A Comprehensive Review on Digital Twin Technologies for Human-Robot Collaboration in Industry 4.0

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**Abstract - In this survey paper, we review recent advancements in digital twin technology with a specific focus on human-robot collaboration (HRC) within the context of Industry 4.0. We critically examine four primary papers, shedding light on their methodologies, key contributions, and areas for future research. Our analysis highlights the importance of data modelling, communication, and machine learning techniques to enhance digital twin capabilities for HRC.**

***Keywords -*** **Digital Twin, Human-Robot Collaboration, Industry 4.0, Cyber-Physical Systems, Data Modelling, Machine Learning.**

## Introduction

The fourth industrial revolution, commonly referred to as "Industry 4. ," revolves around the utilization of advanced smart technologies in manufacturing settings. It signifies the onset of a transformative period in the industrial sector characterized by the integration of intelligent systems and state-of-the-art computer capabilities to enhance production and manufacturing procedures. Key drivers of this revolution include cyber-physical systems, digital twins, and human-robot collaboration (HRC).

Here, ‘human-robot collaboration’ (HRC) means an environment in which people and robots live together amicably or even work together). The objective of HRC is to join forces with the cognitive abilities of humans — e.g., problem-solving and decision-making skills — and leverage the strengths, precision, and speed of robots. The necessity to monitor and analyze data has become even more important, especially with the current manufacturing landscape where efficiency, flexibility and longevity of production systems depend on how effective you can keep your production monitored and analyzed.

The interaction between the physical and virtual worlds is facilitated by digital twins acting as the bridge in this cooperative environment. A digital twin is a virtual and live representation of a physical system/object using real-time as well as additional data sources and allows for learning (predicting), acting (representing) and adaptive resynchronisation for more informed decisions. To make Industrial Processes super Productive and Innovative, one needs this capability of Advanced Analytics & Control on this Digital Twin; which accurately reflects its Physical Counterpart near-real time.

With the addition of advanced technology such as digital twins and human-robot collaboration, Industry 4.0 brings forth agile, flexible, and efficient manufacturing methods to our doorstep. These facilitate the building of a resilient and scalable setup where producers can respond to the challenges and market demands that continuously evolve in nature.

Purpose / Objective — The paper’s objective is to survey and provide a critical review of the state of the art and applications of the advanced digital twin technology and to present its role in the collaborations between humans and robots in the Industry 4.0 context. This article sheds some light on the approach, advancements and further scope of work related to technology of digital twins in HRC (Human Robot Cooperation) emphasizing its implications & importance in the development of industry processes. This is achieved by examining key theories and studies of the subject.

## Background

2.1 Digital Twin Concepts

The definition of a digital twin is an exact replica of a physical entity, existing in the digital world and closely reflecting every aspect of its physical counterpart. It is an integration of the physical and virtual to enable live data analytics and surveillance. It has been making headway, mostly in large scale industry, from aerospace, automotive to energy industries, where digitalization helps optimize processes, reducing cost and improving performance.

2.2 Human-Robot Collaboration(HRC)

HRC refers to the cooperation between human beings and robotics in an integrated work space environment. In today’s production systems, this interaction model plays a key role, bringing together human abilities (creativity for example) and robotic precision and speed.

## Literature Survey

[1] Digital Twin Data Modeling with AutomationML and a Communication Methodology for Data Exchange

**Main Focus:** In this article, we explore a new approach to digital twin data modelling using AutomationML (AML) aimed at improving interoperability and reducing complexity in HRC Systems.

**Methodology:**

* **Data Modeling:** Formation of an accurate AML-based model representing the digital twin.
* **Data Mapping:** Connecting the AML data model to real data sources such as sensors and control system.
* **Data Exchange:** Standardization of the communication protocol to ensure easy data transferral.
* **Data Processing:** Analytics and processing of the data exchange to derive meaningful insights for HRC’s decision making.

**Conclusion:** Research shows that AML-based data modelling could be used to optimize digital twins’ capabilities within HRC systems allowing for seamless data integration, making up for the complexity of systems.

[2] The Digital Twin: Realizing the Cyber-Physical Production System (CPPS) for Industry 4.0.

**Main Focus:** This paper demonstrates the importance of digital twin in the CPPS which is part of the industry 4.0 with regard to real time monitoring, control and optimization.

**Proposed Architecture:**

* **Physical Layer:** That includes real production machines as well as their sensors and actuators.
* **Cyber Layer:** Keeping digital twin models of physical instances and their interconnections in a central location.
* **Cognitive Layer:** It uses advanced AI techniques to perform data analysis, make decisions and exercise control.

**Conclusion:** This top-down architecture as described in the paper highlights the critical role of digital twins as enabler for improving production system efficiency by facilitating real-time integration, monitoring and control.

[3]