Digital Twin in Practice (Basics)

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Objectives

- To show the example of Digital Twin (DT) system in condition monitoring and key components involved in building a DT system
- To show how DT system is built through a step by step procedure

Demo #1
Helicopter computer system

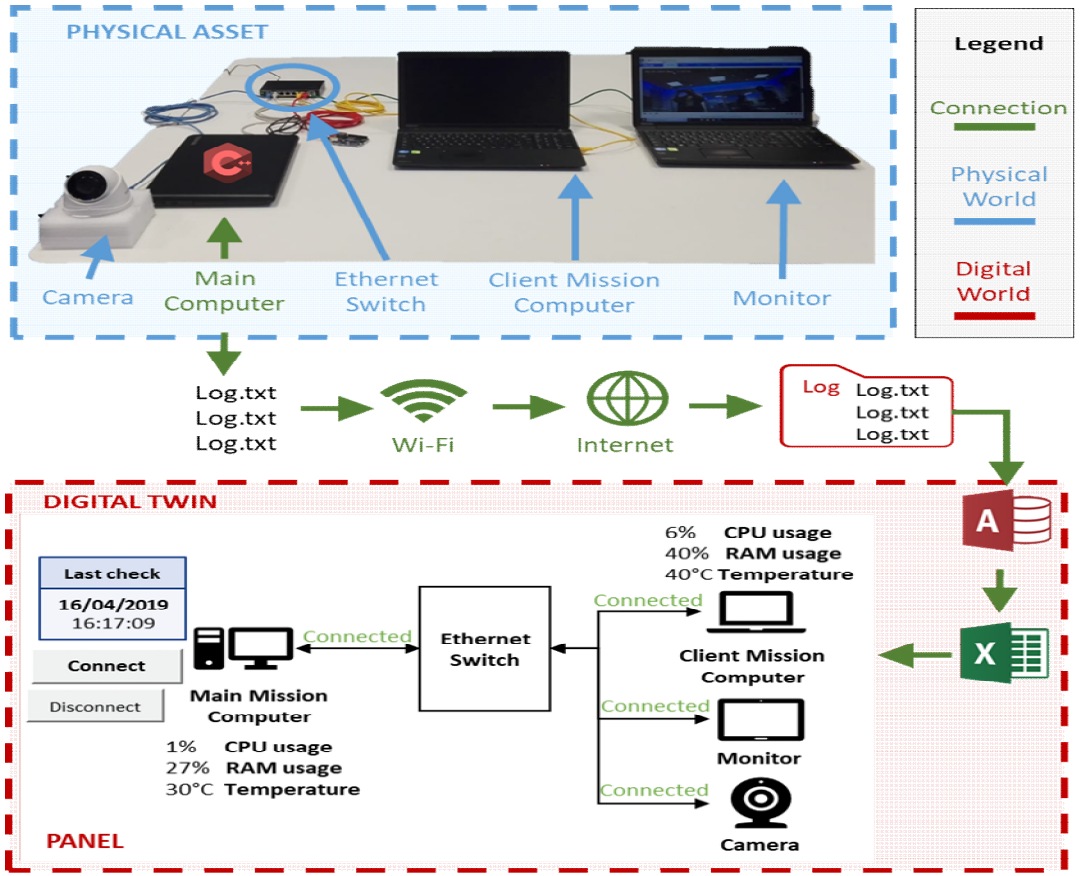

Fig. 1: DT system architecture for condition monitoring of computer system in helicopter

Your turn

- From what you have learned in the previous lecture about Digital Twin, now you are given a task to build a DT system of a gearbox machine for a condition monitoring system – show DEMO #2 Digital twin of a gearbox machine

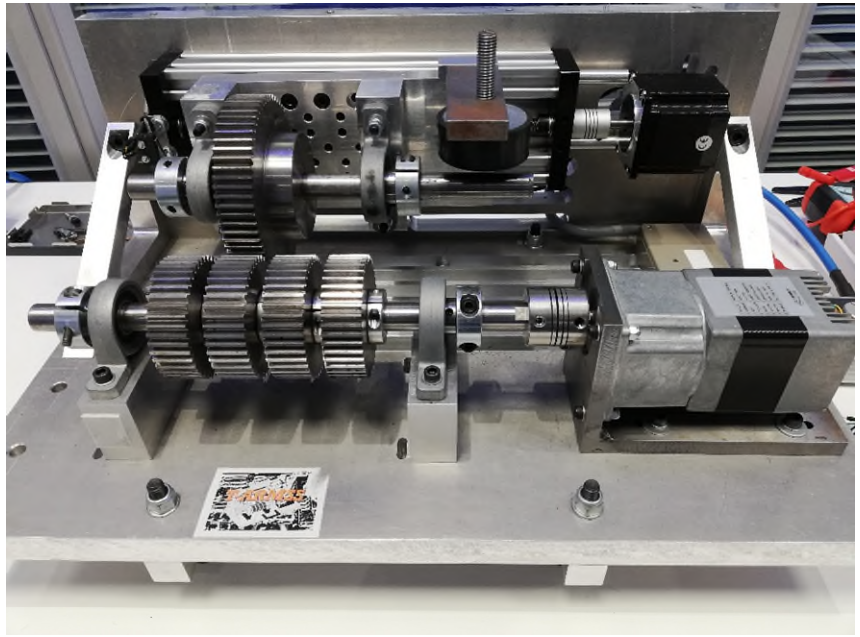

Fig. 2: Gearbox machine

Modules for building digital twin

Group work:

1. Data collection
2. Sending data to a database server
3. Modelling the physical asset
4. Data retrieval to drive Digital Twin

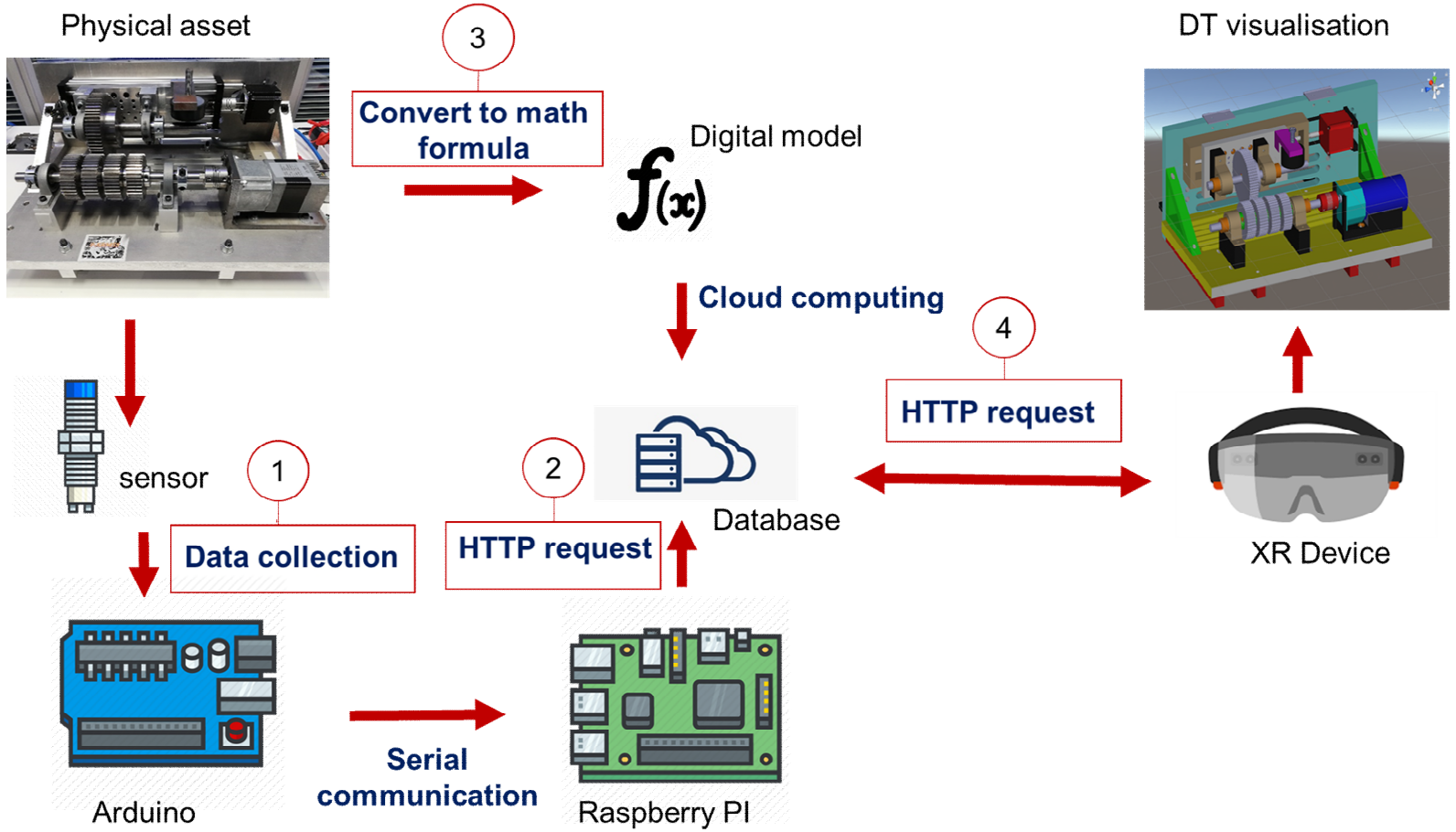

Fig. 3: System Architecture of DT Gearbox

How is a digital twin built?

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Define the requirements	**Develop the information flow**	**Build the virtual representation**	**Develop the data exchange system**	**Verify**	**Carry out analysis**	**Develop actions**	**Validate**
Aim of the digital twin Data needed Constraints	Different sources of data (sensors, internal software, historical data, etc.) Data storage	3D 2D	Network communication Connection security	Does the digital twin work properly?	Output analysis	Decision making Actions	Does the digital twin meet its purpose?

Fig. 4: Building steps of the digital twin

Design elements of DT system

Physical world

- **Equipment/Actuator** (perform functions)
- **Sensor** (detect physical parameter)
- **Controller** (transmit control commands)
- **Device for networking** (antenna, transmitter, receiver)
- **Visualisation device** (desktop, VR/AR/XR devices)

Digital world

- **Source code** of software
- **Data repositories** (database)
- **Data management** (RDBMS, Ontology)
- **Digital model** (CAD models, schematic, CAE models, numerical models, statistic models, etc.)
- **Intelligence** (machine learning, deep learning)

Connection

- **Network & connectivity IT**

Step 1. Define the requirements

- The aim of DT
  - What is the expected outcome?
    - ✓ To monitor the performance degradation of the gearbox (i.e. gear) before failure occurs
  - What is the expected improvement?
    - ✓ Downtime reduced -> availability increased
- What data are needed?
  - ✓ Rotational speed, vibration, temperature
- Constraints?
  - ✓ Lack of sensor data and material degradation model

Physical world

- **Equipment/Actuator** (gearbox)
- **Sensor** (?)
- **Controller** (?)
- **Device for networking** (?)
- **Visualisation device** (?)

Digital world

- **Source code** of software (?)
- **Data repositories** (?)
- **Data management** (?)
- **Digital model** (?)
- **Intelligence** (?)

Connection

- **Network** (?)
- **Connectivity IT** (?)
- **Security** (?)

Step 2. Develop the information flow

- What are the data sources?
  - ✓ Proximity sensors, encoder, piezoelectric, data from controller (Arduino, Raspberry PI, PLC controller), source code of software, user input, etc.
- What type of data storage to use?
  - ✓ SQL database, non-SQL database, SPARQL database
- What data management to use?
  - ✓ RDBMS, Ontology

Physical world

- **Equipment/Actuator** (gearbox)
- **Sensor** (Proximity sensors)
- **Controller** (Arduino, Raspberry PI)
- **Device for networking** (?)
- **Visualisation device** (?)

Digital world

- **Source code** of software (gear equation)
- **Data repositories** (MySQL database)
- **Data management** (RDBMS)
- **Digital model** (?)
- **Intelligence** (?)

Connection

- **Network** (?)
- **Connectivity IT** (?)
- **Security** (?)

Step 3. Build the virtual representation

- How the DT is visually represented?
  - ✓ Desktop-based 2D, Virtual Reality, Augmented Reality, Mixed-reality
  - ✓ 3D CAD model of physical asset is needed

Physical world

- **Equipment/Actuator** (gearbox)
- **Sensor** (Proximity sensors)
- **Controller** (Arduino)
- **Device for networking** (?)
- **Visualisation device** (AR device)

Digital world

- **Source code** of software (gear equation)
- **Data repositories** (MySQL database)
- **Data management** (RDBMS)
- **Digital model** (CAD model)
- **Intelligence** (N/A)

Connection

- **Network** (?)
- **Connectivity IT** (?)
- **Security** (?)

Step 4. Develop data exchange system

- How large is the network coverage area?
  - ✓ Personal Area Network (e.g. Bluetooth)
  - ✓ Local Area Network (e.g. Reuter)
  - ✓ Wide Area Network (e.g. Modem)
- What is the connection protocol?
  - ✓TCP
  - ✓UDP

Physical world

- **Equipment/Actuator** (gearbox)
- **Sensor** (Proximity sensors)
- **Controller** (Arduino, Raspberry PI)
- **Device for networking** (Router)
- **Visualisation device** (AR)

Digital world

- **Source code** of software (gear equation)
- **Data repositories** (MySQL database)
- **Data management** (RDBMS)
- **Digital model** (CAD model)
- **Intelligence** (N/A)

Connection

- **Network** (LAN and WAN)
- **Connectivity IT** (TCP/IP)
- **Security** (N/A)

Step 5. Verify

- Physical asset
  - ✓ Check if physical asset is running properly
- Data logging
  - ✓ Check if sensors are properly installed
  - ✓ Check if right data are measured
- Data storing
  - ✓ Check if all desirable data are stored properly
- Data reading
  - ✓ Check if DT read the right data from database
- Data processing
  - ✓ Check if the right data are fed into the right program/source code
  - ✓ Check if there is a bug in the source code
- Data visualisation
  - ✓ Check if the the status and behaviour of displayed DT reflects its physical twin

Physical world

- **Equipment/Actuator** (gearbox)
- **Sensor** (Proximity sensors)
- **Controller** (Arduino, Raspberry PI)
- **Device for networking** (Modem and Router)
- **Visualisation device** (AR)

Digital world

- **Source code** of software (gear equation)
- **Data repositories** (MySQL database)
- **Data management** (RDBMS)
- **Digital model** (CAD model)
- **Intelligence** (N/A)

Connection

- **Network** (LAN and WAN)
- **Connectivity IT** (TCP/IP)
- **Security** (N/A)

Step 6. Carry out analysis

- Manual analysis
  - ✓Compare data record at different times
- Semi-automatic analysis
  - ✓Identify patterns of data
- Automatic analysis
  - ✓Rule-based data analysis
  - ✓Multi-physics analysis
  - ✓Statistical analysis

Step 7. Develop actions

- Define condition-action rules
  - ✓ Reduce the demand on the current asset and distribute it to the standby asset
  - ✓ Initiate maintenance schedule on the current asset
  - ✓ Shut down the operation of the asset

Step 8. VALIDATE

- Validate the capability of the DT system to monitor the degradation of gears before failure occurs
  - ✓ Conduct an experiment to test whether a user can recognise the early indication of gear deterioration with and without DT
- Validate the capability of the DT system to improve the availability of the gearbox machine
  - ✓ Conduct a periodic inspection to assess whether condition-action rule informed by DT improve the availability of the asset in comparison with the asset without DT

References

Agha et al., 2019. “Digital twin representation. . .”

Stark, Rainer, Carina Fresemann, and Kai Lindow. "Development and operation of Digital Twins for technical systems and services." *CIRP Annals* (2019).