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Smart Monitoring in Tactile Cyber-Physical Systems

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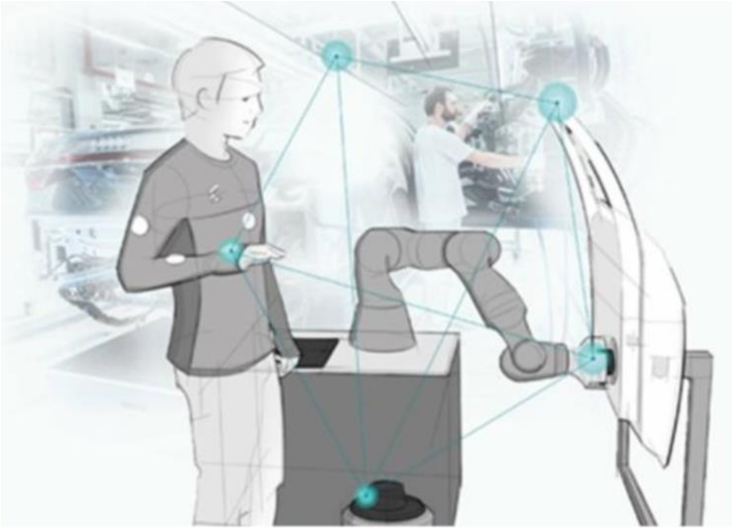
The research is implemented with financial support by Russian Science Foundation, project no. 22-11-20040 jointly with Republic of Karelia and funding from Venture Investment Fund of Republic of Karelia

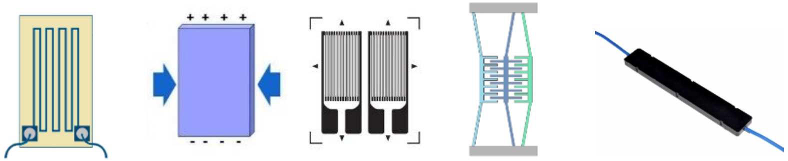
UBICOMM 2022
November 13-17, 2022 – Valencia, Spain

Tactile Cyber-Physical Systems

Development target is **Tactile Cyber-Physical System (TCPS)**

- IoT/IIoT technology shortens the distance between the human and monitored objects
- Analytics are delivered to the user in near real-time
- Tactile Internet (TI) supports human perception of distant objects using haptic data from monitoring
  - Strain sensors for advancing the human touch sense
  - In general, 5 human senses: eyesight, hearing, taste, touch, and smell
- Perception property in Ambient Intelligence (AmI)
  - human is in a digital environment (e.g., IoT environment)
  - surrounding devices construct recognition services
  - Input data are from monitoring the physical, informational, and social world



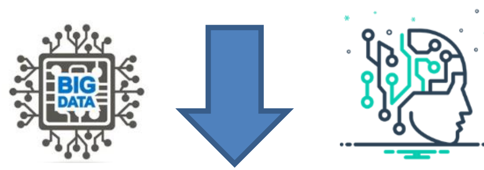


Strain sensors

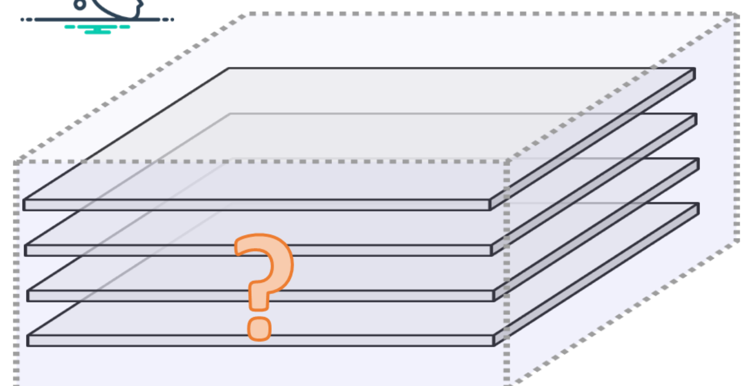
- The tactile sense is based on sensing deformations and mechanical stresses

Requirements to TCPS for Sensed Data Processing

- **The bigdata requirement (R_{BD})**. Data processing is based on Artificial Intelligence (AI) with advanced methods of Machine Learning (ML) and recognition for Bigdata analytics.
- **The smart interaction requirement (R_{SI}).** System components act as smart IoT objects that interact in IoT environment to construct services using Ambient Intelligence (AmI).



Multi-layer TCPS architecture
for near real-time sensed data processing



Properties of Sensorics in a TCPS

- Digitalization of the primary results of measurements.
- Use of many sensors and sensor nodes for monitoring the state of one object as well as processing of the data obtained in parallel from many sensors.
- Correction for noninformative factors (e.g., the influence of temperature on strain sensors).
- Recognition of failures of nodes or communication lines and built-in fault-tolerance capability.
- The sensors used for monitoring are by themselves smart and able to function as IIoT nodes.
- Wireless connection of the components of the system.
- The ability of the components of the system to communicate in real-time mode.
- High-level characterization of the state of the object under monitoring (e.g., normal or dangerous).
- Recognition of abnormal behavior of the object and making decisions on this base.
- The use of the machine learning (ML) methods for classification of the states of the object under monitoring.
- Flexibility of the system, i.e., possibility to re-configure when necessary.

TCPS Applications in Industry using Strain Gauges

Application	Use of tactile sensors
1. Remote manipulation of real or virtual objects in inaccessible and dangerous conditions.	Tracking movement and position of human body parts by flexible strain sensors.
2. Monitoring the state of transport vehicles, ship hulls and airframes, wind turbines, railway lines, dams, oil drilling platforms, structural components of bridges and buildings.	Detection of early structural damage based on the analysis of strain measurements; data source in wireless telemetry system; measurement of mechanical resonance frequencies of structures.
3. Design and exploitation of aerospace and aircraft technologies.	Comparison of deformations with the results of CAD and FEA simulations; monitoring the actual stresses in mechanical parts during flight to ensure that it is safe.
4. The control of deformations of parts during processing to adjust the pressing forces by robotic metalworking equipment.	Strain measuring of the part during machine processing by the pressure of the cutter (e.g., during drilling).
5. Measurement of the torque applied by a motor, turbine, etc. to generators, wheels, etc. for optimization of the regime of the equipment	The torque is calculated from the measured strain and the rotational speed on a shaft.
6. Manufacturing of weight and pressure measuring devices for the creation of robotic systems for industrial production.	Strain sensors are the basic (sensing) elements of load cells.

Related Concepts and Technologies for TCPS architecture

- **Big data technologies** aims at storing and processing huge (in most cases, redundant) sets of continuously arriving sensor data with the possibility of horizontal scaling.
- **Lambda architecture** pattern: the batch processing path and the speed processing path, so providing a unified, merged view to the service layer.

- **Digital Shadow** (the basic component of Digital Twin).
- Any digital object is augmented with additional data collected from the corresponding real object using the **IIoT technology**.

Multi-layer TCPS architecture

The architecture is based on the data life cycle model “data – information – knowledge-decisions”.

(1) physical layer;

(2) edge layer;

(3) network layer;

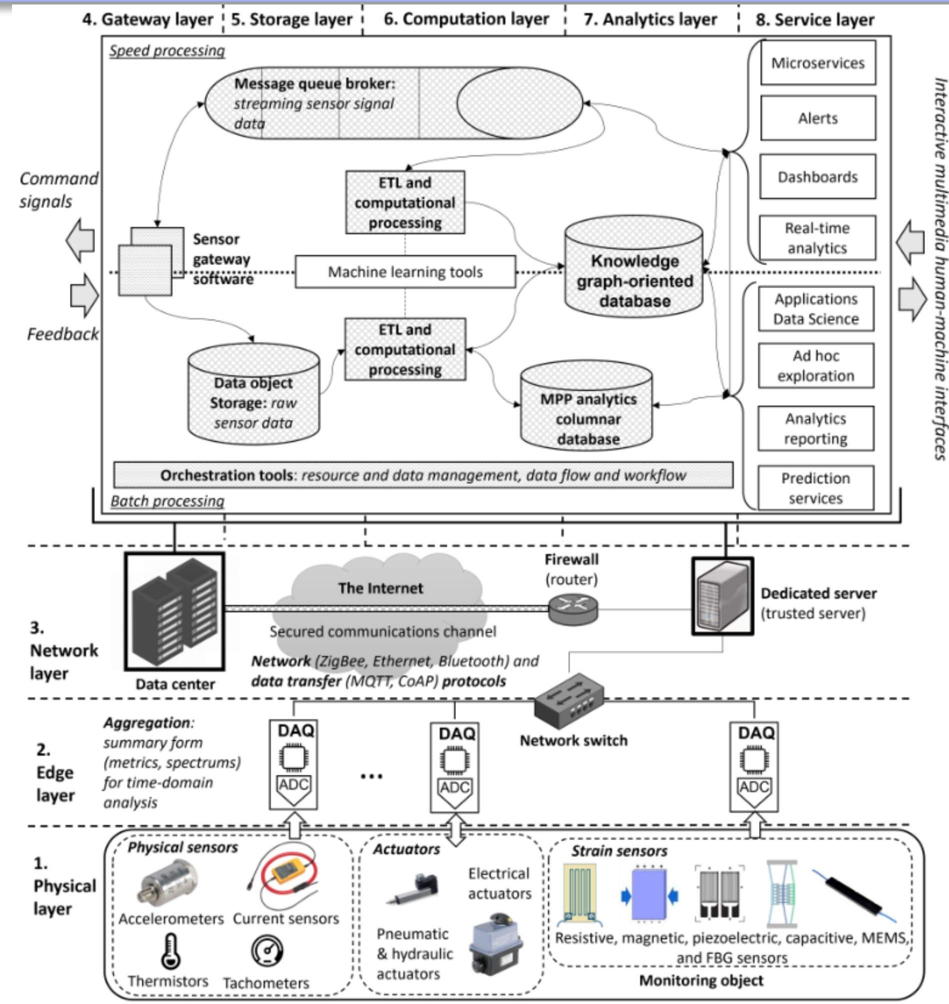
(4) gateway layer;

(5) storage layer;

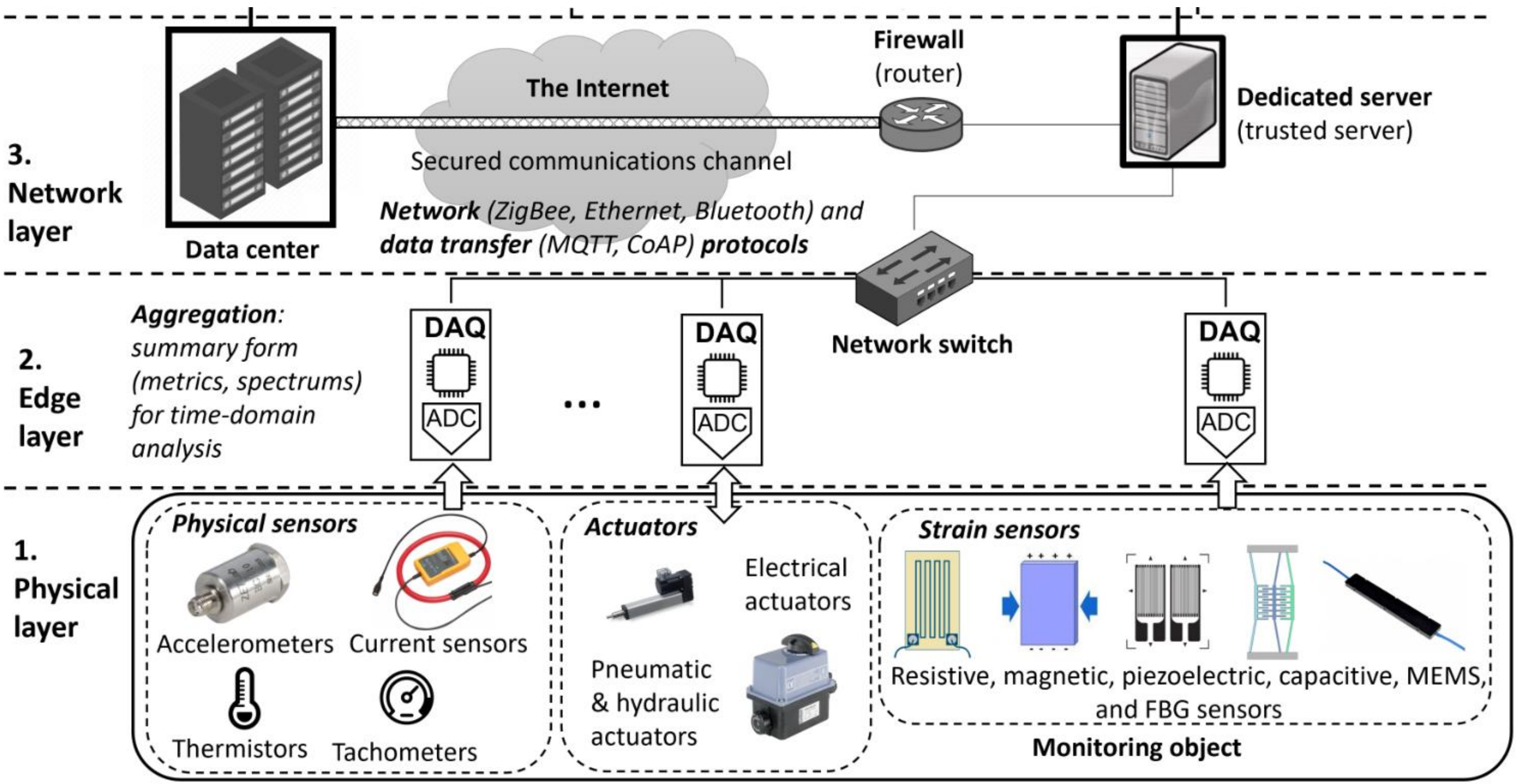
(6) computation layer;

(7) analytics layer;

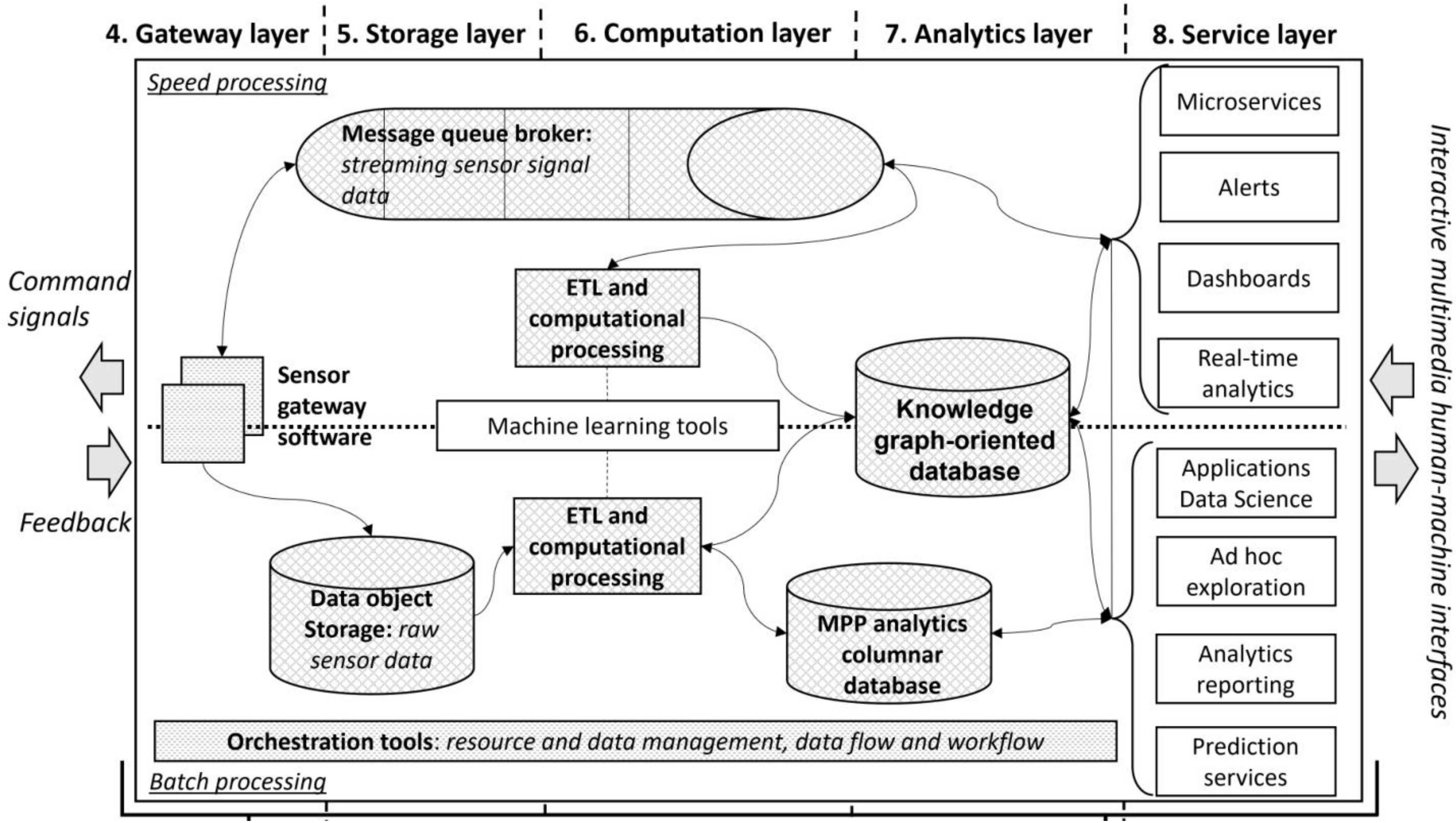
(8) service layer.



(1) physical, (2) edge, (3) network layers



(4) gateway, (5) storage, (6) computation, (7) analytics, (8) service layers



Multi-layer TCPS architecture: Summary of Technologies

Layers	Technologies
Physical layer	• Resistive, piezoelectric, and capacitive strain sensors, strain sensors based on magnetic phenomena, MEMS and optical strain sensors • Physical sensors and actuators
Edge layer	• Sensor computing modules (SCM — data acquisition system instance, DAQ) to calculate statistical metrics as RMS (root mean square), max, min, crest factor, and kurtosis within a given time window
Network layer	• Network protocols: Wi-Fi, ZigBee, Ethernet, Bluetooth, RS-485, CAN • Data transfer protocols: MQTT, CoAP, AMQP, and DDS
Gateway layer	• Message brokers: Apache Kafka, RabbitMQ, ZeroMQ • Extract-transform-load: Apache NiFi, Sqoop
Storage layer	• Object storage: HDFS • Graph databases: MongoDB, Neo4j • Column databases: Vertica, ClickHouse
Analytics layer	• Batch and stream analytics: Spark SQL, Spark Streaming • Machine and deep learning: Mllib, TensorFlow • Query language for advanced analytics and BI: Greenplum, Teradata
Service layer	• Interactive multimedia human-machine interfaces • Orchestration tool: Apache Airflow, Apache NiFi

Conclusion

- This paper studied the use of TCPS to smart monitoring in IoT environments.
- We considered the two requirements of the system development: the big data requirement ($\boldsymbol{R}_{\mathbf{BD}}$) and the smart interaction requirement ($\boldsymbol{R}_{\mathbf{SI}}$).
- The role of the requirements was shown in respect to the tactile sense, when monitoring uses measurements from sensing deformations and mechanical stresses.
- We analyzed the properties from practical application problems and existing technologies for industrial data processing.
- Based on the analysis, we proposed and discussed the multi-layer TCPS architecture for effective processing of sensed data, either in batch mode or near real-time mode.

Thank you,
Questions are welcome,
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