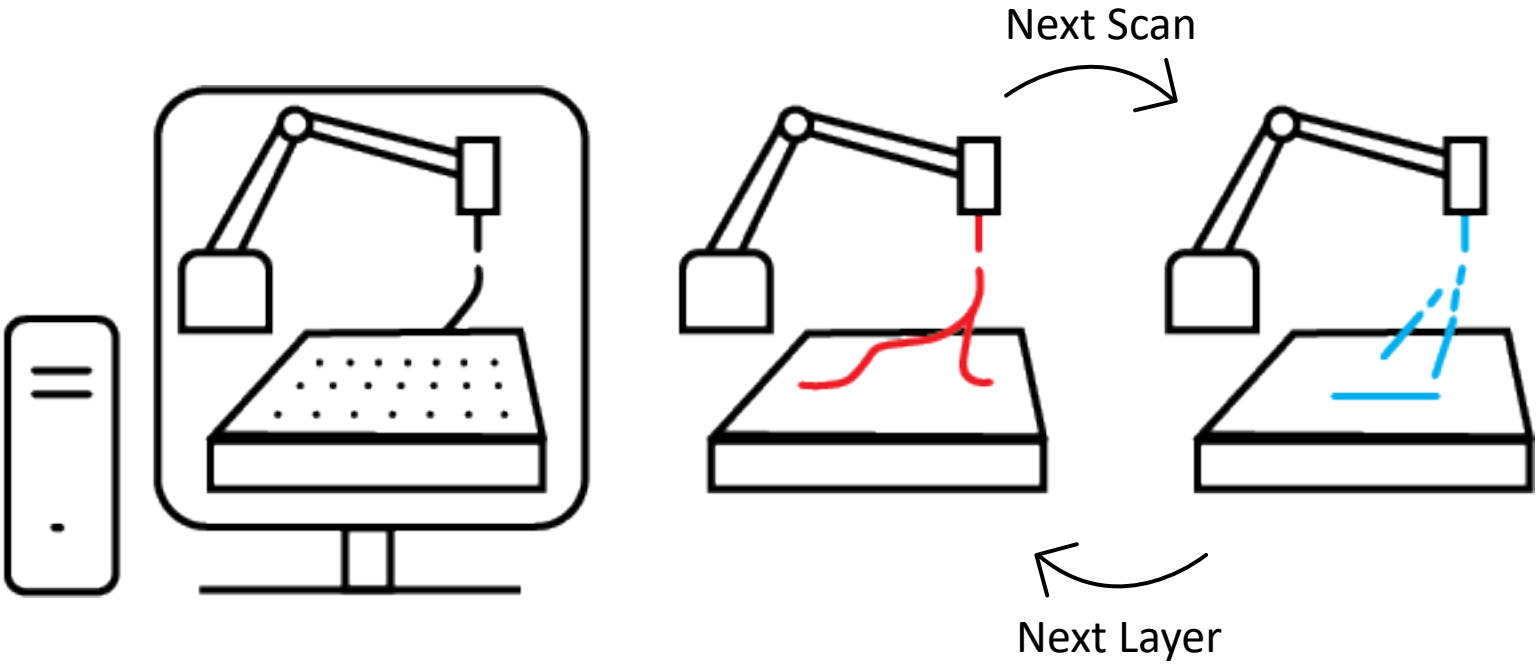
Process Data

Spatial Data

Slicer

Process On

Scanning

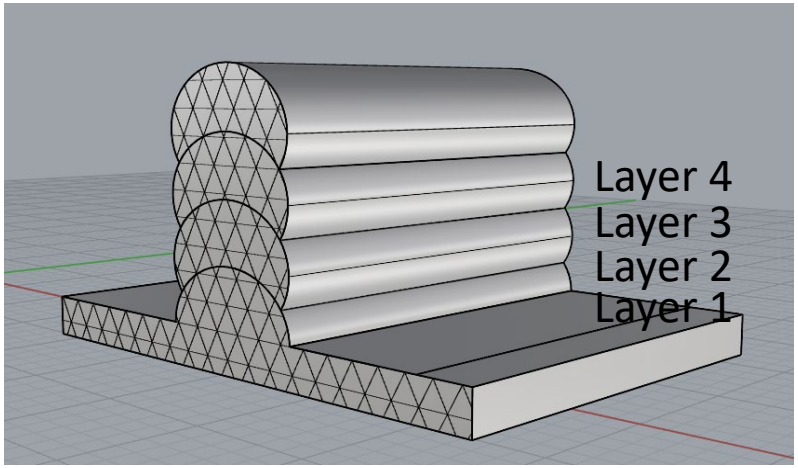


Initial Data

CAD ⇨ Slicer ⇨ Postproces ⇨ .CSV file

The **initial data** is provided in a **CSV file**. The main parameters are:

- **Layer:**
  The stacking order of operations on a layer-by-layer basis; represents the functional concept of a "layer" in the process.
- **Path Planning (X, Y, Z, Rx, Ry, Rz):**
  Movements of the welding head during active and non-active welding stages.
- **TS (Travel Speed, mm/min):**
  Planned movement speed of the robot.
- **WFS (Wire Feed Speed):**
  Feeding rate of the printing wire.
- **Job#:**
  process parameters list.



Functional concept of a "layer"

Process Data

Data collected during printing. This data is acquired **from multiple subsystems.** It's provided in a **TXT file.**

Main process data parameters include:

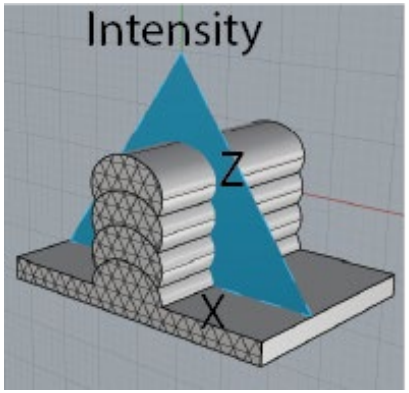
- **Robot Coordinates (Path)**: the actual movement trajectory of the robot.
- **TS** (Travel Speed, mm/min)**:** the real measured speed of the robot's movement.
- **WFS** (Wire Feed Speed): the speed at which the wire is fed during the process.
- **Process Active** / IOArcOn: indicator of whether the printing/scanning process is active.
- **DateTime**: timestamps marking the exact time of each operation or status change.
- **Weld Current**: the actual electrical current used during welding.
- **Weld Voltage**: the actual voltage across the welding arc.

Spatial Data

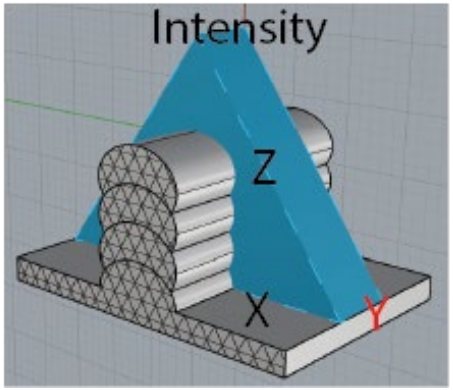
Measurement from **laser sensors** capturing the geometry and characteristics of scanned surfaces. Main spatial data parameters include:

- **DateTime**: timestamps marking when each set of spatial measurements was captured.
- **Laser Coordinates (X, Z):** spatial position of each scanned point in two dimensions (horizontal and vertical axes).
- **Intensity**: the strength of the reflected laser signal from the surface (shows material properties or surface quality).

Spatial coordinates are converted into the **world coordinate system (X,Y,Z).**

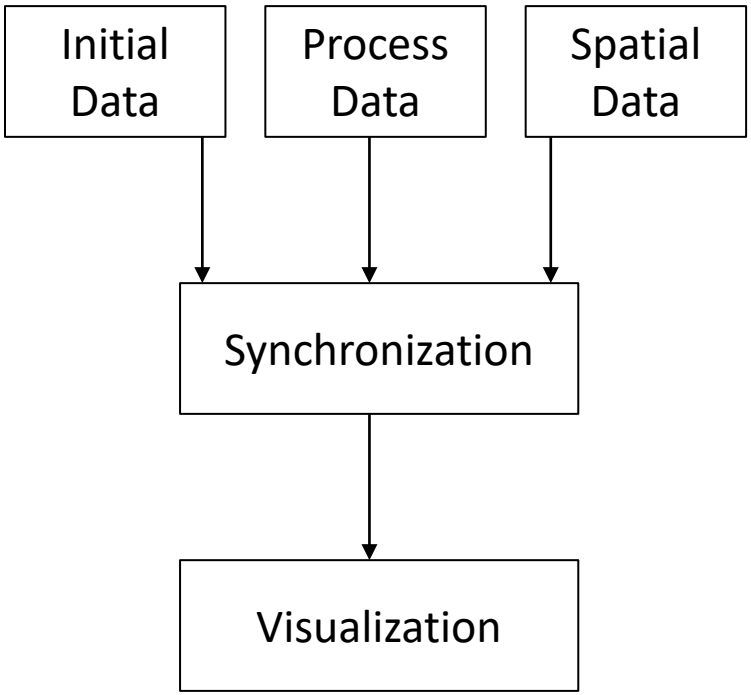


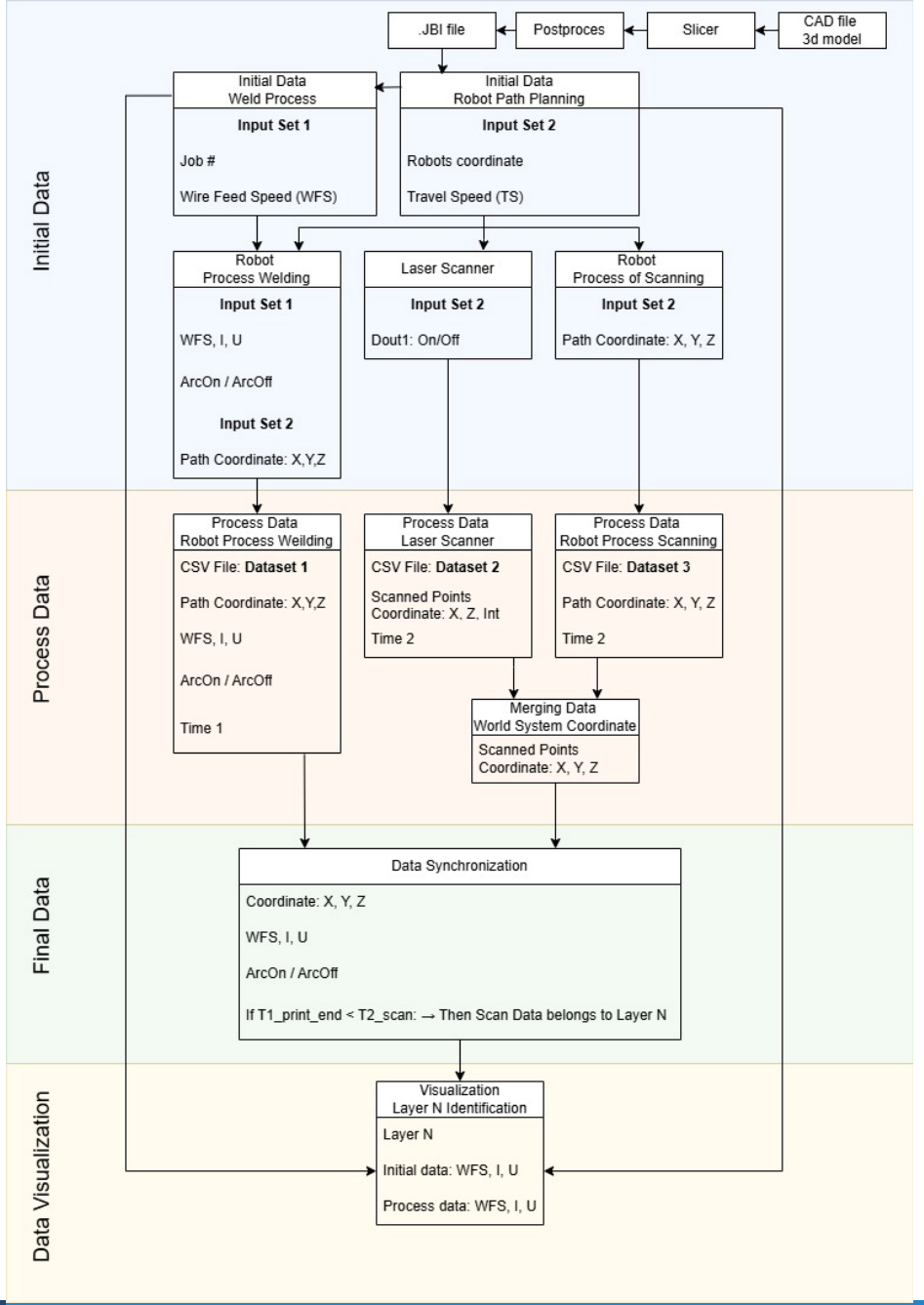
Laser Sensors **2D** Coordinate



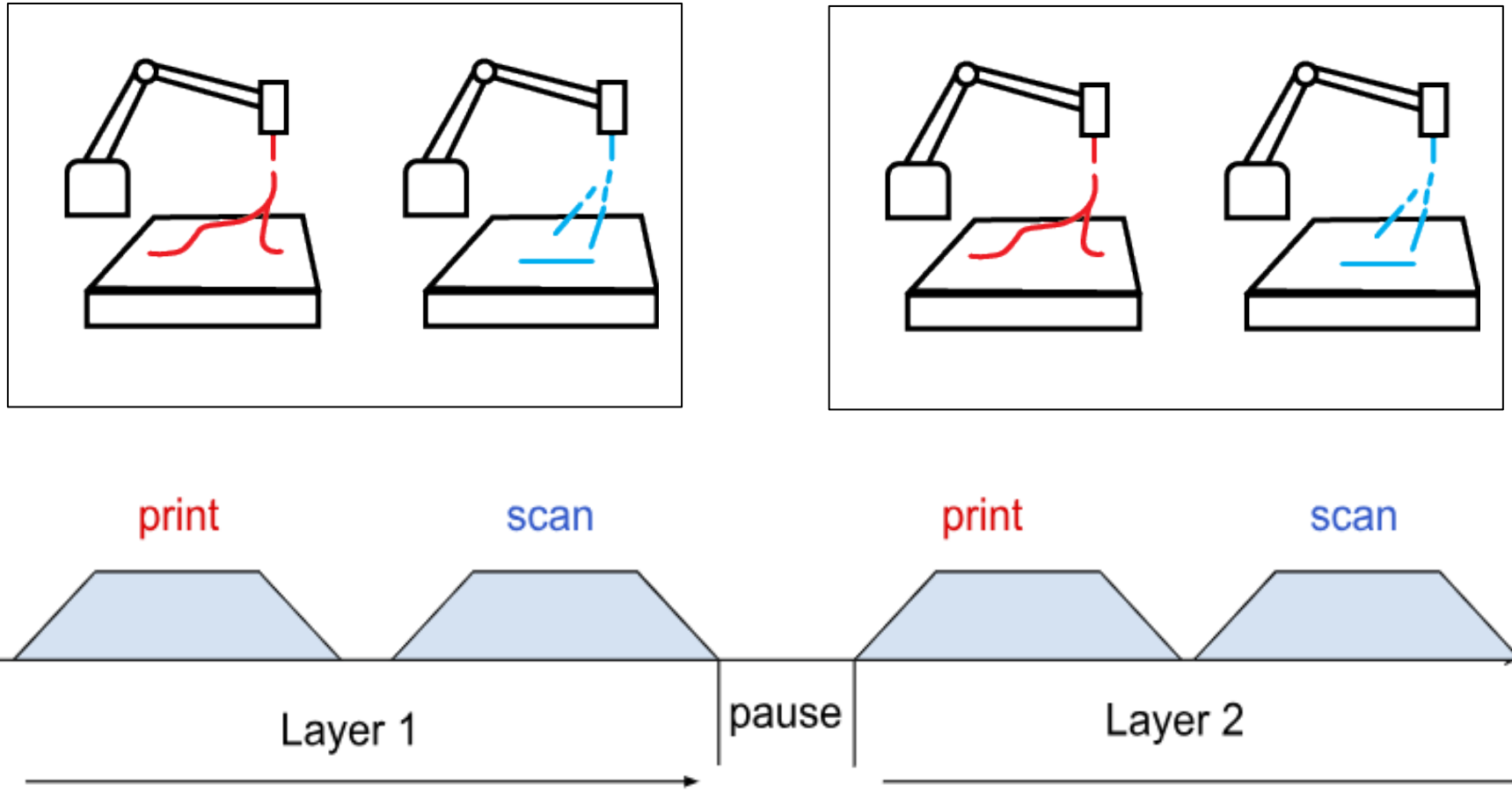
3D world coordinate system

Data Relationship

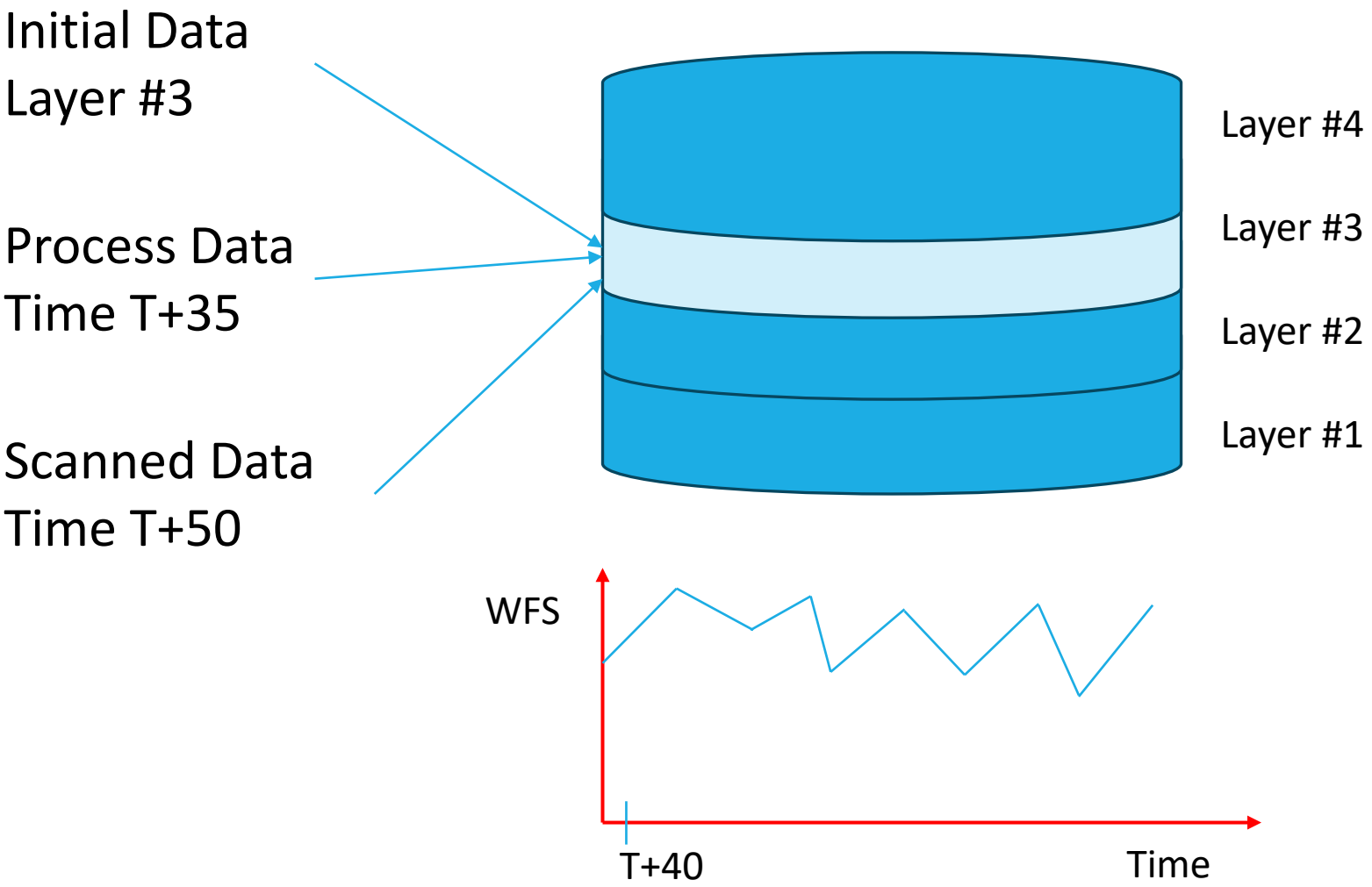




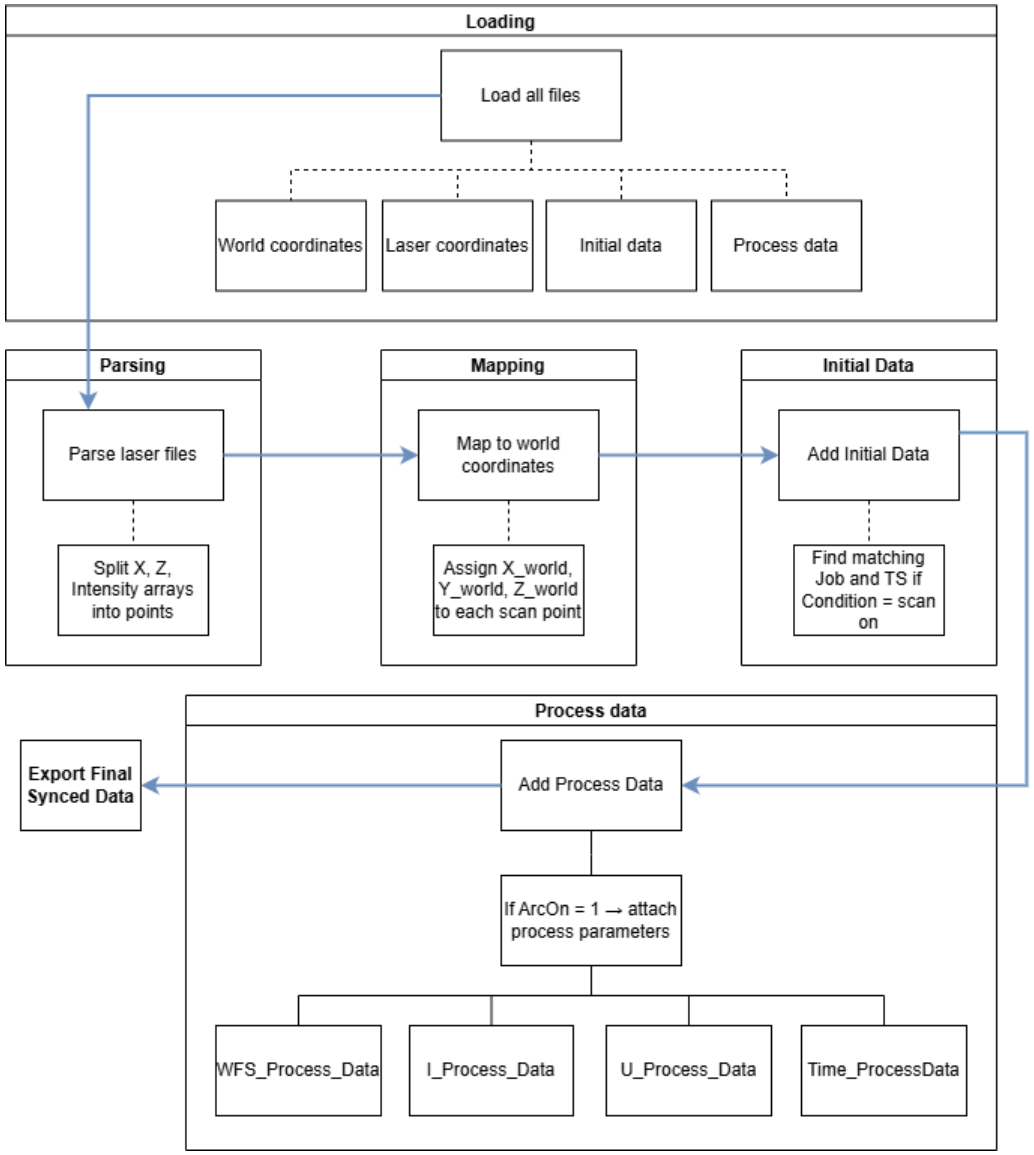
Connect Data in Time & Space



Data Correspondence



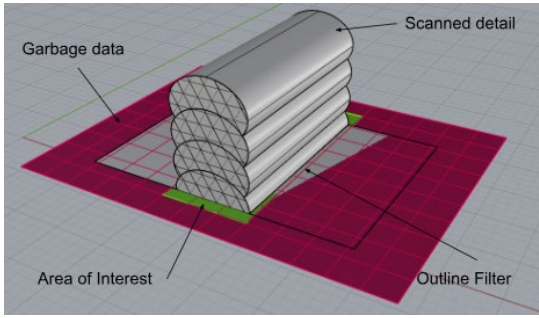
Synchronization Algorithm Diagram



Synchronization Algorithm Block

№	Step	Description	Result
1	Data Loading	Reading world coordinates, laser scans, initial layer conditions, process data	Data loaded into memory
2	Parsing Laser Files	Arrays X, Z, Intensity are created from strings of numbers	Point arrays are ready
3	Point Synchronization	Each laser scan point is assigned X_world, Y_world, Z_world coordinates	List of synchronized points is built
4	Determining Initial Conditions	For each layer, find Job and TS if Condition = Arc on	Initial_Job and Initial_TS filled
5	Identifying Active Weld Segments	Split process data into ArcOff = 0 segments	Weld segments are ready
6	Attaching Weld Parameters to Layers	Add actual values (WFS, I, U, Time) to each layer	New columns filled
7	Final Cleanup and Save	Remove temporary columns and save final file	CSV ready for analysis

Visualization Diagram

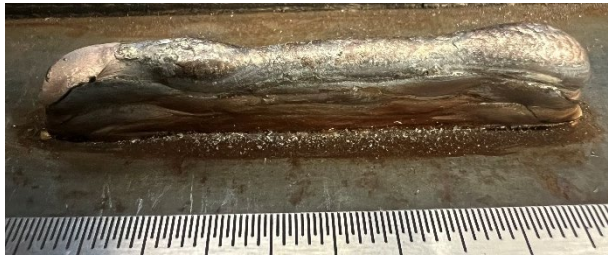



```
1. Load Data
    └ Load CSV into 'data'
    └ Extract X, Y, Z min/max values
    └ Calculate center points and crop ranges
    └ Prepare 'process_data' (Time_ProcessData, WFS, I, U, Layer)

2. Build Layout
    ├ Left Panel (Filters)
    |    ├ Minimum Intensity Slider
    |    ├ X, Y, Z Range Sliders
    |    ├ Layer Selector Dropdown
    |    ├ Buttons:
    |    |    ├ Show All Layers
    |    |    ├ Hide All Layers
    |    |    ├ Fill Table
    |    |    ├ Clear Table
    |    |    ├ Reset Cropping
    |    |    └ Show All Points
    |    ├ Cropping Sliders (Crop X, Crop Y, Crop Z)
    |    └ Max Points Slider
    |
    ├ Center Panel (Graphs and Table)
    |    ├ Top Section
    |    |    ├ 3D Scatter Plot (Points visualization)
    |    |    └ Data Table (Selected Layers info)
    |    └ Bottom Section
    |         └ Process Graph (Time vs WFS, Current (I), Voltage (U))

3. Define Callbacks
    ├ Update 3D Scatter Graph
    |    ├ Filter points based on filters and crop
    |    ├ Sample points (based on max points or show all)
    |    ├ Update scatter plot
    |    └ Show point counts
    |
    ├ Update Process Graph
    |    ├ Filter 'process_data' based on selection
    |    └ Plot WFS, I, U over time
    |
    ├ Layer Management
    |    ├ Show All Layers
    |    └ Hide All Layers
    |
    ├ Cropping Management
    |    └ Reset crop ranges to full limits
    |
    ├ Table Management
    |    ├ Fill Table with all layers
    |    ├ Clear Table
    |    └ Add selected point's layer to table (on click)

4. Run Server
    └ app.run(debug=True)
```

Visualization Block

Block	Description
1. Data Preparation	Load CSV file into data DataFrame. Extract **scene boundaries (min/max) for X, Y, Z**. Calculate center points and crop ranges. Prepare process_data (time series for WFS, Current, Voltage).
2. Layout: Filters Panel	Left sidebar with controls for: Intensity filter, X/Y/Z range filters, **Layer selection**, Cropping settings, Point count limitation. Includes "Show All", "Hide All", "**Fill Table**", "Clear Table" buttons.
3. Layout: Visualization Area	Top: **3D Scatter Plot** of filtered and cropped points. Side: **Data Table** showing information about selected **layers**. Bottom: **Process Graph** (Time vs WFS, Current, Voltage) for selected layers.
4. Callback: Update 3D Scatter	**Filter points** based on current sliders and dropdowns. Optionally sample points based on max-points slider. Render 3D scatter plot and **show number of total/cropped/visible points**.
5. Callback: Update Process Graph	**Filter process_data** for currently selected layers and coordinate ranges. **Display** WFS, Current (I), and Voltage (U) curves **on the time axis**.
6. Callback: Manage Layers	"Show All" button: **Select all layers**. "Hide All" button: **Deselect all layers**.
7. Callback: Reset Cropping	Reset crop sliders (Crop-X, Crop-Y, Crop-Z) **back to full range values**.
8. Callback: Manage Table	"Fill Table" button: **Fill** the **table with** all unique **layers**. "Clear Table" button: **Clear** the **table** completely. Click on 3D point: Add **clicked point's layer** info into the table (only if not already present).
9. Server Run	**Start** the Dash app server in debug mode (app.run(debug=True)).

Results



Laser Scans Data

Initial Data

Filters:

Minimum Intensity:

0 200 400 600 888

X Range:

2k 2k 2k 2k 2k 2k

Y Range:

319.96 330 345 360 375 392.546

Z Range:

-52.6312 0 40 80 134.718

Select Layers:

× Layer_0 × Layer_1 × Layer_2 × Layer_3 × Layer_4 × Layer_5

Show All Layers | Hide All Layers

Fill Table | Clear Table

Cropping:

X Range:

2k 2k 2k 2k 2k 2k

Y Range:

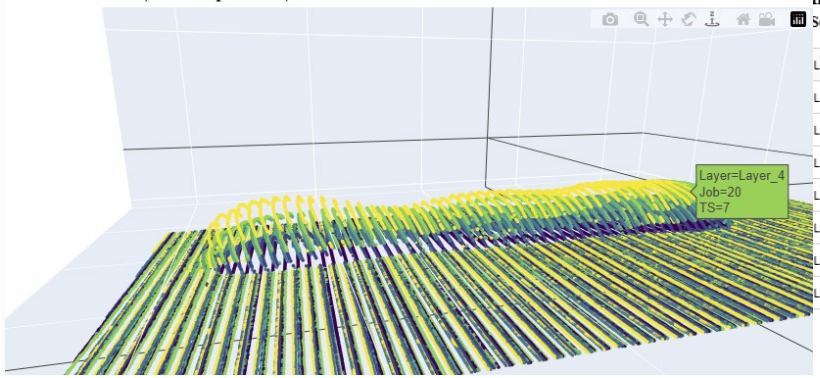
Reset Crop

Points:

10k 250k 500k 750k 1,000k

Show All Points

Total Points: 694020 | After Crop: 186937 | Visible: 161305

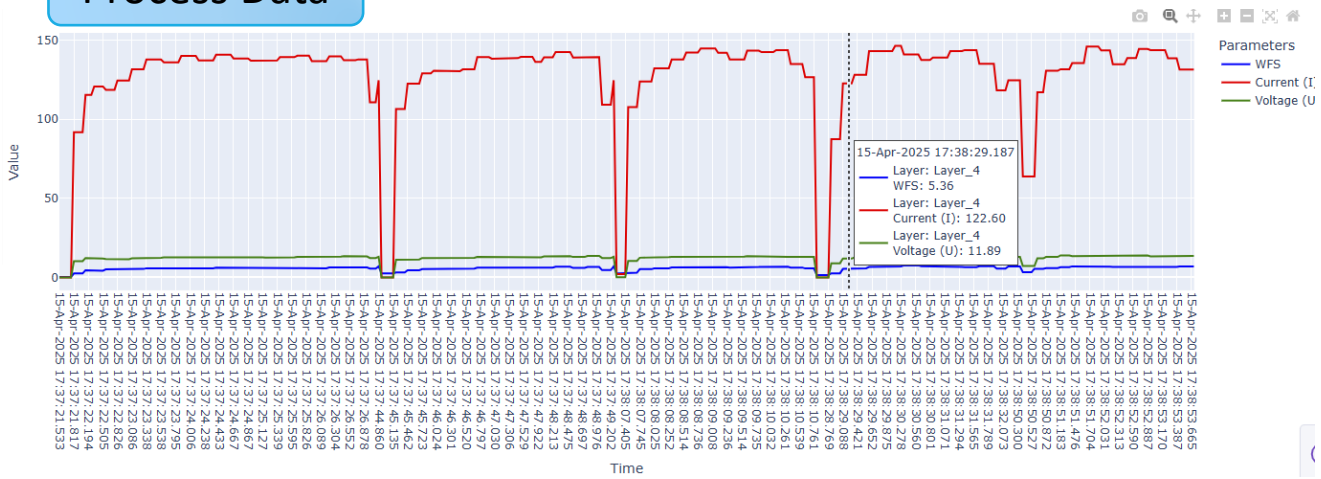


Initial Data

Selected Layers:

Layer	Initial_Job	Initial_TS
Layer_0	20	7
Layer_1	20	7
Layer_2	20	7
Layer_3	20	7
Layer_4	20	7
Layer_5	20	7
Layer_6	20	7

Process Data



Conclusion

A synchronization algorithm was developed to connect data from multiple sources:

- Initial data
- Process data (robot movement, deposition parameters)
- Spatial data (laser scans)

The algorithm helps to match all data in time and space. The data is shown in interactive visual graphs and table to help understand the WAAM process.

Acknowledgements

I would like to express my sincere gratitude to:

- **Dr.sc.ing., Professor Mihails Savrasovs** – for his invaluable supervision, continuous support, and academic guidance throughout this research.
- **Dipl. Engineer Arseniy Kisarev, Head of the TSI Additive Lab** – for his expert consultations and technical insights related to the WAAM process.
- **The AdditiveLab team at TSI** – for providing access to equipment, data, and collaborative support during the project.
- **Transport and Telecommunication Institute (TSI)** – for creating the academic and technical environment that made this work possible

THANK YOU