Digital Twin: From a Modeling Perspective

Presented by Chenyu Wang

Rasheed, Adil, Omer San, and Trond Kvamsdal. "Digital twin: Values, challenges and enablers from a modeling perspective." *IEEE Access* 8 (2020): 21980-22012.

Outline

1. What is Digital Twin?
2. Why is it important?
3. Digital Twin Modeling
4. Applications & An IoT Example
5. Challenges & Future

1 What is Digital Twin ?

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Start from Some Novel Ideas

- **Parallel Universe**: A hypothesis pursued by a few people revolves around the co-existence of other universes alongside ours with different outcomes.

- **Metaverse**: A collective virtual shared space, created by the convergence of virtually enhanced physical reality and physically persistent virtual space.

Trends

Observing these novel ideas, we can find the trends:

- Constraint by the real world and some physical factors, human raise great interest in finding **a universe** which is **different** or **enhanced in virtual space.**

- With the aid of virtual universe, one is encouraged to **simulate and access all possible results** through many decision-making policies.

Motivation

- Instead of presenting a world with an unrealistic magnitude, we represent a group of physical entities as a minuscule abstraction of the world;

- With the recent wave of digitalization, more physical entities can be characterized by digital copies.

digital transformation

Digital Twin - Definition

A commonly accepted definition:

A virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimization, monitoring, controlling, and improved decision making.

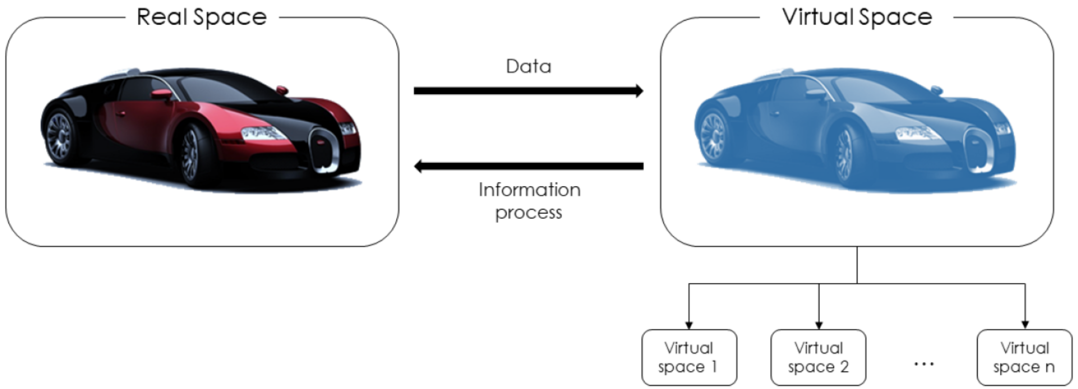

Figure 1: Digital mapping from physical asset.

Barricelli, Barbara Rita, Elena Casiraghi, and Daniela Fogli. "A survey on digital twin: definitions, characteristics, applications, and design implications." *IEEE access* 7 (2019): 167653-167671.

Digital Twin - Definition (Cont.)

What is Digital Twin? How does it work? - https://www.youtube.com/watch?v=iVS-AuSjpOQ

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Why is digital twin important?

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Values of Digital Twin

- Real-time remote monitoring and control

The digital twin allows visibility in the operations of the machines as well as in the larger interconnected systems such as a manufacturing plant or an airport

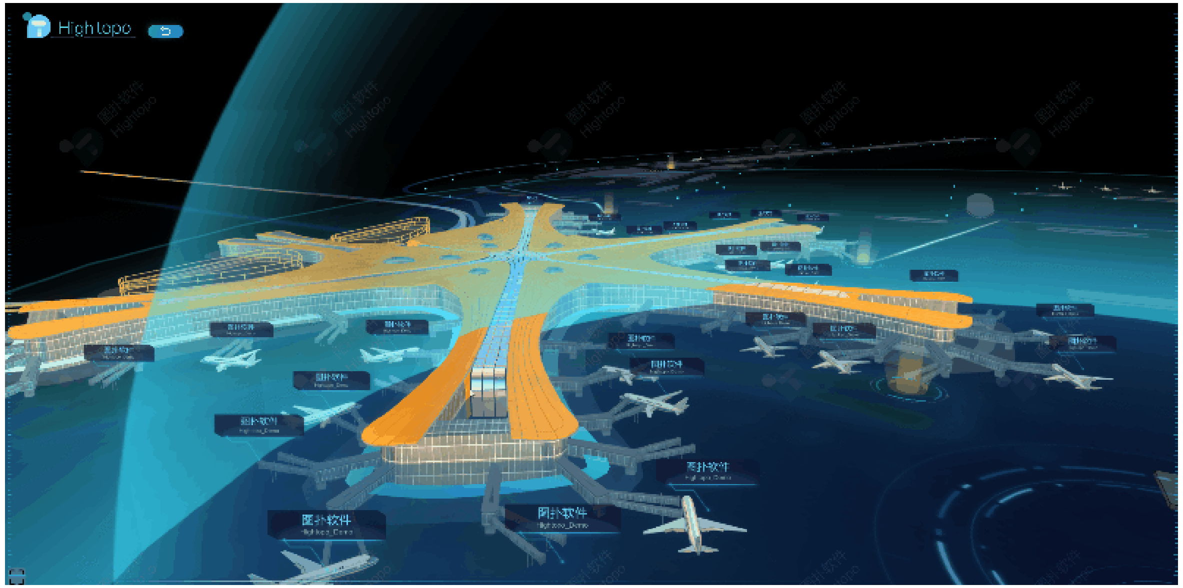


Figure 2: A digital twin of Beijing Daxing airport.

https://developpaper.com/digital-twin-beijing-daxing-airport/

Values of Digital Twin (Cont.)

- Predictive maintenance and scheduling

Using various modeling techniques (physics-based and mathematics-based), the digital twin model can be used to predict the future state of the machines

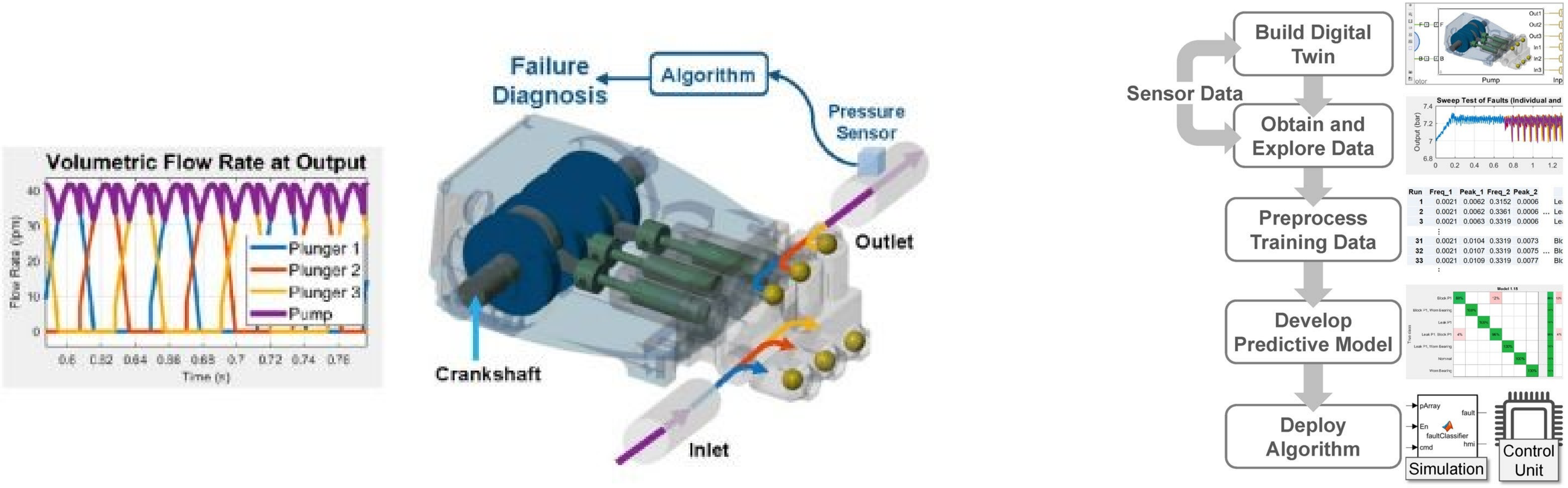


Figure 3: Predictive maintenance for a triplex pump using a digital twin.

https://www.mathworks.com/company/newsletters/articles/predictive-maintenance-using-a-digital-twin.html

Values of Digital Twin (Cont.)

- Scenario and risk assessment

Through properly designed interfaces, it is easy to interact with the model and ask the what-if questions to the model to simulate various conditions that are impractical to create in real life

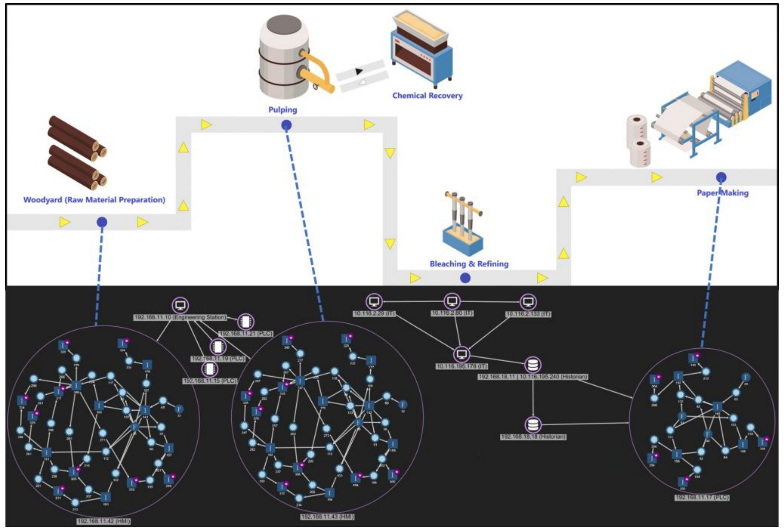


Figure 4:
An illustration of Process-aware risk assessment with cyber digital twin platform (CyTwin).

https://www.accenture.com/us-en/blogs/technology-innovation/klein-engelberg-get-ahead-of-cyberattacks-with-digital-twins

Values of Digital Twin (Cont.)

- Connect disparate systems through backend applications

Connecting with the backend applications to achieve outcomes in the context of supply chain operations including manufacturing, procurement, warehousing, transportation and logistics, field service, etc.

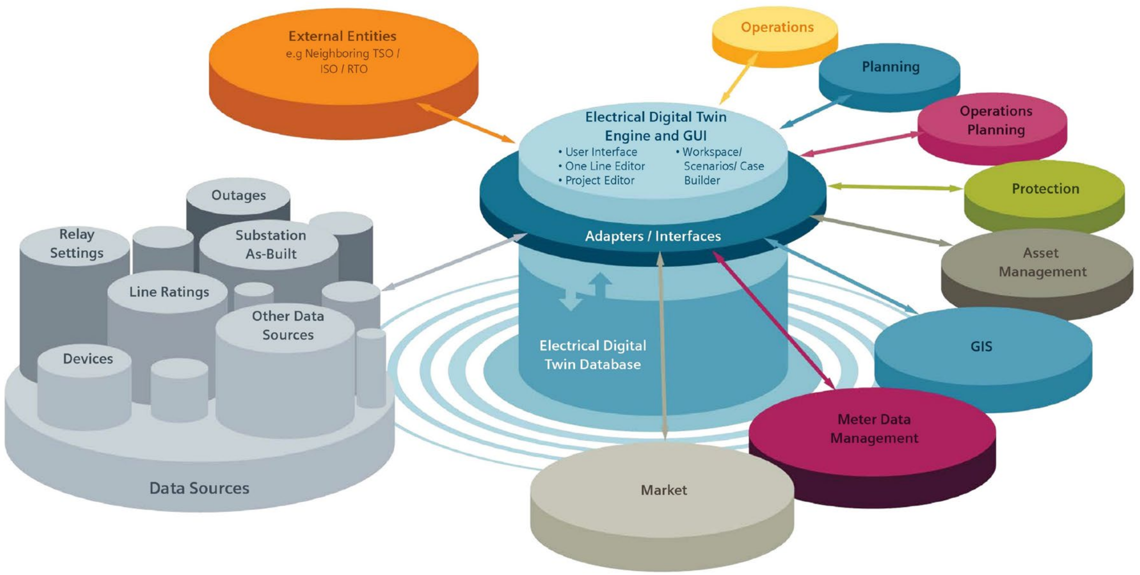


Figure 5:
Siemens Electrical Digital Twin - A single source of truth to unlock tangible results.

https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/electrical-digital-twin.html

Some Other Benefits

- Greater Efficiency and safety
- Better intra- and inter-team synergy and collaborations
- More efficient and informed decision support system
- Personalization of products and services
- Better documentation and communication

3 Digital Twin Modeling

Modeling

- Physics-based Modeling
- Data Driven Modeling
- Big data cybernetics
- Infrastructure and platforms
- Human-machine interface

Physics-based Modeling

1. Observing a physical phenomenon of interest,
2. Developing a partial understanding of it,
3. Putting the understanding in the form of mathematical equations and
4. Ultimately solving the problem.

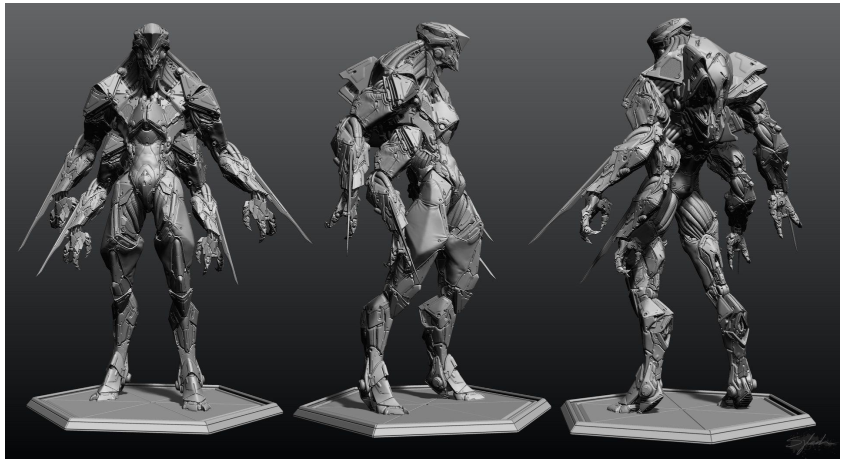


Figure 6: 3D modeling.

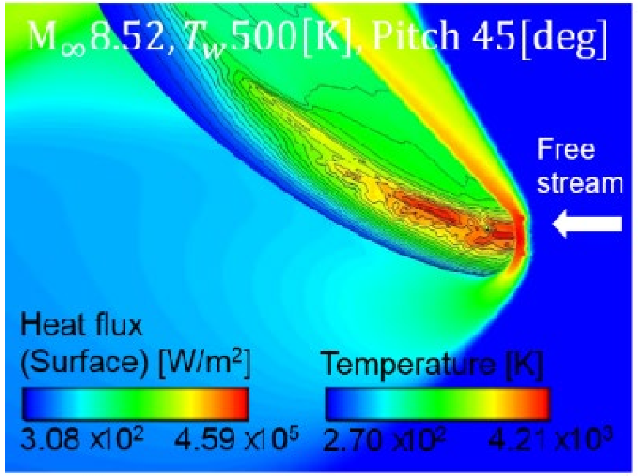


Figure 7: High Fidelity numerical simulation.

Data-Driven Modeling

- **Physics-based Modeling**: Based on physics that is know;
- **Data-Driven Modeling:** Based on the assumption that since data is a manifestation of both known and unknown physics;

Figure 8: Data generation, processing and management.

Data-Driven Modeling (Cont.)

- **Data Privacy and Ethical Issues**
- **Machine Learning (ML) and Artificial Intelligence (AI)**

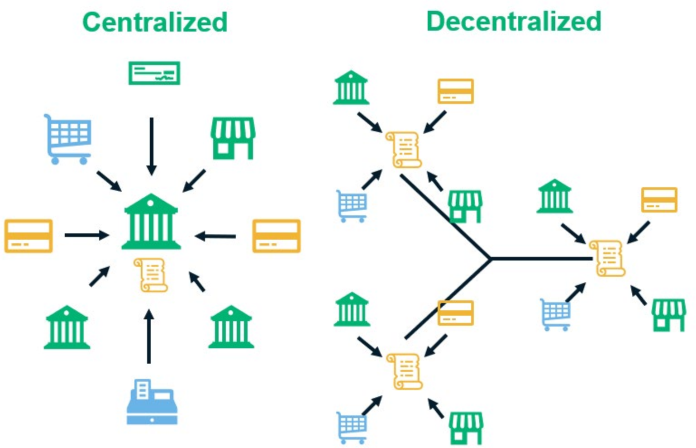


Figure 9: Blockchain Systems.

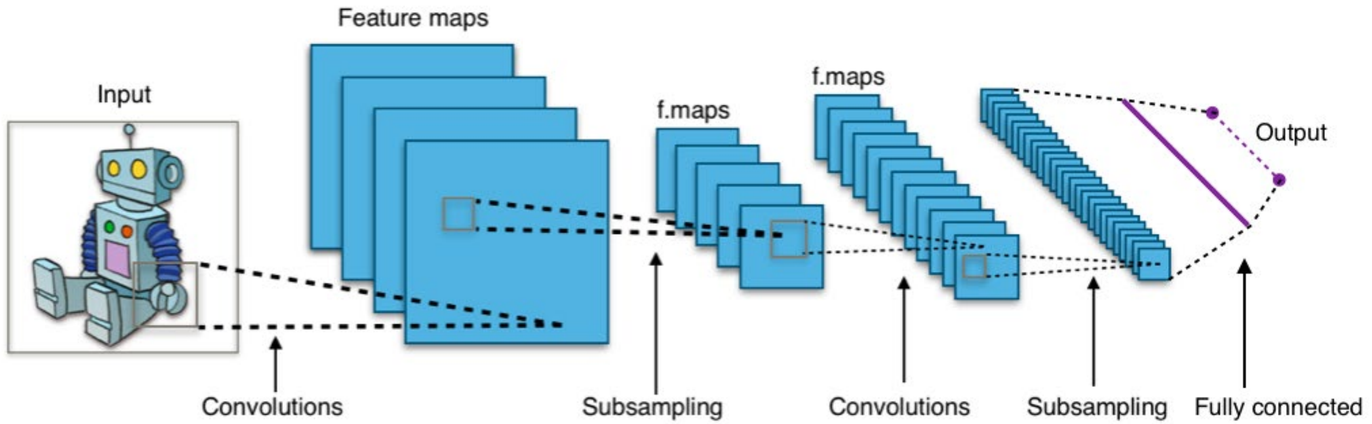


Figure 10: Convolutional Neural Network.

Big Data Cybernetics

- The objective of **cybernetics** is to steer a system towards a reference point.
- Output is continuously monitored, and the difference as **feedback return to the controller** which in turn generates a system input that can **direct the system towards the reference point.**

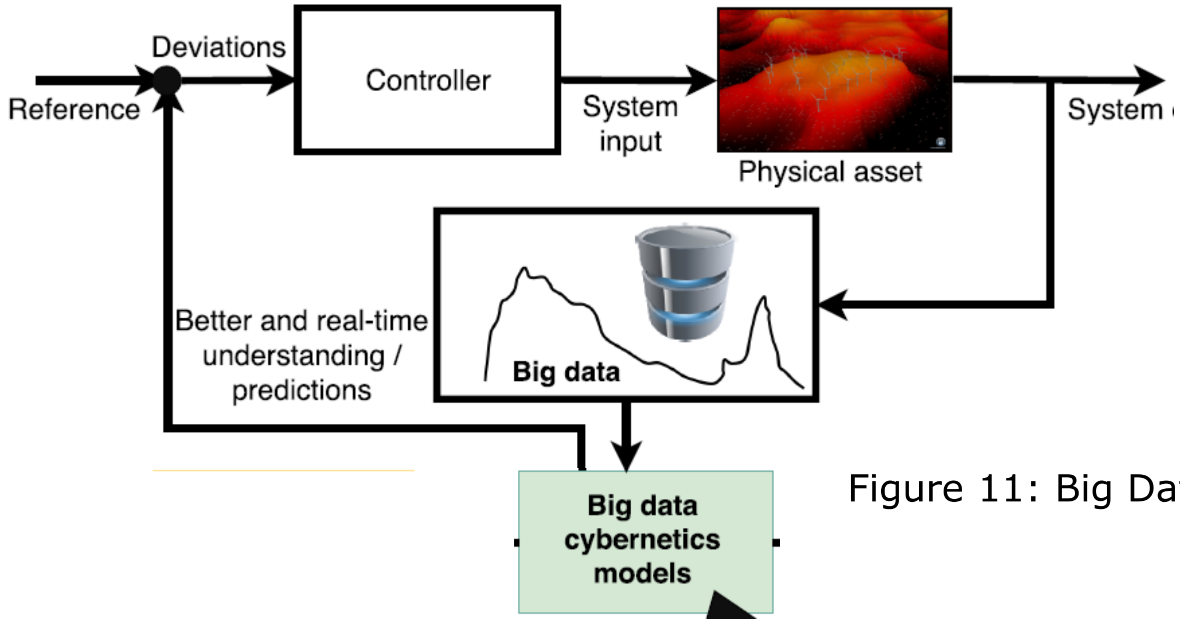


Figure 11: Big Data Cybernetics.

Some Techniques:

- Data assimilation
- Reduced order modeling
- Hardware and software in the loop
- Hybridization techniques
- Physics-informed ML
- Compressed sensing and symbolic regression

Infrastructure and Platforms

- **Big data technology** - The infrastructure for **storing and processing** high volume data
- **IoT technology** - Increasingly popular to develop smart technologies from healthcare to agriculture, from transportation to energy.
- **Communication technology** - A reliable working of any digital twin will require information **arising from different components** to **reach** its intended target **on time**.
- **Computational technology** - Cloud computing, Edge computing

Human-machine interface

- Provide **effective** and **fast** communication and interaction
  - Augmented Reality (AR) and Virtual Reality (VR)


Figure 12: AR and VR.

Figure 13: NLP

  - Natural Language Processing (NLP)
  - Gesture Control

Figure 14: Gesture Control

4 Applications & An IoT Example

Application 1: Health

- A prototype digital twin framework for remote surgery

FIGURE 1. A robotic arm was used to move a set of instruments to simulate a remote surgery of a dummy patient.

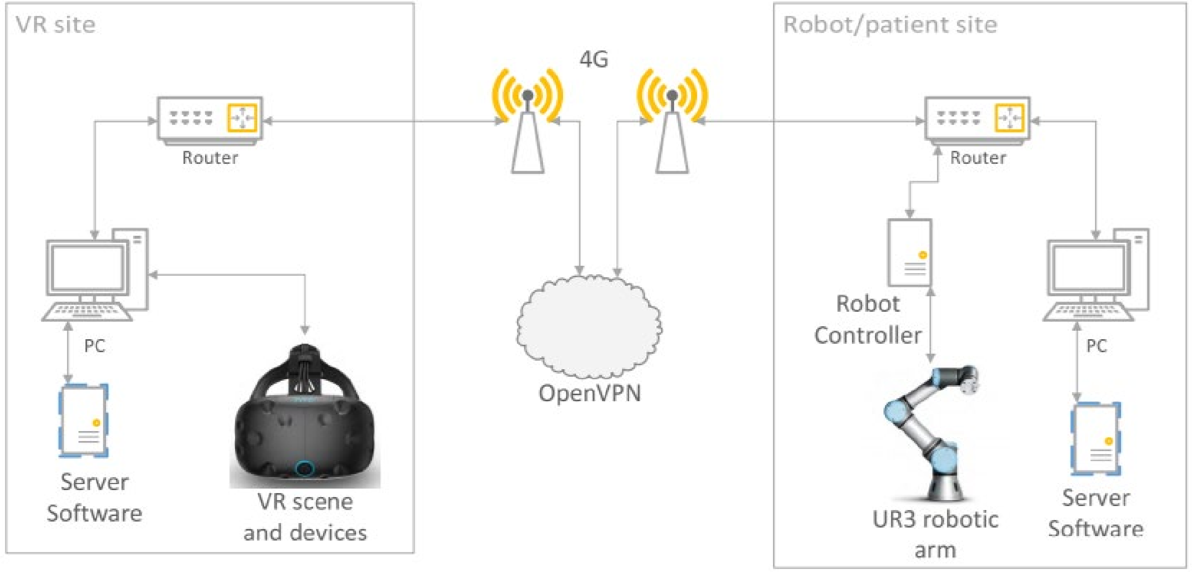


FIGURE 3. Network setup diagram of the prototype system.

Laaki, Heikki, Yoan Miche, and Kari Tammi. "Prototyping a digital twin for real time remote control over mobile networks: Application of remote surgery." IEEE Access 7 (2019): 20325-20336.

Application 2: Cities and Transportation

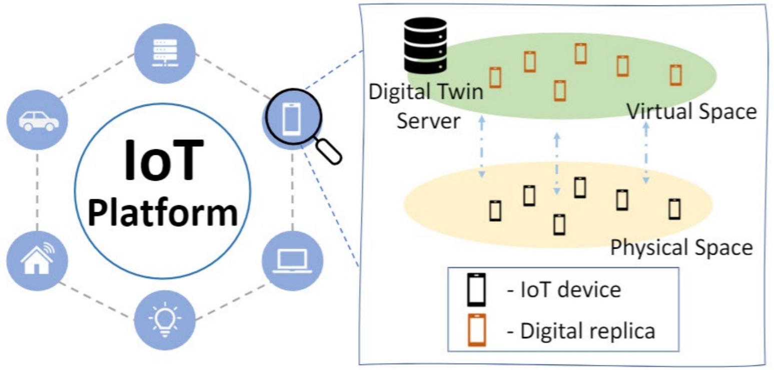
- Large cities are usually characterized by a dynamism that conceals highly complex social structures and services.
- Virtual Singapore
  - Offers 3D semantic modelling;
  - Incorporates other real-time dynamics;
  - Used for simulating emergency situations.

https://www.smartcitylab.com/blog/digital-transformation/singapore-experiments-with-its-digital-twin-to-improve-city-life/

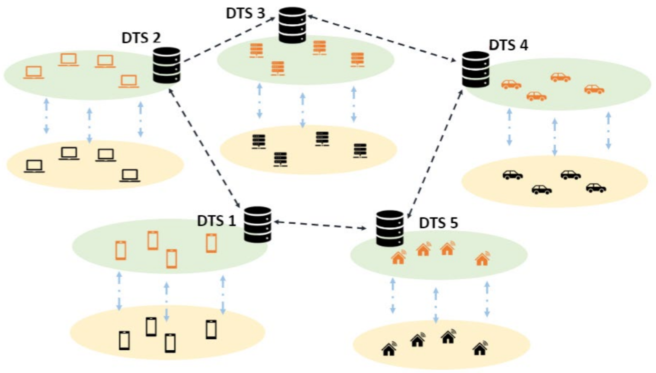
Application 3: Cities and Transportation (Cont.)

An IoT Example

- Consider a large number of **IoT devices** performing different image classification task using the ML-method (label-based training).
- Challenges:
  1. Learning Model efficiently (*Solved by Collaborative Learning*)
  2. Lacking labels at the initial stage of product design (*Solved by utilizing the digital twin of other IoT devices*)
  3. Complex network topology (*Solved by deploying Digital Twin Edge Servers*)



IoT Platform aided by digital twin



Network topology with
Digital Twin Edge Servers

5 Challenges & Futures

Challenges

Challenges	Enabling Technologies
Data management, data privacy and security, data quality	Digital platforms, cryptography and blockchain technologies, big data technologies
Real-time communication of data and latency	Data compression, communication technologies like 5G and internet of things technologies
Physical realism and future projections	Sensor technologies, high fidelity physics-based simulators, data-driven models
Real time modeling	Hybrid analysis and modeling, reduced order modeling, multivariate data-driven models
Continuous model updates, modeling the unknown	Big data cybernetics, hybrid analysis and modeling, data assimilation, compressed sensing and symbolic regression
Transperancy and interpretability	Hybrid analysis and modeling, explainable artificial intelligence
Large scale computation	Computational infrastructure, edge, fog and cloud computing
Interaction with physical asset	Human machine interface, natural language processing, visualization augmented reality and virtual reality

Thank you

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