University of Nottingham
Institute for Advanced Manufacturing

3DMC RESEARCH CENTRE FOR CONNECTED FACTORIES

Aligning Digital-Physical Twins for Reconfigurable Manufacturing Systems using Point Cloud Analysis

Sara Zi Wang

Research Fellow in Aerospace Manufacturing, Omnifactory

Loughborough, UK, 24th -26th September 2024

Agenda

RESEARCH CENTRE FOR CONNECTED FACTORIES

3DMC 3D METROLOGY CONFERENCE

- Introduction
- Aim and Objectives
- Methodology
- Conclusion & Future Work

Intro - Layout in Manufacturing

Layout is important, it determines
- Time and cost – material flow
- Safety zones – Human vs. machine

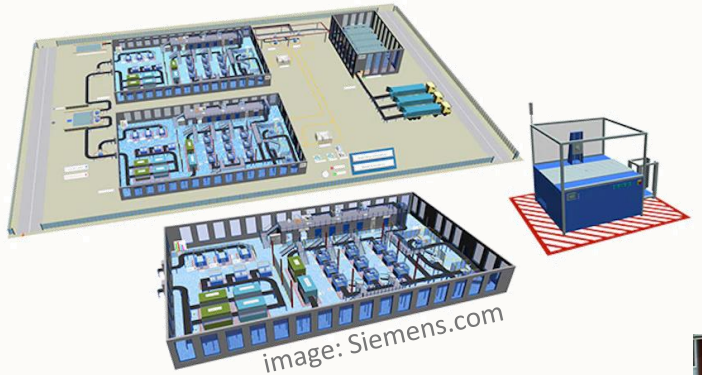


image: Siemens.com

Modelling and Simulation
- Path Planning
- Bottleneck Analysis + Optimisation
- KPI estimation

image: 2wtech.com

Implementation
- Factory in Operation

Intro – RMS & Digital Twin

RESEARCH CENTRE FOR CONNECTED FACTORIES

3DMC 3D METROLOGY CONFERENCE

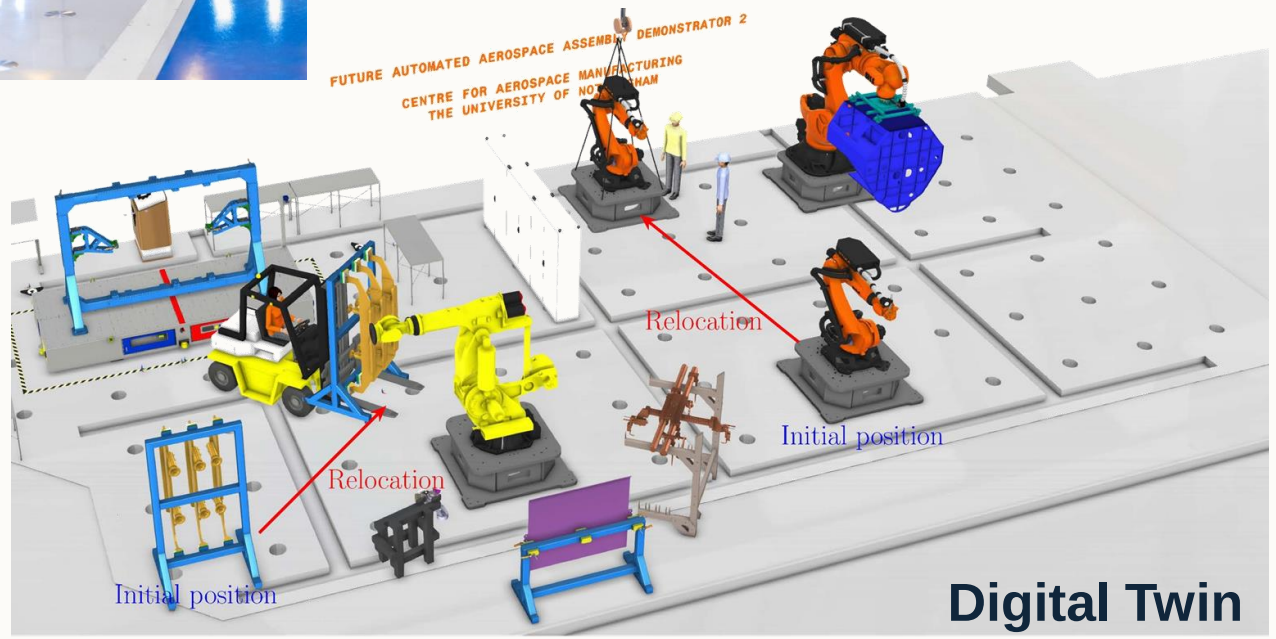
Omnifactory - UK national testbed for manufacturing technologies

Reconfigurable Manufacturing System (RMS)

- Address to fluctuating demands
- Modular capability
- Short lead time
- Maximise facility reuse

- Replica or aspect of a real thing
- Exist in cyber world

- ***Synchronised*** with real counterpart
- Uses ***models***
- Incorporate ***subject-matter*** expertise
- Has a ***purpose*** to impact its environment



Digital Twin

3D Simulation Environment

Layout in RMS with Digital Twin

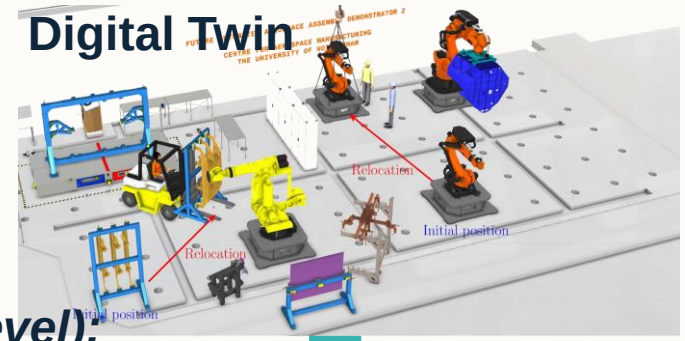
RESEARCH CENTRE FOR CONNECTED FACTORIES

3DMC 3D METROLOGY CONFERENCE

Design

Analyse functional requirements

Digital Twin



Scanned Point Cloud

image: Flaticon.com

Unstructured Data

?

image: Siemens.com

Transformation T

Understand Current State

Purpose (Cell Level):

- 3D path planning
- Robot virtual commissioning
  - Safety critical
- In-process metrology design
  - Measurement volume
  - Visibility etc.

Shopfloor

Aim and Objectives

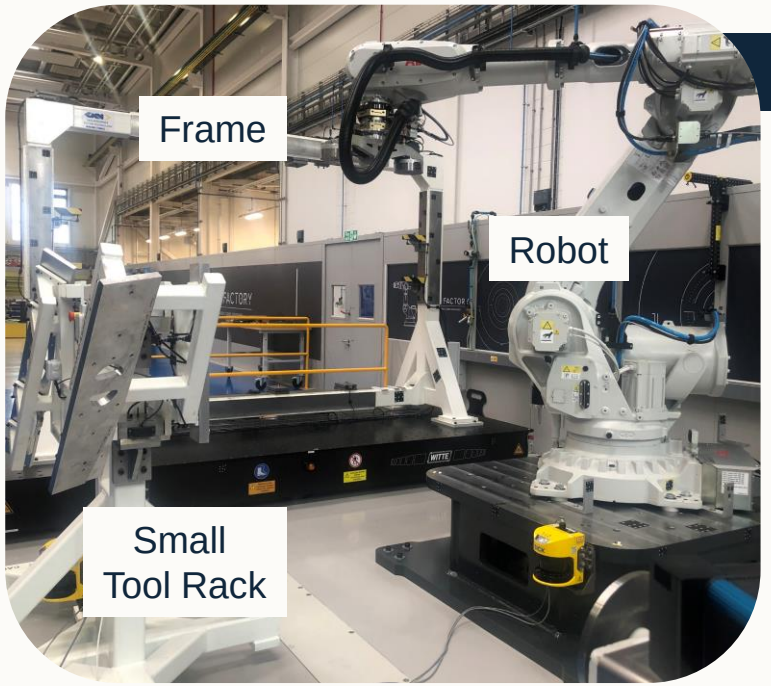
RESEARCH CENTRE FOR CONNECTED FACTORIES

3DMC 3D METROLOGY CONFERENCE

Aligning Digital-Physical Twins for Reconfigurable Manufacturing Systems using Point Cloud Analysis

Aim

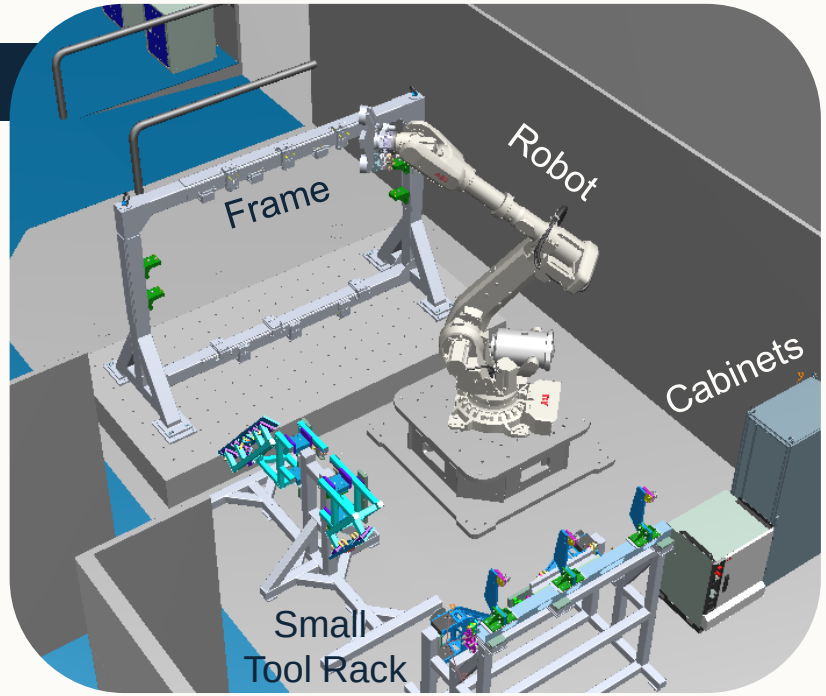
Physical Factory



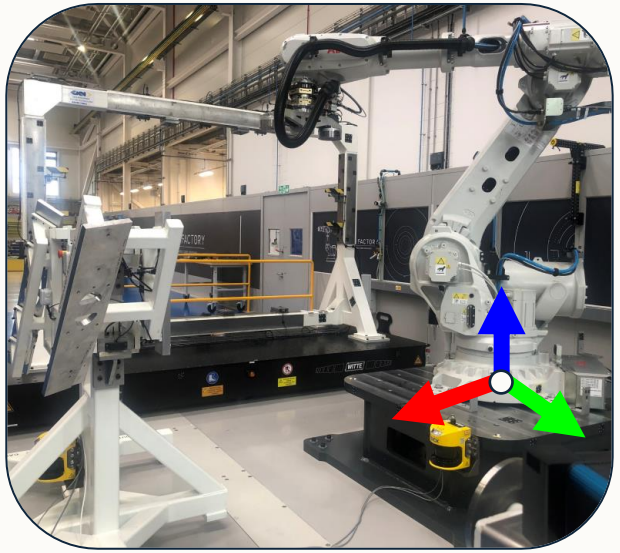
Objective

1. Capture physical layout
2. Align physical-digital twins
3. Calculate deviation T
4. Update digital twin

Digital Twin

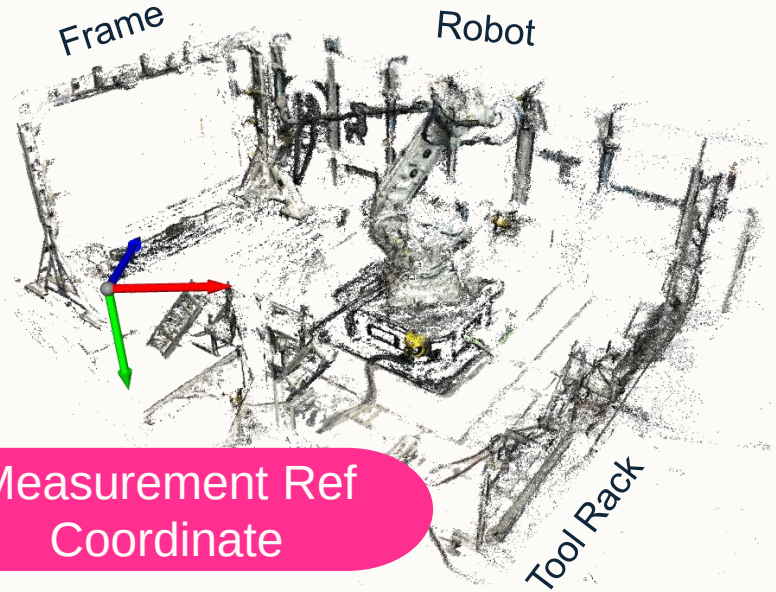


1. Capture Physical Layout



Photogrammetry

Structure from motion
Multi-view stereo



Reconfigurable Cell:

- Multi-product assembly environment
- Fixture mounted in AGV (Automated Guided Vehicle)
- Robotic cell with tooling storage
- ~ 3m x 3m in size

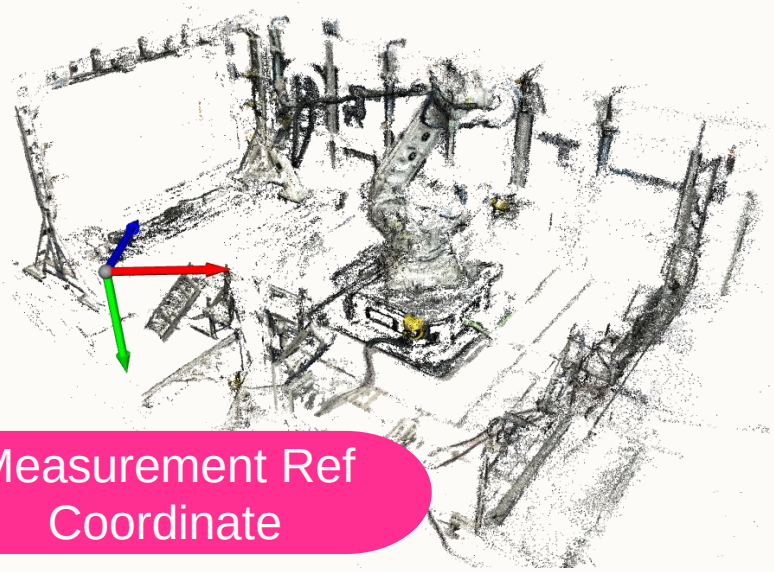
Purpose: Rapid reconfiguration

Robot online path planning -> minimal human intervention

Alternative

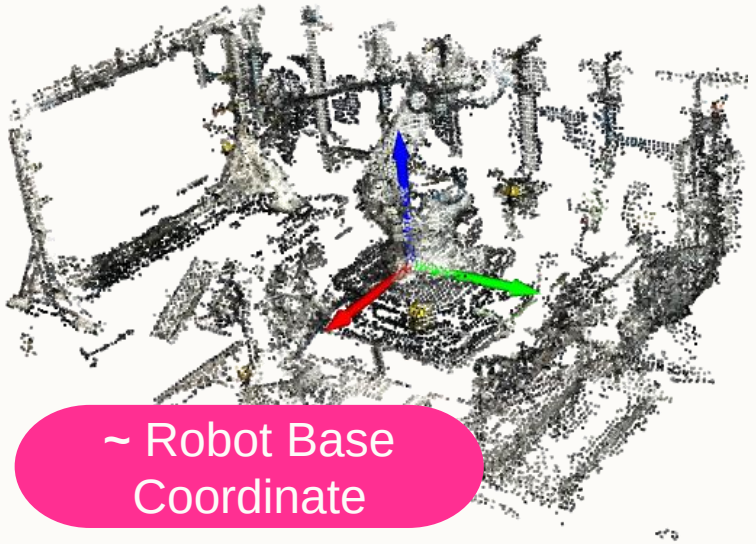
Laser radar type of systems
Any other?

2. Align physical-digital twins



Measurement Ref Coordinate

Coarse Alignment



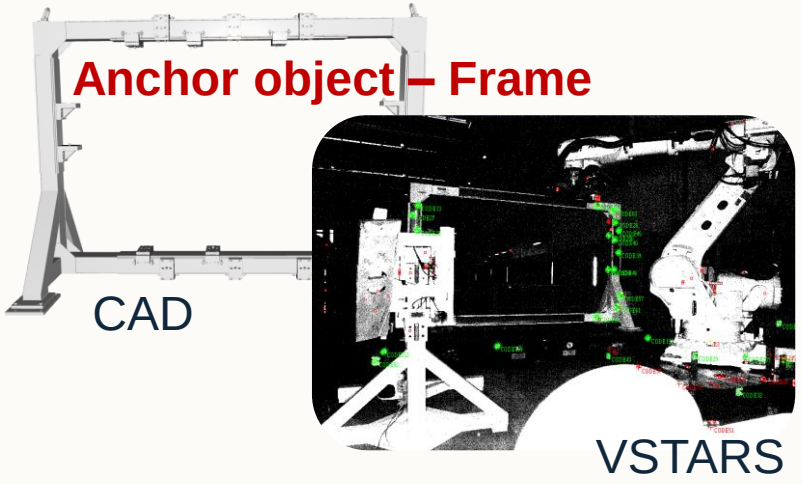
~ Robot Base Coordinate

Open issue:
Scale?
Quantifiable physical-digital deviation?

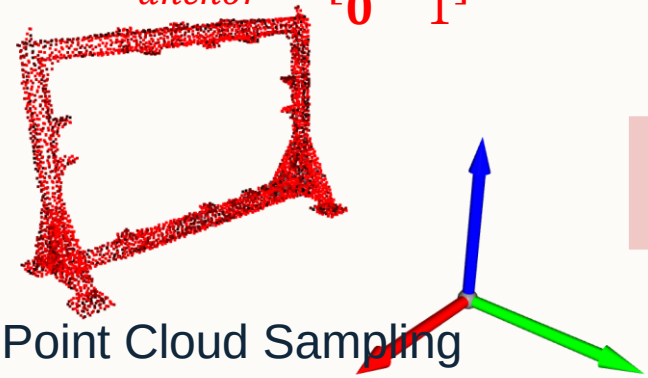
Need:
Anchor object
Object with known location and form

Fine Alignment

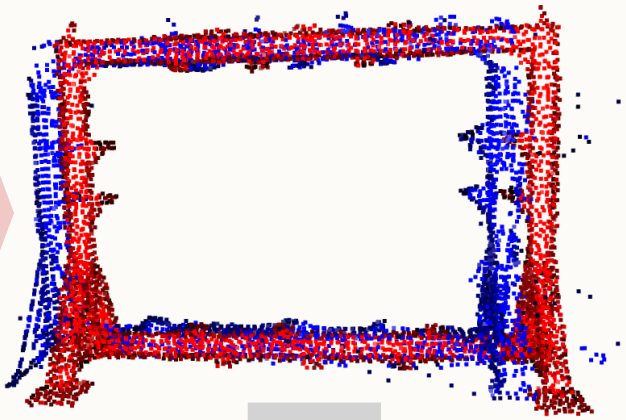
2. Align physical-digital twins



$$T_{anchor} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix}$$



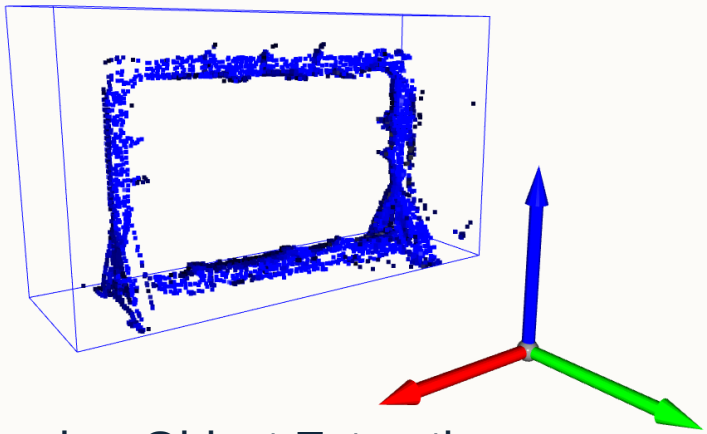
Point Cloud Sampling



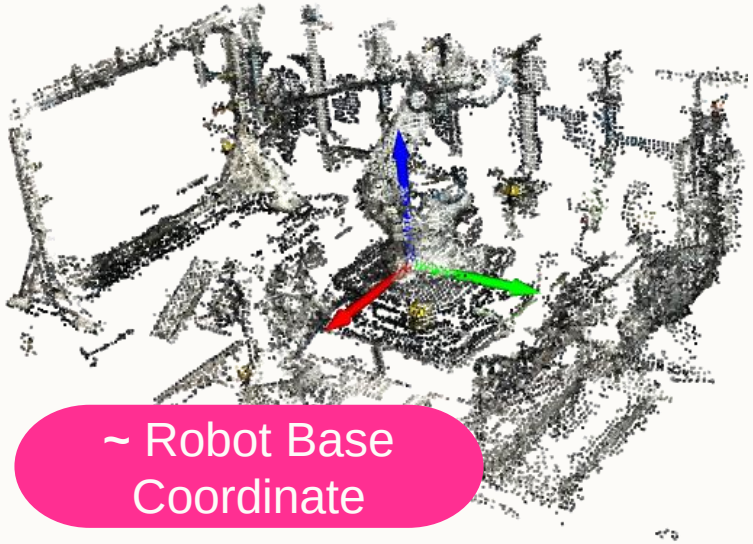
Iterative Closest Point (ICP) Registration

$$T_{Scene}^{P2P} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix}$$

Fine Alignment



Anchor Object Extraction

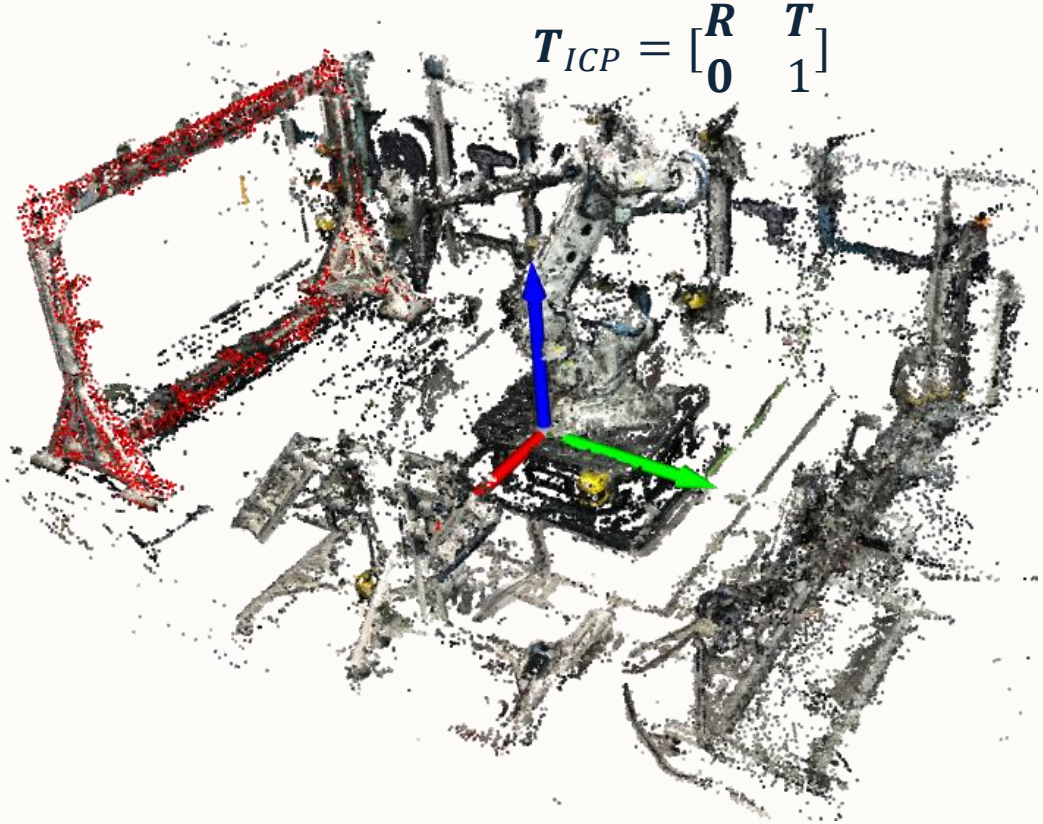


~ Robot Base Coordinate

2. Align physical-digital twins

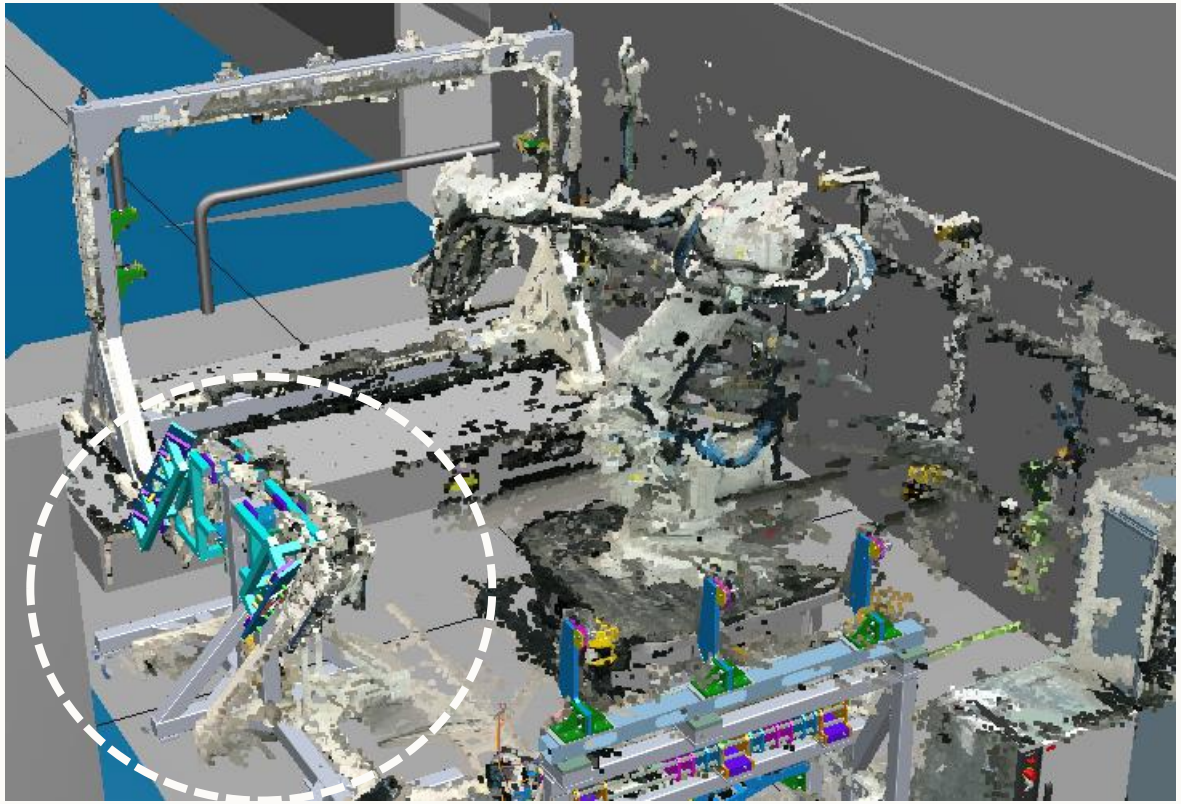
Fine alignment of the entire scene

$$T_{ICP} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix}$$



Aligned Unstructured data

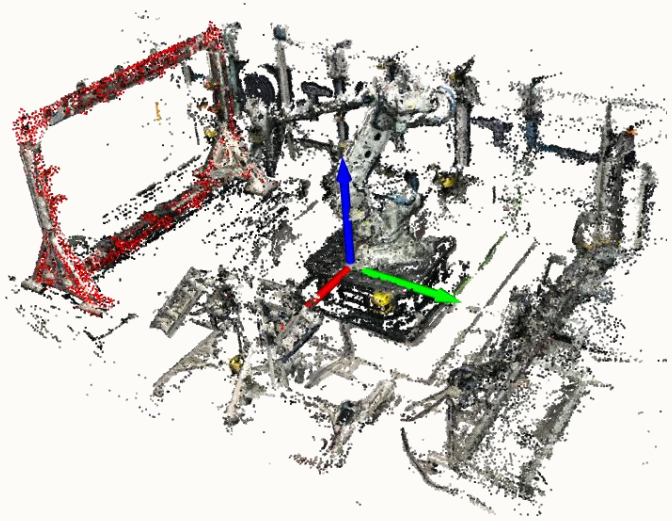
Overlap in digital twin



Not aligned assets

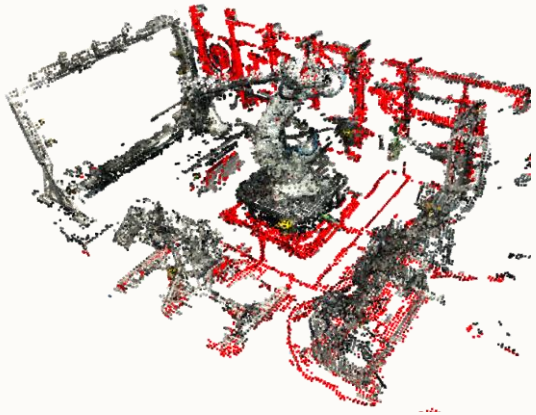
Asset physical location unknown

3. Calculate Deviation



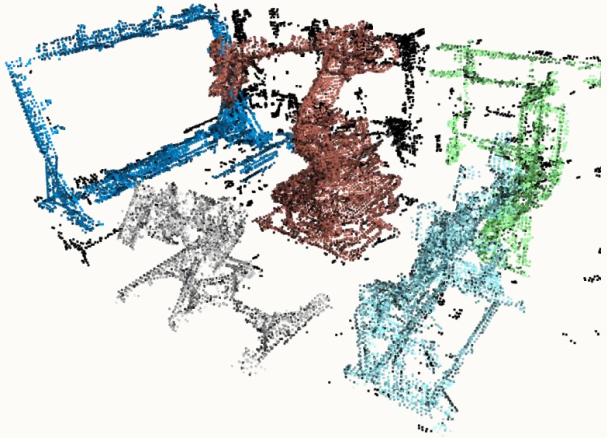
Clustering
- Unsupervised Approach

RANSAC Planar Segmentation



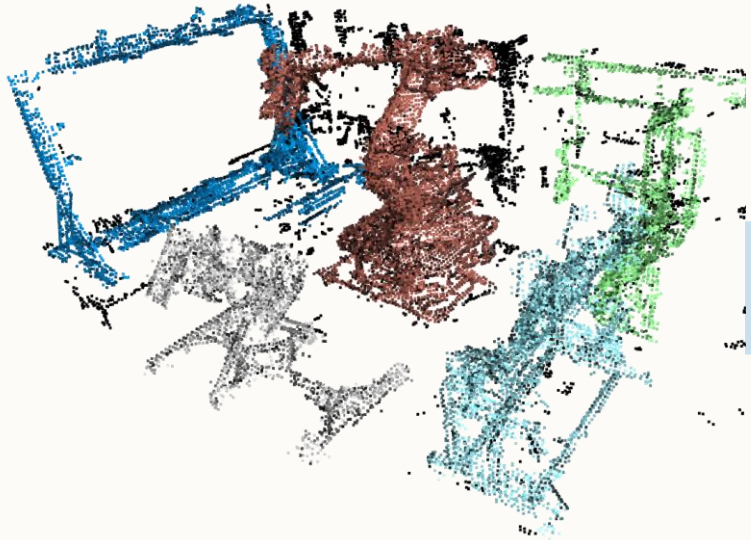
1) Fit data (x, y, z) to plane $ax + by + cz + d = 0$
2) Find the plane that fits the most points
3) Remove these points

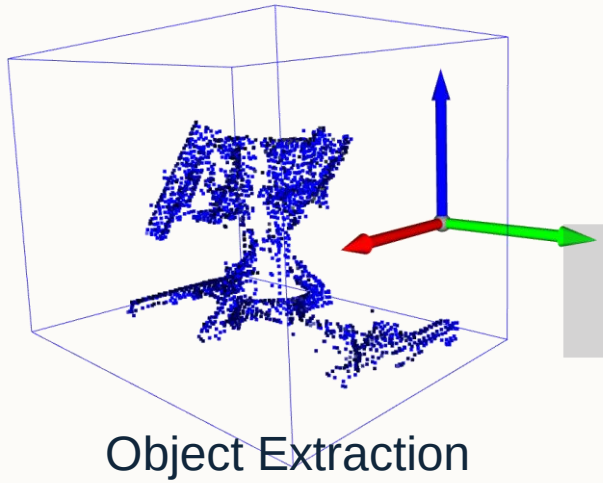
OPTICS Clustering



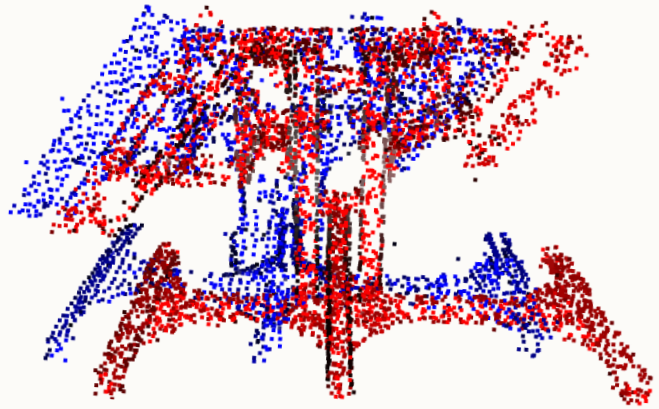
1) Density-based clustering
2) Soft clustering cut-off by gradient
3) Varying cluster density

3. Calculate Deviation

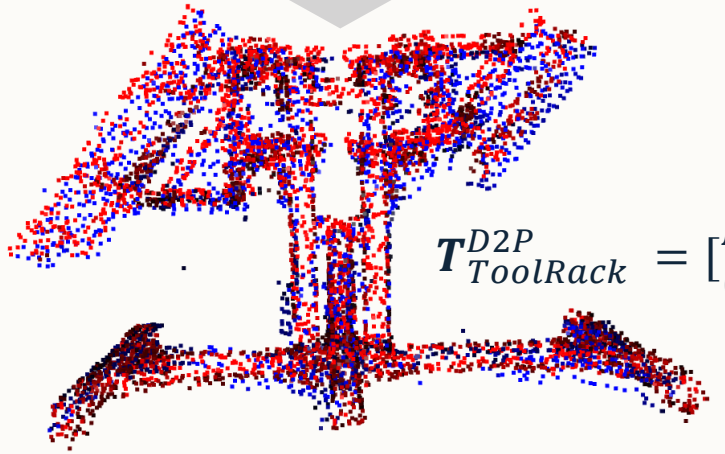




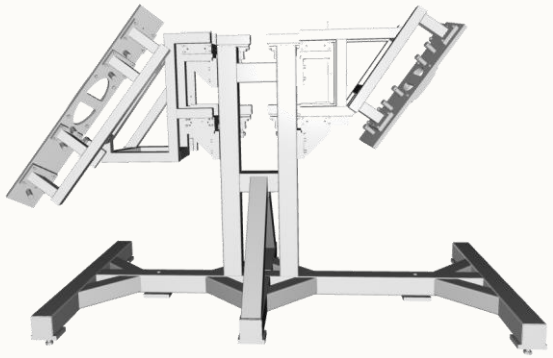
Object Extraction



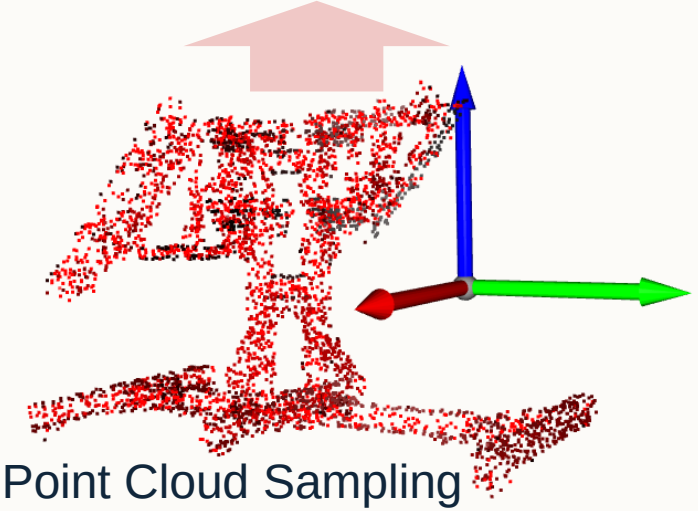
ICP Registration



$$T^{D2P}_{ToolRack} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix}$$



CAD Model Export



Point Cloud Sampling

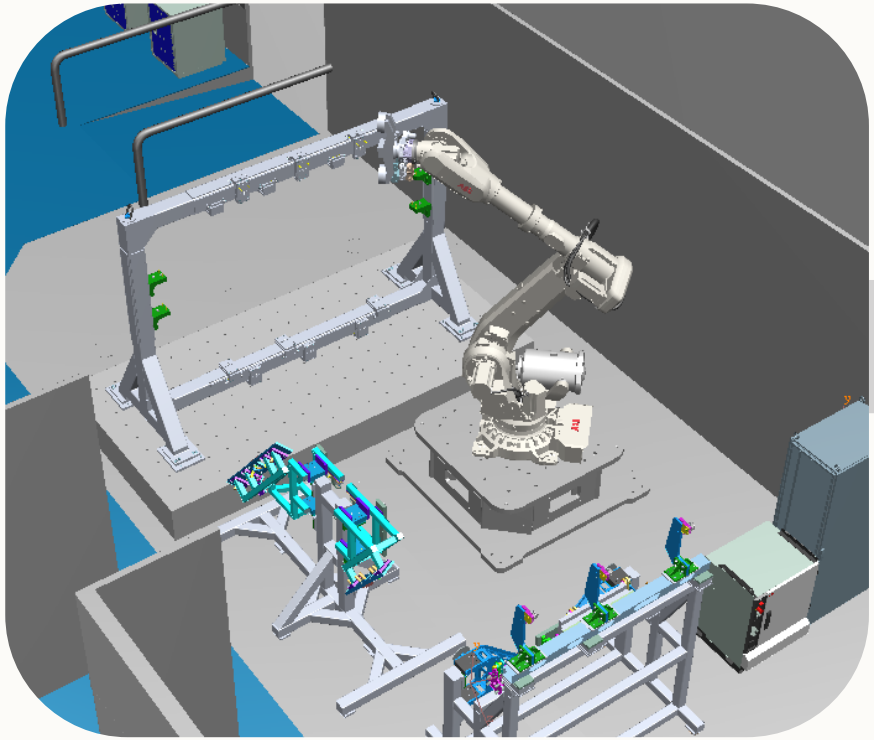
4.Update Digital Twin

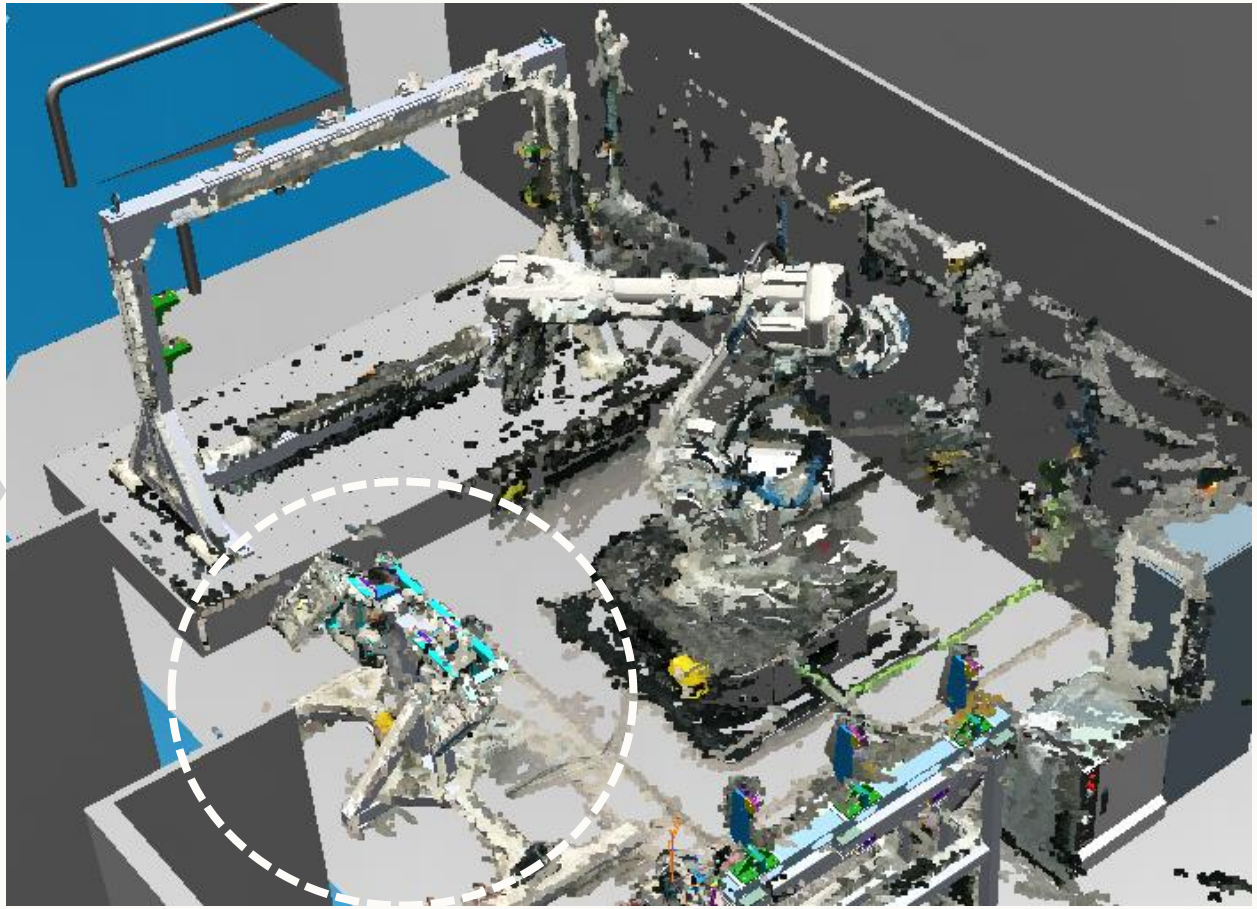
RESEARCH CENTRE FOR CONNECTED FACTORIES

3DMC 3D METROLOGY CONFERENCE

Relocation Small Tool Rack by

$$T^{D2P}_{ToolRack} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix}$$

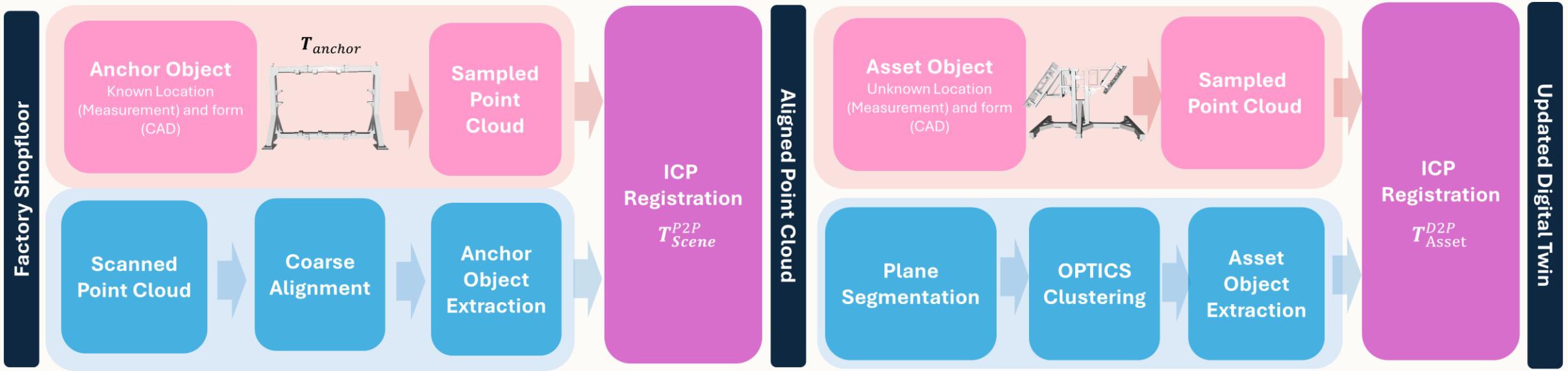




Aligned assets

Summary and Future Work

- Automated pipeline aligning digital twin towards physical factory
- Unstructured data into collection of transformation matrices



Future Work

- Alternative scanning methods
- Validate the asset object location
- Quantify the physical/digital deviation
- Robot offline programming applications

University of Nottingham
Institute for Advanced Manufacturing

RESEARCH CENTRE FOR CONNECTED FACTORIES

3DMC 3D METROLOGY CONFERENCE

Thank you

OMNIFACTORY
MANUFACTURING REDEFINED