University of Stuttgart
Institute of Industrial Automation
and Software Engineering

Development of a Simulation Platform in Digital Twin for Intelligent Manufacturing

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Examiner: Prof. Dr. Ing. Michael Weyrich

Introduction

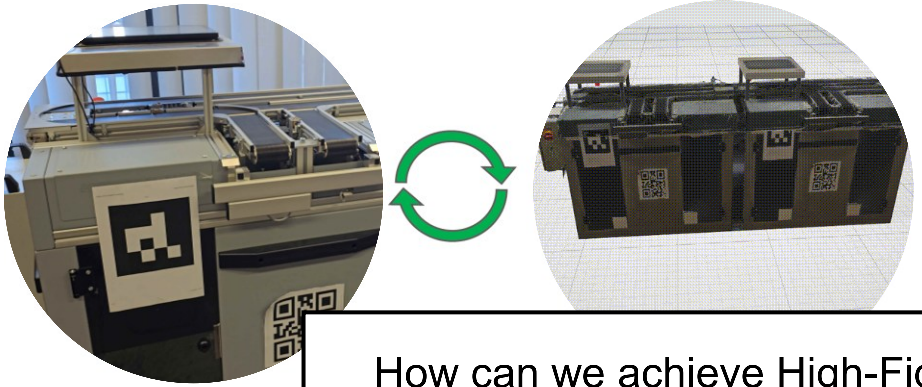
Digital Twins

- **Definition:** representing a physical entity that mirrors real-world conditions, processes, and systems[1].
- **This thesis:** 3D Modeling + 3D Simulation in Digital Twin
- **Management of physical assets:** monitoring, planning, analysis, prediction…

Requirements:

- High-Fidelity
- Low-Cost

Physical *Digital*



Question

How can we achieve High-Fidelity and Low-Cost?

Agenda

① ②

3D Modeling and Simulation

- Quick walk-through
- Basics
- Methods
- Evaluation
- Application
- Conclusion

Quick walk-through

Preview

Quick walk-through - Preview

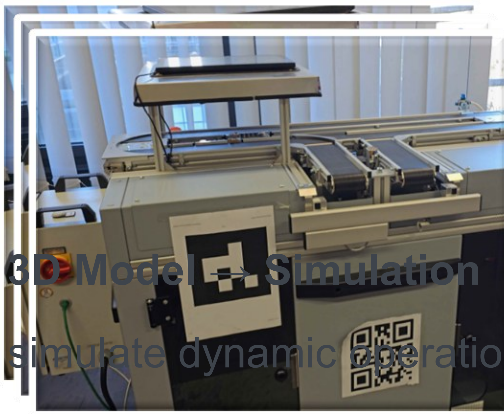
constructing 3D-simulation model

My Master Thesis → 3D-Modeling, 3D-Simulation

1. 3D Modeling

Meshing

texturing



Physical images

White Model

3D-reconstructed Model

2. 3D Model → Simulation

simulate dynamic operations

predictive execution

Agenda

1 2

3D Modeling and Simulation

- Quick walk-through
- **Basics**
- Methods
- Evaluation
- Application
- Conclusion

Basics

1. 3D Modeling Methods
2. Simulation Environment Integration

Basics

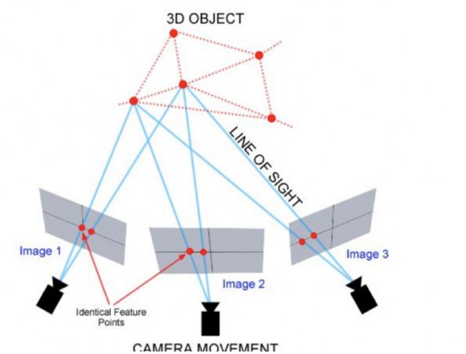
literature review

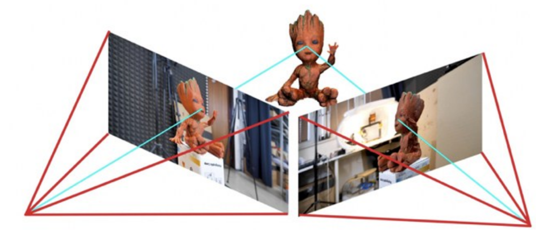
My Master Thesis → 3D-Modeling / 3D-Simulation

3D Modeling Methods (image-based)

1. Multiview Geometry: SfM, MVS[2]

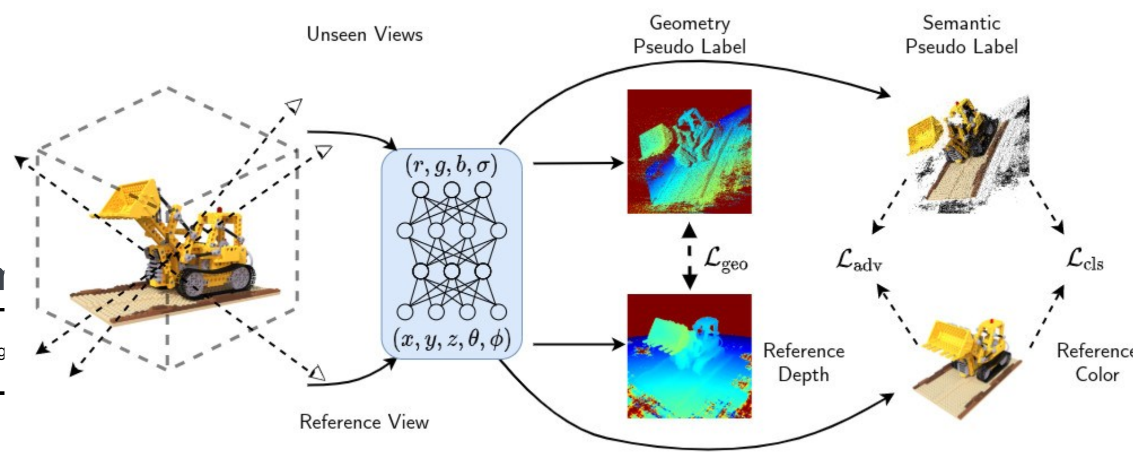
- ✅ computer vision based
- ❌ sensitive to noise





2. DL-based Methods: Instant NeRF (N'

- ✅ rely mainly on neural networks
- ❌ high hardware requirements



3. Data-driven Modeling: Photogran

Natural Feature Extraction → Image Matching → Feature Matching

Basics

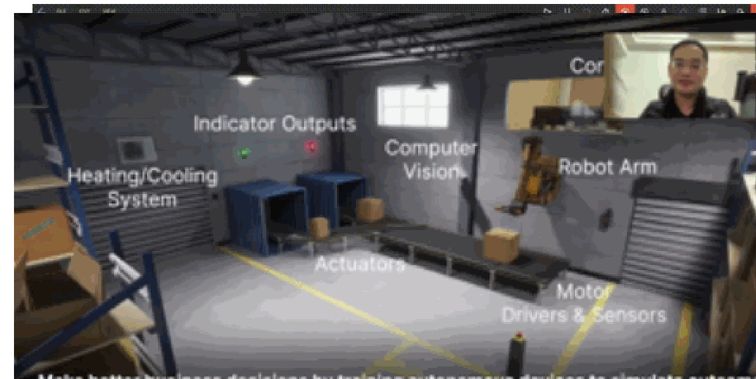
literature review

My Master Thesis
- 3D-Modeling
- 3D-Simulation

Simulation Environment Integration

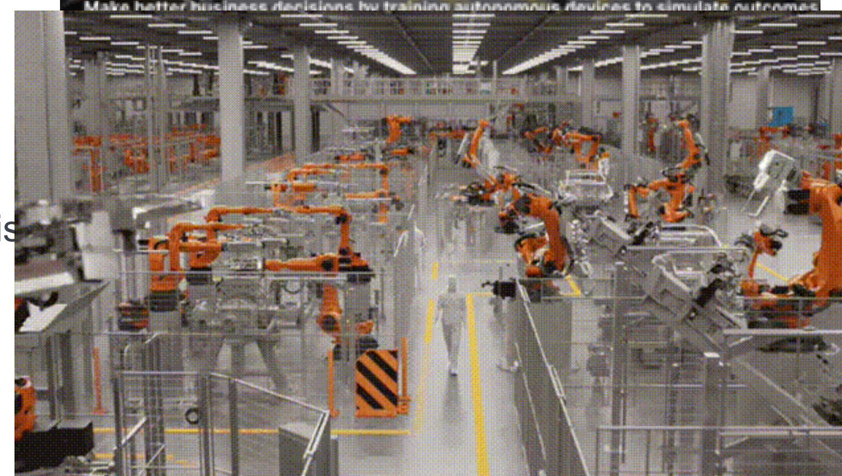
Factory IO[4]

- ✅ PLC logic testing
- ❌ Inflexible Customization



Unity [5]

- ✅ Interactivity
- ❌ limited support for high-fidelity physical mechanis



NVIDIA Isaac[6]

- ✅ High-Performance Physics Simulation

Methods

1. 3D Modeling:
   - create 3D model from images

2. Simulation Environment Integration
   - used for predictive Execution

Methods

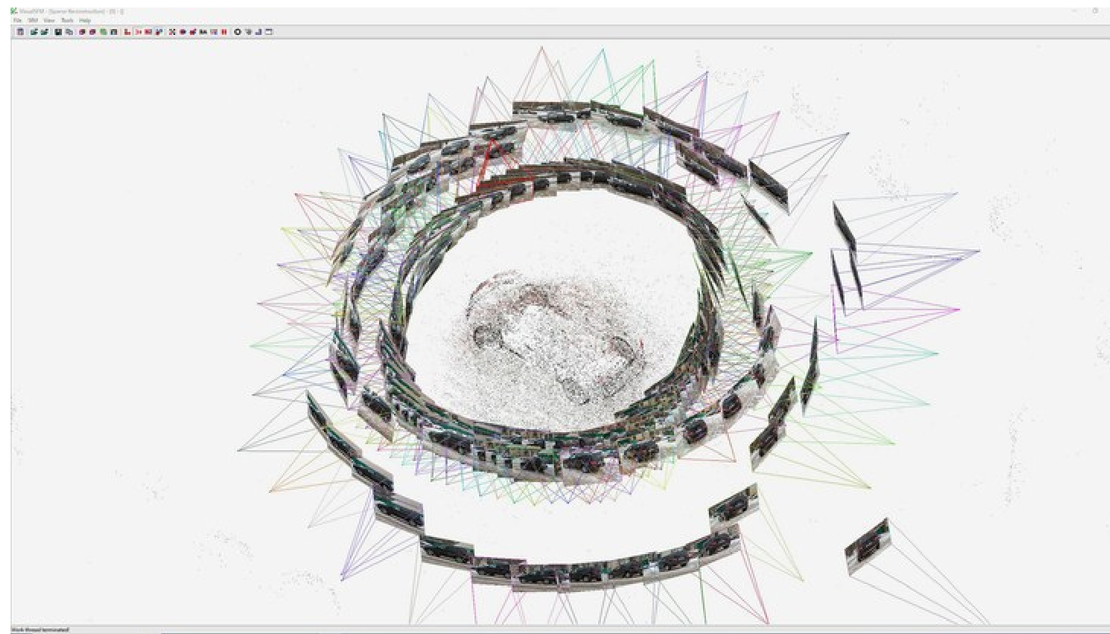
1. 3D Modeling:
   - create 3D model from images

2. Simulation Environment Integration
   - used for predictive Execution

Applied Method

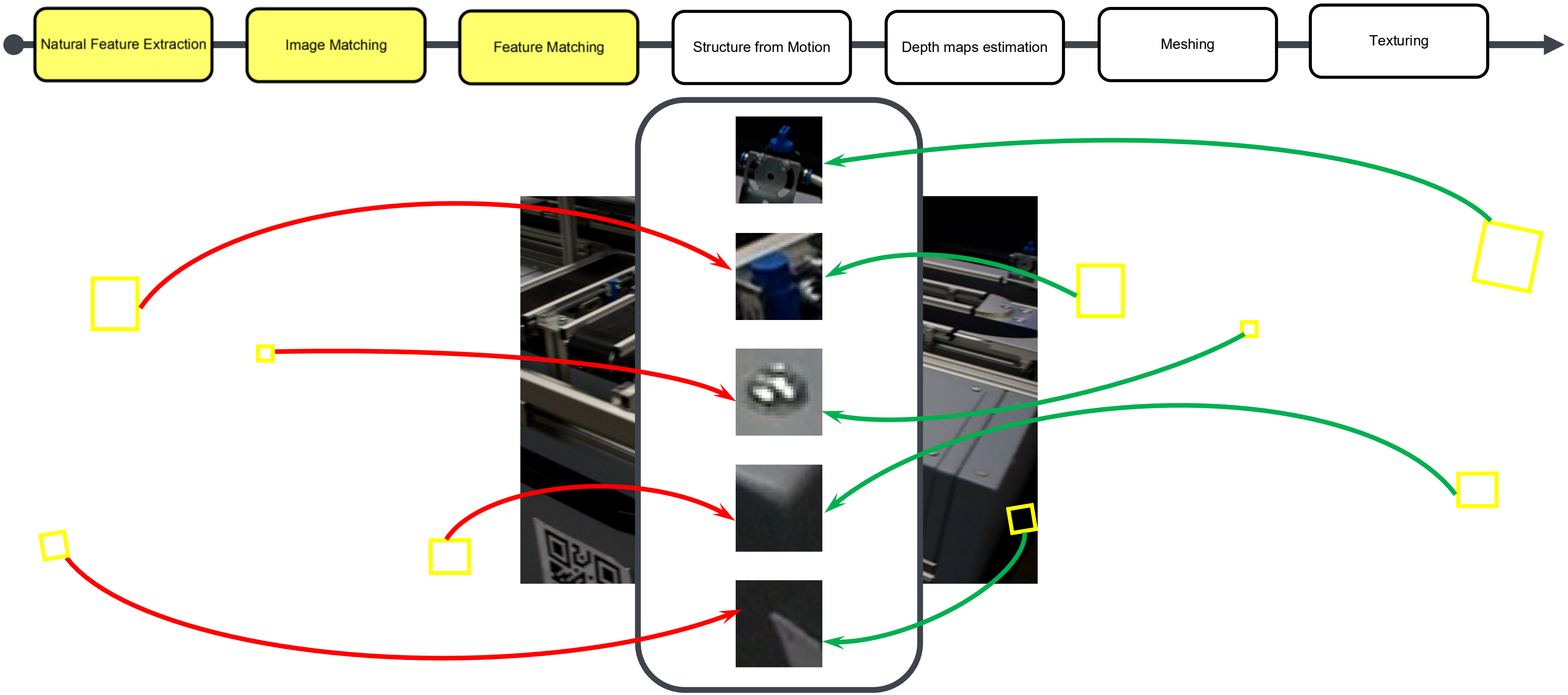
Photogrammetry

- Natural Feature Extraction
- Image Matching
- Feature Matching
- Structure from Motion
- Depth maps estimation
- Meshing
- Texturing



Photogrammetry

applied for our use case

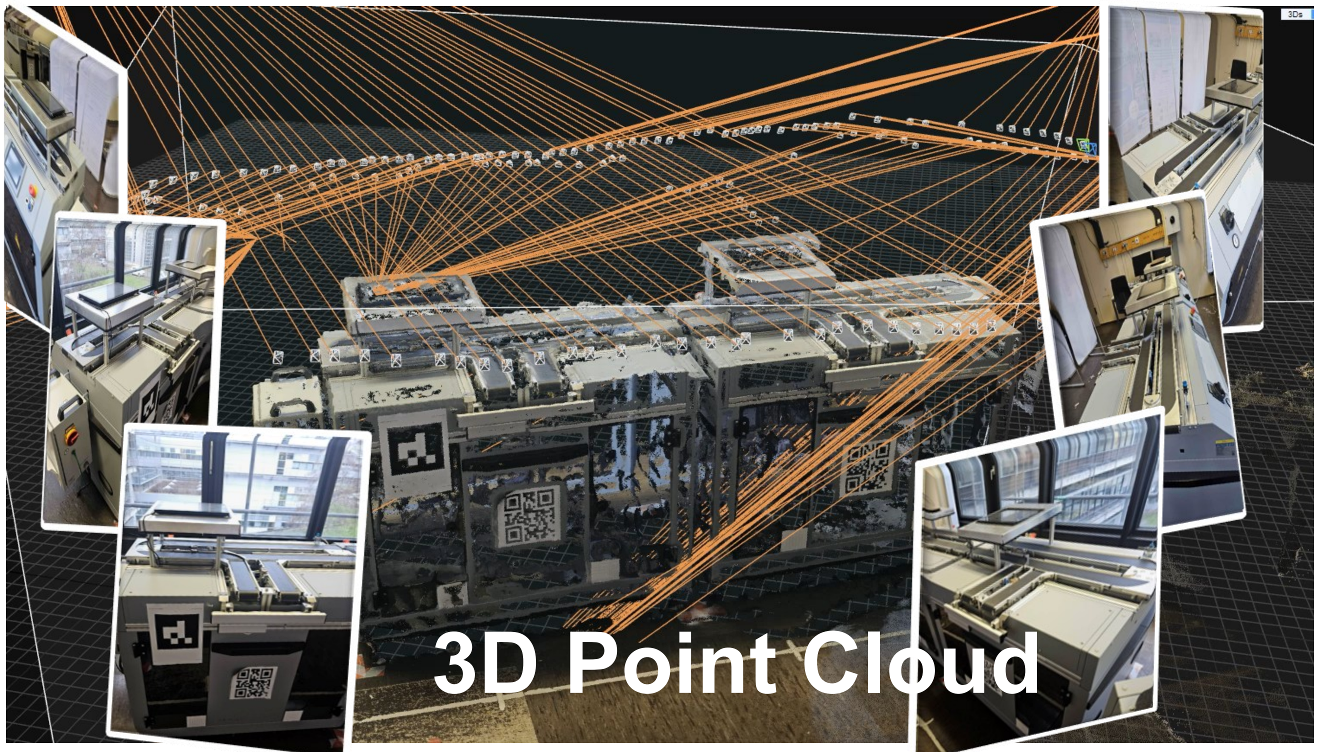


SIFT Features

Photogrammetry

applied for our use case

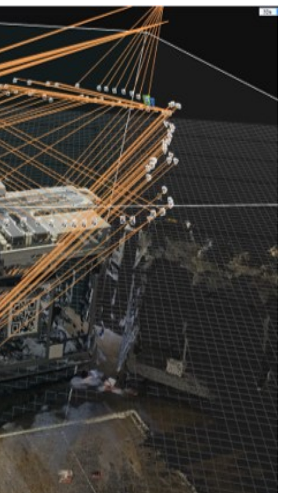
Natural Feature Extraction → Image Matching → Feature Matching → Structure from Motion → Depth maps estimation → Meshing → Texturing



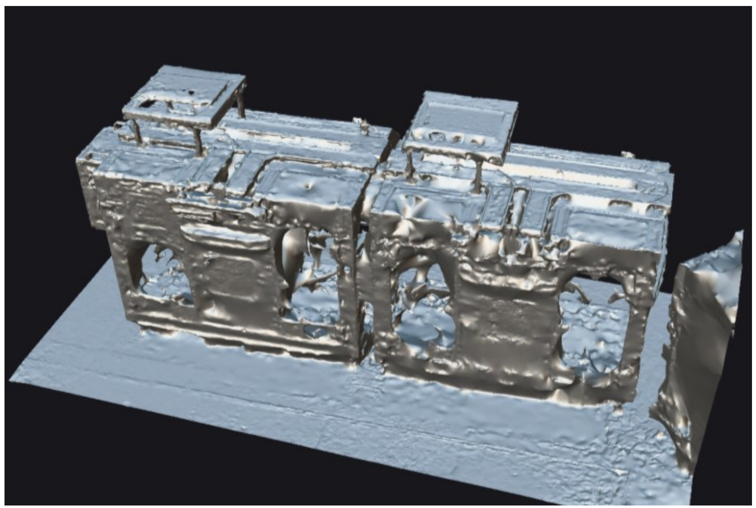
Photogrammetry

applied for our use case

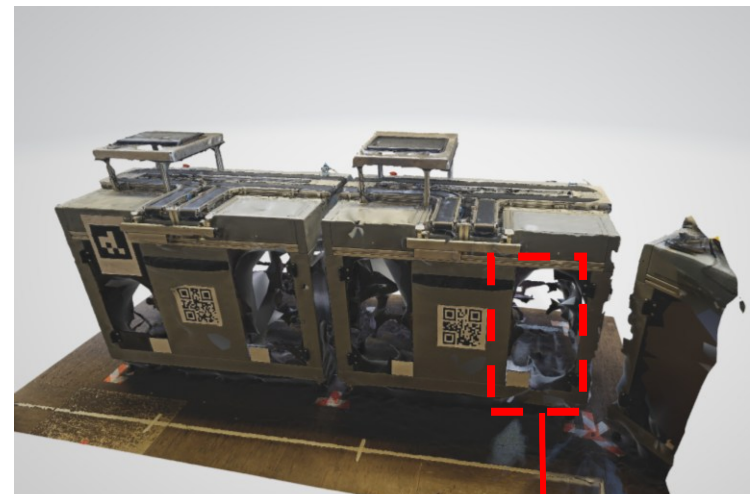
Natural Feature Extraction → Image Matching → Feature Matching → Structure from Motion → Depth maps estimation → **Meshing** → **Texturing**



White Model



Raw 3D Model



meshing

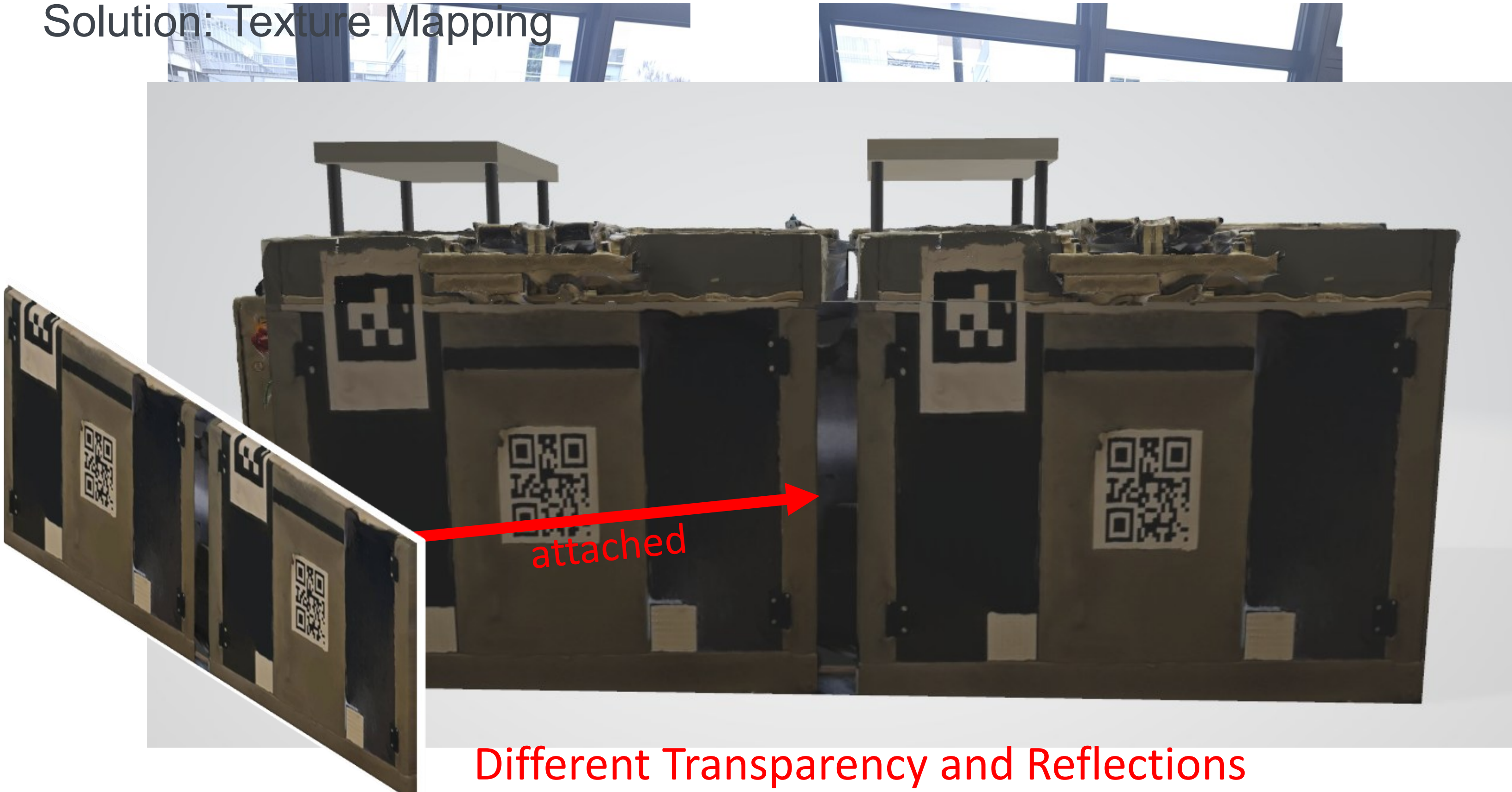
texturing

Incomplete

Post-Processing

Manual Correction

Solution: Texture Mapping



Different Transparency and Reflections

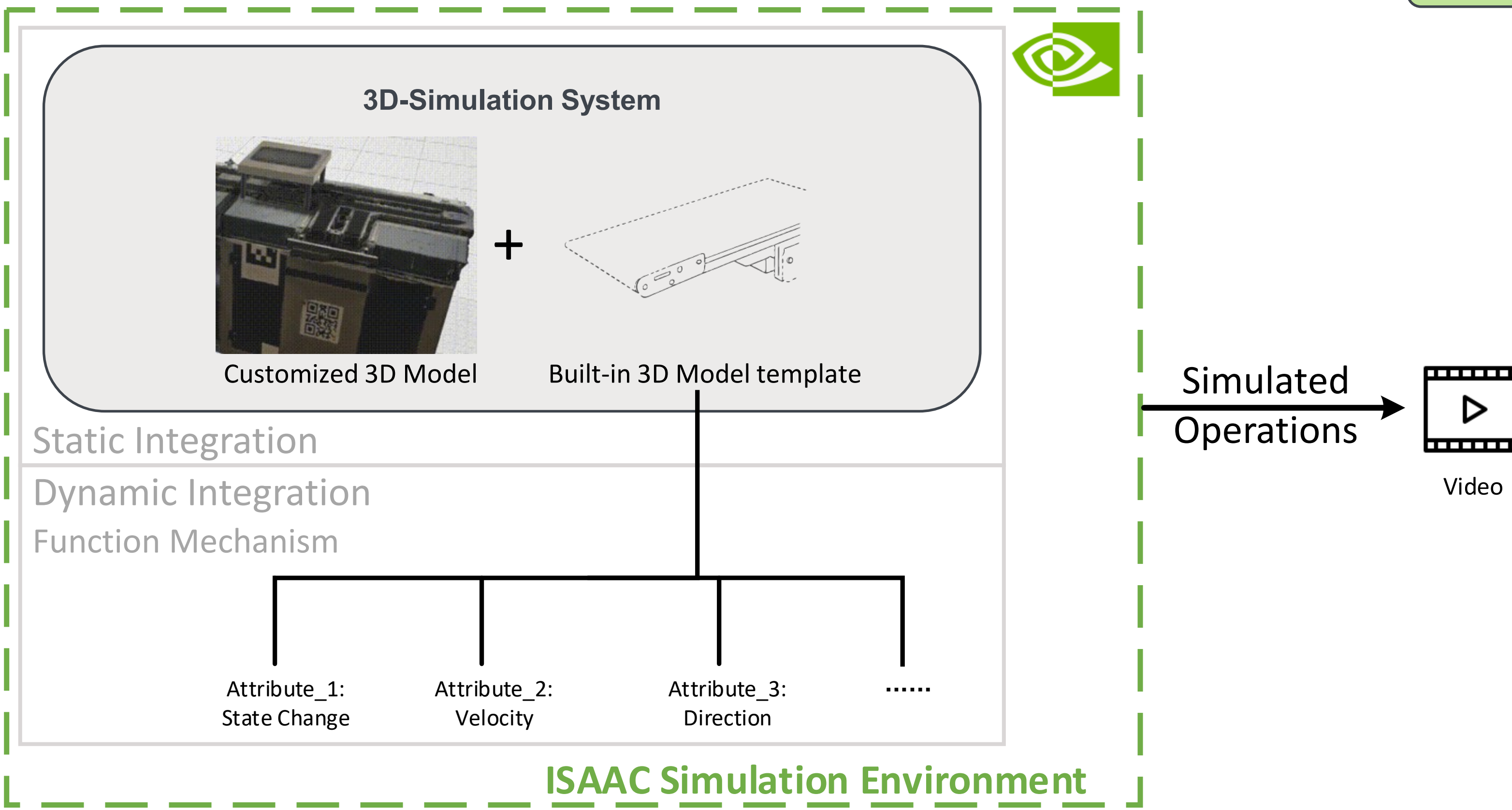
Methods

1. 3D Modeling:
   - create 3D model from images

2. Simulation Environment Integration
   - used for predictive Execution

Integration into Isaac Simulation Environment

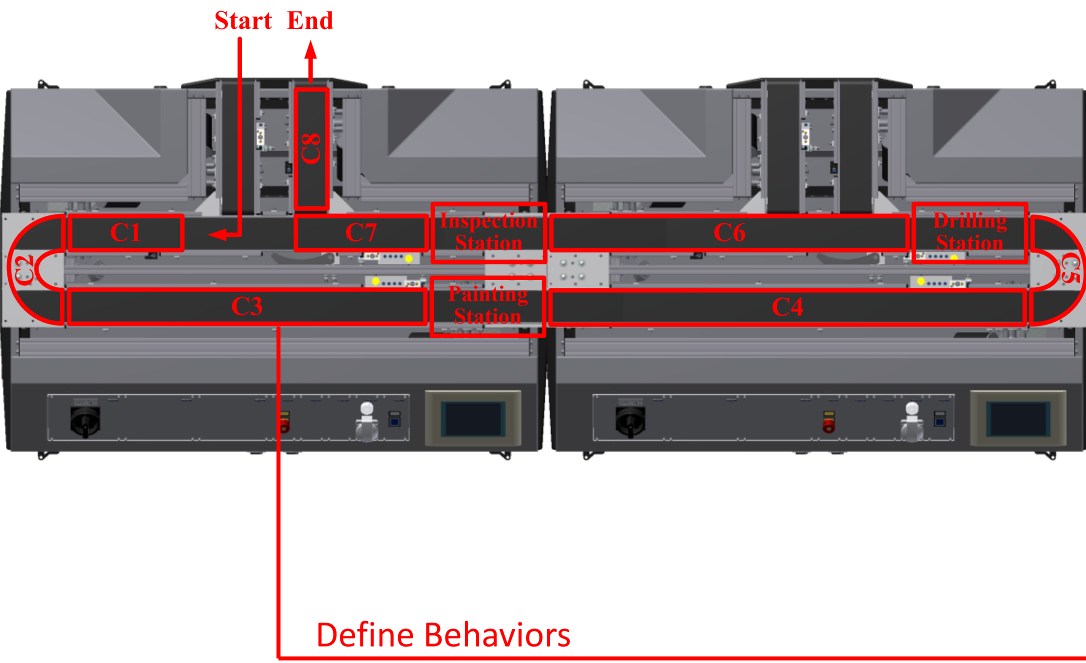
Simulation System Diagram

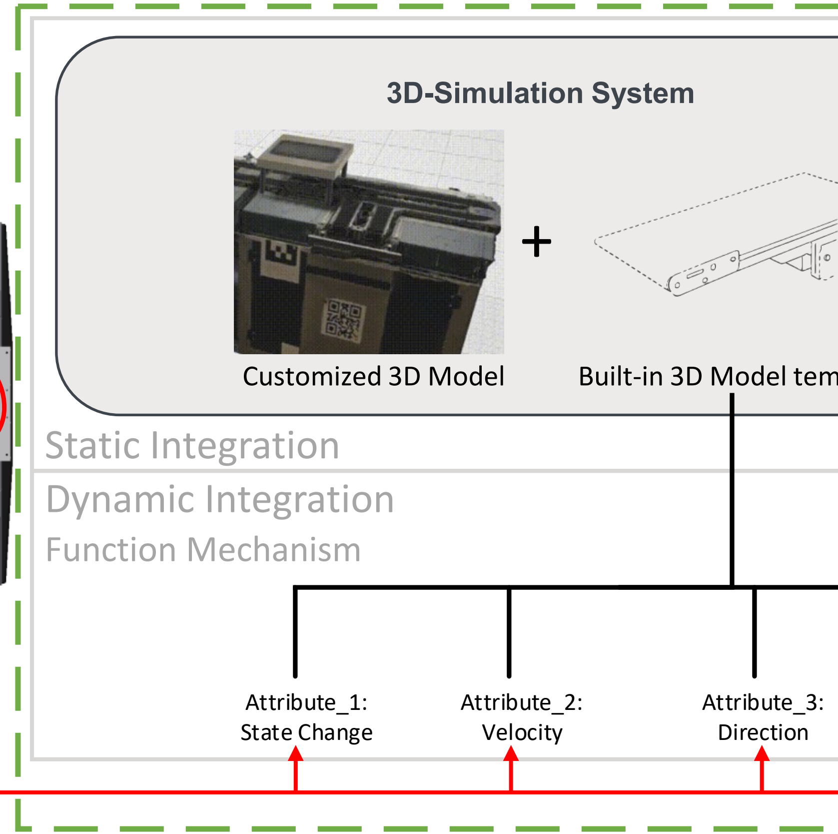


Integration into Isaac Simulation Environment

Simulation System Diagram

My Master Thesis
3D-Modeling
3D-Simulation





Integration into Isaac Simulation Environment

Simulation System Diagram

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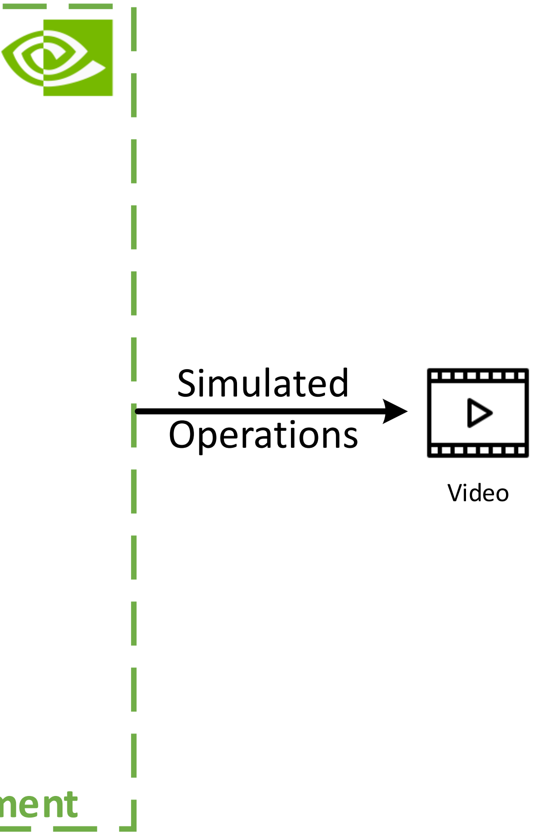


Dynamic Integration

Define Dynamic Behavior of the 3D-Component

Some of the NVIDIA Jargon

Physical Simulation → Physics Laws

"Prims": used for define Entity

- Workpiece Material
- Conveyor Belt

"Transform", "Physics": used for define Attributes

- Position, rotation, scale
- Mass, friction

"Ominigraph": used for define Behavior

- Start, Stop
- Velocity Control

"Relation": used for define Interaction

- Collision Detection
- Connection

Operation Validation

Material Flow + Production Processing

Predictive Execution

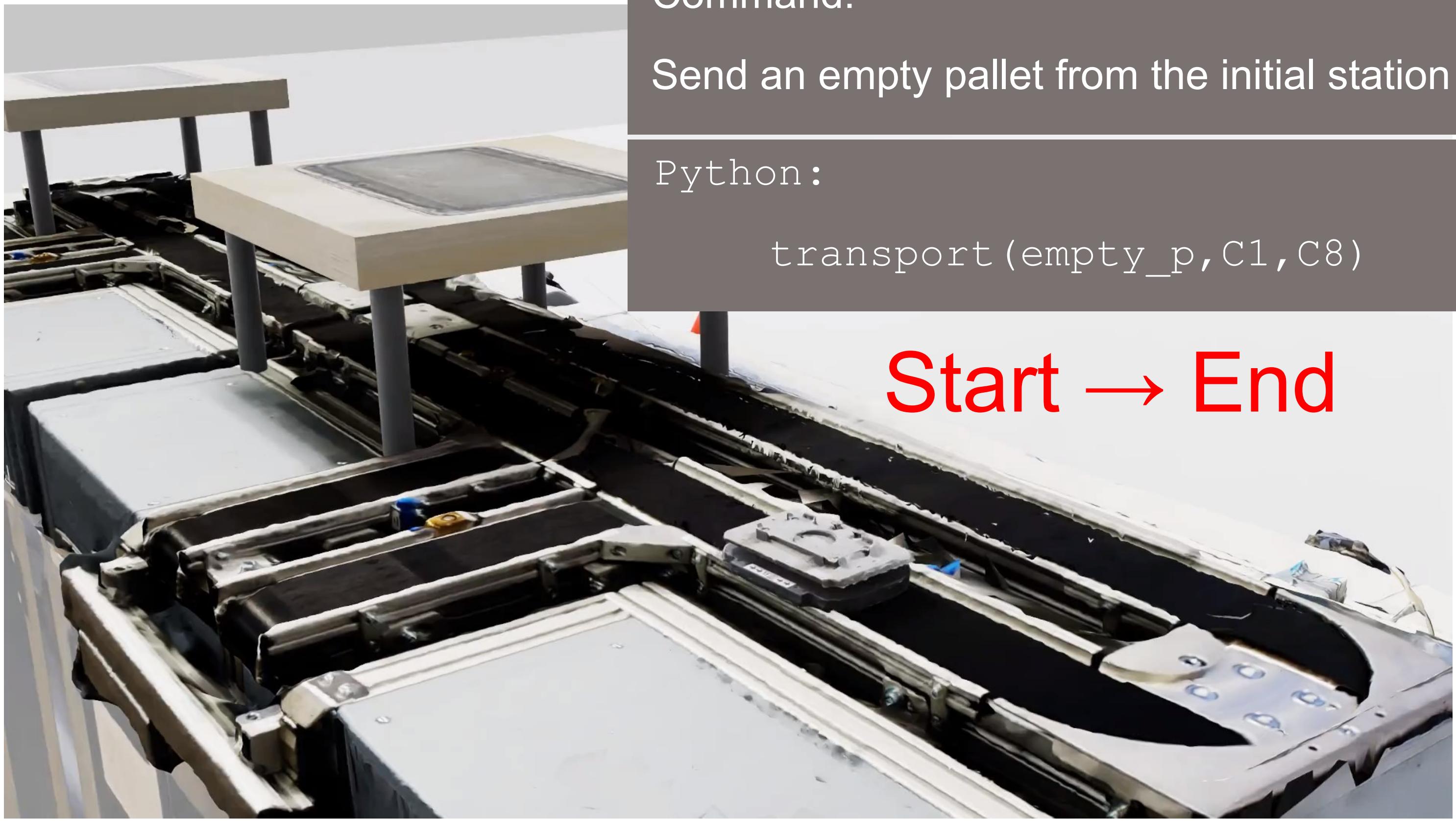
Operation Calling

Command:

Send an empty pallet from the initial station to the final station.

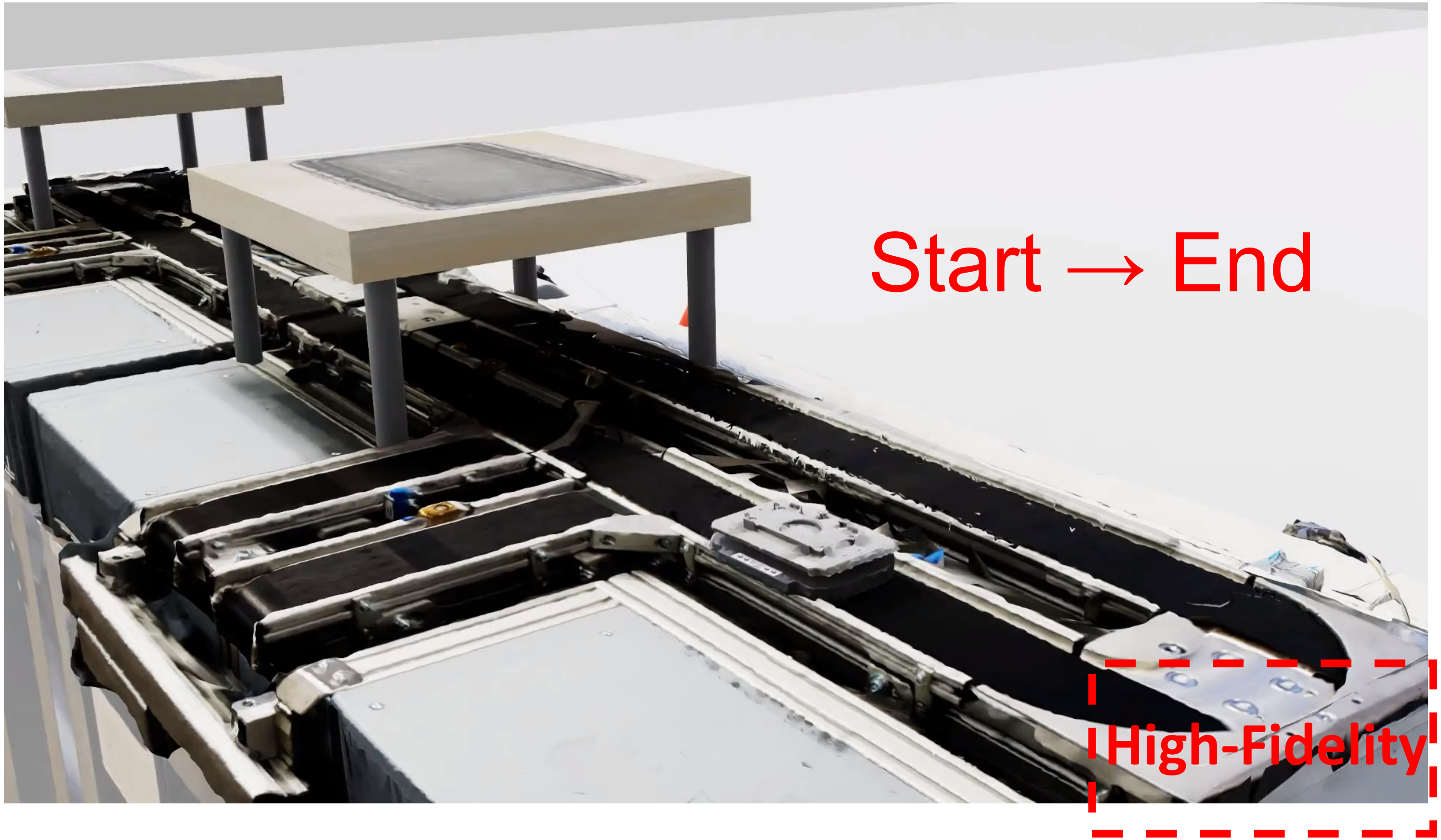
Python:

```
transport(empty_p,C1,C8)
```



Advantage of Isaac

PhysX Physics Engine

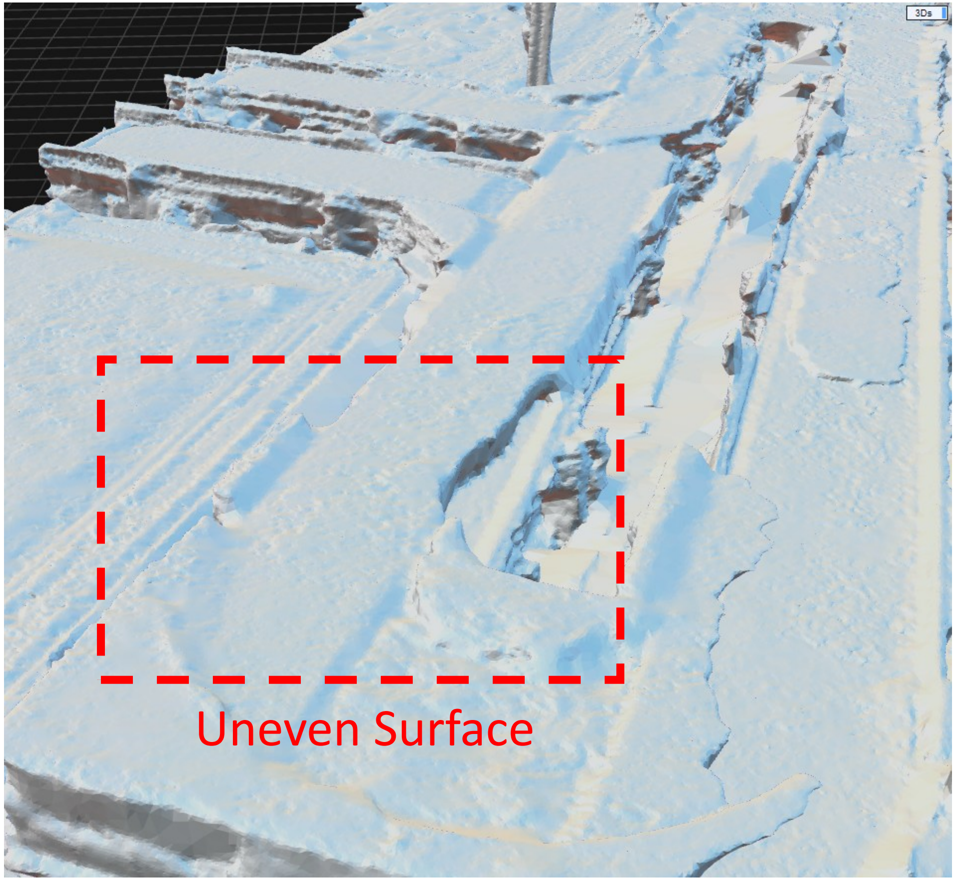


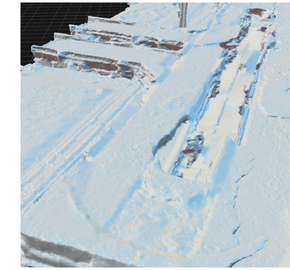
Evaluation

Quality of the 3D Model

3D Model Quality Optimization

Limitation: Uneven Surface





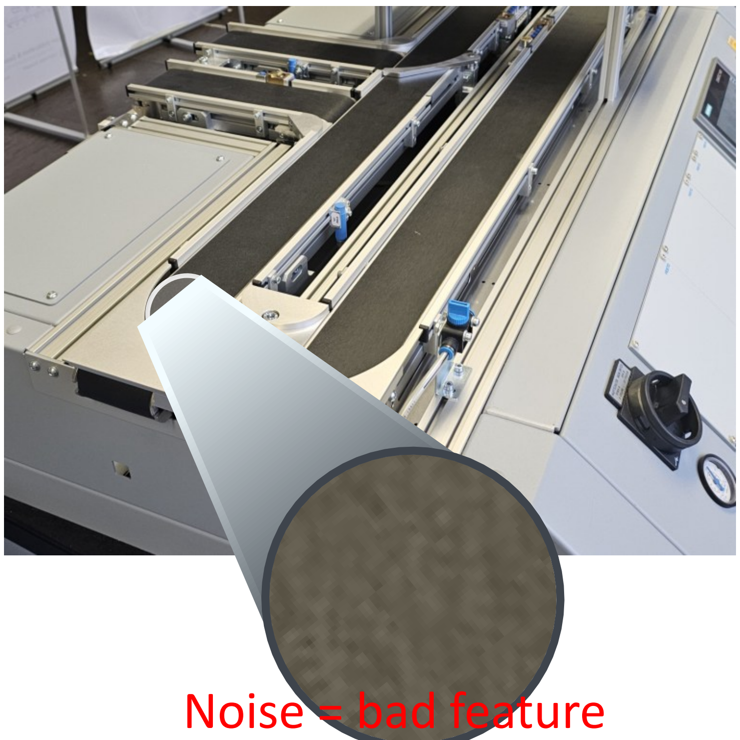
3D Model Quality Optimization

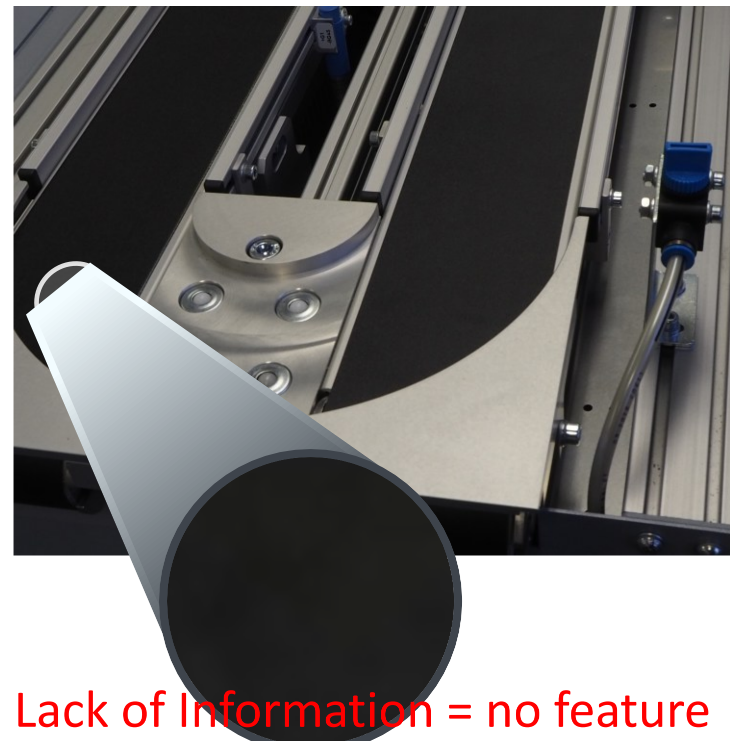
Limitation: Uneven Surface

Better Camera

Low Resolution

High Resolution





Noise = bad feature

Lack of Information = no feature

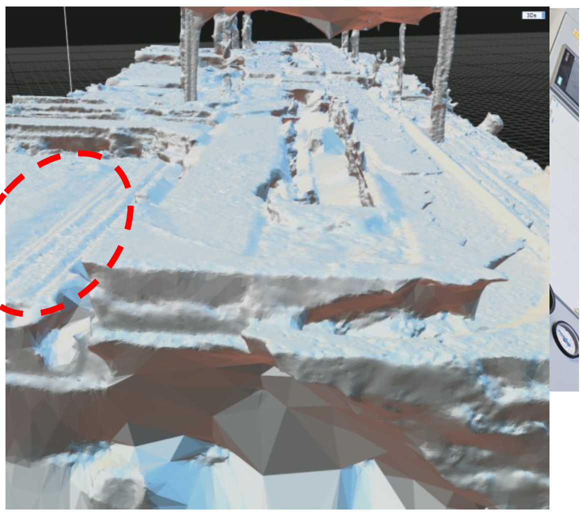
3D Model Quality Optimization

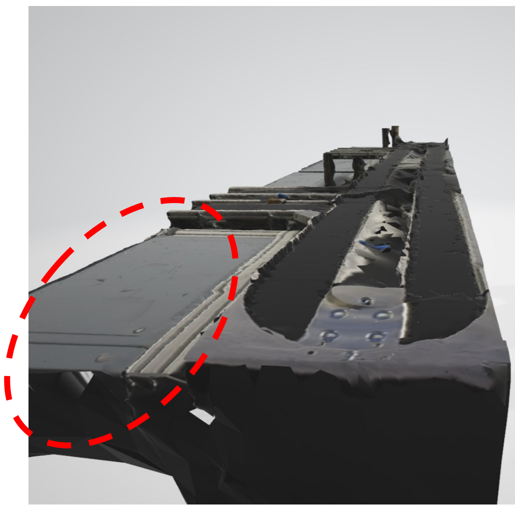
Limitation: Uneven Surface

Better Camera

Low Resolution

High Resolution





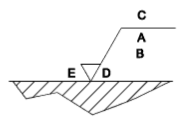
Manual Correction

Evaluation Criteria of 3D Models Optimization

Comparison

Question

How to quantify the quality of 3D model?

Technical Criteria: Errors		Low-Resolution	High-Resolution	Manual Optimization
Roughness 	Conveyor Belt	2.378mm	1.202mm	(0)
	Model Surface	2.498mm	1.089mm	(0)
Straightness —		0.505mm	0.850mm	(0)
Parallelism //		0.237°	0.213°	(0)
Levelness ▽		0.895°	0.825°	(0)
Cost		3h	3h	10-15h

Evaluation Criteria of 3D Models Optimization

Comparison

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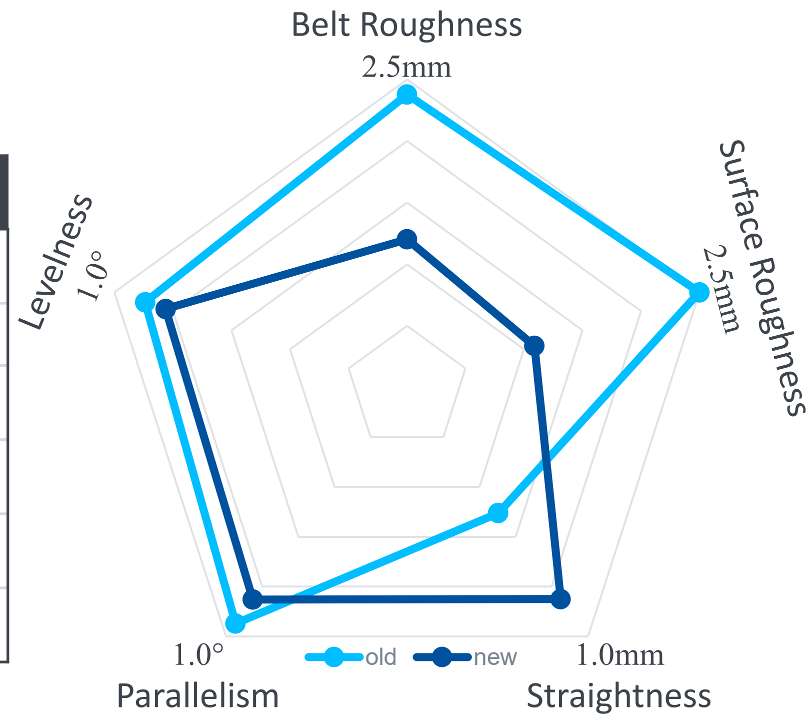


Application

Anomaly Detection by Comparison with Camera Data
(used by another work)

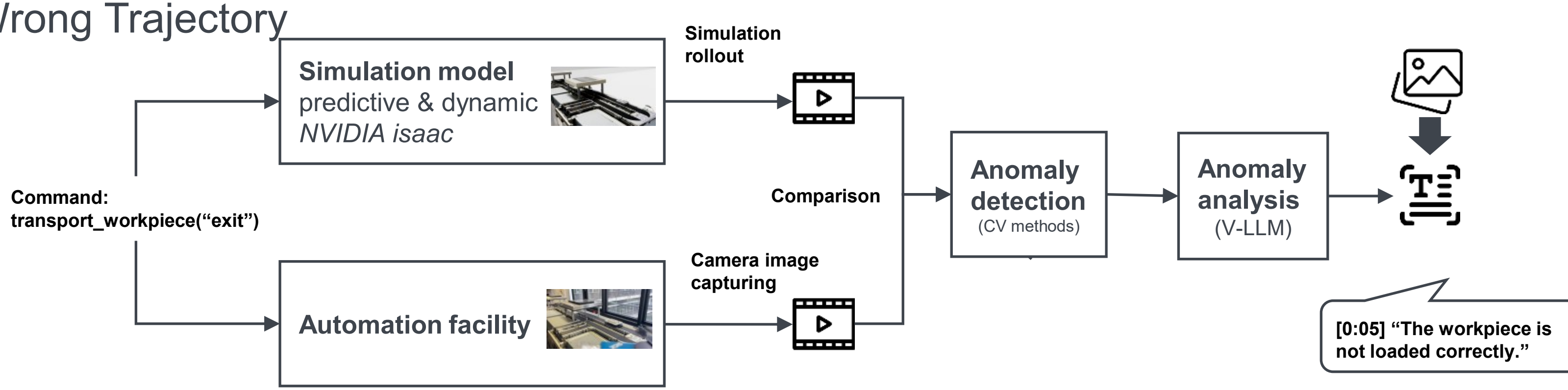
Video Comparison

Anomaly Detection

Applied in Anomaly Detection and Analysis Using Simulated and Real-Time Video Data with Vision Language Model **(MT-3834)**

Anomaly Situations:

- Material Mismatch
- Human Interference
- Conveyor Failure
- Wrong Trajectory



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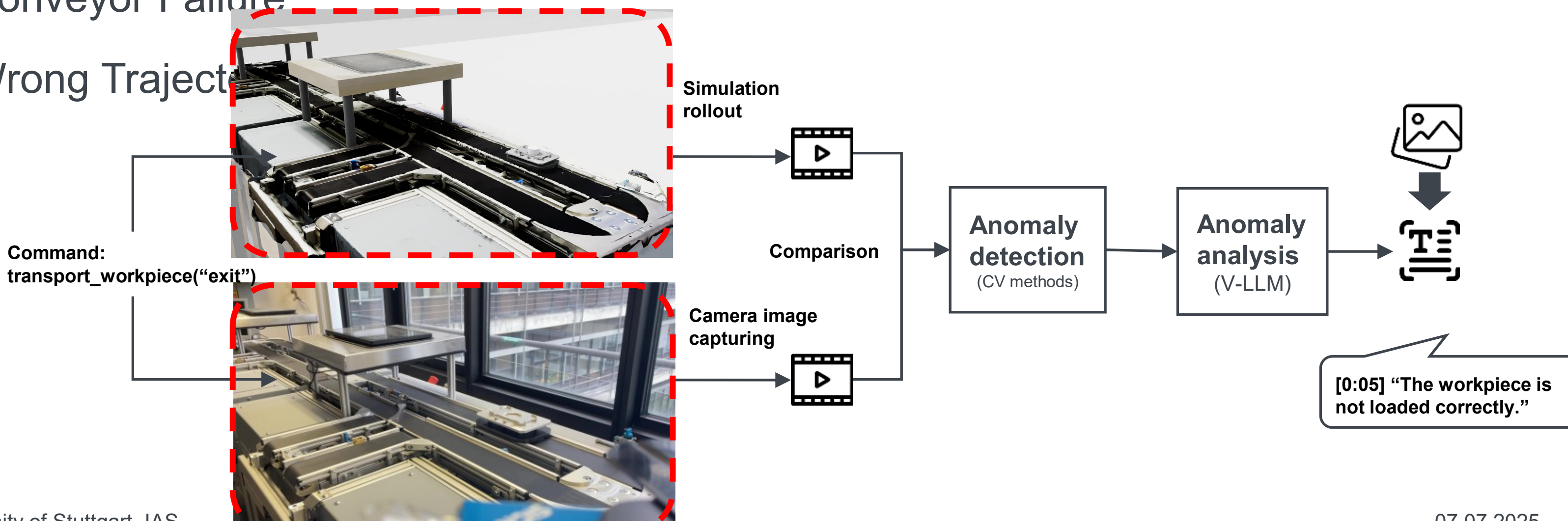

Video Comparison

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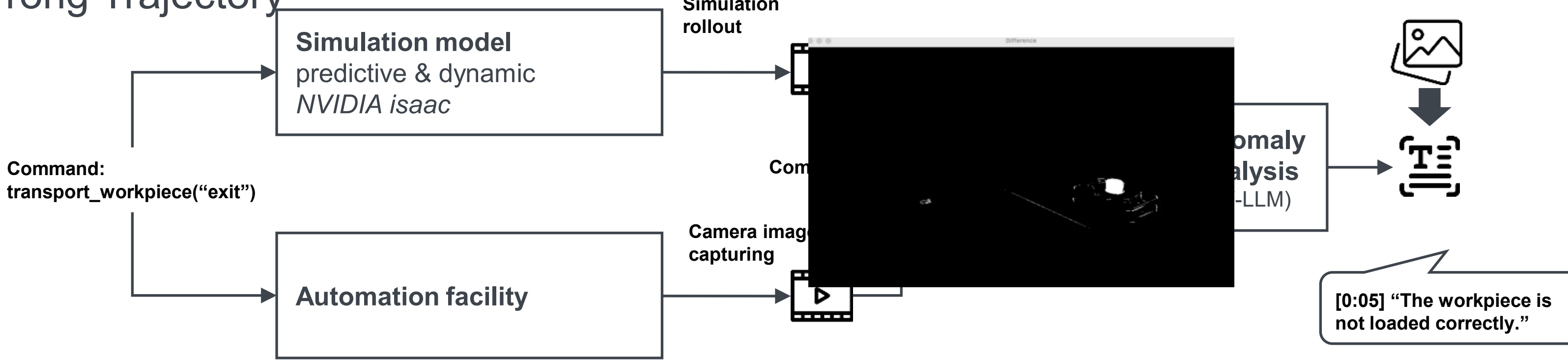


Summary and Outlook

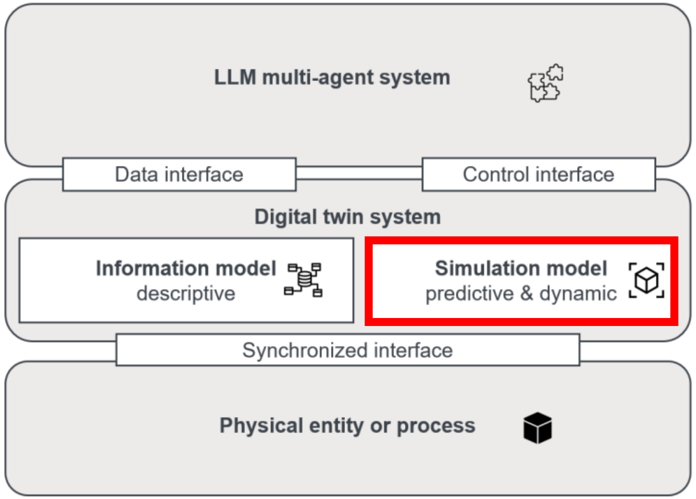
Conclusion

- **Pipeline:** Physical Facility → Digital Twin
- high-fidelity 3D models → highly reliable Simulation & Production Planning
- To predict command execution

```
Python:
    transport(empty_p,C1,C8)
```

Future Research

- Scalability: more complex tasks
- Enable anomaly detection based on Simulation Model
- LLM Integration



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Thank you!

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References

[1] Y. Xia, D. Dittler, N. Jazdi, et al., “LLM experiments with simulation: Large language model multi-agent system for process simulation parametrization in digital twins,” arXiv e-prints, 2024, arXiv:2405.18092.

[2] Taiwan AI Labs & Foundation (Taiwan AI Labs), *Expanding Computer Vision Multi-View Stereo Capabilities: Automatic Generation of 3-dimensional Models via 360 Camera Footage*, Available: https://ailabs.tw/smart-city/expanding-computer-vision-multi-view-stereo-capabilities-automatic-generation-of-3-dimensional-models-via-360-camera-footage/, Accessed on: Apr. 3rd, 2025.

[3] D. Xu, Y. Jiang, P. Wang, Z. Fan, H. Shi, and Z. Wang, “SinNeRF: Training neural radiance fields on complex scenes from a single image,” in *Proceedings of the European Conference on Computer Vision (ECCV)*, 2022, pp. 685-701. doi: 10.1007/978-3-031-20047-2_42.

[4] SIDILAB, *FACTORY I/O 2.0 3D Factory Simulation*, Available: https://www.youtube.com/watch?v=__VO_dEi3Zo/, Accessed on: Apr. 5th, 2025.

[5] X. B. Meng, A. C. Jiang, B. Gao, *et al.*, “Development of virtual TBM construction simulation teaching system based on Unity3D,” in *Expanding Underground—Knowledge and Passion to Make a Positive Impact on the World*, CRC Press, 2023, pp. 2782–2789.

[6] NVIDIA, *BMW Group Starts Global Rollout of NVIDIA Omniverse*, Available: https://blogs.nvidia.com/blog/bmw-group-nvidia-omniverse/, Accessed on: Apr. 5th, 2025.

BACKUP SLIDES AFTER THIS

3D Model Quality Optimization

2. Uneven Surface