DIGITAL TWIN TECHNOLOGIES FOR SMART MANUFACTURING

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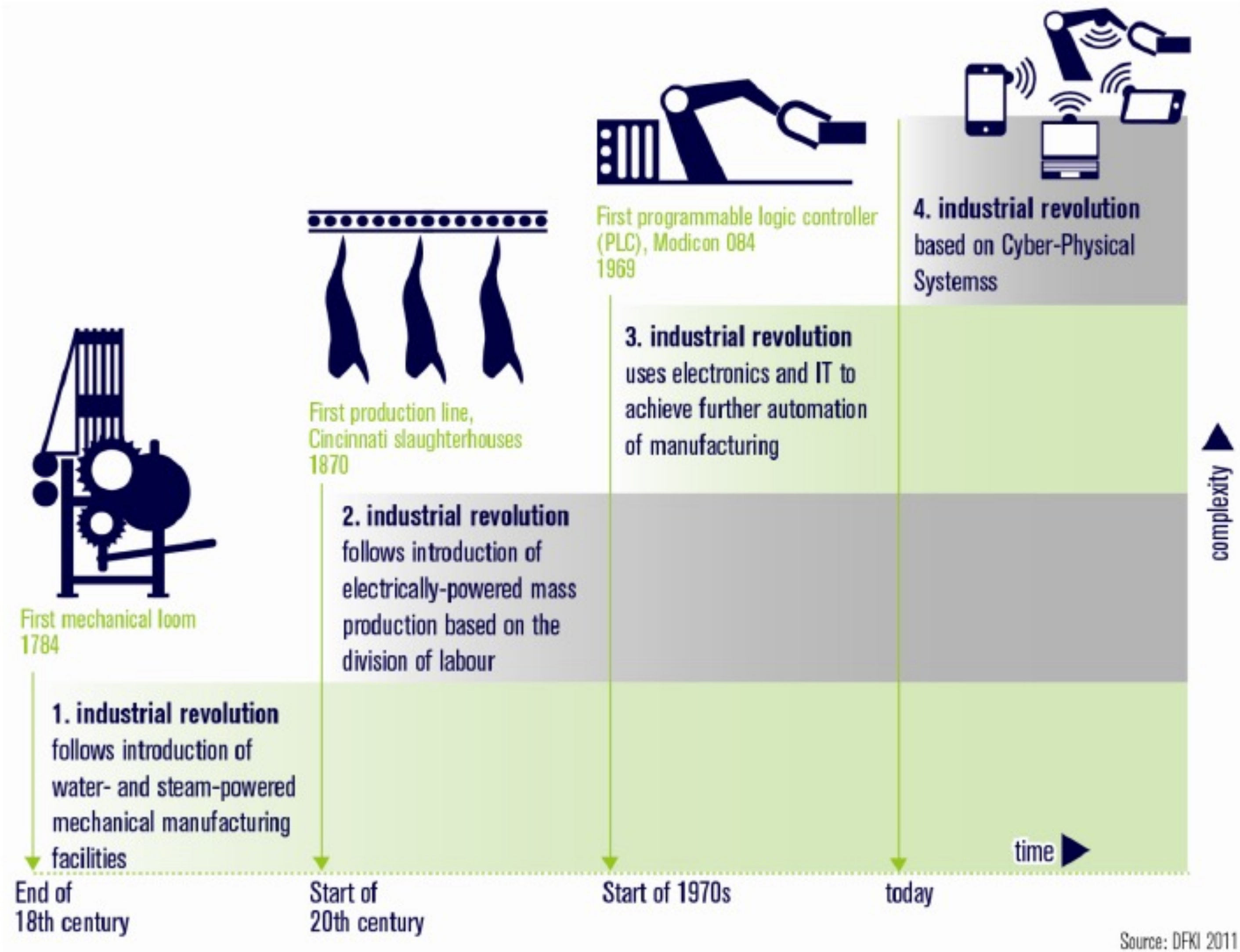
Agenda

- Industrie 4.0 and smart manufacturing (CPPS)
- Digital Twin defined
  - Definitions/Applications/Models/Twinning methods
- International standard for DT framework
- Demonstrative cases

From Industrie 1.0 to Industrie 4.0 - the German vision



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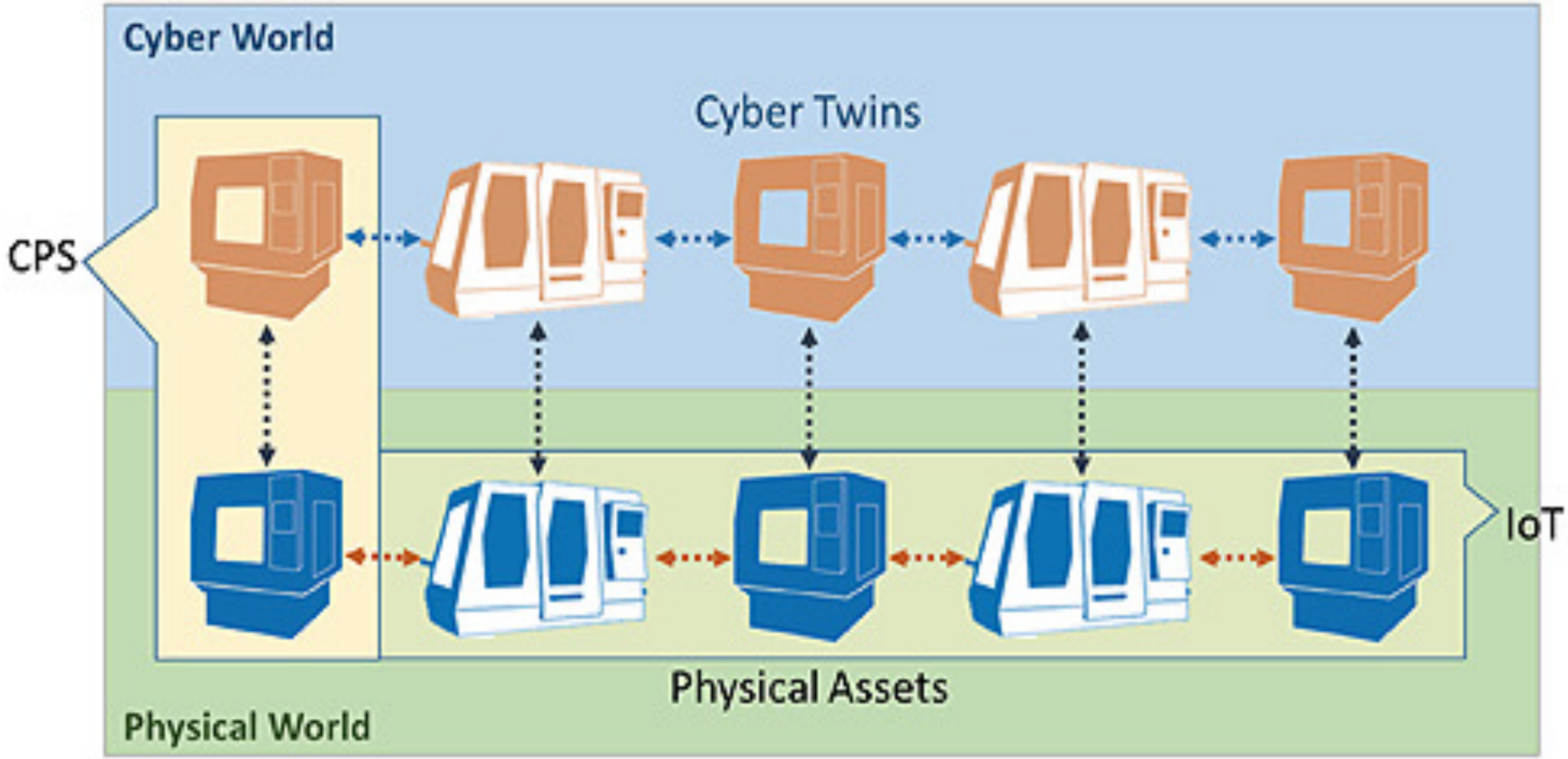
Cyber Physical System (CPS) in support of smart manufacturing

- Marry the *virtual digital (cyber-twin/digital twin)* world with the *real physical* world
- Total connectedness with intelligence
- Semantic machine-to-machine (M2M) communication
  - closed embedded systems
  - self-monitoring, self-healing, proactive communications with other machines and/or operators
- Cyber-physical production systems (CPPS)

Cyber Physical System vs. Internet of Things (IoT)



September 23, 2015, Design World

Digitalization levels and Integration intensity

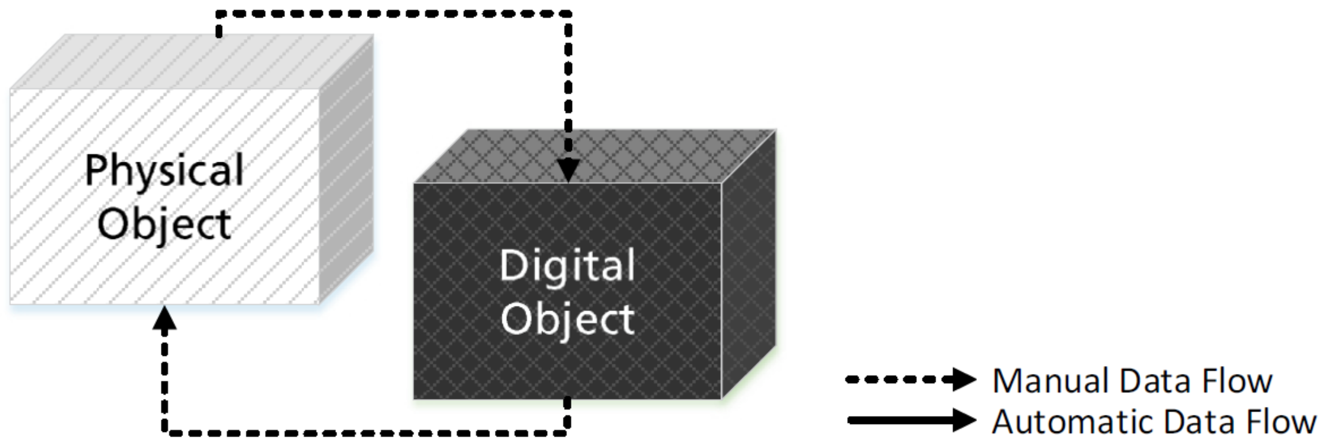
Depending on the level of data integration between the physical and digital counterpart, we can have

- Digital Model
- Digital Shadow
- Digital Twin

They exist for different reasons and applications

Digital Model of a physical object

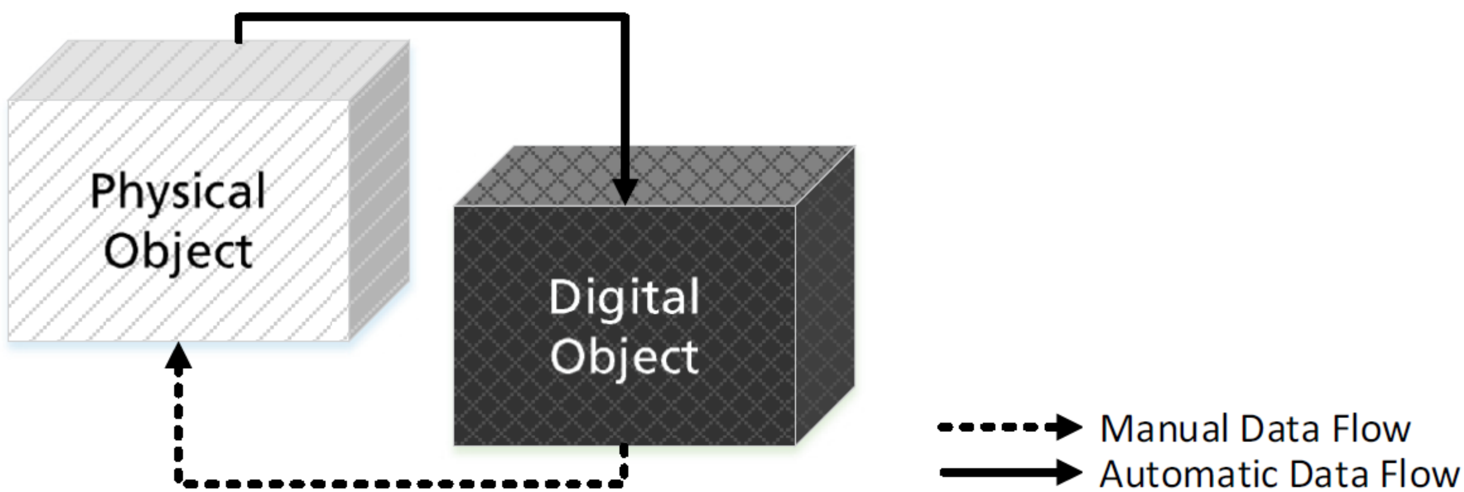
Digital Model is a digital representation of an existing or planned physical object that does not use any form of automated data exchange between the physical object and its digital counterpart.



Kritzinger, W, et al. "Digital Twin in manufacturing: A categorical literature review and classification", IFAC Papers On Line 51-11 (2018) 1016–1022

Digital Shadow of a physical object

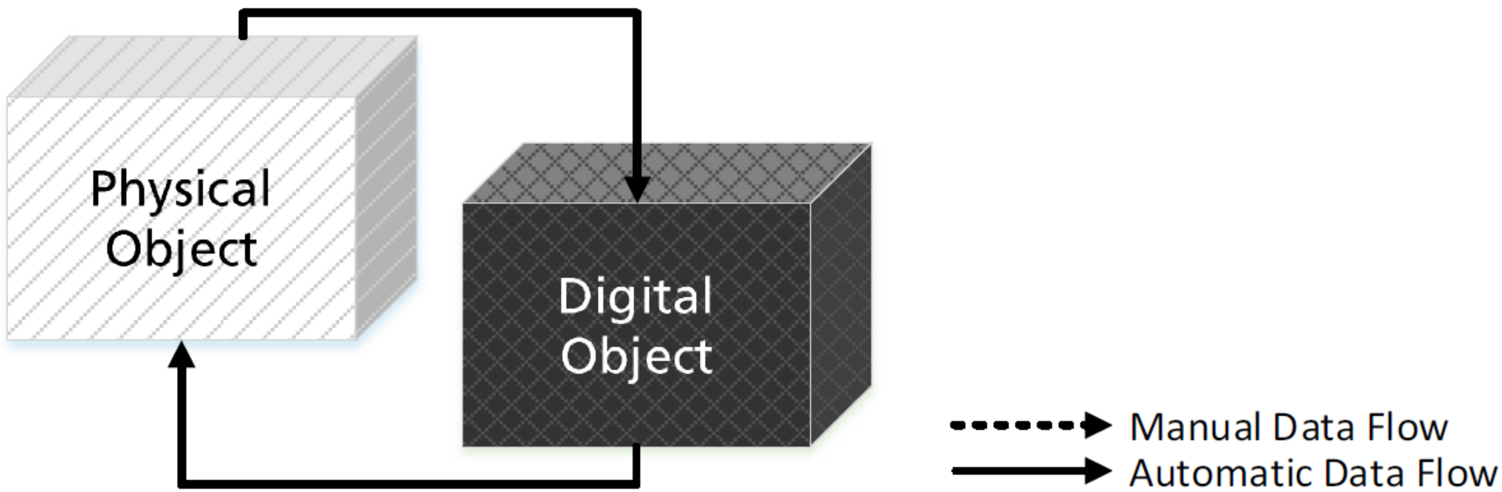
There is an automated one-way data flow between the state of an existing physical object and its digital counterpart.



Kritzinger, W, et al. "Digital Twin in manufacturing: A categorical literature review and classification", IFAC Papers On Line 51-11 (2018) 1016–1022

Digital Twin of a physical object

- The data flows between an existing physical object and its digital counterpart are fully integrated in both directions.
- A change in the state of the physical object directly leads to a change in the state of its digital counterpart and vice versa.



Kritzinger, W, et al. "Digital Twin in manufacturing: A categorical literature review and classification", IFAC Papers On Line 51-11 (2018) 1016–1022

Define Digital Twins:-

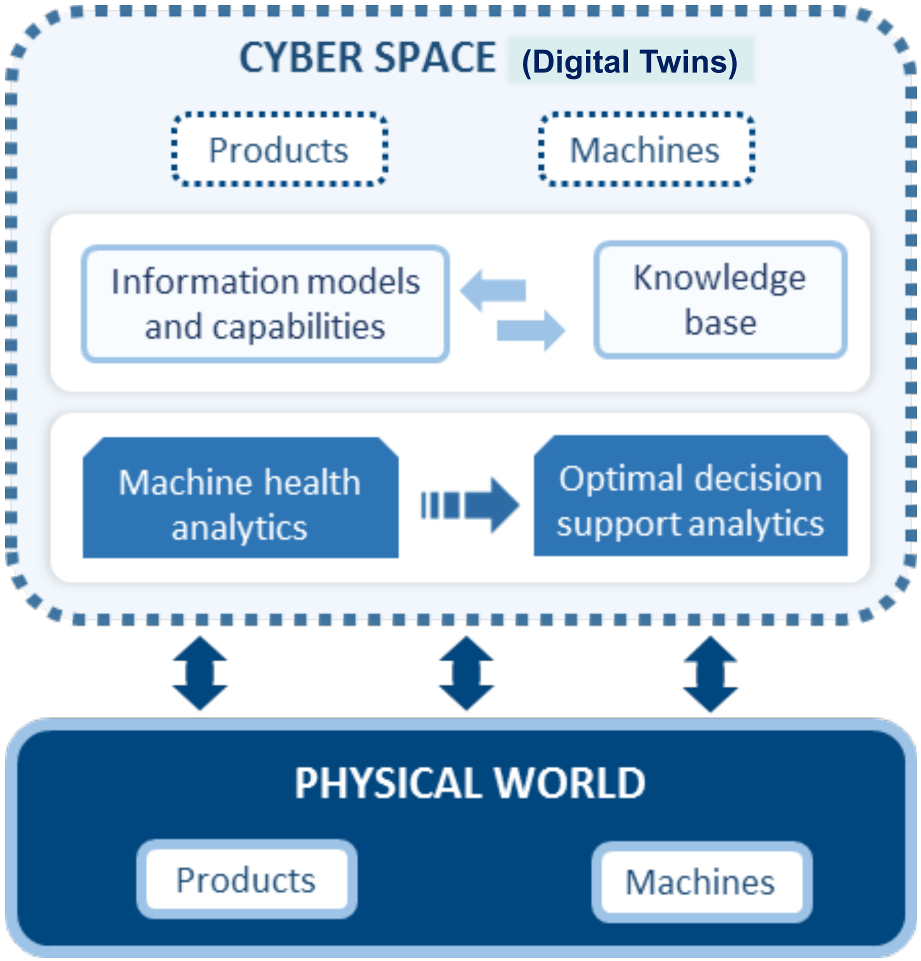
"An integrated multi-physics, multi-scale, probabilistic *simulation* of an as-built system, enabled by *Digital Thread*, that uses the best available models, sensor information, and input data to *mirror* and *predict* activities/performance over the life of its corresponding physical twin."

E.M. Kraft, The US Air Force Digital Thread / Digital Twin – Life Cycle Integration and Use of Computational and Experimental Knowledge II . The Evolution of Integrated Computational / Experimental Fluid Dynamics, in: 54th AIAA Aerosp. Sci. Meet., 2016: pp. 1–22

Examples of Digital Twin

- Digital Twin for Smart Manufacturing
- Digital Twin of Products
- Digital Twin of Manufacturing Assets
- Digital Twin of People
- Digital Twin of Networks

The Role of Digital Twins in a Cyber-physical System

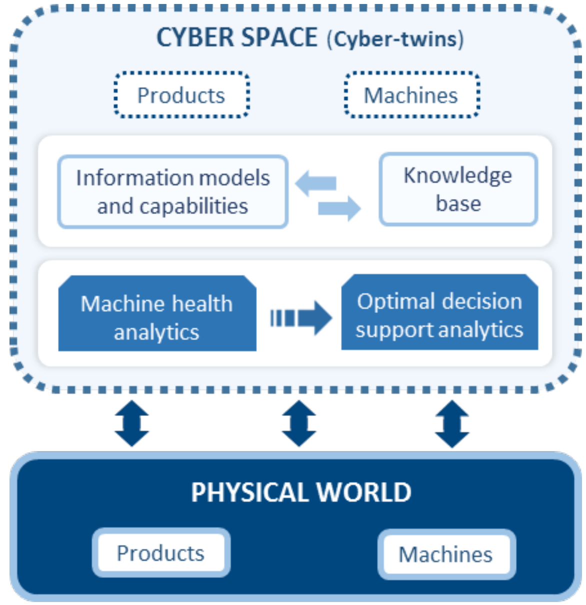


Development of a Digital Twin

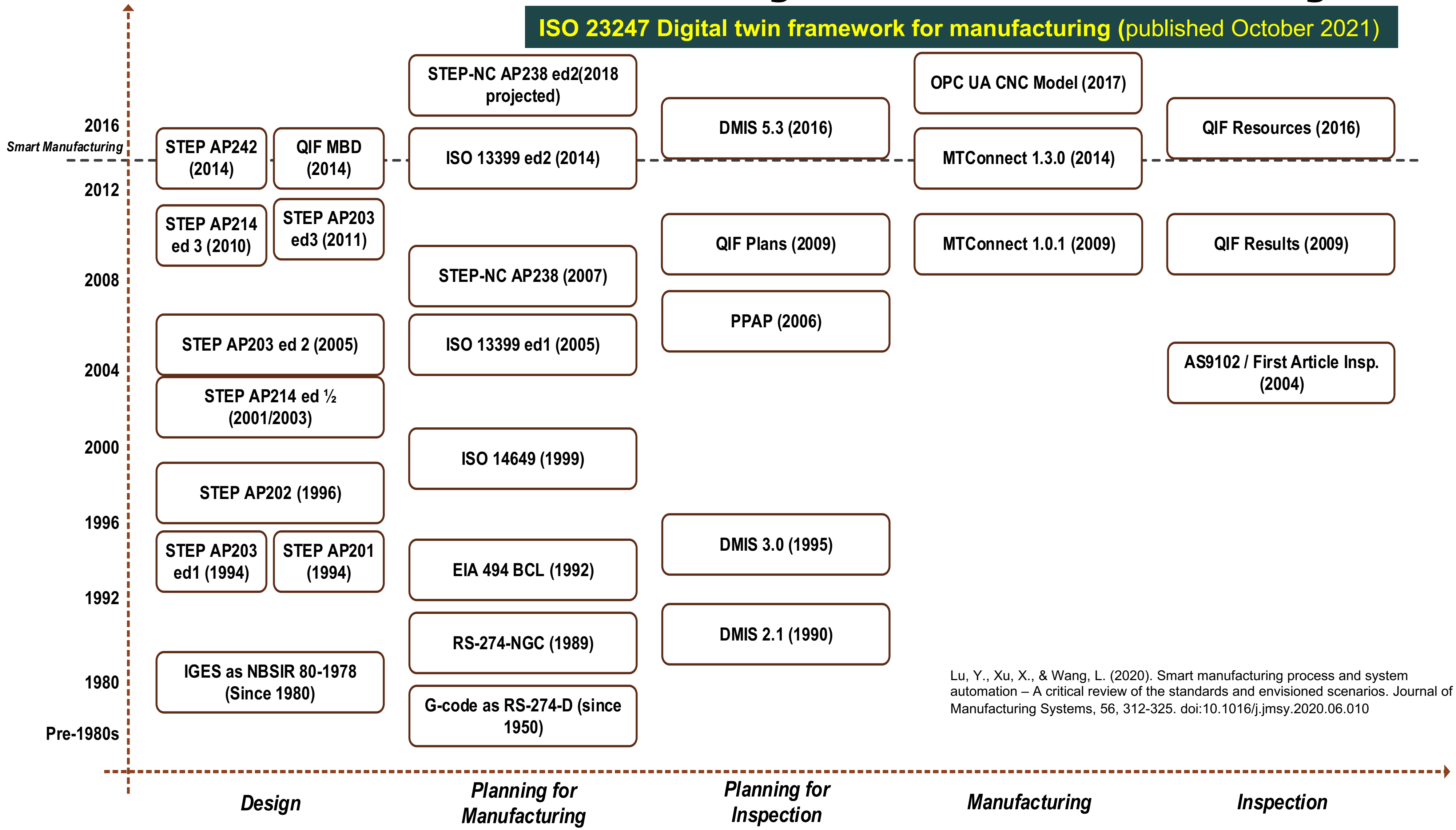
- Building a high-fidelity digital mirror to describe the equipment
- Establishing the interaction between the equipment and its digital mirror
- Consolidating/converging the data from the physical space and virtual space to generate information in support of various applications

Digital Twinning Mechanisms

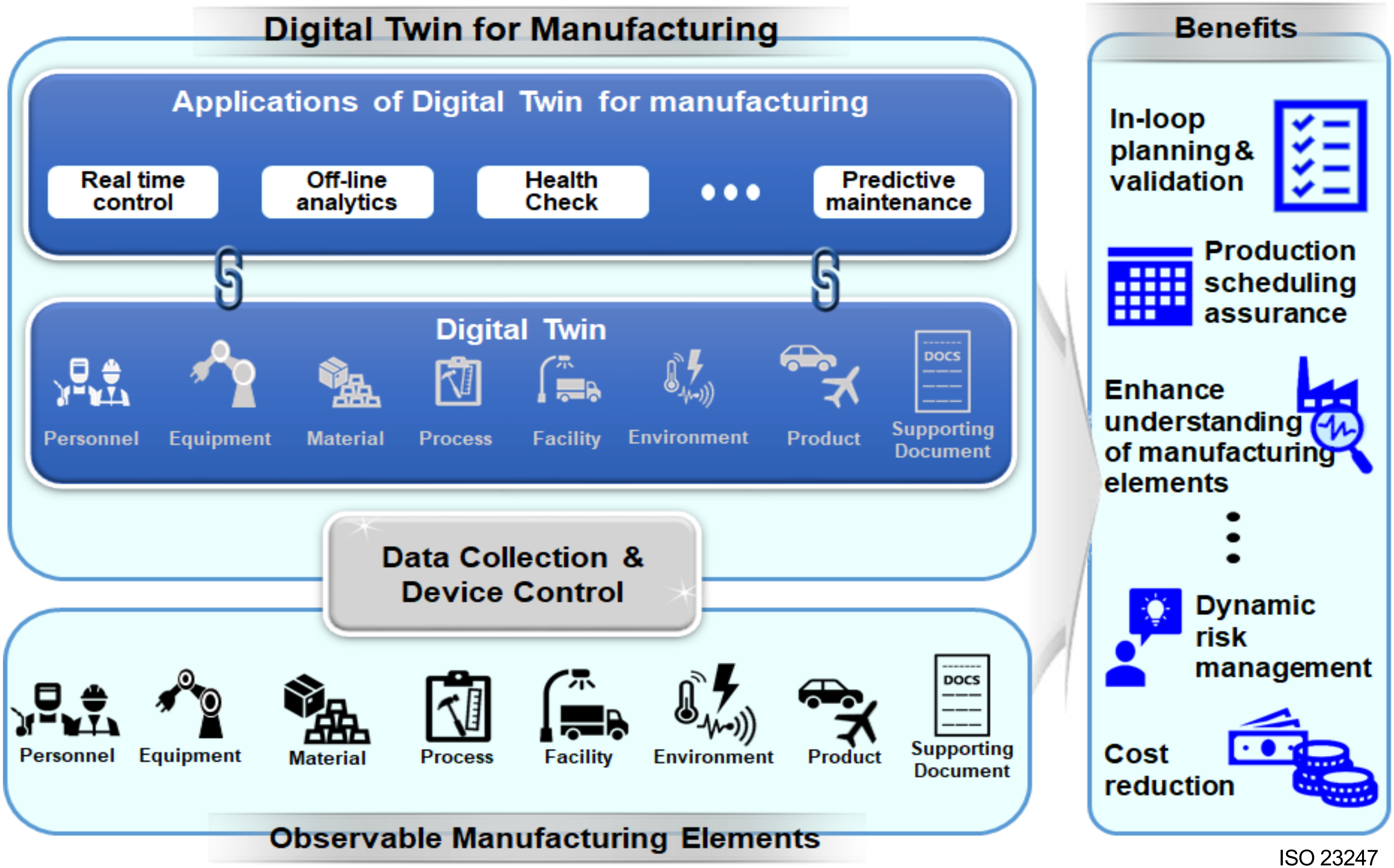
- Fieldbus networks
  - ControlNet
  - DeviceNet
  - Modbus-RTU or ASCII
  - Profibus / Foundation Field Bus
  - PROFINET
  - Modbus-TCP/IP
- Ethernet-based industrial networks
  - EtherNet/IP
  - EtherCAT
  - Time Sensitive Networks (TSN) (Ethernet IEEE 802.1)
  - Highway Addressable Remote Transducer (HART)
- Industrial wireless networks
  - Wireless Sensor Networks (WSN)
  - WiFi-based (IEEE 802.11
  - Bluetooth-based (IEEE802.15.1)
  - Zigbee-based (IEEE 802.15.4)
- Other technologies
  - MQTT, OPC UA, MTConnect



International Standards for Digital Twins in Manufacturing



Lu, Y., Xu, X., & Wang, L. (2020). Smart manufacturing process and system automation – A critical review of the standards and envisioned scenarios. Journal of Manufacturing Systems, 56, 312-325. doi:10.1016/j.jmsy.2020.06.010



Digital Twin for Manufacturing
Applications of Digital Twin for manufacturing
Real time control
Off-line analytics
Health Check
• • •
Predictive maintenance
Digital Twin
DOCS
Personnel
Equipment
Material
Process
Facility
Environment
Product
Supporting Document
Data Collection & Device Control
DOCS
Personnel
Equipment
Material
Process
Facility
Environment
Product
Supporting Document
Observable Manufacturing Elements
Benefits
In-loop planning & validation
Production scheduling assurance
Enhance understanding of manufacturing elements
Dynamic risk management
Cost reduction

ISO 23247

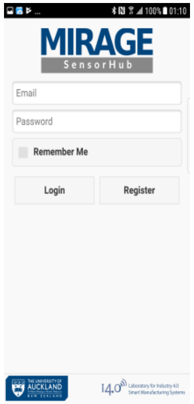
Demonstrative Cases of Digital Twins at Laboratory for Industry 4.0 Smart Manufacturing Systems (LISMS)

- Digital twin of a custom product (bicycle)
- Digital twin of machine tool - Cyber Physical Machine Tool
- Retrofitting a legacy Kuka robot for its digital twin

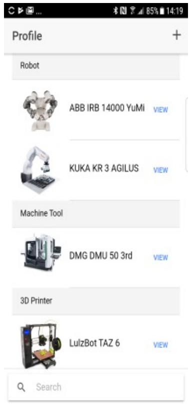
MIRAGE Modular Industrial Realtime Augmented Graphic Engine

MIRAGE Sync

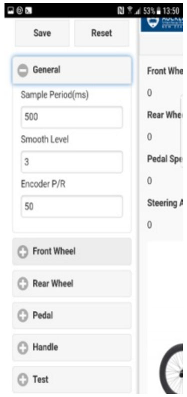
A cross-platform mobile APP that is capable of managing multiple products.



User Management



Product Profiles



Sensor Configuration

MIRAGE Hub

A configurable sensing module that gathers all the sensor data from product.

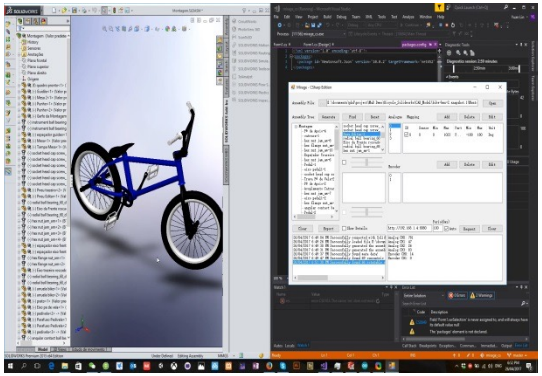
MIRAGE helps users monitor the running status of each equipment,. Digital twins are managed locally by the manufacturer using MIRAGE Station, and the configurations of particular facilities are kept by user with MIRAGE Sync. Representing each node in the Internet of Things (IoT), the sensing module MIRAGE Hub can be easily adapted for specific instruments.

MIRAGE Cloud

MIRAGE Cloud is the centre of the system, which keeps all the profiles of a product. It facilitates the synchronization between the physical product and its corresponding digital-twin.

MIRAGE Station

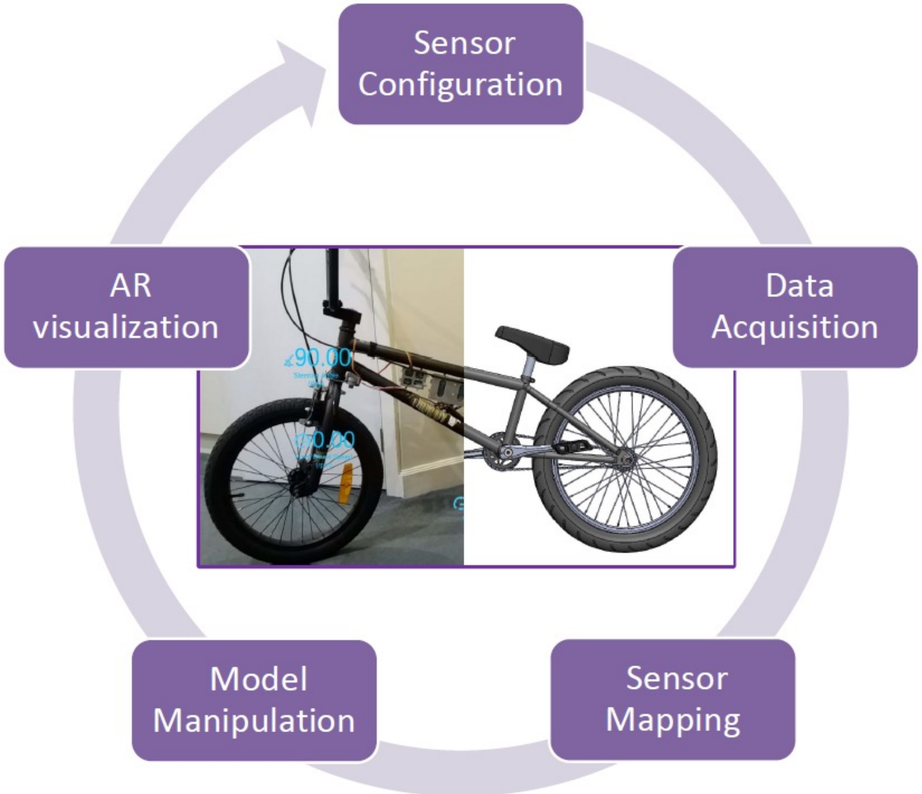
MIRAGE Station is connected to the digital-twin of a product. Once synchronized with physical product, the digital-twin reflects the running status of the product.

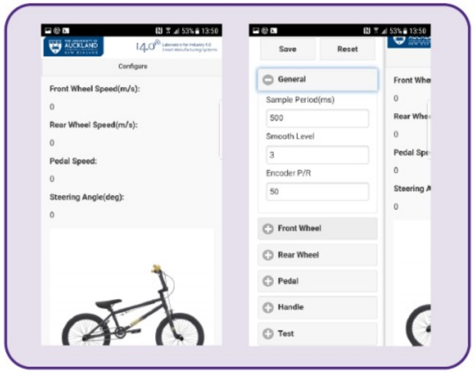


Model Analysis and Synchronization

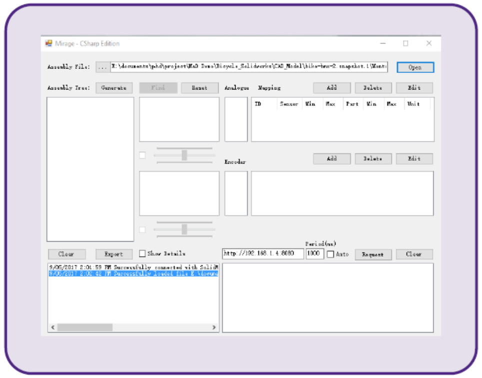
AR Visualization

Digital Twinning of a Bicycle





HMI



Physical and virtual components coupling

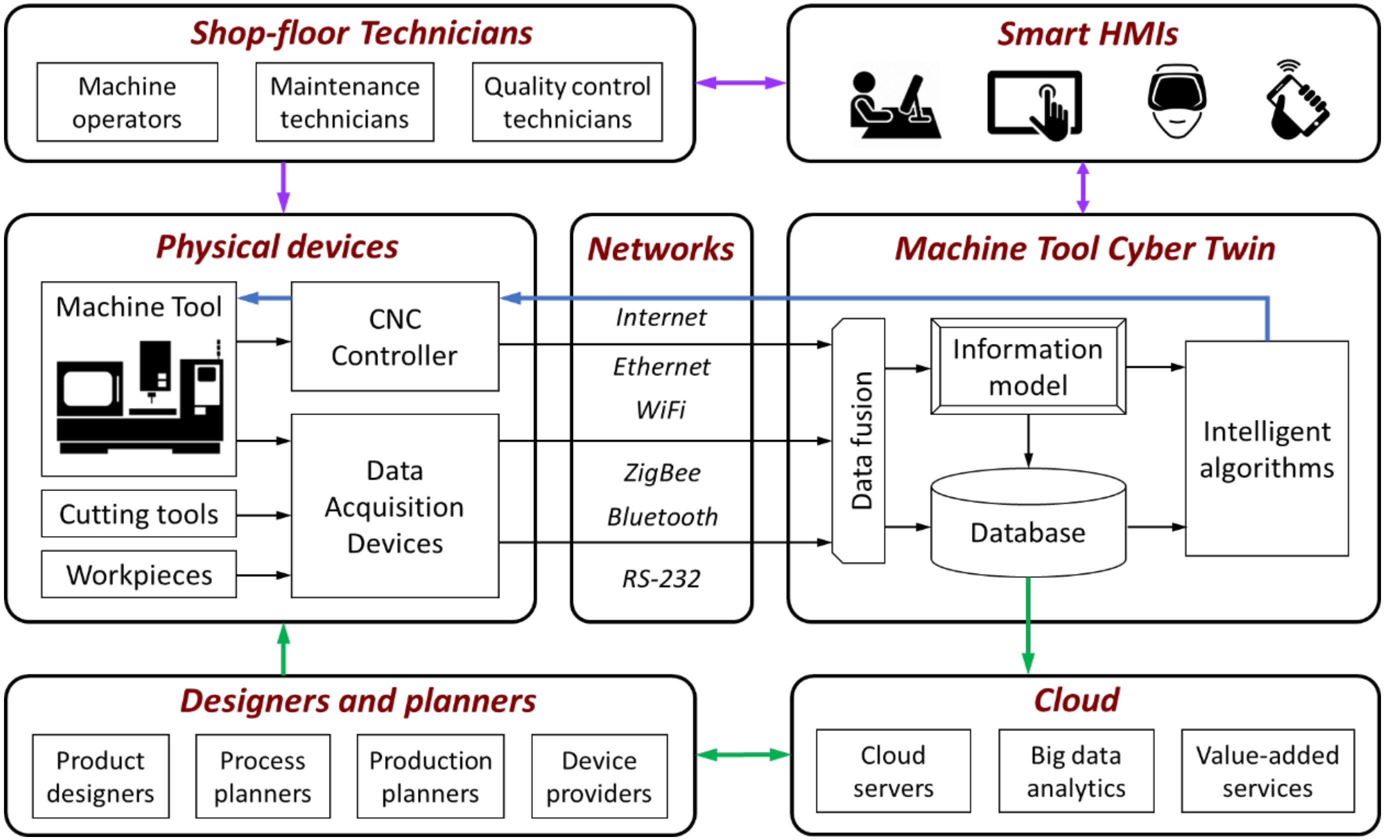
AR applications

Cyber-Physical Machine Tool (CPMT)

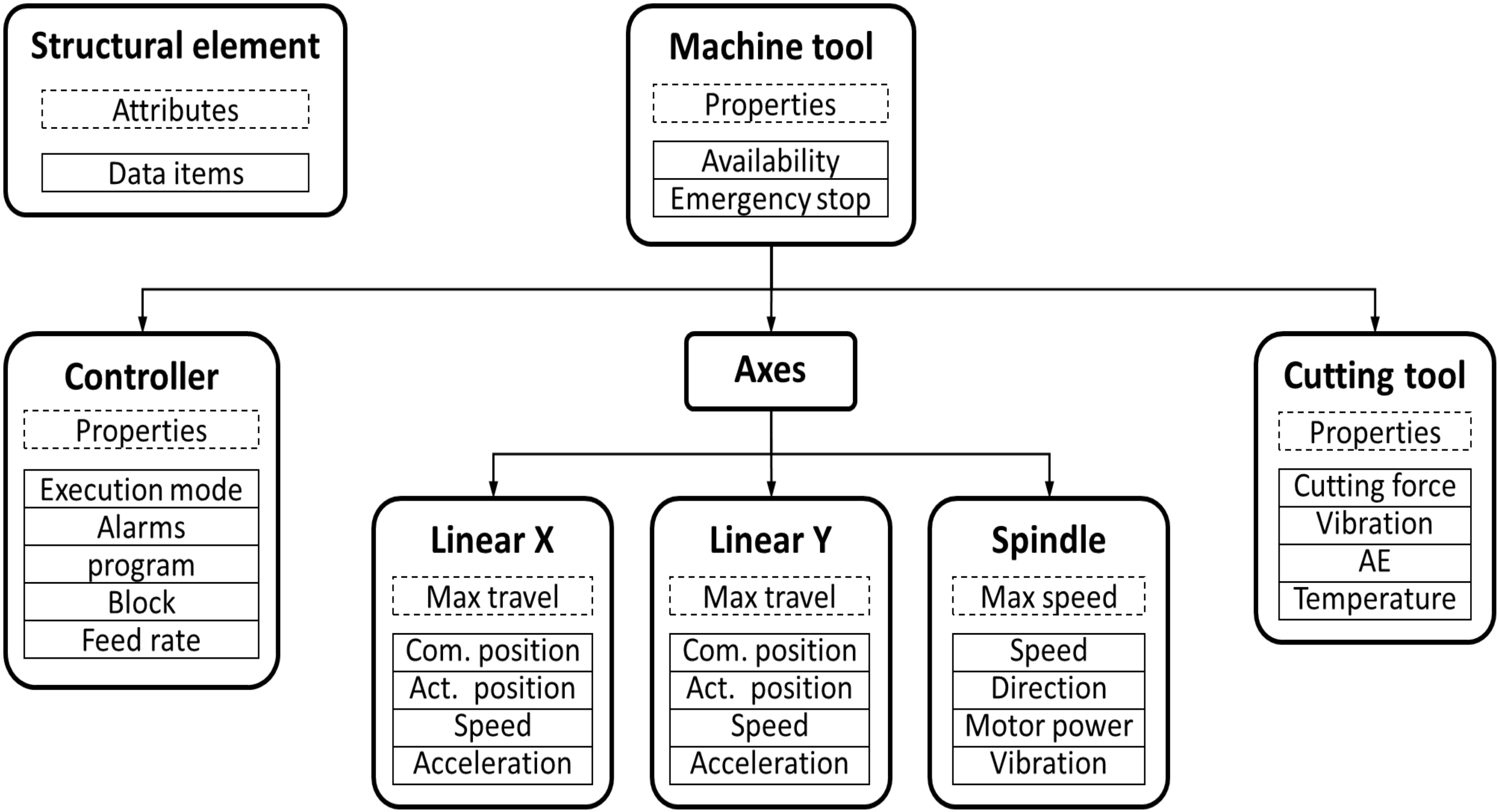
- Deep integration of machine tool, machining processes, computation and networking
- Monitoring, embedded computations and control of the machining processes, with feedback loops in which machining processes can affect computations and vice versa

Features

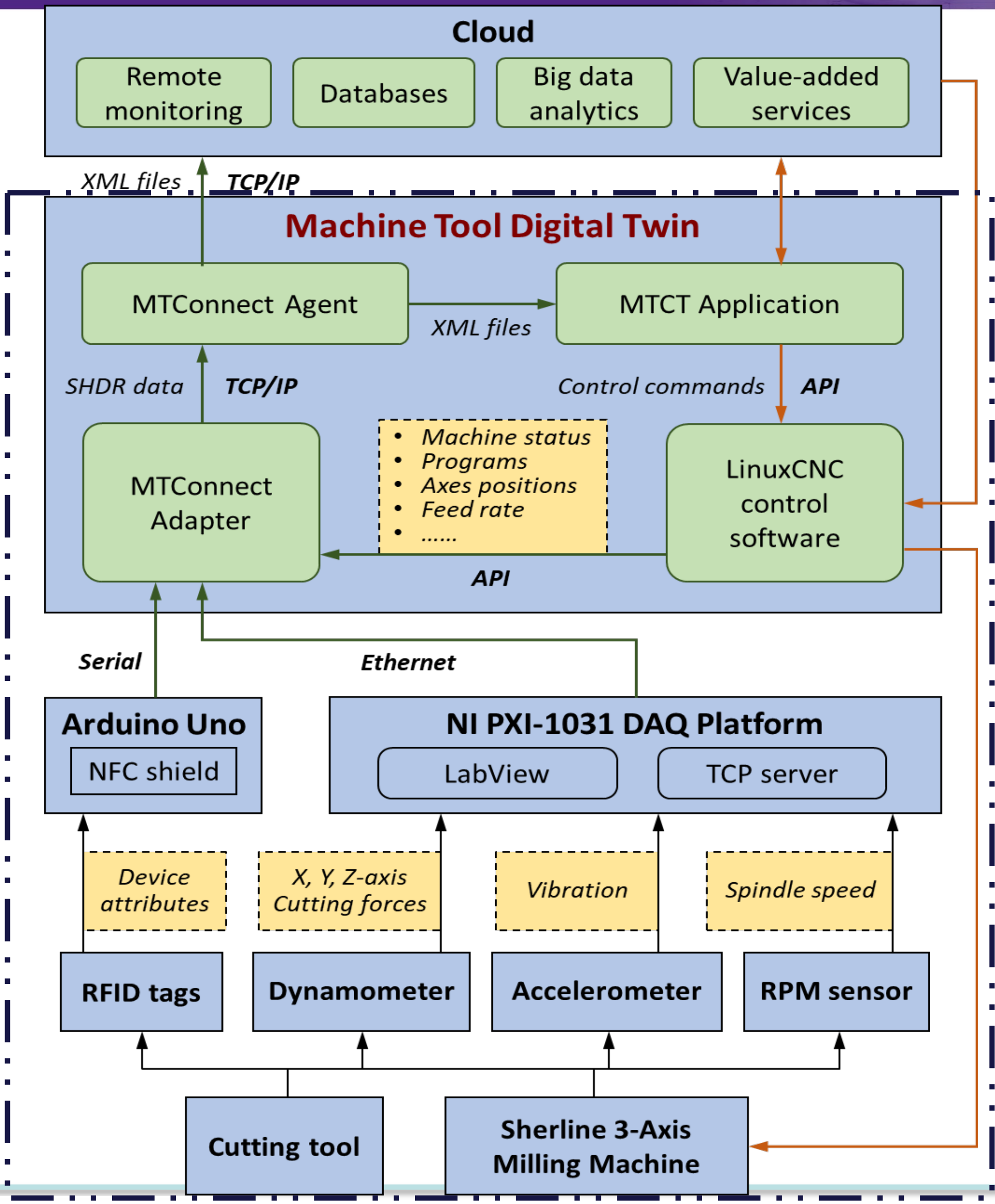
- CPS-based machining system
- Digital Twin technology
- IoT-enabled real-time data acquisition
- Advanced human-machine interactions
- Cloud-based solutions



MTConnect-based Information Model of a Lathe

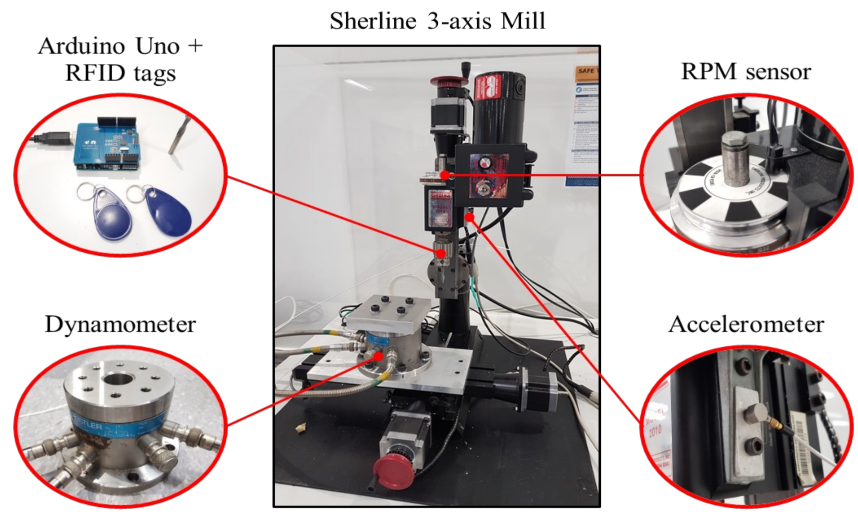


MTConnect-based CPMT Prototype

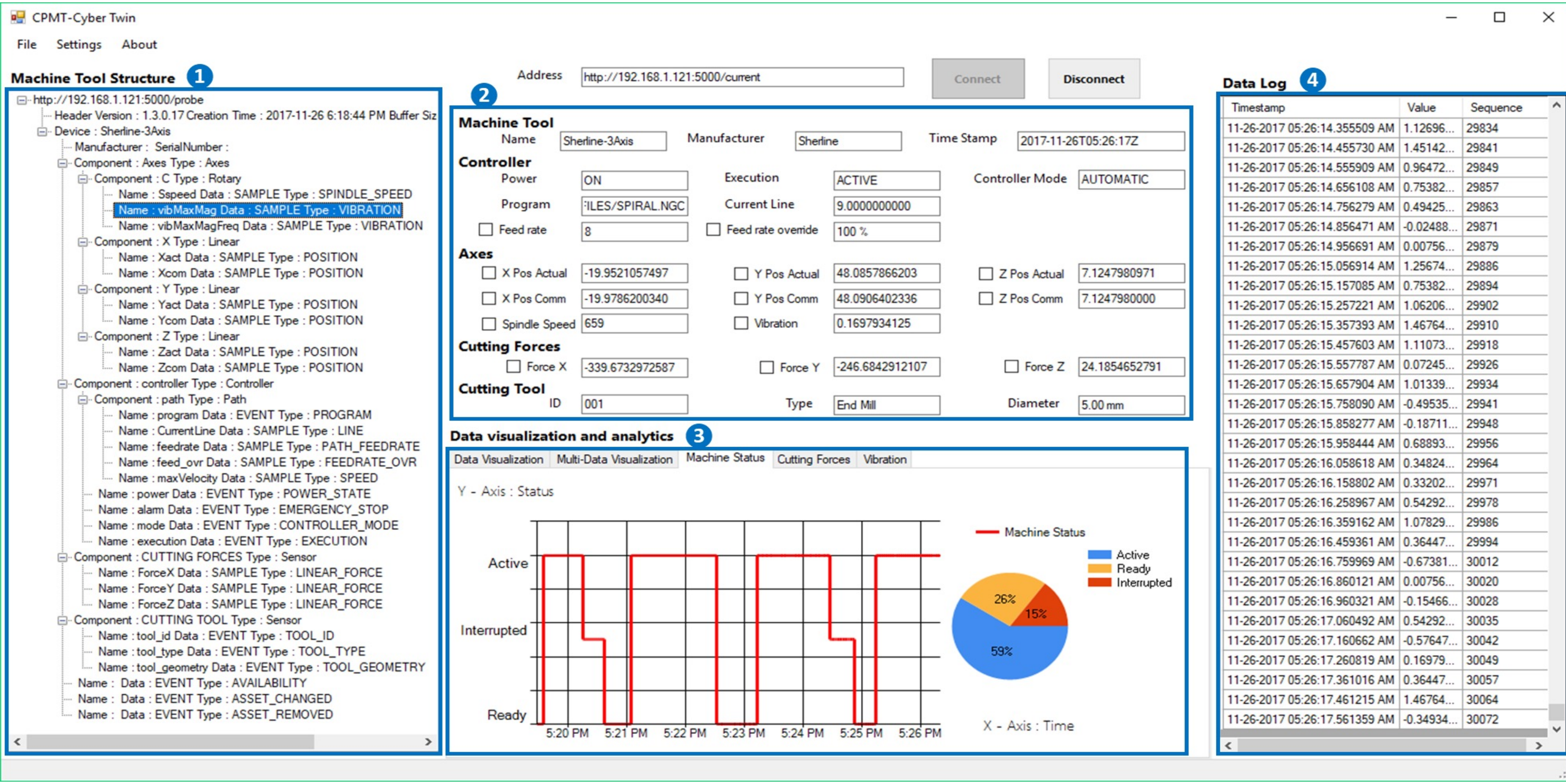


CPMT Digital Twin:

- Represents the capability, structure and real-time status of the machine tool
- Provide field-level data to HMIs and cloud-based services
- Monitors and controls the machine tool with built-in data analytics

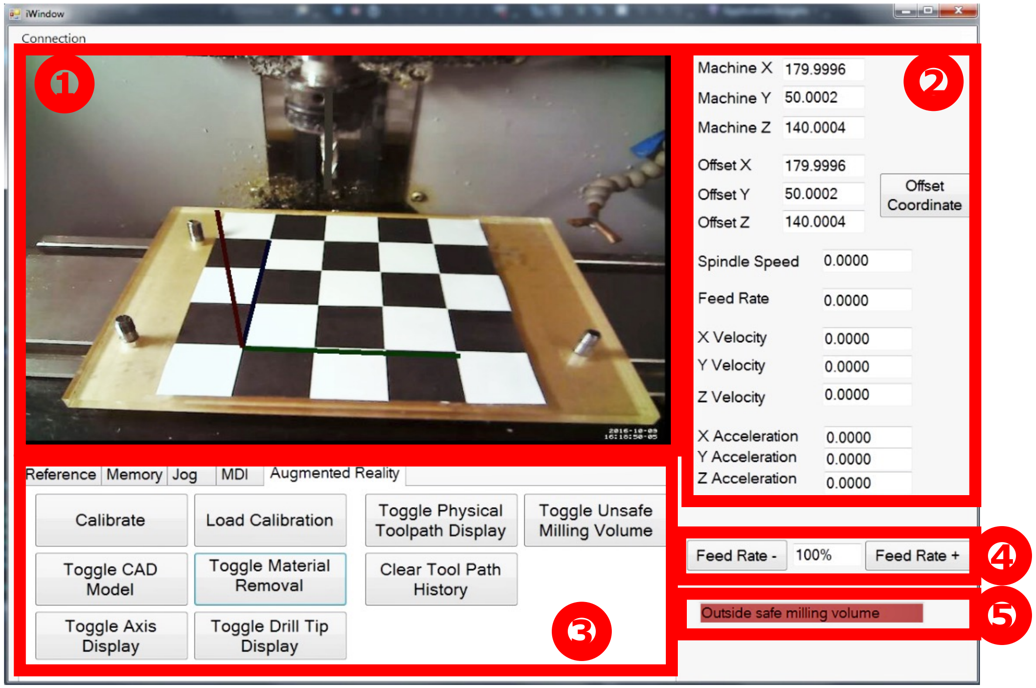


Real-time Process Monitoring via CPMT DT



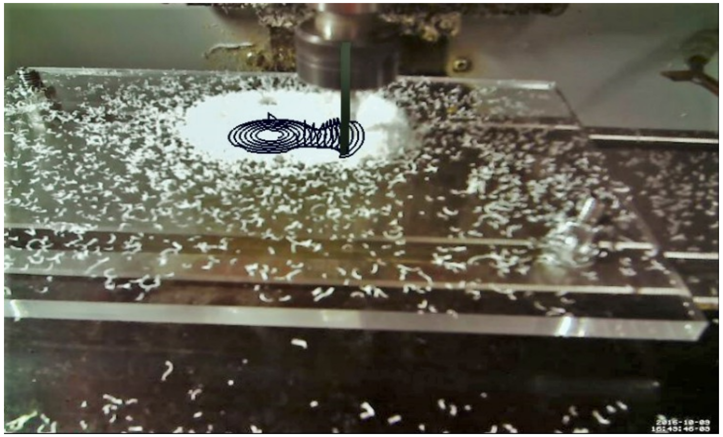
Augmented Reality of the Cyber-Physical Machine Tool

User Interface

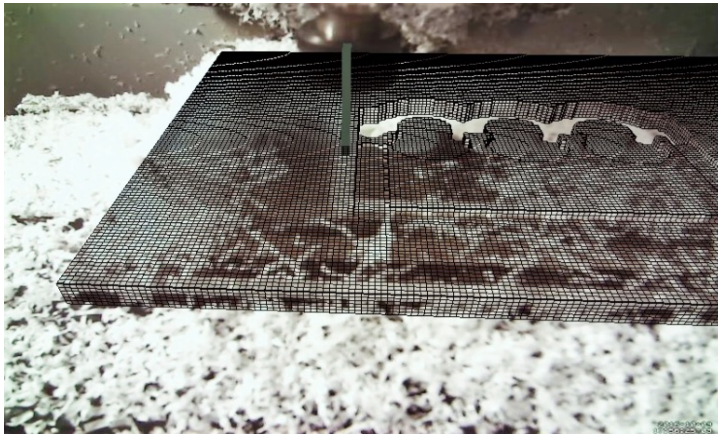


1. AR-assisted process monitoring & machining simulation
2. Real-time machining data visualization
3. Real-time CNC control
4. In-process feed rate control
5. Alarms and warnings

AR-assisted process monitoring



AR-assisted machining simulation



Retrofitting a Legacy System for its Digital Twin

Equipment

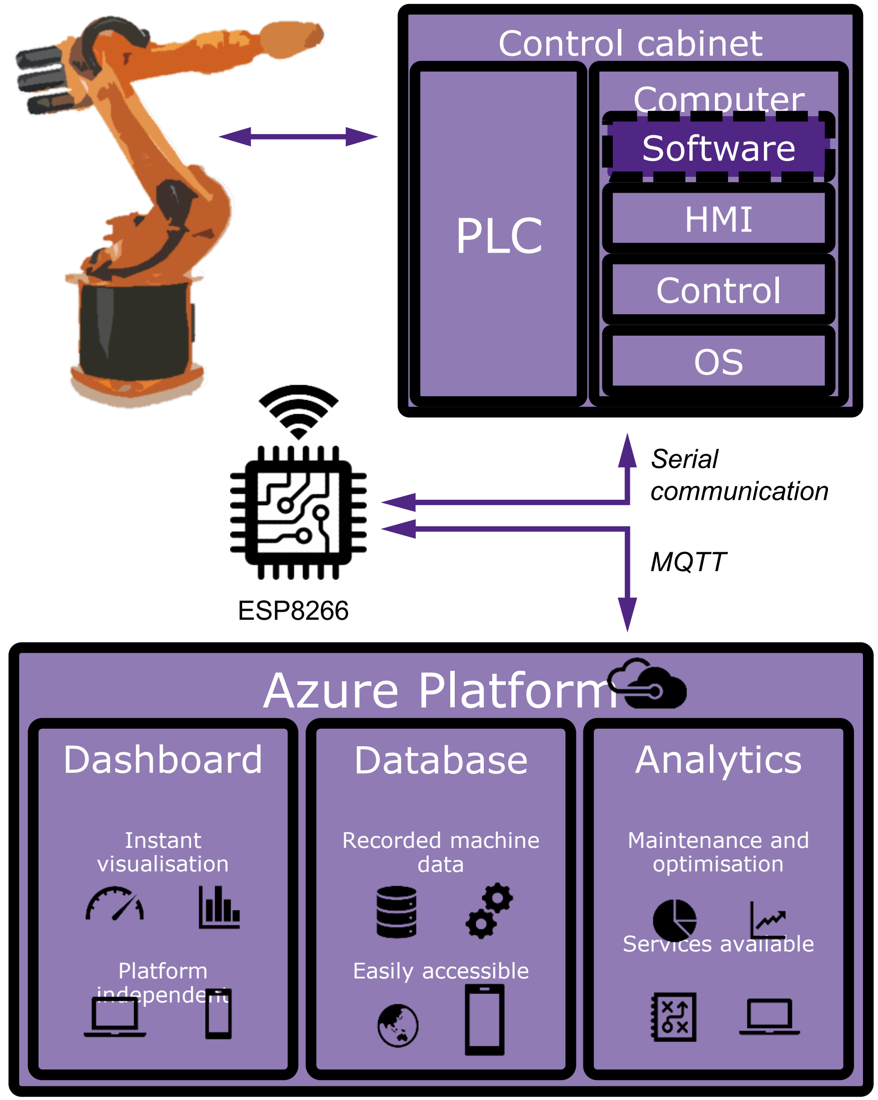
- KUKA KR16 industrial robot and its KR C2 control system
- WiFi-enabled chip (ESP8266)
- Microsoft's Azure Platform
- Know-how

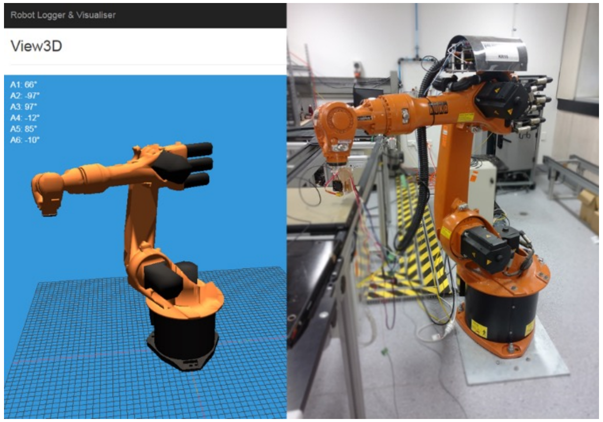
Functions:

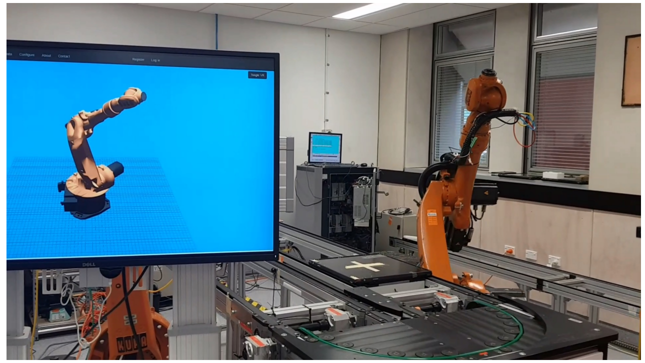
- **Background monitoring:** Custom software on the control computer runs in the background and sends machine data via serial port to the connected chip. The chip connects to the wireless network and forwards the data via internet using an IoT messaging protocol (MQTT). This method deals with hardware and software limitations and does not interfere with existing setup or usage.
- **Mobile visualisation:** The data can be accessed and visualised with near real-time capability through a custom website. It is not limited to a local machine, application or specific platform.
- **Storage and analytics.** A database stores the received data. Historical data can be used to analyse the uptime or reconstruct the robots movements if necessary (e.g. QA). Custom tools can be developed or available services used to connect to the database and performer further sophisticated analyses.

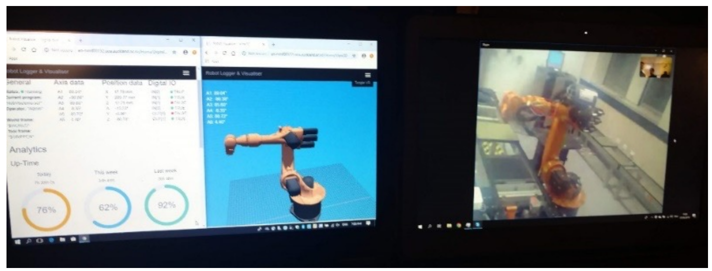
Prospective industrial applications

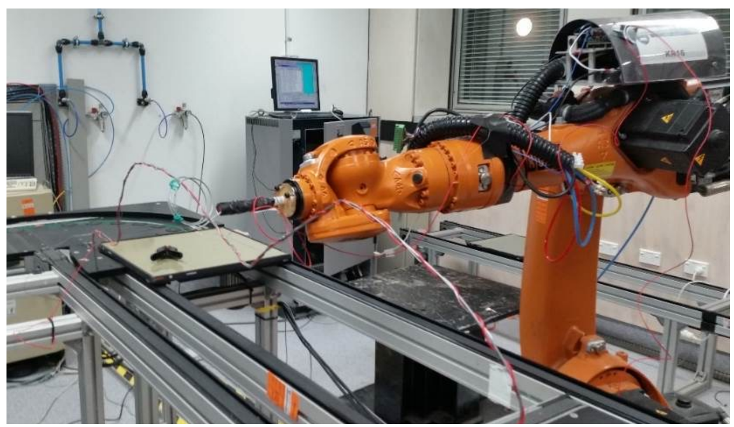
- DT development for a legacy device
- Extension of asset's lifetime
- Mobile and worldwide asset monitoring
- Optimisation of machine uptime
- Assessment of historical data for reconstruction and QA

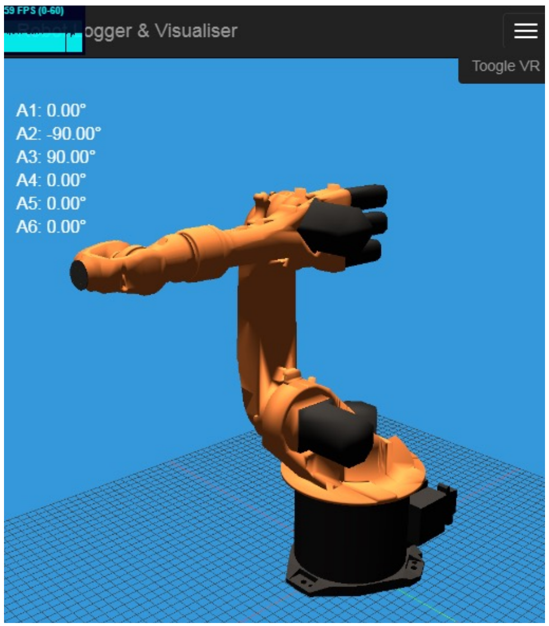








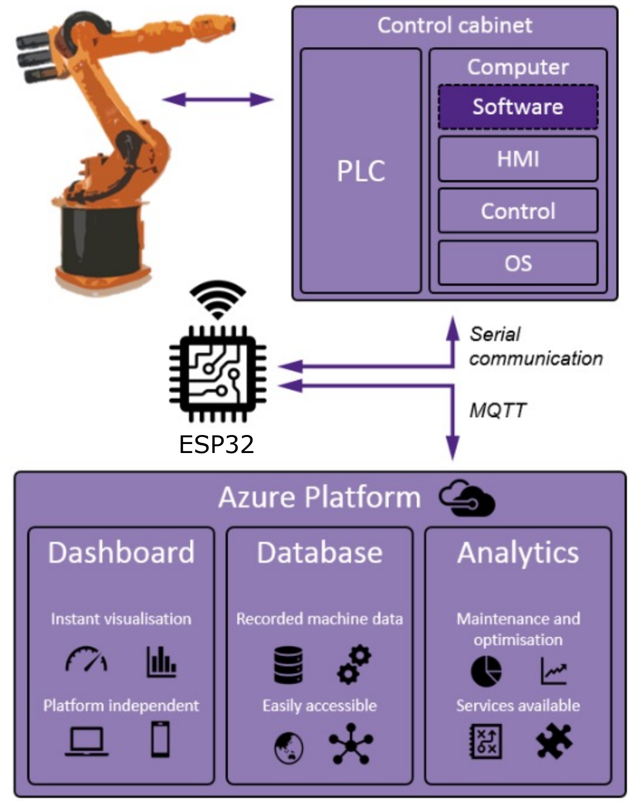




Robot Logger & Visualiser

Retro-fitting for data acquisition and analytics

(To see the demo click the image)



Final Words

- The crux of Industry 4.0 is cyber-physical systems (CPS)
- The key component of CPS is digital twin– digitisation of physical systems
- Digital twin is still a “hot” topic, but most of all an enabling tool for smart manufacturing
- ISO standards on digital twin framework for manufacturing (2021)
- Digital twin examples

THANK YOU FOR YOUR ATTENTION!

Acknowledgement

Yuqian Lu, David Tomzik, Yuan Lin, Chao Liu, Martin Zhu, Sarah Huang, Tang Ji

Scan to take a virtual tour of our lab

http://www.dibadata.com/lab.html

Laboratory for Industry 4.0 Smart Manufacturing Systems
(http://www.mech.auckland.ac.nz/en/about/ourresearch/research-facilities/LISMS.html)
(https://lisms.auckland.ac.nz/)