# Design of Cyber-Physical Systems in Manufacturing

## Development of a Digital Twin for a Robotic Paper Plane Production Line

Cooperative course between


Faculty of Engineering Technology
Information Driven Product Development

Fachbereich Maschinenbau und Verfahrenstechnik
Fertigungstechnik und Betriebsorganisation

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# 1. Introduction

## 1.1. Objective

### Development of a Digital Twin for a Robotic Paper Plane Production Line

The process of building the digital twin for folding a paper plane involves multiple aspects, from the physical components to their digital simulation and optimization. The digital twin development is a collaborative effort between RPTU, which models and simulates the folding process using MATLAB Simulink Simscape, and the team from Twente University, which designs the gripper mechanism and programs the robotic movements.

The primary entity in this project is paper, considered as the material flow throughout the folding process. The objective is to ensure that the robot effectively manipulates the material, allowing for precise and consistent folds that mimic human actions.

## 1.2. Motivation

The development of a digital twin for folding a paper plane using arm robots is driven by the following motivations:

1. **Reduction of Human Intervention**: The automation of the folding process aims to minimize human involvement, particularly in repetitive or intricate folding tasks that require precise coordination.
2. **Optimization of Material Usage**: Another significant motivation is to reduce the material input needed for the folding process. By optimizing the parameters of the robotic folding system—such as grip force, joint movements, and handling techniques—the goal is to minimize waste and ensure that the paper is folded accurately without unnecessary consumption or damage.

## 1.3. Stakeholders

1. **Rheinland-Pfalz Technical University (RPTU):**
   Assigned to: Jr. Prof Patrick Rüdiger Flore
   RPTU is responsible for the modeling and simulation aspect of the project, utilizing MATLAB Simulink and Simscape to develop an accurate digital representation of the paper plane folding process.
2. **Twente University (UT):**
   Assigned to: Ir. Janneke Massa | Ir. Lucas Pronk
   Twente University is tasked with designing the gripper mechanism and programming the movements of the robotic arm used in the folding process.

# 2. Project Expectations

## 2.1. Overall Goal

The collaboration between RPTU and Twente University aims to seamlessly integrate simulation and hardware design to optimize the paper plane folding process. RPTU will utilize Simscape and Simulink to create a digital twin, while Twente will focus on designing and programming the robotic gripper.

## 2.2. Expected Final Product

- Perform a validation of the functioning of cyber-physical systems in production.
- Create a physical model that can fold paper in different steps, considering paper density.
- Develop a reworking station for handling folding errors and ensuring quality control.
- Integrate a buffer system to manage the flow of paper and prevent process interruptions.

# 3. As-Is Situation

Currently, the paper plane folding process is manual, requiring significant human effort, which often results in inconsistencies and material waste. There is no automated system to ensure accuracy and efficiency in the folding process.

The use of MATLAB Simulink and Simscape aims to create a digital twin that accurately simulates the folding process, allowing for the development and optimization of robotic control strategies before hardware implementation. This simulation capability brings a data-driven approach to identify inefficiencies and design solutions that reduce human intervention and improve material utilization.

# 4. System Requirements

## 4.1. Functional Requirements

- **REQ-1.1.1 (High):** The robot should fold a paper plane in three distinct stages, with each stage corresponding to a predefined folding step.
- **REQ-1.1.2 (High):** The robot must utilize different sensors to detect the presence or absence of objects and avoid collisions / queue length, speed, or operational status.
- **REQ-1.1.3 (High):** Synchronize simulated model data with real-time sensor data for accurate process monitoring.
- **REQ-1.1.4 (Medium):** The robot should detect folding errors and notify the user when errors occur.

## 4.2. Non-Functional Requirements

- **REQ-2.1.1 (Medium):** The robot should complete a single folding task within approximately 60 seconds, ensuring high throughput.
- **REQ-2.1.2 (Medium):** Error Handling: The system should recover gracefully from invalid inputs or unexpected behaviors.
- **REQ-2.1.3 (Medium):** The system should support scalability, enabling seamless integration of additional robots, components, or functionalities without significant redesign or performance degradation.

## 4.3. Quality Attributes

### 4.3.1 Maintainability

- **QA-1.1.1 (High):** The robot should maintain an uptime of at least 98% over a 24-hour period.
- **QA-1.1.2 (High):** The digital twin control code should be structured and well-commented.
- **QA-1.1.3 (Medium):** The robot should issue a warning if it remains idle for longer than a specified duration.
- **QA-1.1.4 (Medium):** The DT should provide feedback on errors, including reasons and solutions.

### 4.3.2 Performance

- **QA-1.2.1 (High):** The robots should complete the folding process in cooperation with one another without human intervention.
- **QA-1.2.2 (Medium):** Meet real-time requirements.

### 4.3.3 Reliability /Resilience

- **QA-1.3.1 (High):** Robots should work together without collisions by ensuring their movement ranges do not overlap.
- **QA-1.3.2 (Medium):** The robot should oversee sensor signal errors by utilizing a queue system to prevent disruptions.

### 4.3.4 Safety

- **QA-1.4.1 (High):** The robot should have a safety shutdown mechanism that activates automatically in the presence of unexpected obstacles to prevent collisions.

## 4.4. Collaboration Requirements

- **REQ-4.1.1 (High):** Integrate detailed gripper models from UT Twente into the DT, ensuring they reflect physical behavior accurately. Collaborate through synchronized testing to validate consistency between the DT and physical prototypes.
- **REQ-4.1.2 (High):** Conduct regular sync meetings to align development timelines, showcase progress, and gather feedback from both teams.
- **REQ-4.1.4 (High):** Use unified platforms for simulation, data sharing, and documentation (e.g., shared repositories like GitHub).
- **REQ-4.1.5 (Medium):** Maintain a collaborative testing approach by synchronizing physical and digital operations, refining both the DT and physical prototypes based on test results.