TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

FINAL PROJECT

MET0340

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INTRODUCTION

The rapid evolution of digital technologies has significantly reshaped traditional manufacturing, ushering in the era of Industry 4.0 and enabling the widespread adoption of digital manufacturing practices. With the integration of cyber-physical systems, artificial intelligence, virtual and augmented reality (VR/AR), machine vision, and advanced simulation tools, industries today can streamline operations, boost productivity, and achieve levels of efficiency that were previously unimaginable.

The MET0340 Digital Manufacturing course aims to equip students with a well-rounded understanding of these cutting-edge technologies and their practical use in real-world industrial settings. By combining theory with hands-on experience, the course bridges the gap between academic learning and industry expectations. This final project brings together four major assignments, each focusing on a key area of digital manufacturing:

- **Industry 4.0** – Exploring smart factories, interconnected systems, and the changing landscape of industrial automation.

- **VR/AR with Unity 3D** – Investigating immersive technologies and their role in enhancing industrial training and user engagement.

- **Machine Vision** – Applying image processing to automate quality control, detect defects, and support real-time monitoring.

- **Simulation with Visual Components** – Building digital twins and simulation models to optimize workflows and enable predictive planning.

Each of these components plays a vital role in today's fast-paced, technology-driven manufacturing world, where adaptability, precision, and automation are key to staying competitive. In this report, we bring together insights from each assignment to present an overview of how digital manufacturing technologies can drive innovation and efficiency across various sectors.

Beyond the technical aspects, this report also reflects on the challenges faced throughout the learning journey, how we applied our knowledge in practice. As digital transformation continues to evolve, the ability to adapt and keep learning is more important than ever. This final project not only showcases what we've learned but also serves as a starting point for deeper exploration and future innovation in the field of manufacturing.

INDUSTRY 4.0

This report presents the findings from "Industry 4.0" homework. The goal was to investigate how a real-world company applies Industry 4.0 principles. We selected HANZA Mechanics Tartu for this case study, as it is an Estonian manufacturing company that is known for its automation and digital transformation initiative. They offer manufacturing solutions across various sectors including medical technology, sheet metal production and machining services.

For our group's full review, presented down below is the evaluation of different categories of the company, graded in colours (green being the best, yellow as neutral, red as worst):

Technology Innovation

Assessment: Green – The company effectively utilizes advanced technologies such as CNC machining, automated welding, and AI-driven solutions, demonstrating strong innovation in its production processes.

Technology Access and Inclusion

Assessment: Yellow – While the company is integrating AI and Industry 4.0 technologies, there is potential to further improve access and inclusion, especially in digitizing the manual processes in the ERP system.

Disrupting Jobs, Demanding New Skills

Assessment: Yellow – The integration of AI and automation may disrupt traditional job roles, requiring the workforce to acquire new skills. The company should focus on training and upskilling employees to adapt to these changes.

Agency and Trust

Assessment: Yellow – Building trust with employees and stakeholders about the use of AI and automation is crucial. Clear communication and transparency in the implementation of these technologies can enhance trust and agency.

Agile Technology Governance

Assessment: Yellow – The company is actively participating in initiatives like the Open Innovation Academy Hackathon, indicating a willingness to adapt and govern new technologies. However, there is room for improvement in the governance framework to ensure agile and responsive management.

Ethics and Identity

Assessment: Yellow – As AI and automation technologies are integrated, ethical considerations and the impact on employees' identities should be addressed. Ensuring fair practices and ethical use of technology is essential.

Frontier Technologies

Assessment: Green – The company is exploring and implementing frontier technologies such as predictive maintenance, smart MES, and machine vision quality control, showcasing its commitment to staying at the forefront of technological advancements.

This homework was completed as a group. Here is the input of each team member:

- Aleksander Kuusik: Led company research and Industry 4.0 framework evaluation and came up with the idea of doing the assessment on HANZA Mechanics Tartu
- Vaclav Sacha: Analysed automation and digitalisation aspects of the company
- Gamze Uyaroğlu: Compiled the report for the assignment and helped in analysing digitalisation aspects of the company

VR/AR (UNITY 3D TASK)

Overview

The second homework assignment in the Digital Manufacturing course focused on developing a basic Virtual Reality (VR) application using Unity 3D. The goal was to simulate a simple interactive environment and gain hands-on experience with VR development workflows, including 3D object manipulation, user interaction, and navigation using the XR Interaction Toolkit.

Implementation Process

Project Initialization:

- Opened the provided Homework Starter Pack in Unity.
- Added an Interactor component as a child of the Gripper object of the Motoman GP8 robotic arm.

Setting Up Interactable Objects:

- Converted the predefined objects to Tilia Interactable type.
- Configured additional interaction properties such as Grab Type, Primary Action, and Secondary Action.

Connecting the Gripper to Objects:

- Created a GameObject to link the grab action within the robot’s Interactor.
- Integrated a BooleanAction component to control the grab/release functionality.
- Mapped UI buttons for user control of grabbing actions in the simulation.

Testing and Results:

- Ran the simulation in game mode to test the grabbing mechanism.
- Positioned the robotic arm to align its gripper with target objects.
- Successfully verified the grabbing functionality, with the gripper correctly engaging and releasing objects as expected.

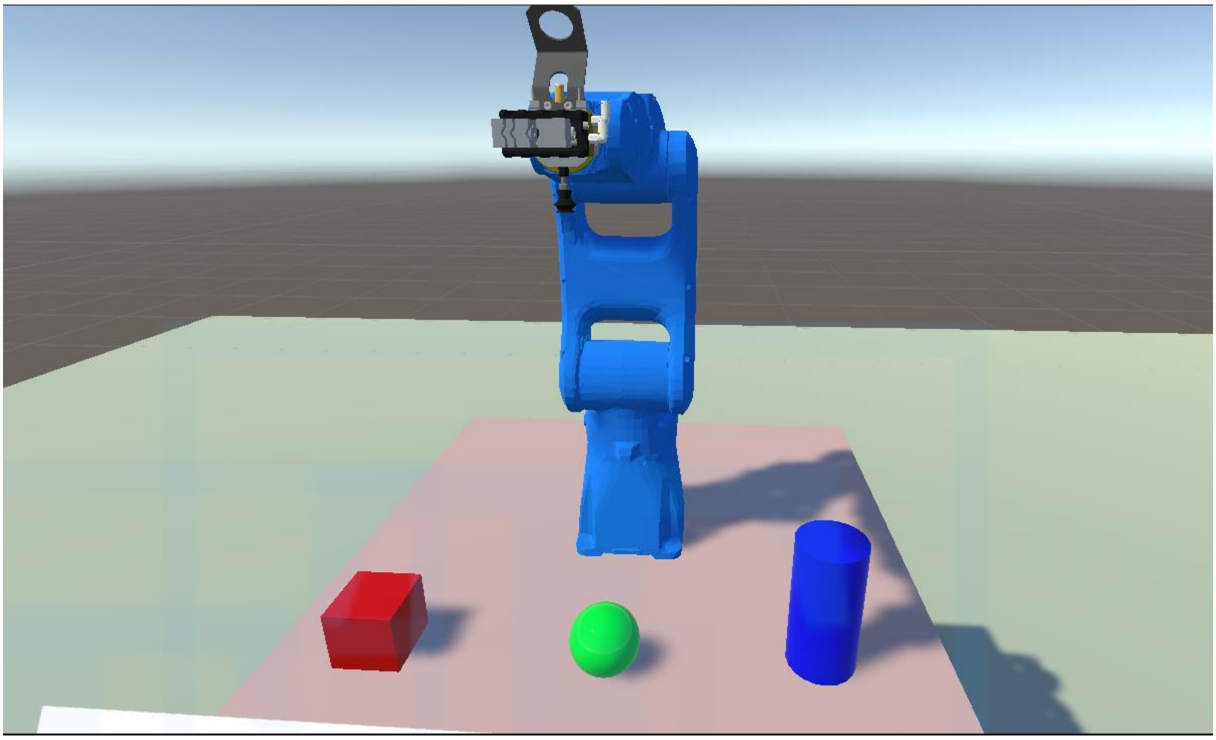

Figure 1: Robotic Arm and Objects

Conclusion

This assignment successfully expanded the functionality of the robotic simulation by integrating a working object-grabbing mechanism. The key challenges included fine-tuning the collider dimensions and accurately mapping the interaction between the gripper and objects. Through iterative testing and adherence to the provided documentation, these obstacles were overcome, resulting in a smooth and functional implementation.

The project not only improved the robotic arm's interactivity but also enhanced our understanding of Unity's physics-based interactions, writing simple C# script, set up an AR environment. Further refinements, such as optimizing the grabbing precision or adding additional object constraints, could further elevate the simulation's realism. Overall, the task was a valuable learning experience, reinforcing fundamental concepts in VR/AR development within Unity.

MACHINE VISION

Overview

In the third homework assignment for the Digital Manufacturing course, our task was to implement an image recognition system using a PC web camera to capture real-world scenes. To complete this assignment, we were provided with a script in Google Colab, which enabled us to train a custom YOLOv4 object detector based on a chosen dataset. Our team was responsible for preparing the data for training and executing the training process using the provided Colab environment.
Google Colab Script

Dataset Selection

The first step was to select an appropriate dataset. Ideally, we wanted a dataset with two clear classes to recognize. Initially, we considered detecting errors on PCB boards. However, we quickly encountered two major issues:

- There were very few freely available datasets on this topic.
- High-quality images were crucial for successful error detection, which we could not reliably obtain using a webcam.

As a result, we shifted our focus to mushroom recognition, specifically classifying mushrooms as either **edible** or **poisonous**. This alternative offered several benefits:

- There were enough datasets and images available online.
- The problem was practical and applicable in various real-world scenarios.
- It was feasible within our timeframe.

Data Preparation

We downloaded a dataset of approximately 3,000 mushroom images from Kaggle. The preparation process included:

1. Defining the two target classes in a text file.
2. Running the provided Python script to label the images accordingly.
3. Selecting a subset of 100 images (50 edible and 50 poisonous mushrooms) for training.

4. Manually annotating the images to indicate the presence of the specified classes.

The Python script converted our annotations into the required text file format, which we then uploaded to Google Drive for access in Colab.

Training and Testing

The final step was to follow the Google Colab workflow:

- Performing file operations and loading the training data.
- Initiating the training process (which finally took approximately 8 hours).
- Re-running the training around 10 times due to occasional runtime errors in the environment.

After two days, the model was successfully trained and ready for testing. We used the provided code to activate the webcam and integrate the trained data for live recognition. For evaluation, we conducted about 10 tests using random images from Google images, which confirmed the functionality of our model.

Team Members and Contributions

- **Václav Šácha** – Trained the AI model using the prepared dataset.
- **Gamze Uyaroğlu** – Collected and pre-processed the dataset.
- **Aleksander Kuusik** – Helped collect and label the dataset and compiled the final report.

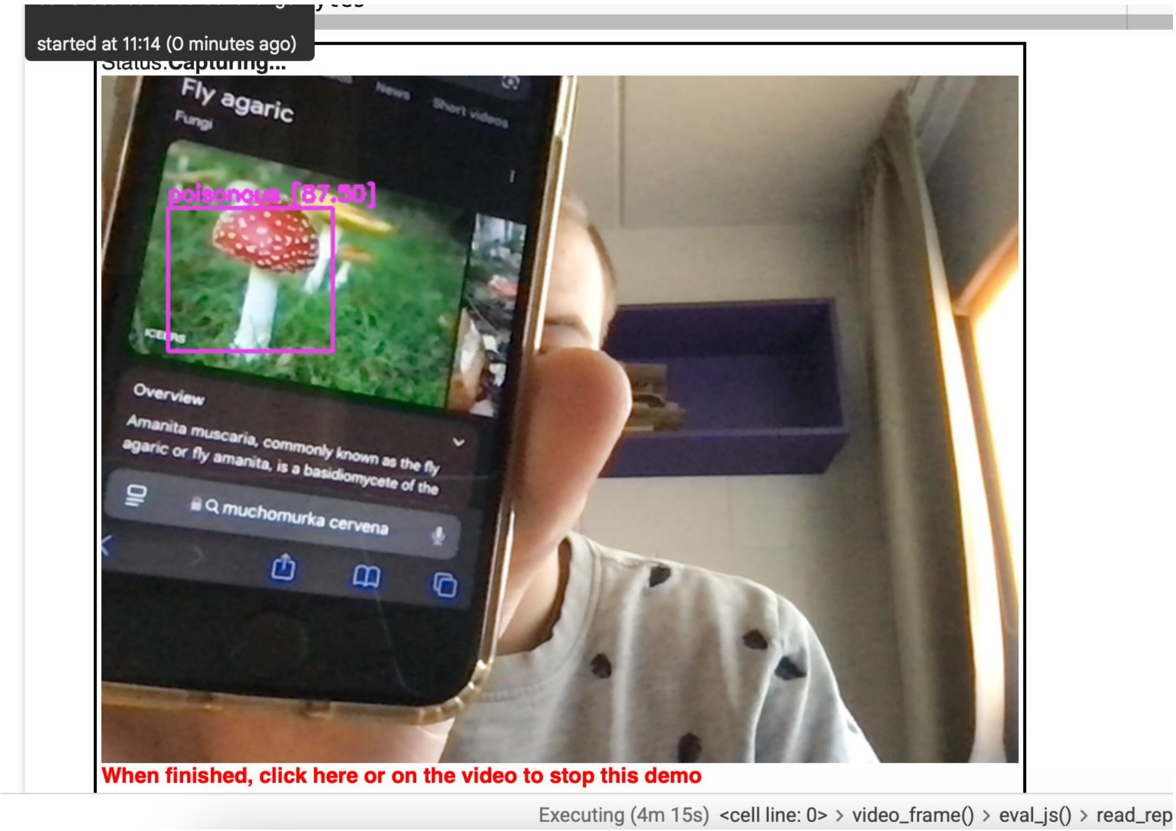

Figure 2: Image recognition on webcam

SIMULATION IN VISUAL COMPONENTS

Overview

In the fourth homework assignment for the Digital Manufacturing course, the task was to implement a production simulation using Visual Components. The goal was to model and analyze a flexible manufacturing system, optimizing workflow efficiency and identifying potential bottlenecks in the system.

To complete this assignment, we used Visual Components' built-in simulation tools to create a digital factory environment, adjusting machine parameters and evaluating different scenarios. This report outlines the steps taken during the simulation, challenges faced, and key findings.

Simulation Steps

We built a digital factory layout using Visual Components, incorporating essential elements such as conveyors, robotic arms, and assembly stations. The modeling process involved:

1. Defining the workspace and placing essential components.
2. Adjusting robot behavior parameters for pick-and-place operations.
3. Integrating conveyors for material transport.
4. Simulating different workflow configurations to evaluate efficiency.

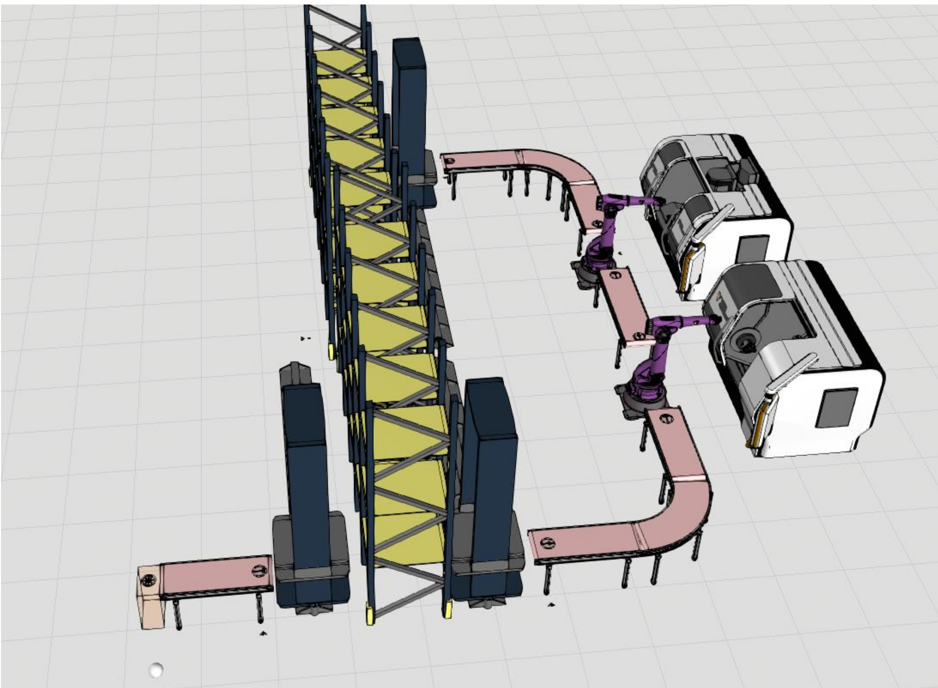

Figure 3: The Layout of the FMS

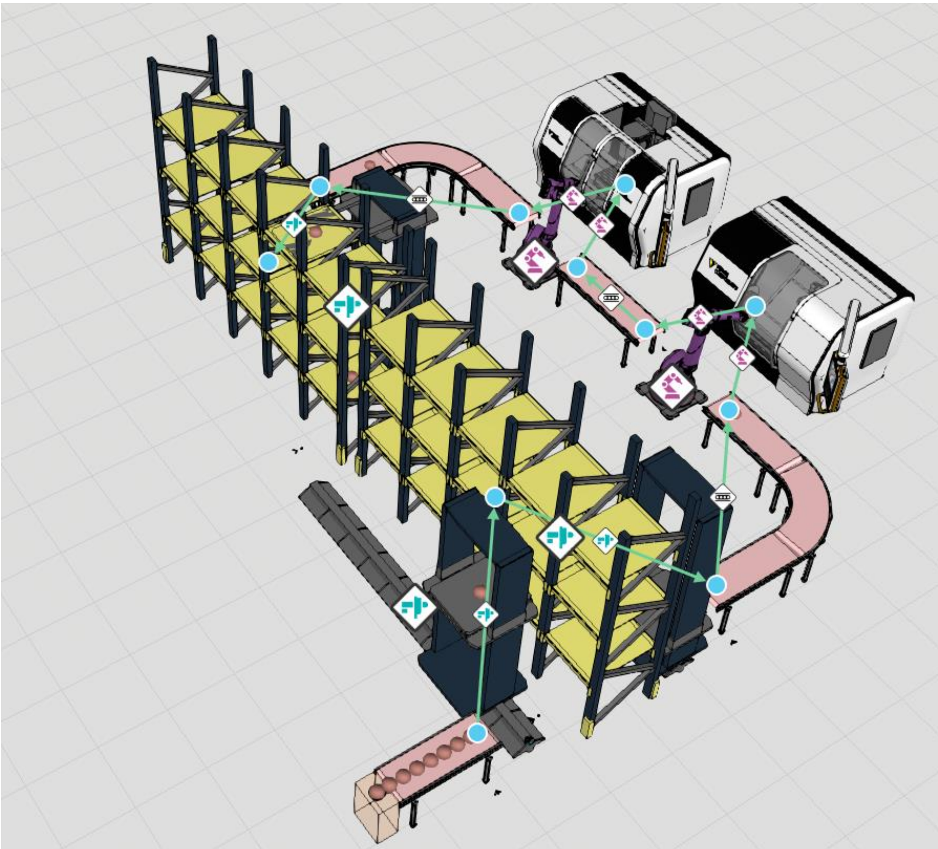

Figure 4: Workflow

Figure 5: Flow Steps

Conclusion

This assignment provided a comprehensive exploration of simulation methodologies within Visual Components, focusing on optimizing industrial workflows through virtual manufacturing environments. The implementation of digital twin-based simulation enabled a systematic evaluation of production parameters, including cycle time optimization, material flow efficiency, and robotic integration.

Key technical takeaways from this study include:

- Process Synchronization – The importance of precise timing between robotic systems and conveyor operations to minimize idle periods.
- Bottleneck Identification – Using cycle time analysis to detect inefficiencies and optimize throughput.
- Data-Driven Adjustments – The iterative refinement of production settings based on simulation feedback to enhance overall efficiency.

The project reinforced the significance of predictive modeling in industrial automation, demonstrating how simulation tools facilitate preemptive process optimization prior to physical implementation. The ability to refine control logic and equipment parameters within a simulated environment contributes to cost-efficient and error-minimizing manufacturing strategies.

By leveraging Visual Components, manufacturers and engineers can effectively design, analyze, and improve production lines while testing multiple configurations in a risk-free virtual environment. These capabilities align with the principles of Industry 4.0, where smart factories rely on digital process validation for enhanced agility and operational robustness.

This study underscores the critical role of simulation-based optimization in modern manufacturing systems, emphasizing the synergy between automation technologies and virtual modeling to drive continuous improvement in industrial workflows.

DISCUSSION

The MET0340 Digital Manufacturing course has provided a comprehensive understanding of Industry 4.0 and its applications in modern manufacturing. Through assignments focused on smart factories, immersive technologies, machine vision, and digital simulations, we have explored how advanced technologies drive efficiency and innovation in industrial settings.

One of the key takeaways from this course was the integration of Industry 4.0 principles into real-world manufacturing environments. The case study on HANZA Mechanics Tartu allowed us to evaluate technological advancements within an operational context, highlighting both strengths and areas for improvement. The use of AI-driven automation, predictive maintenance, and smart MES systems demonstrated the company's commitment to innovation, while challenges related to workforce adaptation and ethical considerations emphasized the complexities of digital transformation.

The VR/AR component provided hands-on experience with Unity 3D, allowing us to visualize and interact with manufacturing processes in an immersive digital space. This assignment underscored the potential of augmented reality in industrial training and operational efficiency. Similarly, the machine vision task involved training an AI model for image recognition, showcasing the practical applications of artificial intelligence in quality control and automated inspection systems. The final simulation project reinforced the importance of digital twin technology for predictive planning and process optimization.

Throughout these assignments, several challenges emerged, including data preprocessing, training AI models effectively, and ensuring accessibility of advanced simulation tools. These obstacles required critical thinking, problem-solving, and teamwork to overcome. In reflecting on this learning journey, it is clear that digital manufacturing requires a multidisciplinary approach—combining technical knowledge with adaptability and collaboration.

To enhance future iterations of the course, several improvements could be considered. Providing more structured guidance on AI model training and dataset selection would help streamline the machine vision assignment. Additionally, incorporating industry expert insights through guest lectures or case studies could offer deeper practical knowledge. Lastly, expanding the hands-on simulation activities would further solidify students' understanding of digital twin applications.

Overall, this course has significantly improved our knowledge of manufacturing digitalization and Industry 4.0, equipping us with essential skills for modern industrial environments. The ability to work with cutting-edge technologies, address real-world challenges, and propose meaningful solutions has strengthened our confidence in applying these concepts professionally.

LIST OF REFERANCES

https://hanza.com/manufacturing-clusters/cluster-baltics/hanza-mechanics-tartu/