Progetto di Eccellenza Informatica per Industria 4.0

A holistic approach to Computer Engineering for Industry 4.0

May 2023

UNIVERSITÀ di VERONA
Dipartimento di INFORMATICA

Dipartimento di Eccellenza 2018/2022

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Agenda

Time		Title	Speaker	Affiliation
09:00		**Project history and main results**	Franco Fummi	Università di Verona
09:20		**Demonstration**	Dong Seon Cheng	Università di Verona
10:00		**Technical session 1: CPS modelling and (re)configuration**		
	10:00	Future perspective in CPS	Samarjit Chakraborty	University of North Carolina - Chapel Hill
	10:20	Service Oriented Manufacturing: modeling, validation and synthesis	Michele Lora	Università di Verona
	10:40	Knowledge Acquisition for Safe Programming	Paolo Fiorini	Università di Verona
11:00		*Coffee break*		
11:20		**Technical session 2: AI, image & signal analysis**		
	11:20	Edge-Brain: Edge Computing AI Solutions for Easy-to-Upgrade of Flexibility in Smart Manufacturing	Sukhan Lee	Sungkyunkwan University - Seoul
	11:40	Real-time Distributed Human Pose Estimation in Industrial Applications	Michele Boldo	Università di Verona
	12:00	Mixed Reality and Interaction	Andrea Giachetti	Università di Verona
	12:20	Anomaly Detection for Mobile Robots	Alberto Castellini	Università di Verona
	12:40	Anomaly Detection on Industrial Scenarios	Francesco Setti	Università di Verona
13:00		*Lunch*		
14:00		**Technical session 3: innovative computing architectures**		
	14:00	Corsi e Ricorsi: Here We Go Again	Alberto Sangiovanni-Vincentelli	University of California - Berkeley
	14:40	On the Kubernetes Orchestration of Mixed-Criticality Software and Checkers	F.Lumpp / S.Germiniani	Università di Verona
	15:00	Computational Design for 3D printing	Andrea Giachetti	Università di Verona
	15:20	Tiny Machine Learning: how to Fit Heavy Networks Almost Everywhere	Luigi Capogrosso	Università di Verona
15:40		*Coffee break*		
16:00		**Technical session 4: robotics, safety and privacy**		
	16:00	Advanced Robot Cooperation for Assembly Tasks	Riccardo Muradore	Università di Verona
	16:20	Multi-robot Coordination for Efficient Logistics	Alessandro Farinelli	Università di Verona
	16:40	Passive Brain Computer Interface for Enhancing Safety in Industry 4.0	Ettore Cinquetti	Università di Verona
	17:00	Techniques to Enforce Safety in a Human-machine Environment	Davide Quaglia	Università di Verona
	17:20	Context-aware Privacy in Emergency Situations	F.Paci / E. Quintarelli	Università di Verona
17:40		**Project closing and future activities**	Alessandro Farinelli	Università di Verona

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Summary

- Project history and main results:
  - initial goal
  - from I4.0 to I5.0
  - roadmap
  - funded research projects
  - communication
  - final demonstrator
- Research outcome
  - research activities for building the demonstrator
  - related research activities

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Project History and Main Results

F.Fummi

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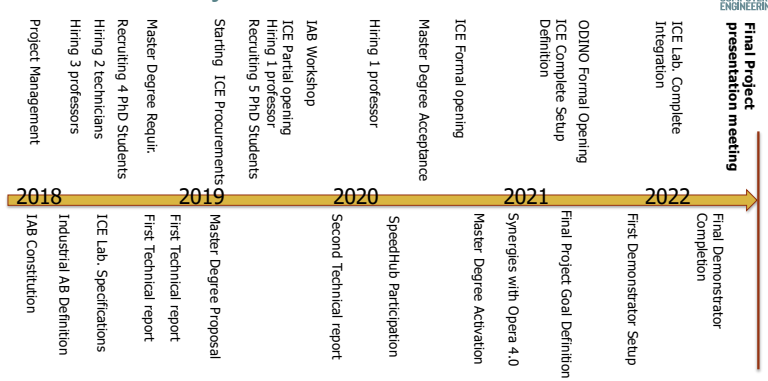
Project Time-Line Evolution



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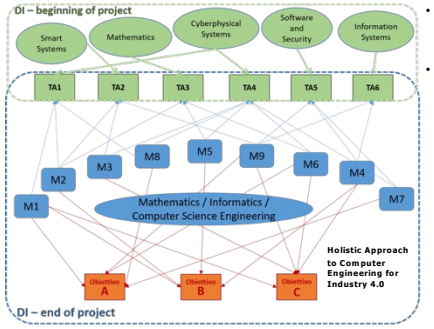
The Starting Idea



- **Objectives**:
  - A. Safety and security
  - B. Automatic design
  - C. Diagnosis and maintenance
- **Methodologies:**
  - M1. High level specifications of a production line using formal methods (TA1);
  - M2. Design of the line to compose verified basic elements (TA1, TA2, TA3);
  - M3. Modeling of the system and of workflows using common description languages (TA2, TA4);
  - M4. Integration of data flows and operation flows in one common representation environment (TA5, TA6);
  - M5. Optimization of the process with typical techniques from operation research (TA3, TA4);
  - M6. Verification of the line realization and of the process with (semi)formal methods based on efficient simulation of the line and process, and probabilistic identification methods (TA3, TA4):
  - M7. Security and privacy analysis to compose assessed modules with application of uniform techniques on the data flow from IoT sensors to cloud (TA4, TA5);
  - M8. Protection guarantee, with algorithms of interaction control with operators and users, and real-time estimation of the work environment (TA1, TA4);
  - M9. Realization of remote assistance with telecontrol, network security protocols, quality of service analysis, and visualization methods based on augmented reality (TA2, TA5, TA6).

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Promised Actions

- Creation of a **control structure** for the project
- Enrolment of the **new personnel** and their integration i… existing research areas
- **Focus of the research** towards the 3 project c… with doctoral fellowships and rewards
- Realization of the **laboratory for in… puter engineering**, to support research and training
- Preparation of the **teachi…**, with the support of the structured personnel and a first… a master class funded by companies
- Creation of **res… gies with companies** via the CSP, Joint Projects, re… ts (RIR)
- Activatio… **new MSc courses**
- Preparati… of **EU project proposals**

Mission Accomplished

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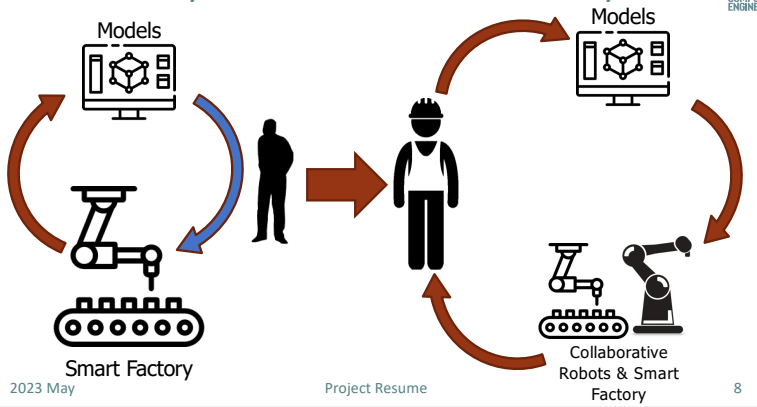
Industry 4.0 versus Industry 5.0



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Project Evolution

- Main 2021 and 2022 IAB review feedback:
  - identify a **real** and **innovative** problem and **converge** all project activities to solve it
- Solution:
  - direct the project to the current shift from I4.0 to I5.0
  - design a demonstrator including all competences of the project team going in the direction of I5.0
- Final project goal:
  - *theory, methodology and tools to build a completely reconfigurable production line able to interact with humans*

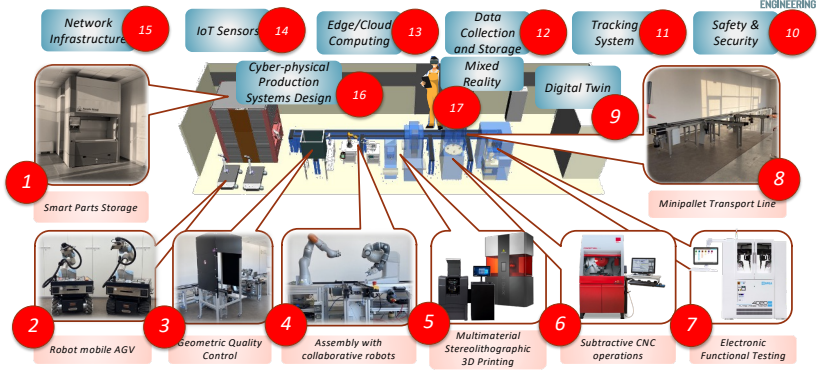
Industrial Computer Engineering (ICE) Lab

ICE Lab Evolution

A Patchwork of Industrial Contributions

ABB, ASEM DIGITAL AUTOMATION TECHNOLOGIES, DWS, EDALAB, emco, Ferretto Group Every solution, just one provider, FESTO, EXOR, FIA AUTOMAZIONI, FTP I.T. NEVER STOPS, GIMATIC A business of BARNES GROUP INC, KIRATECH WE DEVOPS IT, KUKA, PLUMAKE make it better, Robotnik, SIEMENS Ingegno per la vita, SPEA, energy group member of THE 3D GROUP, stratasys, rexroth A Bosch Company

A Completely Reconf. Production Line



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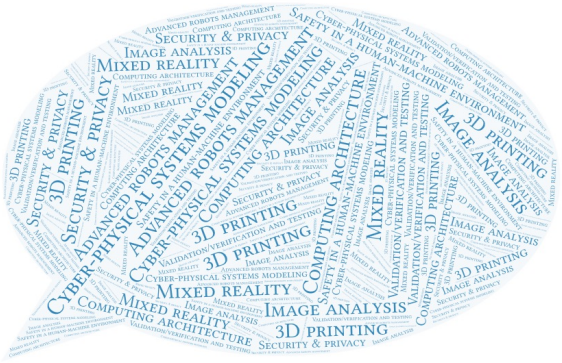
Technologies at a Glance

ICE Lab
INDUSTRIAL COMPUTER ENGINEERING



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Computer Engineering for Robotics and Smart Industry

Objective of the course

Dominate ICT technology for the *design*, *integration* and *management* of industrial production plants

Target professional figures

- Industrial IoT and Robotic Systems Designer
- Industrial Systems Integrator
- Production Programmer and Analyst

Strategic skills

- Industrial robotics
- Cyber-physical systems
- Data analytics
- Digital manufacturing

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Technology Transfer

- Industrial contacts:
  - Industrial Advisory Board (IAB) composed of 40 companies
  - > 40 companies visited ICE (2020-2022)
- Agreement with technology transfer company of Confindustria Verona (SpeedHub)
- ICE Research contracts (2020-2022):
  - Industrial: € 842.907
  - Regional/national/European: € 969.392
- Regional Innovative Networks:
  - Premani – Reload – ICT4SSL – AIR …
- PNNR Innovation Ecosystems:
  - iNEST: SubSpoke PD + Spoke UNIVR

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€ 660.907,00

Spin-off Companies

- NEEDLEYE Robotics
  - *reshaping biopsy and needle-based therapy through **AI-powered robotics***
- FACTORYAL
  - *a modular software architecture to fill the **automation gap** of current production lines following service-oriented manufacturing*
- Under construction:
  - THERMALX
    - *thermal ablation techniques through the use of **electrosurgical units***
  - MAEVE
    - *real-time 3D **Human-Pose estimation** for Industrial and Medical Systems*
  - QUALYCO
    - *solutions for **quality control** and predictive maintenance with the help of modern deep learning technologies avoiding long time for the user to train the system*

needleye robotics

FACTORYAL

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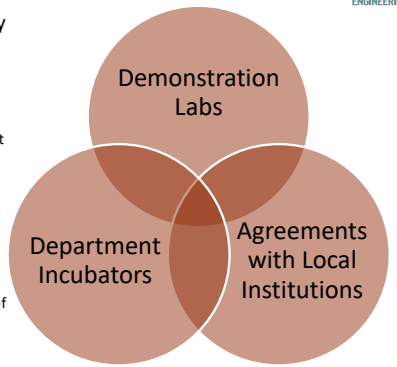
Technology Transfer Center

- ICE is a **Demonstration Lab**, a laboratory aiming at:
  - enabling the teaching of specialized courses
  - allowing research from realistic environments
  - working in demonstration mode to interact with companies
- They keep **research close to business** needs and therefore are facilitators of technology transfer
- Starting from this positive example, **other** demonstration labs have been constructed / are under construction:
  - *La Fabbrica del Vino* – on the value chain of the wine production
  - *Logistics* – integration of supply chains
  - *Biomed* – biomedical systems



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Spin-off Department

Computer Science	Engineering for Innovation Medicine
Information Systems	Cyber-Physical Systems
Theoretical Computer Science	Robotic Systems and Automation
Software Engineering & Security	Bioengineering
Artificial Intelligence	Intelligent Systems and Analytics

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UNIVERSITÀ di VERONA Department of ENGINEERING FOR INNOVATION MEDICINE

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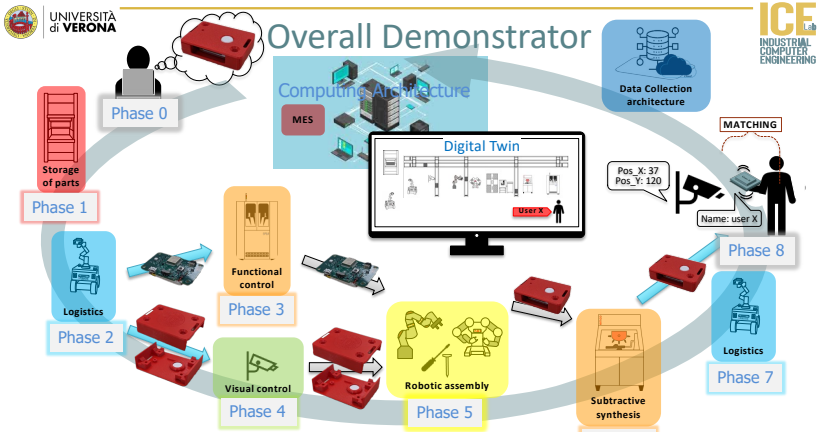
Overall Demonstrator



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Research results related to the different parts of the demonstrator

RESEARCH OUTCOME

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TECHNICAL SESSION 1:
CPS MODELLING AND (RE)CONFIGURATION

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Future perspective in CPS

CPPS MODELING AND (RE-)CONFIGURATION

Samarjit Chakraborty

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Role in the demo:

- CPPS configuration (phase 0)
- dashboard with digital-twin

CPPS MODELING AND (RE-)CONFIGURATION

Service Oriented Manufacturing: modeling, validation and synthesis
M. Lora

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Introduction

- **Unprecedented challenges in the design and management of manufacturing systems**
  - Constant demand of flexibility and efficiency
  - Production processes interacting with complex computational infrastructures
- Efficient manufactory requires to **evaluate** in advance the **impact** of:
  - Unexpected incoming **orders**, machines' **failures**, etc.
  - Production **planning**, **scheduling** and **re-scheduling**
  - Production line **reconfiguration**

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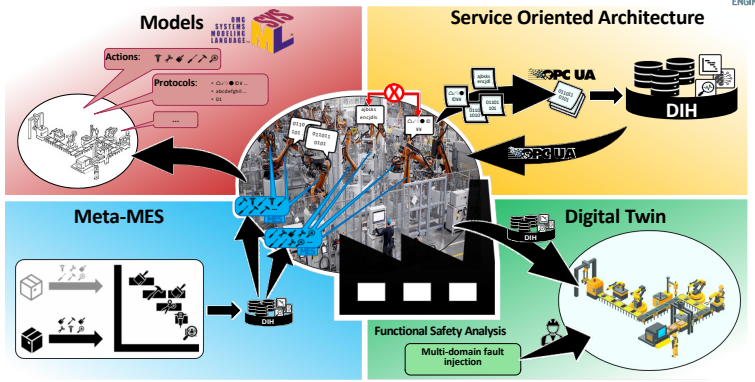
Factory Abstraction Philosophy



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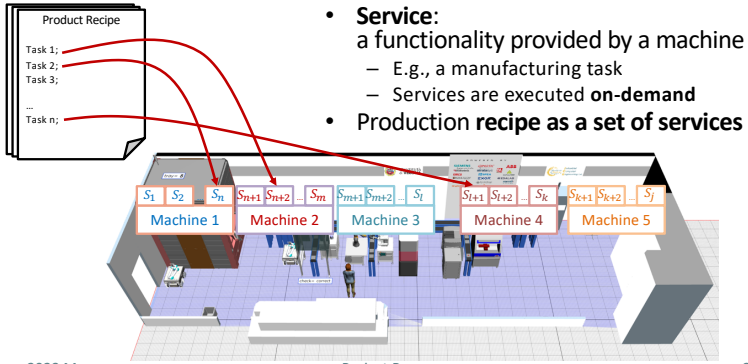
Service-oriented Manufacturing



- **Service**:
  a functionality provided by a machine
  - E.g., a manufacturing task
  - Services are executed **on-demand**
- Production **recipe as a set of services**

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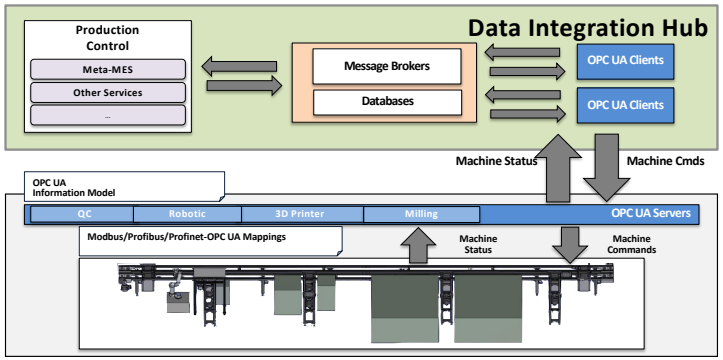
Service-oriented Manufacturing @ ICE Lab



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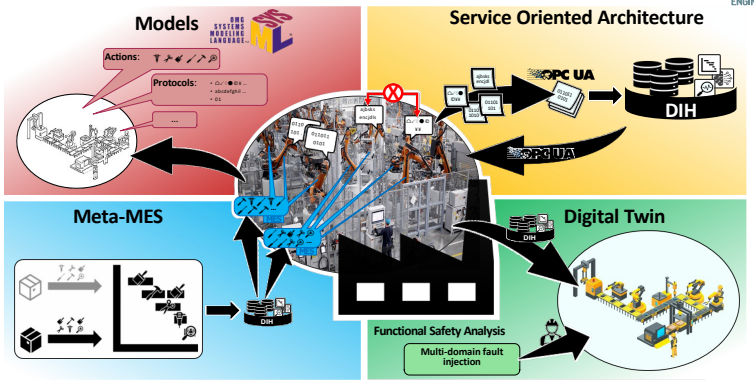
Factory Abstraction Philosophy



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Modeling Smart Manufacturing

- State-of-the-Art:
  - Equipment and Functions: **AutomationML**
  - Products and Production Recipes: **BPMN**
- Limited due to a **lack of expressiveness**
  - Not capable of modeling machines' advanced **behaviors**
  - Not capable of modeling **events**
  - Cannot represent **types of information** flowing through components
  - Cannot specify and elaborate **system requirements**

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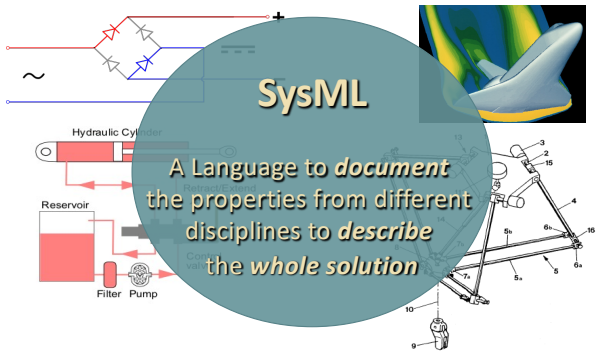
A Unified Systems Language



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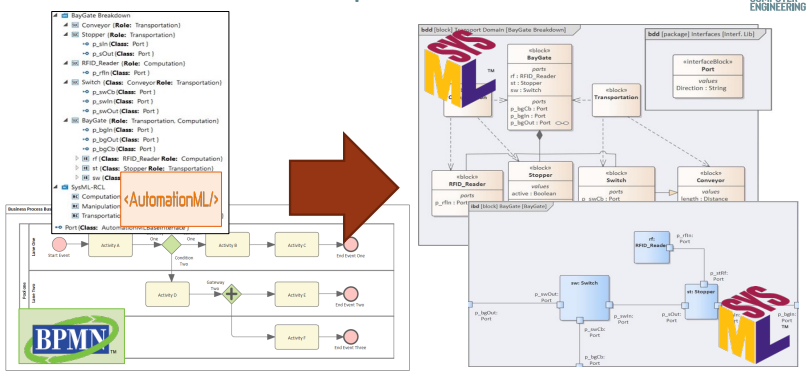
Bottom-up: Model Reuse



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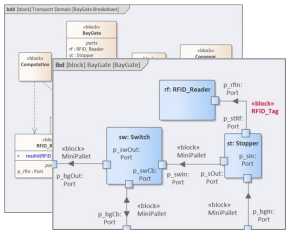
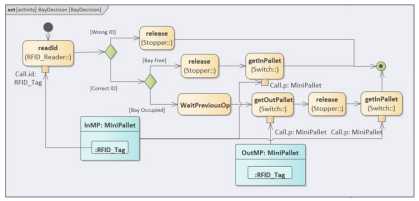
Top-down Modeling

- Generated diagrams can be **refined** with further information
  - Refining the **architecture** with additional information
  - Specify **functionalities** of the system's architecture
  - Specify products' **recipes**





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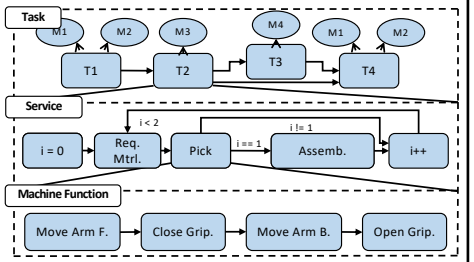
Hierarchical Process Modeling

- Three layers of knowledge
  - Each one depicting a particular abstraction perspective

- **Task Level**: recipe as a set of tasks
  - Task-resources graph
    - Nodes: **tasks**
    - Edges: partial order over tasks execution
  - Machines/Tasks associations
- **Service Level**: task as a set of services
  - Control flow graph
    - Nodes: **machine** or **infrastructure service**
    - Edges: control and data flows
- **Machine Function Level**: service as a sequence of actions
  - Directed graph
    - Nodes: machines' actions
    - Edges: partial order over actions execution



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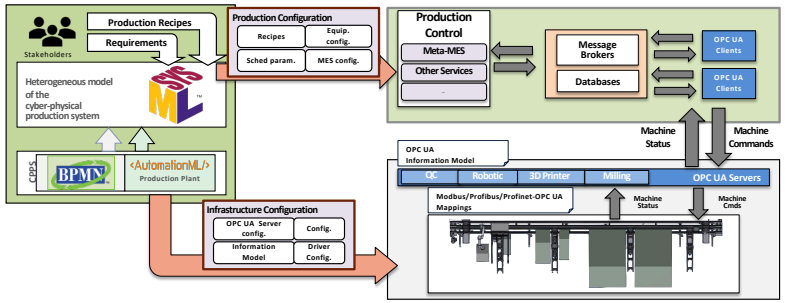
Model-based Configuration



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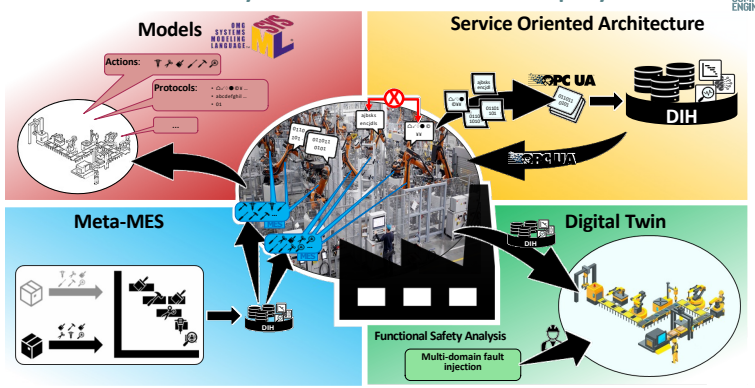
Factory Abstraction Philosophy



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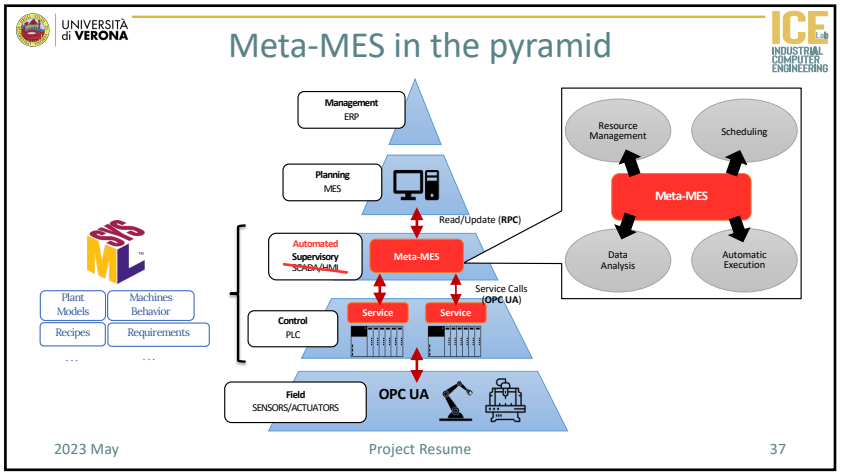
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ICE INDUSTRIAL COMPUTER ENGINEERING
Meta-MES in the pyramid
Management ERP
Planning MES
Automated Supervisory SCADA/HMI
Control PLC
Field SENSORS/ACTUATORS
Read/Update (RPC)
Meta-MES
Service Calls (OPC UA)
Service
Service
OPC UA
Resource Management
Scheduling
Meta-MES
Data Analysis
Automatic Execution
Plant Models
Machines Behavior
Recipes
Requirements
2023 May
Project Resume
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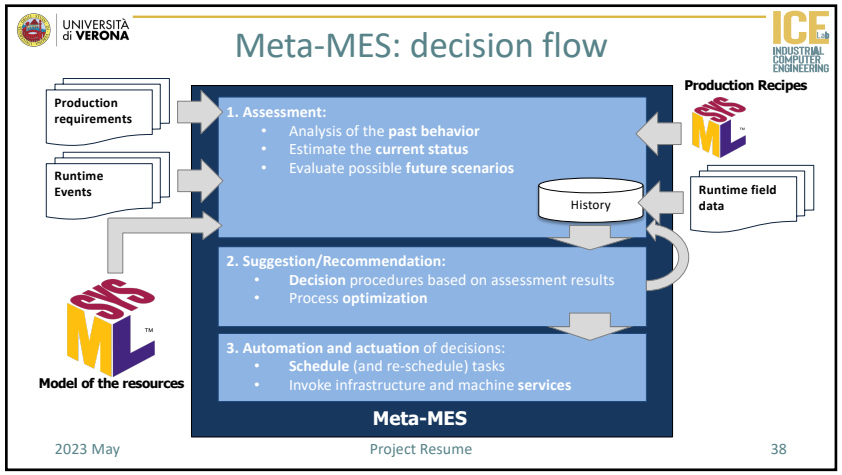
UNIVERSITÀ di VERONA
ICE INDUSTRIAL COMPUTER ENGINEERING
Meta-MES: decision flow
Production requirements
Runtime Events
Model of the resources
1. Assessment:
Analysis of the past behavior
Estimate the current status
Evaluate possible future scenarios
2. Suggestion/Recommendation:
Decision procedures based on assessment results
Process optimization
3. Automation and actuation of decisions:
Schedule (and re-schedule) tasks
Invoke infrastructure and machine services
Meta-MES
History
Production Recipes
Runtime field data
2023 May
Project Resume
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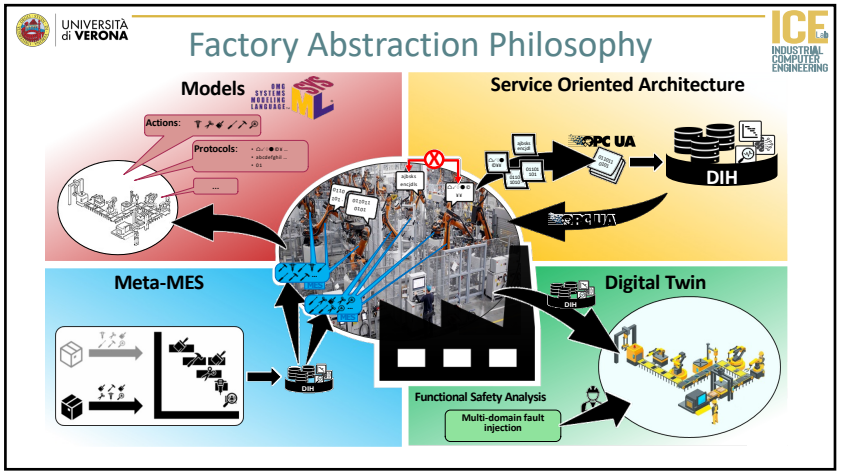
UNIVERSITÀ di VERONA
ICE INDUSTRIAL COMPUTER ENGINEERING
Factory Abstraction Philosophy
Models
Actions:
Protocols:
Service Oriented Architecture
OPC UA
DIH
Meta-MES
Digital Twin
Functional Safety Analysis
Multi-domain fault injection

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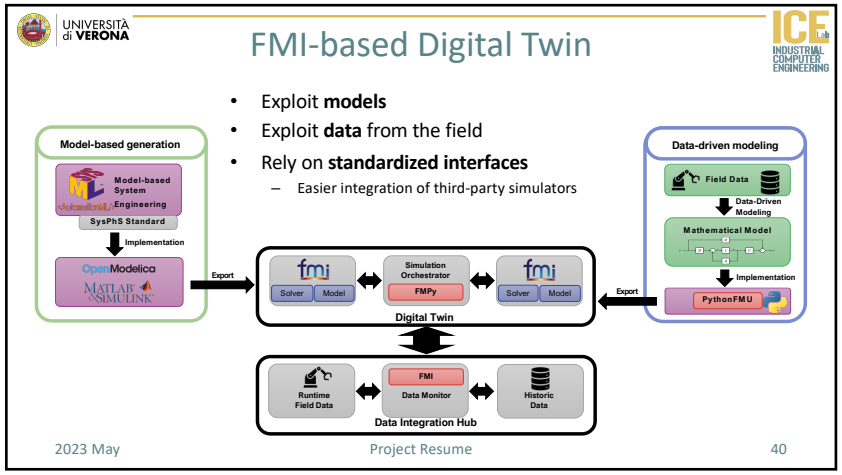
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ICE INDUSTRIAL COMPUTER ENGINEERING
FMI-based Digital Twin
Exploit models
Exploit data from the field
Rely on standardized interfaces
Easier integration of third-party simulators
Model-based generation
Model-based System Engineering
SysPhS Standard
Implementation
OpenModelica
MATLAB SIMULINK
Export
fmi
Solver
Model
Simulation Orchestrator
FMPy
Digital Twin
Data-driven modeling
Field Data
Data-Driven Modeling
Mathematical Model
Implementation
PythonFMU
Runtime Field Data
FMI
Data Monitor
Historic Data
Data Integration Hub
2023 May
Project Resume
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Related Publications

- **Production lines modelling**
  - S.Spellini, S.Gaiardelli, M.Lora, F.Fummi, *"Enabling Component Reuse in Model-based System Engineering of Cyber-Physical Production Systems"*, Proc. IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) 2021.
  - S.Gaiardelli, S.Spellini, M.Lora, F.Fummi, *"Modeling in Industry 5.0: What Is There and What Is Missing"*, Proc. Forum on specification & Design Languages (FDL) 2021.
  - S.Spellini, R.Chirico, M.Panato, M.Lora, F.Fummi, *"Virtual Prototyping a Production Line using Assume-Guarantee Contracts"*, IEEE Transactions on Industrial Informatics, vol. 17, n. 9, pp. 6294-6302, 2020.
  - S.Spellini, R.Chirico, M.Panato, M.Lora, F.Fummi, *"A Contract-based Methodology for Production Lines Validation"*, Proc. IEEE International Conference on Industrial Informatics (INDIN) 2019.
- **MES and Meta-MES**
  - S.Gaiardelli, S.Spellini, M.Lora, F.Fummi, *"A hierarchical modeling approach to improve scheduling of manufacturing processes"*, Proc. IEEE 31st International Symposium on Industrial Electronics (ISIE) 2022.
  - S.Gaiardelli, S.Spellini, M.Lora, F.Fummi, *"RRPDG: A Graph Model to enable AI-based Production Reconfiguration and Optimization"* submitted to IEEE Transactions on Industrial Informatics.
  - S. Gaiardelli, D. Carra, S. Spellini and F. Fummi, *"On the Impact of Transport Times in Flexible Job Shop Scheduling Problems"*, 27th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) 2022.
  - S. Gaiardelli, S. Spellini, M. Pasqua, M. Ceccato and F. Fummi, *"Integrating Smart Contracts in Manufacturing for Automated Assessment of Production Quality"*, IECON 2022 - 48nd Annual Conference on IEEE Industrial Electronics, 2022.
  - S.Spellini, R.Chirico, M.Panato, M.Lora, F.Fummi, *"Production Recipe Validation through Formalization and Digital Twin Generation"*, Proc. Design, Automation and Test in Europe Conference and Exhibition (DATE) 2021.

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Related Publications

- **Data Integration Hub**
  - S.Gaiardelli, S.Spellini, M.Lora, F.Fummi, *"A Software Architecture to Control Service-Oriented Manufacturing Systems"*, Proc. Design, Automation and Test in Europe Conference and Exhibition (DATE) 2022.
  - N. Dall'Ora, K. Alamin, E. Fraccaroli, M. Poncino, D. Quaglia and S. Vinco, *"Digital Transformation of a Production Line: Network Design, Online Data Collection and Energy Monitoring"*, in IEEE Transactions on Emerging Topics in Computing, vol. 10, no. 1, pp. 46-59.
  - S.Centomo, N.Dall'Ora, F.Fummi, *"Industrial-IoT Data Analysis Exploiting Electronic Design Automation Techniques"*, Proc. IEEE International Workshop on Advances in Sensors and Interfaces (IWASI) 2019.
  - S. Gaiardelli, N. Dall'Ora, F. Ponzio, E. Fraccaroli, S. Vinco, S. Di Cataldo and F. Fummi, *"A Data Fusion Service-Oriented Infrastructure for Production Line Monitoring"*, submitted to IEEE Transactions on Industrial Informatics.
- **Digital Twin**
  - F. Tosoni, N. Dall'Ora, E. Fraccaroli, S. Vinco and F. Fummi, *"Thermal Digital Twin of a Multi-Domain System for Discovering Mechanical Faulty Behaviors"*, Proc. IEEE International Conference on Industrial Informatics (INDIN) 2023.
  - F. Tosoni, N. Dall'Ora, E. Fraccaroli and F. Fummi, *"The Challenges of Coupling Digital-Twins with Multiple Classes of Faults"*, Proc. IEEE 23rd Latin American Test Symposium (LATS) 2022.
  - K. Alamin, S. Vinco, M. Poncino, N. Dall'Ora, E. Fraccaroli and D. Quaglia, *"Digital Twin Extension with Extra-Functional Properties"*, Proc of Design, Automation & Test in Europe Conference & Exhibition (DATE) 2021.
  - S.Centomo, A.Avogaro, M.Panato, C.Tadiello, F.Fummi, *"A Design Methodology of Multi-level Digital Twins"*, Proc. International Conference on Industrial Technology (ICIT) 2021.
  - S.Centomo, N.Dall'Ora, F.Fummi, *"The Design of a Digital-Twin for Predictive Maintenance"*, Proc. IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) 2020.
  - S.Spellini, M. Lora, F. Fummi, S. Chattopadhyay, *"Compositional Design of Multi-Robot Systems Control Software on ROS"*, ACM Transactions on Embedded Computing Systems, vol 18, n. 71, pp.1-24, 2019.

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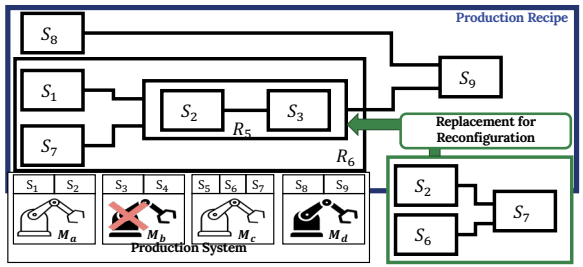
Ongoing Work

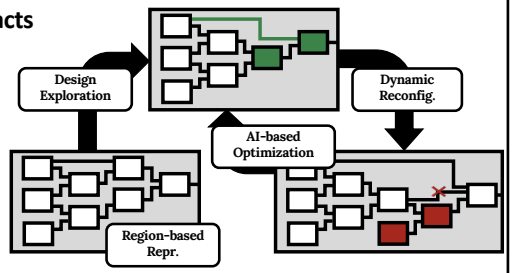
- **Regionalized Resource Process Dependence Graphs** (RRPDGs)
  - Inspired by Regionalized Value State Dependence Graphs
  - Enable **compositional reasoning** over production recipes



43

Future Work

- RRPDGs-based recipes modeling and optimization algorithms
  - **Formal analysis** and **compositional methods** for production optimization
- **Assume-Guaratee Contracts** paired with RRPDGs
- Modeling: **SysML v2**
  - Standard under development
- **Ontologies** to enrich models' information



44

Role in the demo:

- CPPS configuration (phase 0)
- dashboard with digital-twin

CPPS MODELING AND (RE-)CONFIGURATION

Knowledge Acquisition for Safe Programming
P. Fiorini

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ADDING AUTONOMOUS FEATURES

Problem:
The plant should autonomously plan its own tasks
The plant should deal with soft and deformable materials
The plant should be aware of the current status of the task
The plant should react to unexpected events and replan its tasks

Activity: Development of basic technologies for robot autonomy
Step 1: Represent the task knowledge from text and/or from data
Step 2: Plan the task phases
Step 3: Simulate the task in a realistic environment
Step 4: Execute and Monitor tasks
Step 5: Identify causal relations from the data
Step 6: Sensorize Tools and Instruments
Step 7: Extract plan on its own

People involved

- Paolo Fiorini
- Diego Dall'Alba
- Bogdan Maris
- Marco Bombieri
- Michele Ginesi
- Daniele Meli
- Giovanni Menegozzo
- Giovanni Muscolo
- Andrea Roberti
- Nicola Sansonetto
- Eleonora Tagliabue
- Maria Camilla Fiazza

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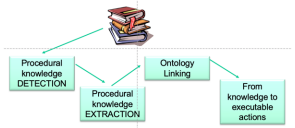
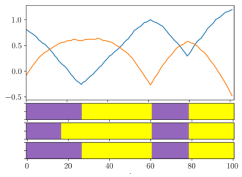
Konwledge Representation

- Top down (from textual description):
  - Text book interpretation:
    - extraction of procedural sentences
    - terms disambiguation
    - identification of logical rules
  - Bottom up (from practical execution)
    - developing suitable sensors
    - learning actions
    - identifications of task phases





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Extraction of Procedural Sentences

Development of annotated corpus to train the classifier

Robot-Assisted minimally invasive surgery

Described in:

Tons of books and academic papers

Contain: Surgical Procedural Knowledge

Useful for: Development of clinical decision support systems; Development of automation methods for some steps

We need: RSPF — Robotic Surgery Procedural Framebank

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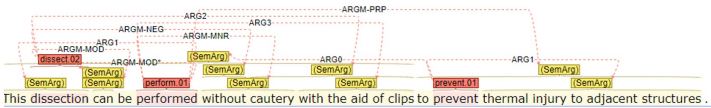
Extraction of Procedural Sentences

Classification of sentences in the surgical domani



1. Marco Bombieri, Marco Rospocher, Simone Paolo Ponzetto, and Paolo Fiorini. 2022. **The Robotic Surgery Procedural Framebank**. In Proceedings of the Thirteenth Language Resources and Evaluation Conference, pages 3950–3959, Marseille, France. European Language Resources Association. 2022
2. Bombieri, Marco; Dall'Alba, Diego; Fiorini, Paolo, "**A Linguistic Comparison Between Textual Datasets to Assess the Complexity of Surgical Robotic Procedural Descriptions**", 11th Joint Workshop on New Technologies for Computer/Robot Assisted Surgery 2022.
3. Marco Bombieri, Marco Rospocher, Simone Paolo Ponzetto, Paolo Fiorini, "**Machine understanding surgical actions from intervention procedure textbooks**", Computers in Biology and Medicine, Volume 152, 2023, 106415, ISSN 0010-4825,

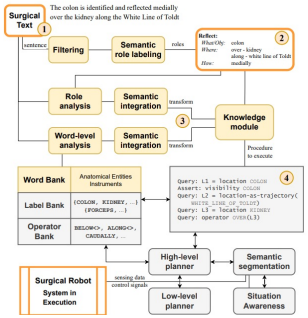
49

Terms Disambiguation for Safety

Understanding the true meaning of words:
- the case of "along"
- the construction of trust
- the implications for liability of autonomous systems

"Human supervision"
a) Reporting on performance;
(b) Providing binary feedback;
(c) Coaching;
(d) Giving approval to proceed with a given plan;
(e) Interrupting operation;
(f) Giving authorization to operate;
(g) Exercising prelation.

The meaning of "trust"
(1) personally trusting the technology enough to use it,
(2) societally certifying that the technology can be considered safe, and
(3) technically building cyberphysical human systems in manners that are worthy of being considered safe.



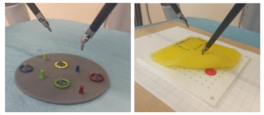
1. M.C. Fiazza, "**Whose Fault is it? Liability Profiles in Surgical Robotics**", Algorithmic Futures Policy Lab. Dec 1-2 2022, Human-Machine Collaboration in a Changing World.
2. Work in progress

50

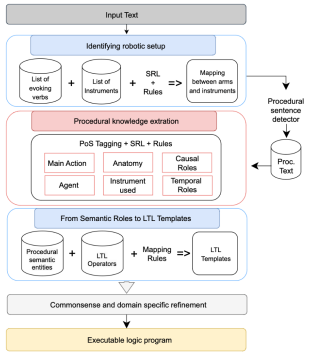
Extraction of Logical rules

AUTOMATE (lAngUage To lOgic teMplATEs), a pipeline for the automatic extraction of procedural Linear Temporal Logic addressing the three questions:

- [RQ1] Is the automatic translation of procedural textual descriptions to LTL templates a feasible task without relying on too strict and unrealistic language constraints?
- [RQ2] If the answer to RQ1 is positive, can the obtained templates be automatically translated to logic programs for direct implementation in an autonomous robotic architecture?
- [RQ3] Is there any advantage, e.g., in terms of performance, in using task knowledge extracted from texts rather than expert-written logic programs?



(a) Peg transfer. (b) Tissue retraction.



1. Accepted for publication in IEEE-RAL

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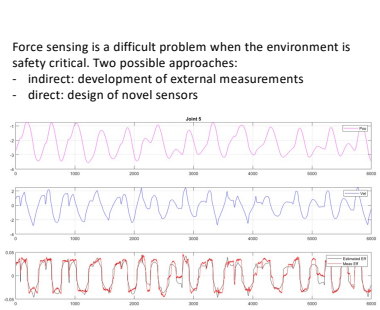
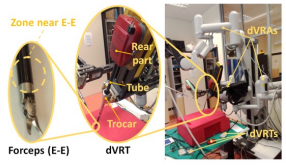
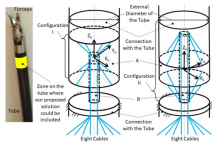
Novel Sensors for Data Collection

Force sensing is a difficult problem when the environment is safety critical. Two possible approaches:
- indirect: development of external measurements
- direct: design of novel sensors







1. G. Muscolo, P. Fiorini "**Force-Torque Sensors for Minimally Invasive Surgery Robotic Tools: an overview**", IEEE Transaction of Medical Robotics and Bionics, to be published in 2023.
2. G. Muscolo, P. Fiorini, et al. "**Compliant Legs In Biped Robots For Running Optimization",** International Journal of Mechanics and Control, Vol. 23, No. 02, 2022 ISSN 1590-8844

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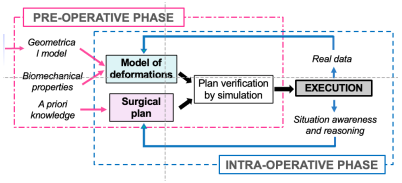
Learning Actions

Difficult to model actions can be learned with DL approaches.



Soft Tissue Simulation Environment to Learn Manipulation Tasks in Autonomous Robotic Surgery

Authors:
Eleonora Tagliabue, Ameya Pore, Diego Dall'Alba
Enrico Magnabosco, Marco Piccinelli, Paolo Fiorini

1. Sandro Ferrari, Eleonora Tagliabue, Bogdan Mihai Maris, Paolo Fiorini, "**Autonomous robotic system for breast biopsy with deformation compensation**", IEEE Robotics and Automation Letters, 2023.
2. P. M. Scheikl, E. Tagliabue, P.Fiorini et al., "**Sim-to-Real Transfer for Visual Reinforcement Learning of Deformable Object Manipulation for Robot-Assisted Surgery**," in IEEE Robotics and Automation Letters, vol. 8, no. 2, pp. 560-567, Feb. 2023, doi: 10.1109/LRA.2022.3227873.

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Identification of Task Phases

- We address the Generalization of Auto-Regressive Hidden Markov Models to Non-Linear Dynamics and Non-Euclidean Observation Space

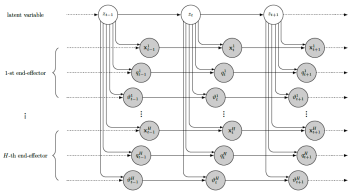
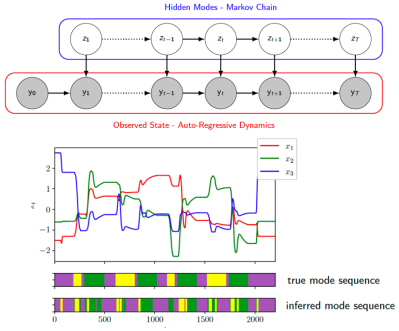


Figure 3: Graphical representation of a Pose+Gripper ARHMM.



1. M. Ginesi, N. Sansonetto, and P. Fiorini. Overcoming some drawbacks of dynamic movement primitives. Robotics and Autonomous Systems, 144:103844, 2021.
2. Under review in IEEE-RAL

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Technical Session 2: AI, Image & Signal Analysis

55

Edge-Brain: Edge Computing AI Solutions for Easy-to-Upgrade of Flexibility in Smart Manufacturing

Computing Architecture

Sukhan Lee

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Role in the demo:

- target person identification (phase 8)

IMAGE ANALYSIS

Real-time Distributed Human Pose Estimation in Industrial Applications
M. Boldo, M. De Marchi, E. Martini, S. Aldegheri, D. Quaglia, F. Fummi and N. Bombieri

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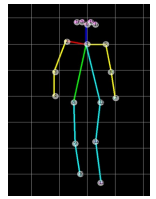
Background

- In Industry 4.0, operators and machinery coexist in the production line
- Collaboration between operator and machine
- Safety risk: possible injuries and production line down times



- **GOAL: Having a detailed knowledge of the operators' positions in the production line using visual Human Pose Estimation (HPE)**

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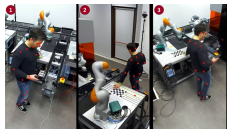
Motivation and Challenges

- Industrial environments are vast and machinery-rich
- Traditional **single-view HPE** is limited by occlusions and incomplete laboratory visibility.
- **Multi-view approach** for complete spatial coverage
- In a multi-camera approach, the redundancy of data (i.e. the same operator from different PoV) provides complete information



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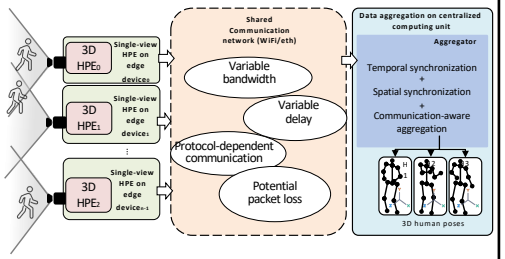
Overview

Applying a distributed system in an industrial environment poses several challenges:

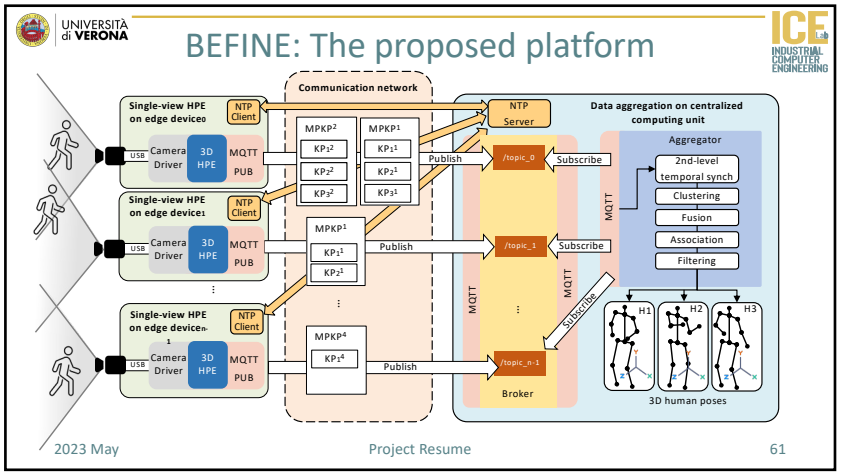
- Scalability
- Robustness to network variability
- Privacy-compliancy



Possible solution: A distributed network of edge devices

M. Boldo, M. D. Marchi, E. Martini, S. Aldegheri, D. Quaglia, F. Fummi, and N. Bombieri, "Real-time Multi-camera 3D Human Pose Estimation for Industrial Applications," Submitted to *IEEE Transactions on Automation Science and Engineering*.

60


UNIVERSITÀ di VERONA
BEFINE: The proposed platform
ICE INDUSTRIAL COMPUTER ENGINEERING
Communication network
Single-view HPE on edge device0
Single-view HPE on edge device1
Single-view HPE on edge device n-1
USB
Camera Driver
3D HPE
MQTT PUB
NTP Client
NTP Server
Data aggregation on centralized computing unit
Aggregator
2nd-level temporal synch
Clustering
Fusion
Association
Filtering
Publish
Subscribe
MQTT
/topic_0
/topic_1
/topic_n-1
Broker
H1
H2
H3
3D human poses
2023 May
Project Resume
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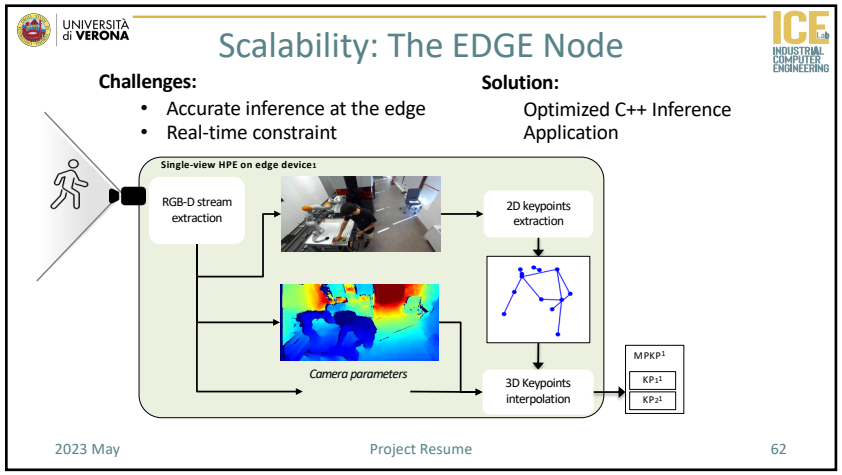
UNIVERSITÀ di VERONA
Scalability: The EDGE Node
ICE INDUSTRIAL COMPUTER ENGINEERING
Challenges:
Accurate inference at the edge
Real-time constraint
Solution:
Optimized C++ Inference Application
Single-view HPE on edge device1
RGB-D stream extraction
2D keypoints extraction
Camera parameters
3D Keypoints interpolation
2023 May
Project Resume
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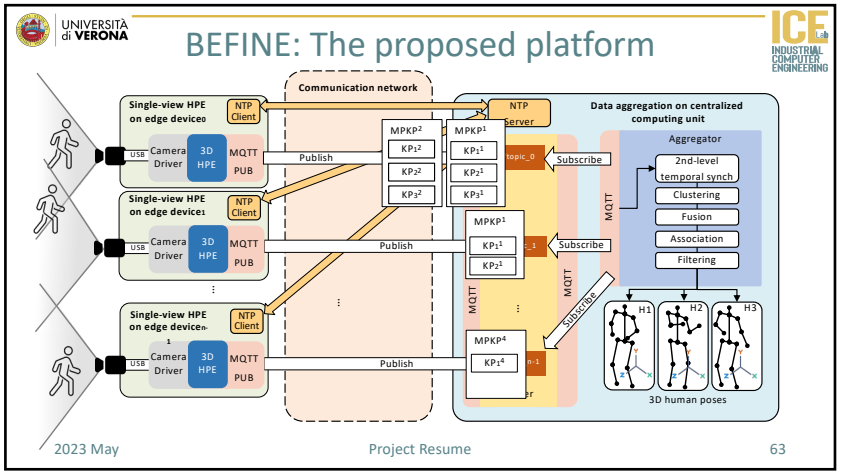
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Publish
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H1
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3D human poses
2023 May
Project Resume
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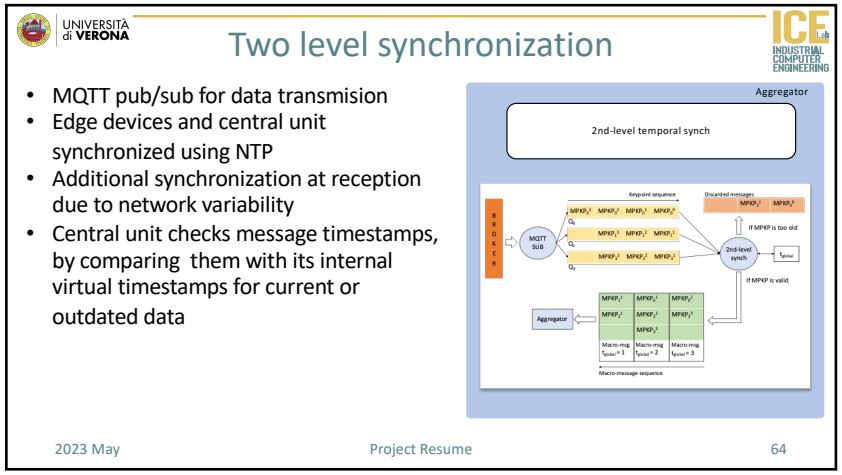
UNIVERSITÀ di VERONA
Two level synchronization
ICE INDUSTRIAL COMPUTER ENGINEERING
MQTT pub/sub for data transmision
Edge devices and central unit synchronized using NTP
Additional synchronization at reception due to network variability
Central unit checks message timestamps, by comparing them with its internal virtual timestamps for current or outdated data
Aggregator
2nd-level temporal synch
2023 May
Project Resume
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The aggregation

Aggregator

DBSCAN to identify the keypoint sets from each camera for each operator — Clustering

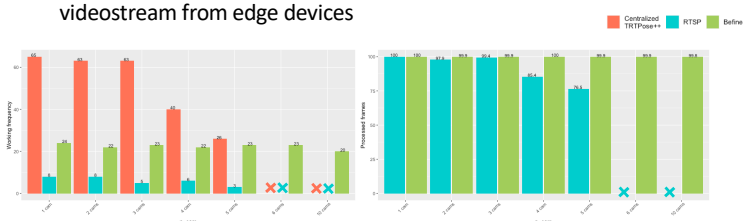
Merge multiple keypoints set for the same operators — Fusion

Munkres algorithm to assign the same id to skeletons belonging to the same person in two consecutive moment — Association

Filtering to correct errors in human pose approximation using a Gaussian filter within a sliding window for real-time data accumulation and filtering — Filtering

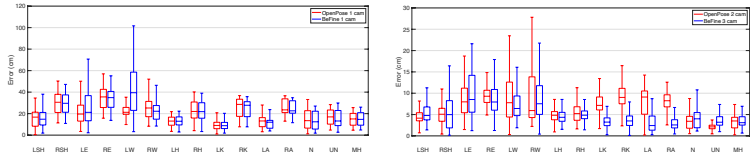
Scalability analysis

- We compare the proposed approach with:
  - Fully Centralized: RGB-D camera plugged on the centralized Server
  - RTSP with Centralized Inference: the Centalized Server receive the videostream from edge devices



Accuracy analysis

- We compared our approach with a Marker-Based Motion Capure System:



Another work on this topic:

A Dynamic and Collaborative Deep Inference Framework for Human Motion Analysis in Telemedicine

M. Boldo, D. Carra, D. Quaglia and N. Bombieri

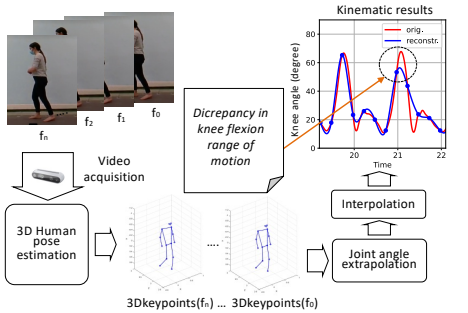
M. Boldo, D. Carra, D. Quaglia, N. Bombieri, "A Dynamic and Collaborative Deep Inference Framework for Human Motion Analysis in Telemedicine", Accepted at IEEE International Conference on EDGE COMPUTING & COMMUNICATION 2023 (IEEE EDGE 2023)

Background

Many applications need high accuracy

Network for accurate HPE are often heavy and cannot be run on edge devices

Solution: Collaborative inference



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Split Computing challenges

- When implementing a split computing strategy, the following factors need to be considered:
  - Latency of neural network inference on the edge device
  - Transmission time of pre-processed intermediate data from the first layers of the network
- For some applications, a guaranteed minimum working frequency is crucial to ensure QoS and avoid undersampling errors.

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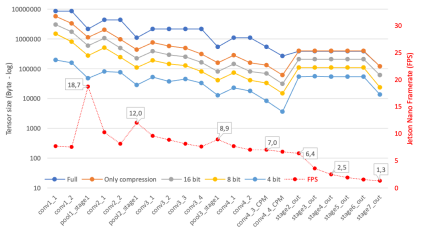
Neural Network profiling

Our solution involves a split computing methodology that includes **quantization** and **compression** of the neural network's output tensor.

- Profiling to determine data size
- Assess inference, quantization, and compression times



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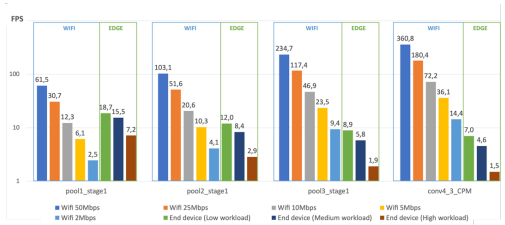
Neural Network profiling

A split neural network can exhibit latency variability due to the load on the edge device and the transmission network.

- Latency variability due to device load
- Latency variability due to transmission network load



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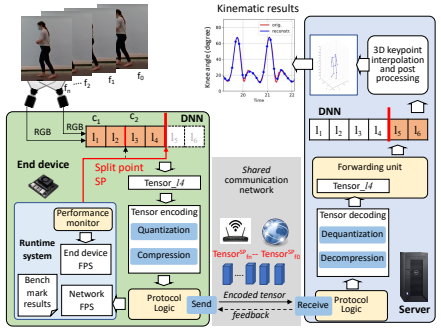
The proposed system

- Ad hoc UDP-based protocol to monitor the current bandwidth in the transmission network
- Dynamic algorithm for selecting the layer at which to apply the split to ensure the minimum required framerate



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Future works

Develop new methodologies to enhance accuracy and reduce latencies in human pose estimation applications.

- Optimize neural networks using **compression** techniques like pruning and quantization.
- Explore **split computing** techniques that consider underlying hardware.
- Data fusion with **inertial sensor** to enrich human pose estimation data.

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Role in the demo:

- target person identification (phase 8)
- augmented production line exploration

MIXED REALITY

Mixed Reality and Interaction
A. Giachetti, A.Caputo, M. Emporio, D. Pintani, M. Cristani, F.Cunico, F.Girella, A. Avogaro

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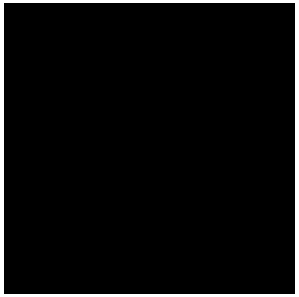
Mixed reality in ICE

Enabling technology (demos):

- Digital modeling: graphical twin of the lab
  - Training environment, monitoring real parameters
- Real world augmentation with Hololens 2
  - Updated information overlayed on the line
  - Internal/external tracking of subjects with computer vision
- Gestural interaction
  - Enabling system control



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Mixed reality in ICE

Enabling technology (demos):

- Digital modeling: graphical twin of the lab
  - Training environment, monitoring real parameters
- Real world augmentation with Hololens 2
  - Updated information overlayed on the line
  - Internal/external tracking of subjects with computer vision
- Gestural interaction
  - Enabling system control

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Scientific challenges and research results

- Effective navigation in the virtual factory
  - Our research**: characterize/avoid motion sickness in VR locomotion**
    - Paper conditionally accepted at INTERACT 2023 (A.Caputo et al.)
- Effective manipulation of virtual contents
  - Our research: **development and test of manipulation solutions**
    - Paper submitted at ISMAR 2023 (under review A.Caputo et al., under review)
  - Our research: **managing collaborative editing in mixed reality**
    - Paper submitted at CHItaly 2023 (D. Pintani et al., under review)
- Real time, continuous recognition of heterogeneous gestures
  - Our research: **recognition benchmarks, gesture recognizers development**
    - M Emporio, A Caputo, A Giachetti, M Cristani et al. **SHREC 2022 track on online detection of heterogeneous gestures** Computers & Graphics 107, 241-251
    - F.Cunico et al. **O-dMVMT: A Deep Multi-view Multi-task Classification Framework for Real-time 3D Hand Gesture Classification and Segmentation.** Computer Vision for Mixed Reality Workshop@CVPR 2023

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Navigation sickness (INTERACT 2023)

- We contributed to the reseach on motion sickness when navigating in VR with a novel user study
  - Goal: analyze sickness vs spatial orientation with different navigation control: manual (controller), teleporting, teleporting + animation
  - Novelty: evaluation with eye/head/torso tracking
  - Characterization of subjects according susceptibility to sickness

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Task

Eyes on teleporting: comparing locomotion techniques in Virtual Reality with respect to presence, sickness and spatial orientation

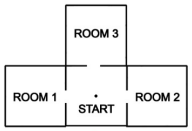
Anonymous ISMAR 2023 submission

80

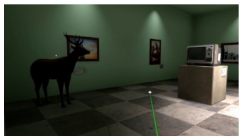
Task

- Follow the instruction on the plates navigating for 5 minutes
  - Number of items seen recorded
  - Eyes/head/torso movements recorded
- Compile questionnaires on sickness, presence
- Recall the position of selected items to check orientation

(a)



(b)



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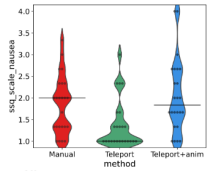
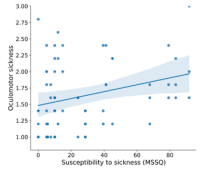
Outcomes

- Teleport technique induces less sickness (as in previous studies)
  - small correlation of oculomotor sickness with declared susceptivity only with the manual technique
- Subjects who rotated the head more in manual navigation suffered from increased sickness
- we did not find differences in the spatial dimension of presence among the methods

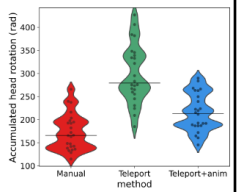


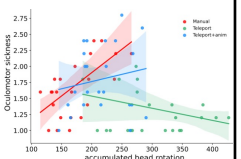


82

Outcomes

- subjects perceive the instant teleport as less difficult and more pleasant
- the manual technique gives a higher general presence (sense of being in a place) than teleport+animation, the tendency is also higher than teleport
- The manual technique seems to induce fewer eyes and body movements than the other two.
- small but significant negative correlation between the variation of the head angle and sickness in the manual condition only

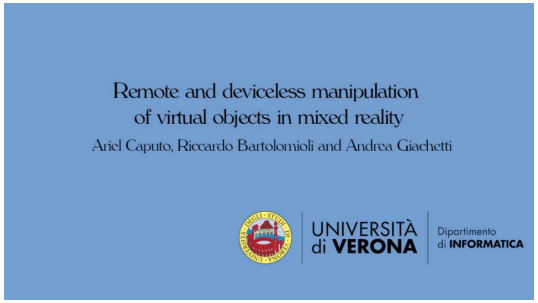




83

Manipulation in XR

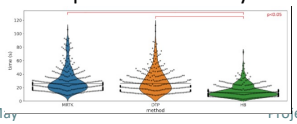
- Task: remote manipulation in XR
  - Three methods compared with an user study
  - Submitted to ISMAR 2023

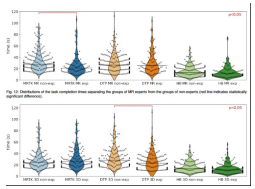


84

Outcomes

- Handlebar more efficient than default MRTK (despite the latter also support similar symmetric interaction)
  - Different affordance and constraints does influence the subjects behavior
  - Previous experience makes difference and widget-based desktop like interaction can be better for people used to work with 3D on desktops
  - Efficiency not strictly correlated to the perceived usability



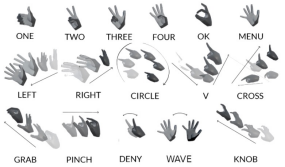


85

Gesture recognition benchmarking

- Gesture recognition methods are not often tested on realistic benchmarks
- We developed a novel benchmark for skeleton-based hand gesture recognition featuring:
  - Gesture spotting in continuous sequences
  - Specific evaluation metrics
  - Heterogeneous dictionary

  (static, dynamic coarse and fine gestures)

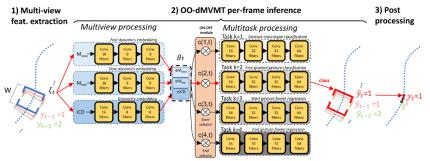


- M. Emporio, A.Caputo, A. Giachetti, M. Cristani, et al. SHREC 2022 track on online detection of heterogeneous gestures, Computers & Graphics, Volume 107 2022

86

Continuous gesture recognition

- Method beating the state of the art and implemented in Hololens 2 demos
  - F.Cunico et al. **O-dMVMT: A Deep Multi-view Multi-task Classification Framework for Real-time 3D Hand Gesture Classification and Segmentation**



OO-dMVMT
A Deep Multi-view Multi-task Classification Framework for Real-time 3D Hand Gesture Classification and Segmentation

Paper ID 11040

87

Gesture recognizer (**O-dMVMT**)

- Basic idea: exploit
  - multiple descriptors derived from hand poses (multi-view)
  - multiple annotations (but not always available) related to the continuous gesture recognition task
    - spotting, labelling, initial frame/last frame predictions
- Fast and reliable (low false positive rate)

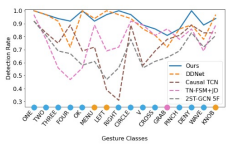


Figure 3. Detection rate per gesture class for SHREC'22. Points

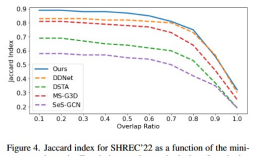


Figure 4. Jaccard index for SHREC'22 as a function of the minimum overlap ratio. For clarity, we show only the best 5 methods.

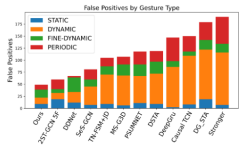


Figure 5. Stacked False Positives for SHREC'22 per model. The gestures are divided into 4 types (colors). The FPs for each type are then summed to show the total value. Lower is better.

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Use of the recognizer

- In the ICE lab using Hololens 2 headsets
- Future work: evaluate usability of gesture dictionaries for different tasks

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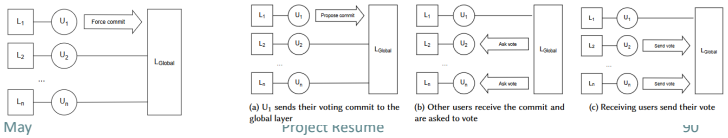
Collaborative editing in XR

- Collaborative design can be an important application of extended reality. But how to manage the virtual objects during the modifications?
  - Single shared scene with concurrency handling? Not ideal
  - Our solution: local and global layers with commit-based update of the global design
  - Submitted paper (CHITALY 2023)



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Collaborative editing in XR

CIDER

Collaborative Interior Design in Extended Reality

A system for the collaborative editing of 3D augmented scenes allowing two or more users to manipulate the virtual scene elements independently and without unexpected changes

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Role in the demo:

- logistics (phases 2 and 7)

ADVANCED ROBOTS MANAGEMENT

Anomaly Detection for Mobile Robots
A.Castellini, N. Fretti, F. Trotti, C. Morasso, A. Farinelli

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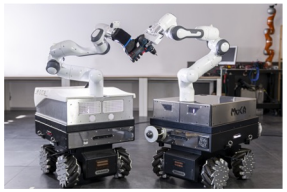
Introduction

Let the robots work with:

- Environment
- People
- Other robots
- And so on…



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Motivation

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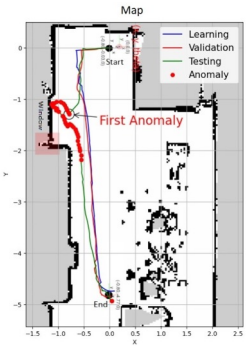
Focus On Anomalous Behaviors



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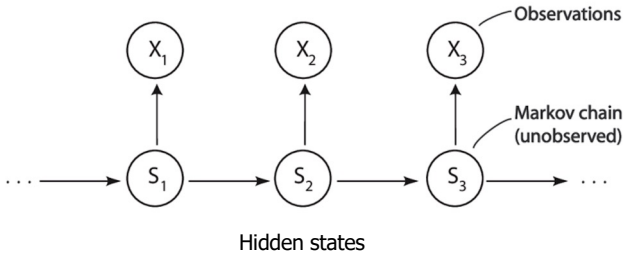
Anomaly detection: HMM



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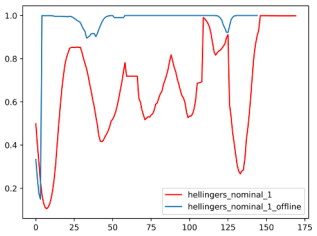
Anomaly detection: Hellinger Distance

Compute the similarity between two probability distribution, analytically:

$$H^2(P,Q) = \frac{1}{2}\int_{\mathcal{X}} \left(\sqrt{p(x)} - \sqrt{q(x)}\right)^2 \lambda(dx).$$



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Anomaly detection: *State of art

HMM:
- State → Robot behaviour
- Observations → Robot actuators and sensors
- Sequential

Hellinger Distance:
- Compare the observed distribution with the expected one

*[D. Azzalini, A. Castellini, M. Luperto, A. Farinelli, F. Amigoni] HMMs for Anomaly Detection in Autonomous Robots

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Anomaly detection: Training

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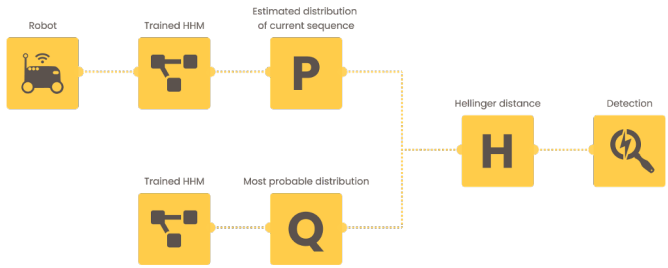
Anomaly detection: Online detection



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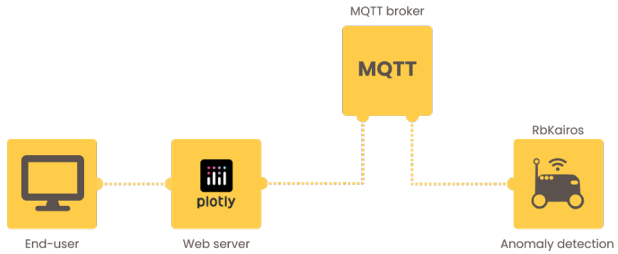
Application structure



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Result: nominal

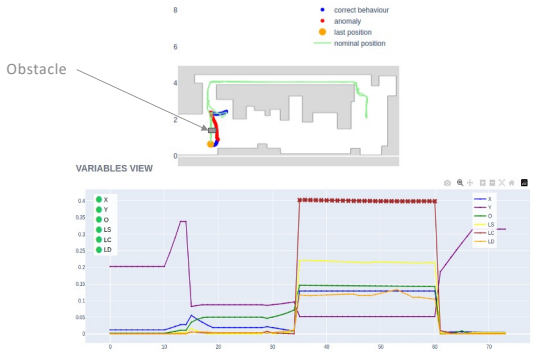
102

Result: nominal [gif]

*[A. Castellini, C. Morasso, and A. Farinelli]. HMM-based anomaly interpretation for intelligent robots in Industry 4.0.

103

Result: anomaly



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Result: anomaly [gif]

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Result: Main Difficulties

- Generation of anomaly components
- Integration with the Robot infrastructure, the anomaly detection is on the RB-Kairos
- Components communication in the ICE Lab
- Real-time User Interface

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Summary of publications related to this work

- D. Azzalini, A. Castellini, M. Luperto, A. Farinelli, and F. Amigoni. **HMMs for anomaly detection in autonomous robots**, in Proc. AAMAS 2020, p. 105–113, 2020.
- A. Castellini, C. Morasso, and A. Farinelli. **HMM-based anomaly interpretation for intelligent robots in Industry 4.0**. In 9th Italian Workshop on Artificial Intelligence and Robotics (AIRO 2022 @ AIxIA 2022), CEUR Workshop Proceedings AI*IA Series, accepted.
- A. Castellini, F. Masillo, D. Azzalini, F. Amigoni, A. Farinelli. **Adversarial Data Augmentation for HMM-based Anomaly Detection**. Submitted

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Summary of projects related to this work

GHOTEM
Global HOuse Thermal & Electrical energy Management

CORE-WOOD
Riposizionamento competitivo della filiera del legno

SAFE PLACE
Sistemi IoT per ambienti di vita salubri e sicuri

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Conclusions

The proposed application manages to detect anomalies of the RB Kairos in real-time and to identify the source of the anomaly using the Hellinger distance decomposition.

Future work:

- Improvement of the **performance** using larger datasets and data augmentation
- Improvement of the **explainability** extending the anomaly signal decomposition
- Extension to **active** anomaly detection merging HMM into Markov Decision Processes

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Role in the demo:

- gadget validation (phase 4 and 6)

Validation/verification and testing

Anomaly Detection on Industrial Scenarios
F.Setti

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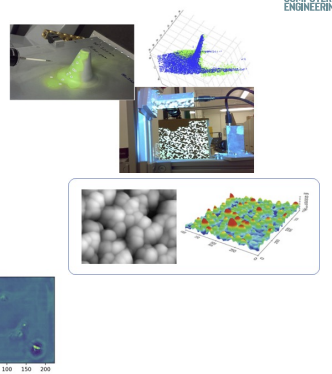
Industrial quality control

- 3D shape reconstruction
  - Single Point Incremental Forming
  - Multicamera vision system
  - Random pattern projection
- Surface analysis
  - Grain segmentation in thin film deposition
  - Atomic Force Microscope
  - Surface defect detection



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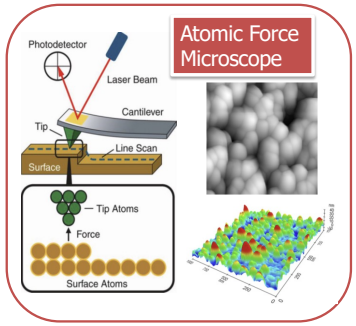
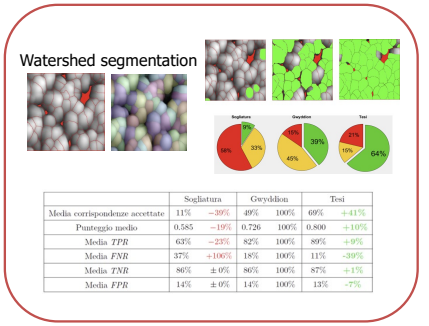
Surface Analysis





	Sogliatura		Gwyddion		Tesi	
Media corrispondenze accettate	11%	−39%	49%	100%	69%	+41%
Punteggio medio	0.585	−19%	0.726	100%	0.800	+10%
Media *TPR*	63%	−23%	82%	100%	89%	+9%
Media *FNR*	37%	+100%	18%	100%	11%	-39%
Media *TNR*	86%	± 0%	86%	100%	87%	+1%
Media *FPR*	14%	± 0%	14%	100%	13%	-7%

N Lanza et al. "Grain Segmentation in Atomic Force Microscopy for Thin-Film Deposition Quality Control". ICIAP 2019

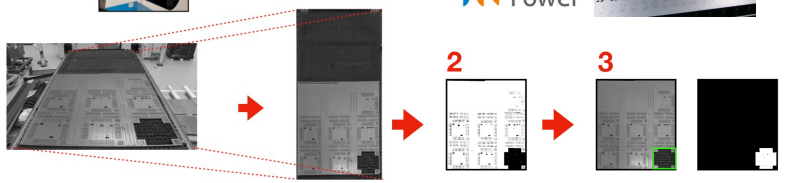
112

Manual sorting assistant

- Identify objects from cut planning file
- Identify picked object
- Return the destination box
- Highlight objects of the same customer

Prima Power

21MPx camera



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Character recognition

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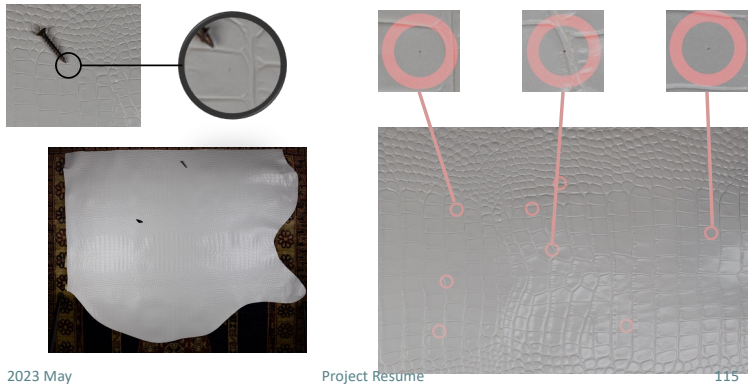
Defect detection on leather tissue



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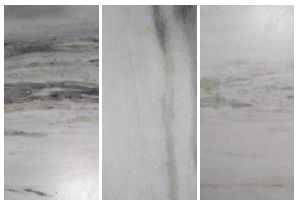
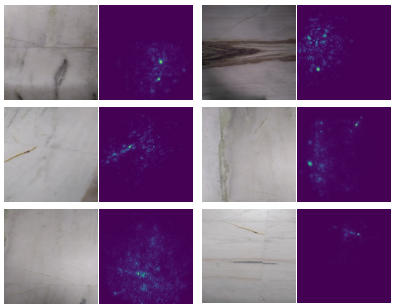
Surface defect detection on marble

Weakly supervised learning

- 8 training images of good samples
- Dataset: Marble surface anomaly detection





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Surface defect detection on marble

Unsupervised learning

- Training images with no labels (good/bad)
- Dataset: Marble surface anomaly detection

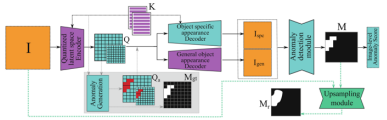
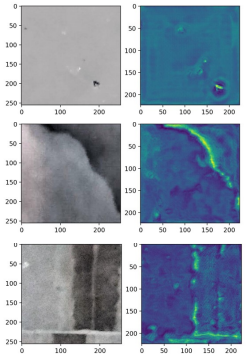


Fig. 2. The DSR architecture. During training, the non-anomalous image quantized feature maps (Q_{hi}, Q_{io}) are replaced by the anomaly augmented feature maps (Q_{ahi}, Q_{aio}) generated by the latent space sampling procedure (shaded block). The pathway marked with green arrows are used when training the Upsampling module with simulated smudges and at inference.



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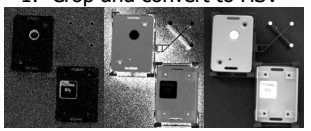
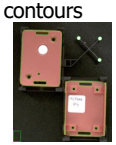
Quality Control in ICE demo

1. Crop and convert to HSV



2. Adaptive thresholding

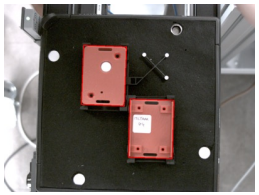
3. Extract contours



4. Fit the model

5. Return the validation output

```
V=[[1,1],[1,1]]
```



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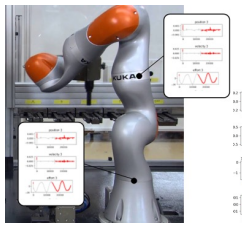
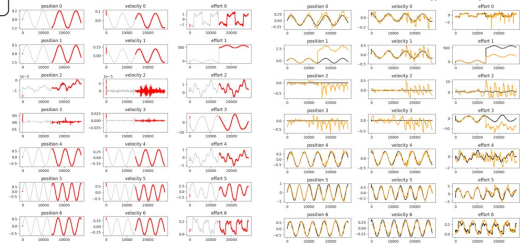
Industrial robot anomaly detection



Multivariate anomaly detection

Anomalies (red) Reconstruction (yellow)



E Fiorini et al. "IndRAD: A Benchmark for Anomaly Detection on Industrial Robots". IML 2022

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Future directions

- Reduce setup effort
  - Few-shot Learning
  - Continual Learning
  - Natural Language Processing
  - Diffusion Models
- Smart maintenance
  - Forecasting with Transformers
  - Generative Anomaly Detection

QUALYCO
A quality company

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TECHNICAL SESSION 3:
INNOVATIVE COMPUTING ARCHITECTURES

121

Corsi e Ricorsi: Here We Go Again

COMPUTING ARCHITECTURE

Alberto Sangiovanni-Vincentelli

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Role in the demo:

- computing architecture

COMPUTING ARCHITECTURE

On the Kubernetes Orchestration of Mixed-Criticality Software and Checkers
F.Lumpp – S.Germiniani
N. Bombieri – F. Fummi – G. Pravadelli

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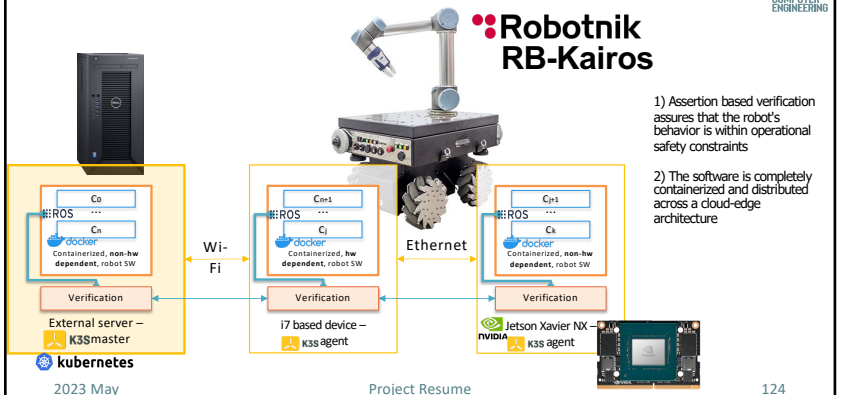
Kairos K3s architecture



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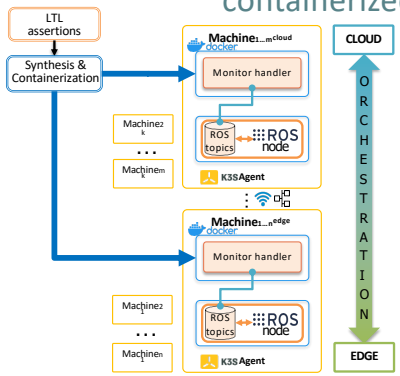
Edge-Cloud assertion-based containerized verification



- Assertions are encoded through Linear Temporal Logic (LTL)
- Automatically synthetized in ROS-compatible C++ code
- Monitors use pub-sub paradigm to read ROS topics and perform verification
- Containerized for orchestration
- Assertions are dynamically distributed onto the edge-cloud architecture through load balancing and assertion makespan minimization

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Containerization and Mixed Criticality in Robotics

- *Containerization* & *Orchestration* of *mixed criticality systems*: a container may encapsulate ***real-time tasks***
  - Additional schedulability parameters for orchestration needed
- State-of-the-art orchestration platforms (e.g., Kubernetes) do not support real-time parameters

kubernetes

The goal

- Extend Kubernetes (the de-facto reference standard for container orchestration) to schedule software for robotic applications with mixed-criticality requirements

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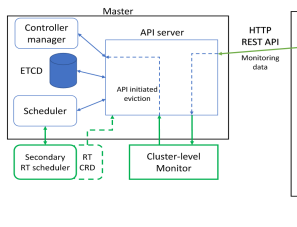
Real-Time containers

Extension of the Kubernetes architecture to schedule and monitor containerized Real-Time tasks



1) Plugins to include and consider RT information during scheduling
2) A container-level monitor that integrates into ROS nodes and communicates to a cluster-level monitor that checks for temporal violations to apply a mitigation strategy

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1) Real-Time data in Kubernetes

```
15 apiVersion: apps/v1
16 kind: Deployment
17 metadata:
18   name: nginx-deployment
19   labels:
20     app: nginx
21 spec:
22   replicas: 1
23   selector:
24     matchLabels:
25       app: nginx
26   template:
27     metadata:
28       labels:
29         app: nginx
30         rt-scheduling: example-realtime-data
31     spec:
32       schedulerName: RT-scheduler
33       containers:
34       - name: nginx
35         image: nginx:1.14.2
36         ports:
37         - containerPort: 80
38       tolerations:
39       - key: "RealTime"
40         operator: "Equal"
41         value: "RT"
42         effect: "NoSchedule"
```

RT information is included through a CRD in the standard Kubernetes deployment

```
1  apiVersion: rt.scheduling/v1
2  kind: RealTime
3  metadata:
4    name: example-realtime-data
5  spec:
6    criticality: C
7    rtPeriod: 100
8    rtDeadline: 100
9    rtWcets:
10   - node: nodeA
11     rtWcet: 50
12   - node: nodeB
13     rtWcet: 60
```


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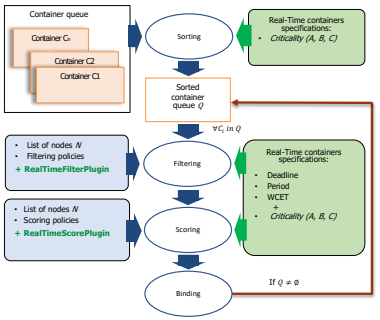
1) Extended RT scheduling



- Extend the container specification to add Real-Time scheduling parameters (deadline, period, WCET, criticality)
- Extend the scheduler to consider those parameters and perform the schedulability analysis

1) Filtering and Scoring plugins

Filtering plugin:

$$\sum_{i}^{RT \cup \{t_{new}\}} \frac{\text{WCET}_i}{P_i} \leq M * \frac{\text{sched\_rt\_runtime\_us}}{\text{sched\_rt\_period\_us}}$$

- Perform the schedulability analysis for the container on each node, if the schedulability equation is not satisfied, the node is unschedulable*

Scoring plugin:

$$\forall n \in N: \quad nRank = \begin{cases} 1 - \frac{n.\text{thresholdUT} - \text{newUT}_n}{n.\text{thresholdUT}} & \text{if criticality} = A \\ \frac{n.\text{thresholdUT} - \text{newUT}_n}{n.\text{thresholdUT}} & \text{if criticality} = C \end{cases}$$

If criticality = B:

$$\forall n \in N: \quad nRank = \begin{cases} h\left(\frac{n.\text{thresholdUT} - \text{newUT}_n}{n.\text{thresholdUT}}\right) & \frac{n.\text{thresholdUT} - \text{newUT}_n}{n.\text{thresholdUT}} \leq \frac{1}{K} \\ g\left(\frac{n.\text{thresholdUT} - \text{newUT}_n}{n.\text{thresholdUT}}\right) & otherwise \end{cases}$$

- Containers are distributed on nodes depending on their criticality and the node RT load

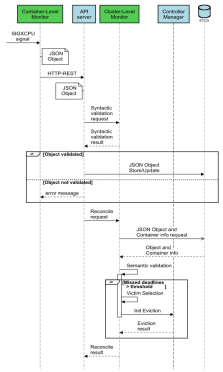
*A non-schedulable node is intended in the Kubernetes terminology, i.e., the node does not satisfy the requirements set by the container that has to be scheduled.

2) Cluster-level monitor

- The cluster level monitor communicates with a library and Kubernetes through custom resource definitions

```
apiVersion: rt.monitoring/v1alpha1
kind: Monitoring
metadata:
  name: monitoring-test
spec:
  node: nodeA
  containerName: nginx
  missedDeadlinesPeriod: 0
  missedDeadlinesTotal: 0
```

The custom monitoring object



Analyzing the Real-Time plugins and operator

- 16 RT containers with 100% RT utilization for two nodes and total CPU utilization is 40% (instant T_0)
- There is CPU time available for the (standard) orchestrator, while the CPU is fully loaded for the RT containers
- 8 RT containers with 100% RT utilization for one node (instant T_0)
- When a new RT container arrives during RT admission test
- When a new RT container has to be deployed, in execution (instant T_0+t_α) resulting in an overload of the node RT utilization selected by the standard Kubernetes
- The proposed orchestration platform guarantees that the correct node (one with 0% RT utilization) is always selected.
- With the proposed solution, the new container remains pending until any RT resource becomes available in any of the nodes of the cluster

Configuration	T_0 Deployed	T_0 Pending - Rejected	$T_0 + t_\alpha$ Deployed	$T_0 + t_\alpha$ Pending - Rejected
Native-K3S	N_1: 8 N_2: 8	1 - 0	N_1: 9 N_2: 8	0 - 1
Proposed RT-K3S	N_1: 8 N_2: 8	1 - 0	N_1: 8 N_2: 8	1 - 0
Native-K3S	N_1: 8 N_2: 0	1 - 0	N_1: 9 N_2: 0	0 - 1
Proposed RT-K3S	N_1: 8 N_2: 0	1 - 0	N_1: 8 N_2: 1	0 - 0

RT-containers isolation performance improvements

- The ARM driver communicates with the HW at 120Hz
  8ms deadline, 7.6ms WCET, 95% utilization
- RT SLAM running as RT (2nd row) or RT criticality B (3rd row) with the same or lower priority compared to the ARM respectively

1. Native K3S orchestration maps tasks into cluster **randomly**
2. Non-RT + RT does **not** have enough **isolation**
3. Multiple criticality levels and isolation reduce the number of **missed deadlines** for the ARM driver to the **minimum**

Config.	Avg runtime (ms)	Std. dev.	Observed WCET (ms)	Max. lateness (ms)	Missed deadlines: arm driver	Missed deadlines: SLAM
Native	7.15	3.58	32.32	-	24.50%	-
non-RT + RT	0.20	0.11	5.72	0.95	1.28%	≈ 0%
non-RT + A + B + C	0.15	0.07	2.06	0.49	0.17%	≈ 0%

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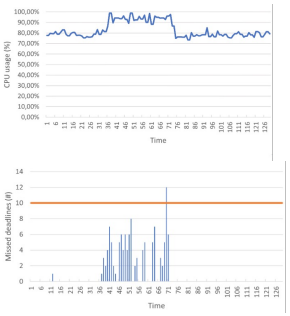
Real-Time monitoring and state-less migration

- Hog application deployed on the RT-capable Jetson as non-RT mixed criticality task
- At time **36**, the CPU usage spikes due to the **additional** load
- At time **71**, the missed deadlines cross the **threshold**, and the cluster-level monitor starts the eviction process
- The hog application has the highest CPU utilization and is evicted
- Hog application is sent back to the scheduling queue and **restarted** elsewhere (performing a de facto state-less migration)



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Results summary

- Edge-Cloud Assertion-based containerized verification allows to monitor custom values from the standard ROS interface and guarantee the safe behavior of the robot
- Real-time containers are deployed with a new set of specifications and dedicated plugins to improve task placement and reduce risks of temporal violations
- Unforeseen situations are handled through a state-less migration of containers by the cluster-level monitor to reduce load on devices with a high number of missed deadlines

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Future work and summary

- Future work includes improving assertion generation to include real-time constraints such that constraint violation notifications are received in a guaranteed time
- Improve the cluster-level monitoring with more sophisticated techniques to reduce the number of temporal violations instead of relying only on eviction-based state-less task migration

1. F. Lumpp, S. Aldegheri, H. Patel, and N. Bombieri, "Task mapping and scheduling for OpenVX applications on heterogeneous multi/many-core architectures," *IEEE Transactions on Computers* (***TCOMP '21***)
2. F. Lumpp, M. Panato, N. Bombieri, and F. Fummi, "Container-based Design Methodology for Robotic Applications on Kubernetes Edge-Cloud architectures," *2021 Forum for Specification and Design Languages* (***FDL '21***)
3. F. Lumpp, F. Fummi, H. Patel, and N. Bombieri, "Containerization and orchestration of software for autonomous mobile robots: a case study of mixed-criticality tasks across edge-cloud computing platforms," in 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (**IROS '22**)
4. F. Lumpp, M. Panato, N. Bombieri and F. Fummi, "A Design Flow based on Docker and Kubernetes for ROS-based Robotic Software Applications, " in ACM Transactions on Embedded Computing Systems (**TECS '23**)
5. N. Bombieri, S. Germiniani, F. Lumpp and G. Pravadelli, "Enabling Runtime Assertion-based Verification of Robots on Edge-Cloud Architectures," in IEEE Transactions on Computers (pending review) (**EDGE '23**)
6. F. Lumpp, F. Fummi, H. Patel and N. Bombieri, "Enabling Kubernetes Orchestration of Mixed-Criticality Tasks in the Edge-Cloud Continuum," in IEEE Transactions on Computers (pending review) (**T-RO '23**)

Thank you for your attention

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Role in the demo:

- gadget parts production (phase 1)

3D PRINTING

Computational Design for 3D printing
A.Giachetti, F.A. Fanni

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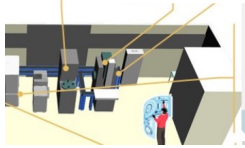
Digital manufacturing in ICE

- Enabling technology (demos):
  - Milling machine (EMCO ConceptMill 105)
  - 3D printers (3D DWS Systems X PRO S printer, 3D Stratasys J826 printer)


Subtractive CNC Machine



Stereolithographic and Multimaterial 3D Printing

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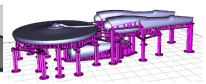
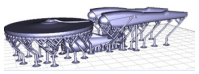
Digital manufacturing in ICE

- Scientific challenges?
  - Optimize the printing processes (e.g. supporting, material use, etc.)
  - Support the design of nice printable shapes

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Scientific challenges and research work

Our work:

- Development of techniques to create decorations on surfaces
  - Not trivial on generic surfaces: the standard solution (texture parametrization+texture mapping)induces distortions in patterns
  - Work on particular and difficult artistic design tasks
    - Clay-like volumetric decorations on surface: Fanni, F. A., Pellacini, F., Scateni, R., & Giachetti, A. (2022). **PAVEL: decorative patterns with packed volumetric elements.** ACM TRANSACTIONS ON GRAPHICS, 41(2), 1-15.
    - Geodesic lines creating floral design on manifold surfaces Albano V, Fanni FA, Giachetti A., Pellacini F., **Floralsurf: space-filling geodesic ornaments** Eurographics Symposium on Rendering 2023
- Development of methods for shape decomposition
  - F.Fanni et al, **Outside-in Priority-based Approximation of 3D Models in LEGO Bricks** Eurographics conf. on Smart Tools and Applications in Graphics 57-67

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PAVEL: volumetric patterns

- Idea
  - Surface packing
  - Soft body deformation
  - Desirable artisanal appearance
  - Mimicking artworks with parametric control

Courtesy of Heather Knight, @elementclaystudio

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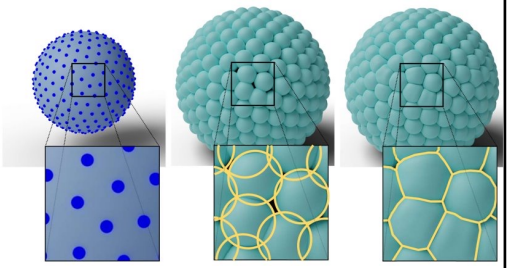
The pipeline

- Surface sampling
- Element initialization
- Element deformation



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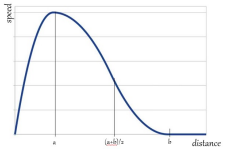
The deformation

- Overlapping elements
- Remove the overlap
- Volume recovery
- Drive the growth with speed fields

$$f_{a,b}(x) = \begin{cases} 0 & x \le 0 \\ -\frac{x^2}{a^2} + 2\frac{x}{a} & x > 0, x < a \\ -\frac{2(x-a)^2}{(b-a)^2} - 1 & x > a, x \le \frac{a+b}{2} \\ \frac{2(x-a)^2}{(b-a)^2} + b(x-a) + 2 & x > \frac{a+b}{2}, x \le b \\ 0 & x > b \end{cases}$$



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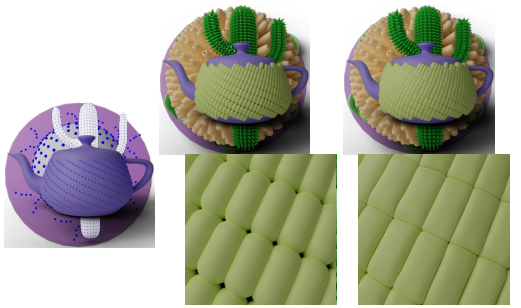
The sampling

- Manual
- Isotropic
- Anisotropic



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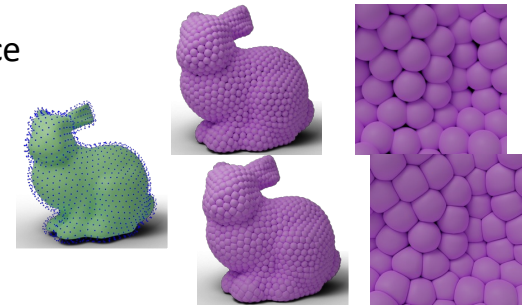
Offset surface sampling

- On surface
- Offset surface



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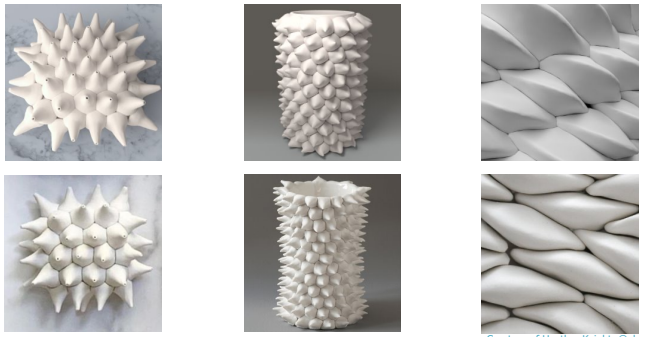
Results – Real v. Digital



Courtesy of Heather Knight, @elementalavstudio

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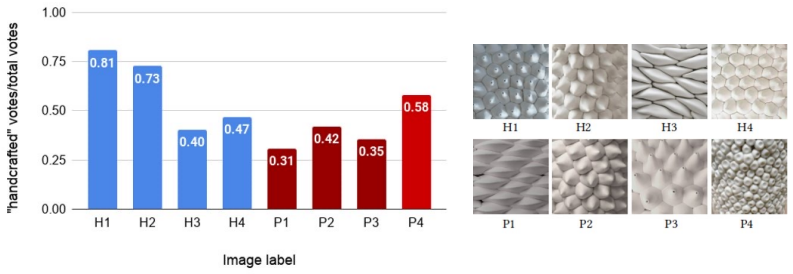
Results – User study



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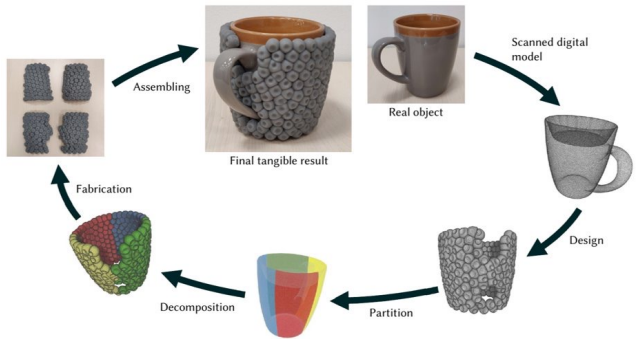
Results – fabrication



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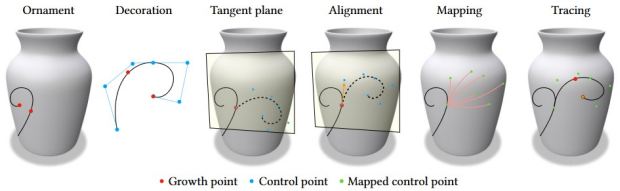
Floralsurf

- Idea: geodesic Bezier Curves started on seed points and branching at special points
- Iterative growth with space filling properties ensured by collision avoidance and best candidates selection rules



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Floralsurf

- Idea: geodesic Bezier Curves started on seed points and branching at special points
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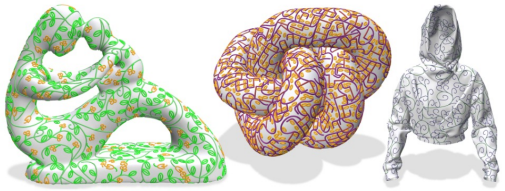

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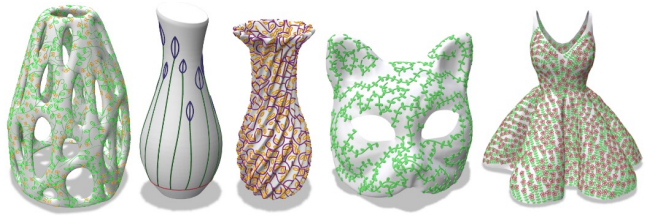
Floralsurf

- Users control the decorations selecting size and shape of the decorative elements and growth points location
- Works on on surfaces with high genus, with and without borders



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Floralsurf

- Similar decorations not feasible with texture mapping
  - Discontinuities or distortions
- Different effects obtained with
  - Single vs multiple seeding
  - Flow fields driving the growth

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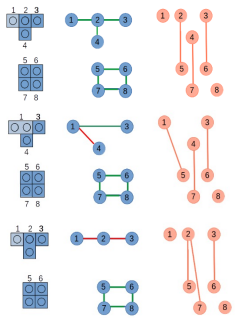
Shape decomposition

- Decomposition of shapes in connectable blocks (e.g. LEGO)
- Complex problem, interesting for manufacturing
- Several heuristics proposed, starting from shape voxelization
  - We proposed a novel approach based on a graph aggregation in standard LEGO blocks and outside in priority-based rules



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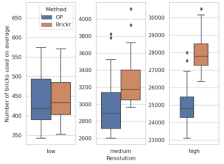
Bricks dataset

- To evaluate comparatively heuristics we created a dataset of already voxelized shapes to make comparisons fair



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Role in the demo:

- computing architecture

COMPUTING ARCHITECTURE

Tiny Machine Learning: how to Fit Heavy Networks Almost Everywhere
L.Capogrosso

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Agenda

- What is TinyML?
- Why Split Computing?
- Human Tracking in Industrial Enviroments

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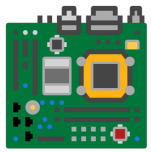
The ML Evolution

Cloud ML
(~ 2006)

Large models focus on their accuracy

Edge ML
(~ 2016)

Optimized models, accuracy vs efficiency trade-offs



TinyML
(~ 2019)

Extremely optimized models focus on efficiency

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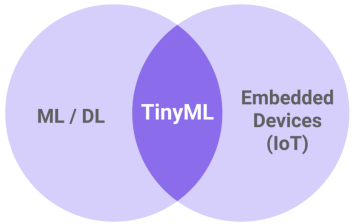
TinyML Definition

- The usual definition is ***running machine and deep learning models on embedded devices with power levels of mW or less***
- This ***power requirement is important*** because ***it allows unattended devices on batteries or energy harvesting***



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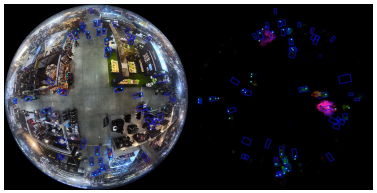
A TinyML Example

- ***HS.Vision*** by Humatics Sys-Dat Group* is an ***edge video analytics system to detect people's presence***
- ***Tested on:***
  - ***71 events*** organized with over ***1 Million visitors***
  - ***Exhibition grounds of 309,000 mq*** with 13 pavilions
  - More than ***400 video surveillance cameras***



(*) For further information see:
www.sys-datgroup.com/humatics/

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Another of Our Work on TinyML

- A ***TinyML model* to discriminate ventricular fibrillation and tachycardia*** from single-lead IEGM recordings @ ***ICCAD2022***
- ***Our solution was based on a 1D CNN*** with many tricks, and ***achieves the 8th place + honorable mention over 150 participants***

2022 ACM/IEEE TinyML Design Contest

Eighth Place Winner

presented to

VIPS4Lab @ UNIVR

Luigi Capogrosso, Federico Cunico, Andrea Avogaro, Federico Girella, Andrea Toaiari, Geri Skenderi, Franco Fummi and Marco Cristani

Zhenge Jia Zhenge Jia Dawei Li Dawei Li Lichuan Ping Lichuan Ping Yiyu Shi

CEDA sigda 无双医疗

(*) For further information see https://github.com/vips4/tinyML_contest_iccad2022

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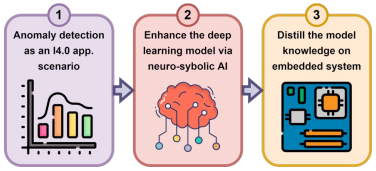
Our Current Work on TinyML in I4.0

- Starting from the open problem of ***anomaly detection in an Industry 4.0 scenario***
- We propose to use ***diffusion models*** to address this problem, by ***enhancing them with neuro-symbolic learning****
- Finally, we are working on strategy to ***transfer the knowledge into an embedded system for real-time usage on the product line***



(*) Article under revision

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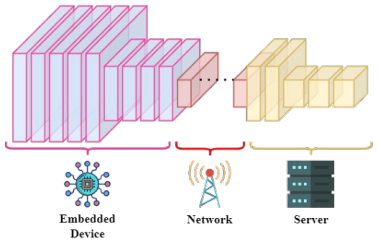
What is Split Computing?

- ***Split computing*** breaks a deep network and ***fits it on edge + cloud***
- ***Combined with the TinyML, it allows the calculation to be offloaded to smaller devices***
- It ***satisfies time/space constraints,*** but for the ***accuracy*** of the final split model there ***were no guarantees, before our works***



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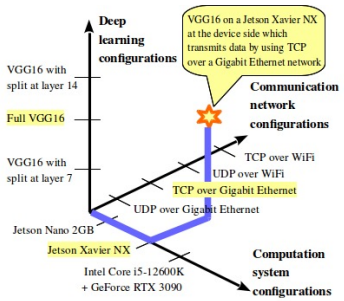
The Design of Distributed DL

- The design of distributed deep learning consists in exploring a ***three-dimensional design space***
- The final implementation will be determined by the choices of:
  - ***DNN***
  - ***Communication architecture***
  - ***Computation platform***



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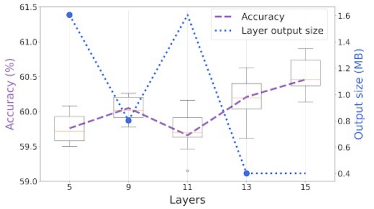
The SC problem: Where to Split?

- ***SOTA focusing on the bandwidth and latency constraints,*** *i.e.*, reducing the intermediate data size
- Decision ***based on the type of layer and its dimensionality [2]***
- But ***this choice may lead to non-optimal split point w.r.t. accuracy***



[2] *"Cut, Distil and Encode (CDE): Split Cloud-Edge Deep Inference"*. Sbai, M., Saputra, M.R.U., Trigoni, N. and Markham, A., 2021, July.

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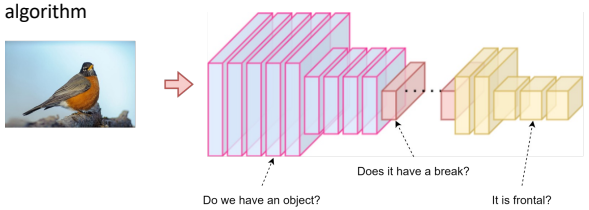
I-SPLIT

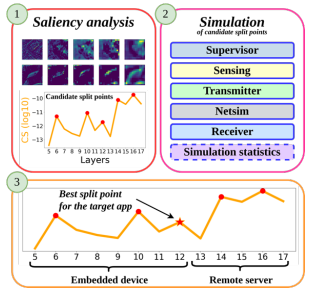
- We could think that, at ***each layer***, the network tries to answer some ***questions*** (*i.e.*, filters) which gives insights about the final class
- ***We split*** the network ***after the most discriminative*** question has been asked [3]
- Discriminability of a layer has been computed by a novel implementation of Grad-CAM algorithm



[3] *"I-SPLIT: Deep Network Interpretability for Split Computing"*. Cunico, F., Capogrosso, L., Setti, F., Carra, D., Fummi, F., & Cristani, M., ICPR 2022.

Split-Et-Impera

- Determines the set of the ***best-split points of a neural network***
- Performs a ***communication-aware simulation [4]***
- Suggests the ***best match between*** the ***QoS requirements of the application*** and the performance in terms of ***accuracy and latency time***



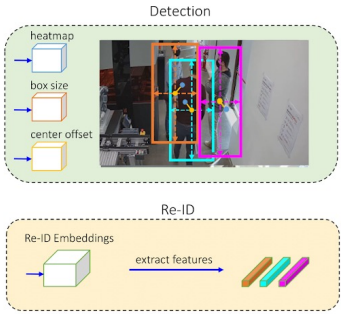
[4] *"Split-Et-Impera: A Framework for the Design of Distributed Deep Learning Applications"*. Capogrosso, L., Cunico, F., Lora, M., Cristani, M., Fummi, F., & Davide, Q., DDECS 2022.

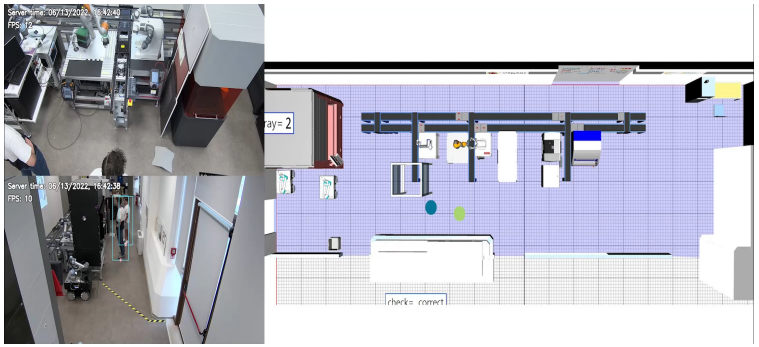
The Multi-Camera Tracking System

- Features:
  - ***Supports Multi-Camera streams***
  - Fully integrated in the ICE GPU cluster via ***Kubernetes*** and ***Docker technology***
  - ***Efficient inference via TinyML and SC optimization techniques with real-time performances at 14 FPS on average***
- Partially solved issues:
  - **Occlusions**
  - Hard fine-tuning
  - **Better 3D mapping/calibration**

The Algorithm

- A ***multi-task deep neural network*** is used to ***extract the detection*** and ***the embedding*** for ***each person in the image***
- Specifically, ***the embeddings*** of the people ***are used for i) associate the person from the previous frame*** and **ii) keep the position updated**





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TinyML: how to Fit Heavy Networks Almost Everywhere

Luigi Capogrosso, F. Cunico, F. Girella, D. S. Cheng, F. Setti, D. Quaglia, D. Carra, F. Fummi, M. Cristani

170

TECHNICAL SESSION 4:
ROBOTICS, SAFETY AND PRIVACY

171

Role in the demo:

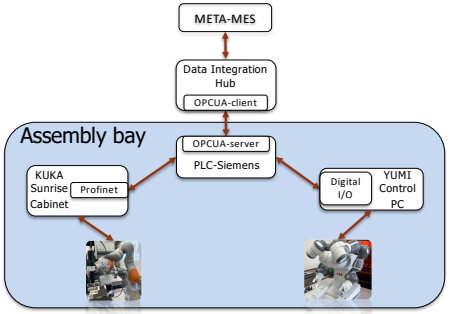
- assembly (phase 5)

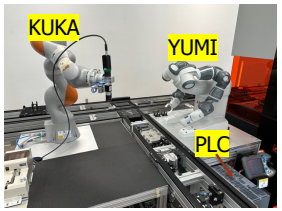
ADVANCED ROBOTS MANAGEMENT

Advanced Robot Cooperation for Assembly Tasks
R. Muradore

172

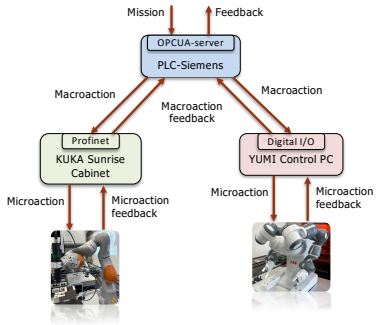
System architecture





173

Robotic cell I/O



PLC
IN:
- Mission
  E.g., "AssemblyGadget"

OUT:
- Feedback and state of the mission

KUKA Cabinet
IN:
- Macroaction to be execute
  E.g., "pickScrew"

OUT:
- Feedback and state of the macroaction
- Microaction
  E.g ., joints command to reach the pose

YUMI PC
IN:
- Macroaction to be execute
  E.g., "pickBoardFromPallet"

OUT
- Feedback and state of the macroaction
- Microaction
  E.g., joints command to reach the pose

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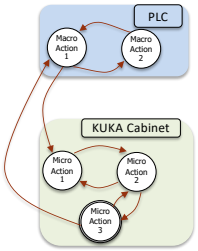
Robot cooperation

The robot cooperation is based on the evolution of **hierarchical FSM** structures

PLC works as observer of the robots' FSM
- Based on robot feedback, it changes its state
- Each PLC FSM state triggers the robot FSMs

Each robot has its own FSM
- Based on control feedback it changes its state



Trotti, F., Ghignoni, E., Muradore, R., & Farinelli, A., "*Synthesis and Monitoring of Complex Tasks for Heterogeneous Robots in an Industry 4.0 Scenario*". In *Intelligent Autonomous Systems 17: Proceedings of the 17th International Conference IAS-17* (pp. 737-749). Cham: Springer Nature Switzerland.

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PLC Observer

A state of the PLC FSM is composed of
- a Macroaction to be executed
- the Robot where the Macroaction has to be executed
- the Event for the change of state (E.g., "macroactionComplete")
- the Next state

Each PLC state triggers the right robot FSM passing the Macroaction to be executed (E.g., "pickScrew")

E.g., state for a KUKA macroaction

Action: "PickScrew"
Robot: "KUKA"
Event: "actionComplete"
NextState: "Screw"

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Robot FSM

A state of the robot FSM is composed of
- a Microaction to be executed
- the Event for the change of state (E.g., "microactionComplete")
- the Next state

The microaction provides the desired waypoints to the robot trajectory planner to reach the desire pose

E.g., "moveToDispenser" represents a list of joint positions (waypoints) toward the desired pose

E.g. state for KUKA

Action: "moveToDispenser"
Event: "actionComplete
NextState: "Screw"

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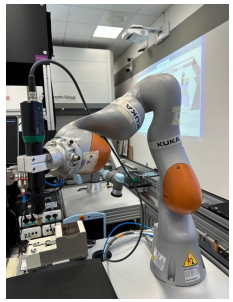
LBR-IIWA KUKA



- Collaborative robot (cobot)
- 7 degrees of freedom
  - The elbow joint is redundant
- 14 kg of payload
  - A smart screwer is currently applied at the end-effector
- ROS API allows to use different types of controllers
  - Position
  - Velocity
  - Force
- Position trajectory planner works both in
  - joint space, and
  - Cartesian space

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YUMI ABB

- Collaborative robot (cobot)
- Two arms of 7 degrees of freedom each
- 0.5 kg of payload each arm
- A vacuum tool is available at the grippers
- Custom ROS driver to control the arms in position
- Position trajectory planner works in
  - Joint space, and
  - Cartesian space

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KUKA Macroactions

The **Macroactions** of the KUKA robot
- "goHome"
  → Action to go home
- "pickScrew"
  → Pick screw from dispenser
- "screwFirstHole"
  → Screw first hole
- "screwSecondHole"
  → Screw second hole
- "detectHoles"
  → Detection of the holes using the camera to make the alignament screwer-hole more robust

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YUMI Macroactions

The **Macroactions** of the YUMI robot
- "goHome"
  → Action to go home
- "pickBoardPallet", "pickBoardArea"
  → Pick the board from conveyor or deposit area
- "placeBoard", "placeBoardArea"
  → Place the board on top cover or in deposit area
- "placeBackCover"
  → Place back the cover to close the gadget
- "holdGadget"
  → Hold the gadget during the screwing

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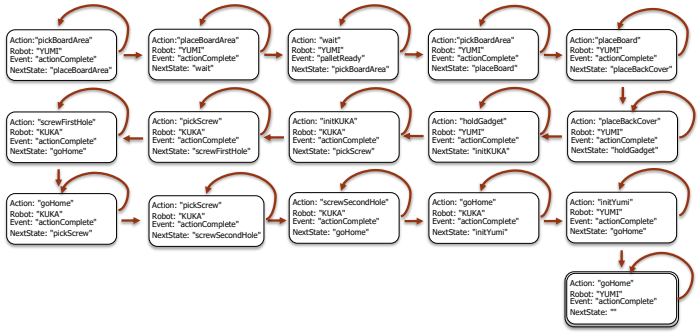
Complete PLC FMS



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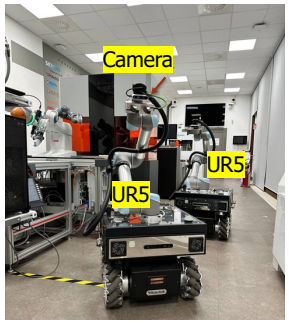
RB-Kairos UR5

The UR5 manipulators on the RB-Kairos mobile robots receive high-level commands as the robots in the assembly bay.

- Throught OPCUA the Macroactions to be performed are received
- The Microactions exploit the position trajectory planner to reach the desired Cartesian pose or Joint angles
- Visual control is implemented to pick-and-place the gadget from the warehouse into the pallet



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RB-Kairos UR5 Macroaction

The **Macroactions** of the UR5 robot are
- "goHome"
  → Action to go home
- "pickBoard", "pickTopCover", "pickButtomCover"
  → Pick board, top and bottom covers from the wharehouse
- "placeBoard", "placeTopCover", "placeButtomCover"
  → Place board, top and under cover to the conveyor
- "detectComponent"
  → Detect the position of the gadget components with camera on the EE

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Future works

- Implementation of algorithms for shared control and physical human-robot interaction (e.g., human in the loop)
- Integration within the control architecture of algorithms for predictive maintenance, fault detection and cyber-attack detection
- Developing a user-friendly interface to define the hierarchical FSMs

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Role in the demo:

- logistics (phases 2 and 7)

ADVANCED ROBOTS MANAGEMENT

Multi-robot Coordination for Efficient Logistics
A. Farinelli, F. Trotti, A. Contini.

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Multi-Robot Pick-Up and Delivery

- Fleet control for Pickup and Delivery tasks
- Guarantee conflict-free paths in challenging environments
- Robots can handle unexpected events replanning their paths

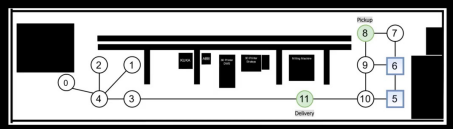
Coordinated path replanning for multi-robot Pickup and Delivery in logistic scenarios
ICE-Laboratory experiment - two task MAPD instance with replanning

Two RB-KAIROS mobile platforms will execute one pickup and delivery task each.

Each robot will pick up an item from a pickup area (vertex 8) and will deliver it to a manifacturing machine (vertex 11).

During execution, part of the working space will be occupied. Robots will replan and avoid the introduced obstacle.

(2x speedup)



Department of Computer Science - University of Verona
Antonello Contini · Riccardo Astolfi · Denis Quartaroli · Alessandro Farinelli

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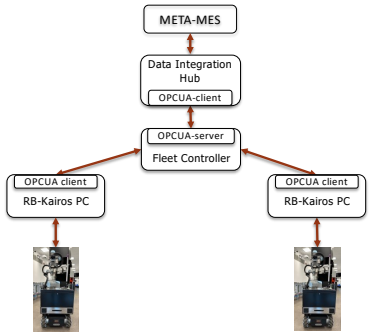
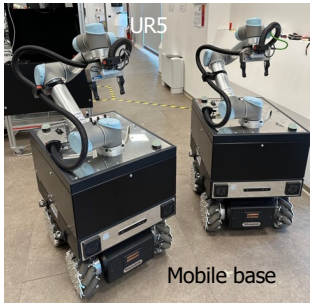
System architecture





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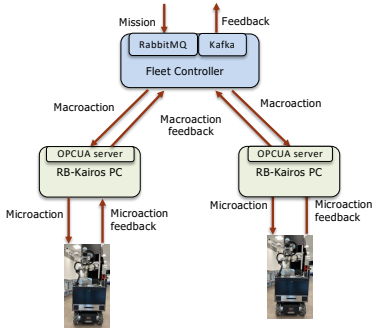
System Architecture I/O



Fleet controller

IN:
- Mission
  - E.g. "transportGadget"

OUT:
- Feedback and state of the mission

RB-Kairos PC

IN:
- Macroaction to be execute
  - E.g "gotoWarehouse"

OUT:
- Feedback and state of the macroaction
- Microaction
  - E.g wayponts to navigate towards warehouse

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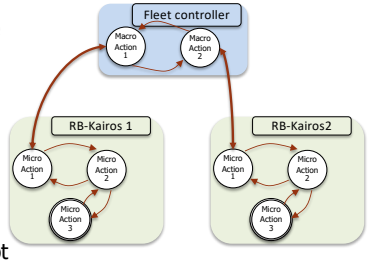
Multi-Robot high-level control

The robots cooperation is based on the evolution of an hierarchical FSM structure

- Fleet controller schedules the macroaction between the two robots
- Each robot has its own FSM to implement the specific macroaction
- FSM evolution is based on action feedback
  - Fleet controller -> feedback from robot FSM
  - Robot FSM -> feedback from robot controller



Trotti, F., Ghignoni, E., Muradore, R., & Farinelli, A., "Synthesis and Monitoring of Complex Tasks for Heterogeneous Robots in an Industry 4.0 Scenario". In Intelligent Autonomous Systems 17: Proceedings of the 17th International Conference IAS-17 (pp. 737-749). Cham: Springer Nature Switzerland.

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Fleet controller FSM

A state of the fleet controller FSM is composed by:

- Macroaction to be executed
- Robot where the macroaction has to be executed
- Event that controls the change of state
  - E.g macroactionComplete"
- Next state

Each fleet controller state triggers the right robot FSM passing the macroaction to be executed
E.g. "gotoWarehouse"

E.g.
Action: "gotoWarehouse"
Robot: "kairos1"
Event: "actionComplete
NextState: "gotoBay5"

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RB-KAIROS

- Collaborative robot (cobot)
- Omnidirectional drive
- 360 lidar
  - Two lidars (Sick)
- Stereo and depht Zed camera (front)
- UR5 manipulator with Realsense camera
- Full navigation stack in ROS
  - Full access to sensor information
- API to control in position the mobile base

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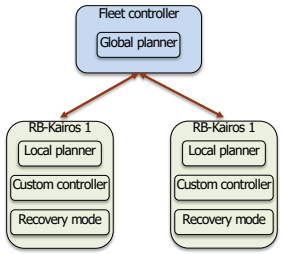
RB-Kairos - Navigation stack

Navigation stack is composed by :
- Multi-Robot planner
  - Collision free planning between the robot
- Single-Robot planner
  - Navigation between waypoints, global path-planning + collision avoidance
- Recovery routines
  - Predefined Recovery action when robot is not well localize
- Custom controller
  - Navigation in narrow passages



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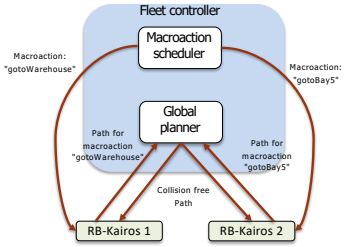
RB-KAIROS – Fleet controller

Fleet controller is composed by:
- Macroaction scheduler based on the mission type
- A multi-agent global planner
  - Collision free path generator based on a topological map
  - A multi-agent path finding (MAPF) solution to avoid conflicts
- Synchronized execution among robots



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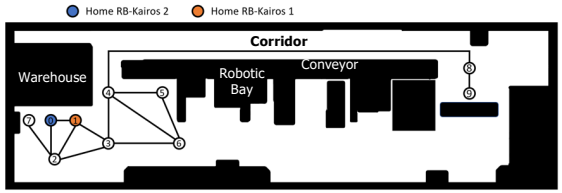
Global planner – Topological map

For a safety navigation a topological map is used
- An undirected graph that maps physical positions to graph nodes
- Shared among all robots

Priority Based Search (PBS) is used to generate collision free trajectory from the global planner
- Given a macroaction the robots ask to the global planner a collision free path to reach the desired position



H. Ma, D. Harabor, P. Stuckey, J. Li and S. Koenig. Searching with Consistent Prioritization for Multi-Agent Path Finding. In *Proceedings of the AAAI Conference on Artificial Intelligence (AAAI)*, pages (in print), 2019.

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RB-KAIROS - Macroaction

The macroaction of the RB-Kairos:
- "gotoWarehouse"
  - Action to go to the warehouse
- "gotoBay5"
  - Action to go to the load/unload bay
- "gotoBay4"
  - Action to go to the control quality bay
- "delivery"
  - Deliver the gadget
- "gotoBin"
  - Action to go to the bin

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RB-KAIROS - Custom controller

To navigate in narrow spaces a custom controller is used

- The navigaton is based on a PID controller with collision avoidance module
- The custom controller is used when the robot has to pass in the corridor back the conveyor

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Future works

- Dynamic Obstacles:
  - Obstacles that block robot path for an (uncertain) interval of time
  - Re-plan based on uncertain information to minimize makespan (or TTD)
  - Key decision: change path or wait for obstacle to move away
- Capacitated Multi-Item Pick-Up and Delivery:
  - Robots can carry a given amount of item (based on capacity)
  - Group items and plan coordinated paths to optimize logistic operations
  - Key issues: complex combinatorial optimization problem
- Adapt macro-actions for flexible operations:
  - Adapt robot actions based on current environment configuration
  - Decide how to execute the macroactions to address uncertainty
  - Key topic: Reinforcement learning to adapt robot operations

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Publications related to this work

- Francesco Trotti, Eros Ghignoni, Riccardo Muradore, Alessandro Farinelli: Synthesis and Monitoring of Complex Tasks for Heterogeneous Robots in an Industry 4.0 Scenario. IAS 2022: 737-749.
- Antonello Contini, Alessandro Farinelli: Coordination approaches for multi-item pickup and delivery in logistic scenarios. Robotics Auton. Syst. 146: 103871 (2021).
- Alessandro Farinelli, Antonello Contini, Davide Zorzi: Decentralized Task Assignment for Multi-item Pickup and Delivery in Logistic Scenarios. AAMAS 2020: 1843-1845

199

Role in the demo:

- assembly (phase 5)

SAFETY IN A HUMAN-MACHINE ENVIRONMENT

Passive Brain Computer Interface for Enhancing Safety in Industry 4.0
E.Cinquetti, I.Siviero, G.Menegaz, S.F.Storti

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Safety Challenges in Human-Machine Environment

- Industry operators engage in **long and repetitive tasks**, especially under increased automation brought by Industry 4.0 paradigm
  - Supervising Tasks
  - Mechanical Manual Tasks
- Time-on-task may lead to **potential accidents**

Driving
G. Borghini et. Al., 2012
10.1109/EMBC.2012.6347469

Air Traffic Management
G. Flumeri et. Al., 2017
10.1109/RBME.2017.2694142

Power Transmission Control
Aaron J. Small et. Al., 2014
10.1002/acp.3016

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Enhancing Performance and Safety

- Importance of monitoring of **Mental Qualities** in real time

Vigilance
Capacity to *sustain attention* during a prolonged activity

Mental Workload
Caused by parallel work, temporal pressure, memory load

- Applied to the **industrial setting could improve performance and safety**

Power Transmission Control

Industry 4.0
new!

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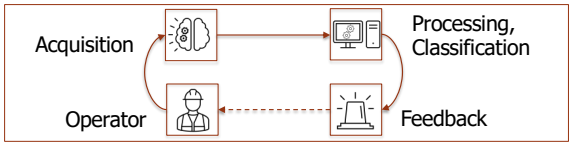
Monitoring Mental Activity

The problem: **Vigilance decrement** and the effects
- accidents
- reduced performance
- increased error rates

Possible solution: creation of a non-intrusive system capable of **identifying risky situations** related to the operator's psycho-physical state, in real time, to enhance **work safety**



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How? Passive BCI

BCI provide a **communication bridge** between the human brain and computers

Using electroencephalography (**EEG**), BCI enables monitoring of monitor operators' **mental state** (**Passive BCI**).

Aim: **leveraging Passive BCI to enhance safety in Industry 4.0**

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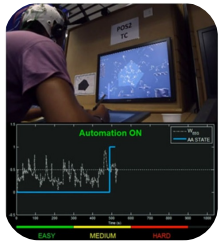
Passive BCI - Beyond the Clinic

Driving applications
G. Borghini et. Al., 2012
10.1109/EMBC.2012.6347469

Traffic Monitoring applications
G. Flumeri et. Al., 2017
10.1109/RBME.2017.2694142



Piloting applications
G. Borghini et. al., 2014
https://doi.org/10.1016/j.neubiorev.2012.10.003

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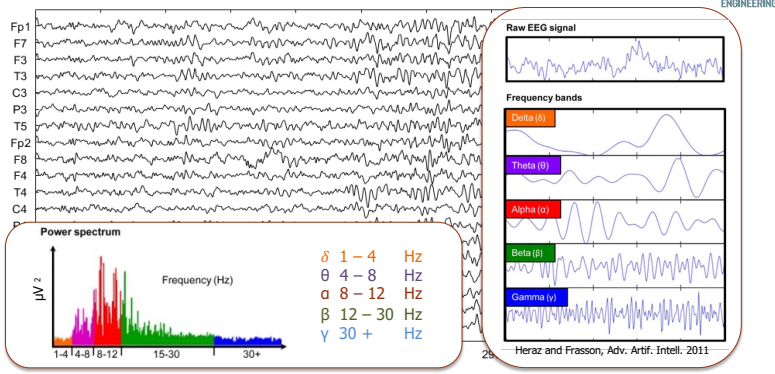
EEG brain rhythms



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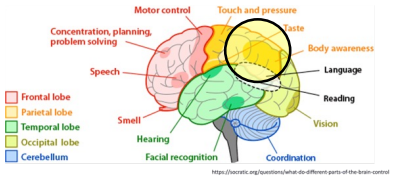
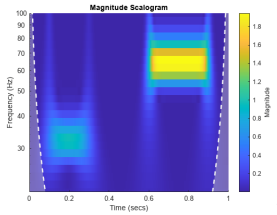
Case study: Vigilance monitoring

- A drop in vigilance is linked to specific EEG behaviour
  - α and θ frequency bands increase in activity with vigilance decrement in the parietal area
  - β band increases in activity with vigilance decrement in the frontal area
- Time-variant spectral analysis can identify persistent variations in frequency band activities
  - achieved through Continuous Wavelet Transform





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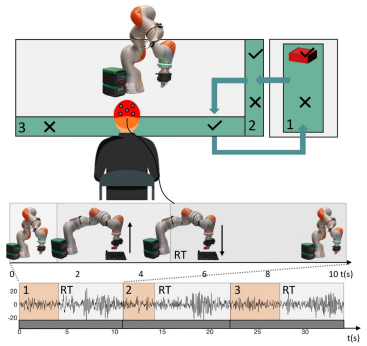
Case study: Vigilance monitoring

Aim: **assess the feasibility of vigilance monitoring** through an EEG interface

- Inducing a state of lowered vigilance through a **long and repetitive task**
- Verify each "pick and place" operation by pressing a button
- 5 subjects. Task length is 23 min, composed of 40 cycles



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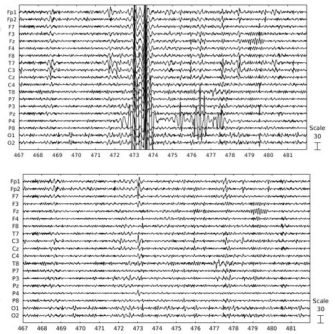
Case study: Vigilance monitoring

Challenges in reconstructing clean EEG data corrupted by external interference

- **Butterworth filter** [1-30 Hz] to remove drift and high frequency noise
- **Electrode re-referencing** in respect to average reference
- **Interpolation** of badly damaged channels
- **ICA** to remove eye blinking and muscular artefacts
- **PCA** to reconstruct data corrupted by external interferences



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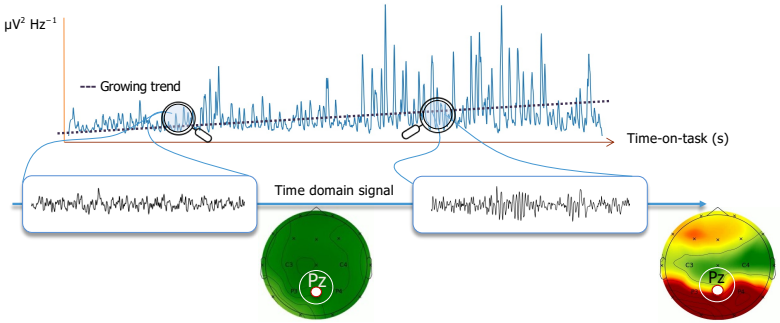
Vigilance Task Results

E. Cinquetti, I. Siviero, G. Menegaz, S.F. Storti, ***Enhancing Safety in Industry 4.0: The Use of Passive Brain Computer Interfaces for Vigilance Monitoring***, Accepted GNB 2023

- Subjects show an **increase** in α band oscillations with increased time-on-task



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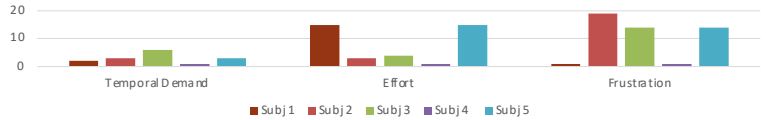
Vigilance Task Results

E. Cinquetti, I. Siviero, G. Menegaz, S.F. Storti, ***Enhancing Safety in Industry 4.0: The Use of Passive Brain Computer Interfaces for Vigilance Monitoring***, Accepted GNB 2023

- **Positive growth** trend in the amplitude signal is confirmed for all subjects at centro-parietal electrodes
  - by applying first order linear regression, and by looking at the angular coefficient
- Subjects commit few **mistakes**, occurring in the **latter part** of the task
- Self-reported questionnaires show an overall sense of **fatigue and boredom** in performing the task

Subject N.	Errors	Timestamps
1	-	-
2	2	16, 19 min
3	-	-
4	1	21 min
5	2	14, 20 min



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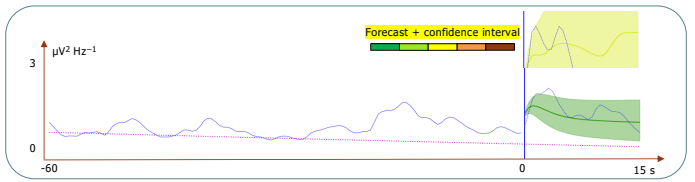
Forecasting the Vigilance State

Aim: identify a **tired state of mind** through real-time α frequency band monitoring

- Transforming EEG signals into a **stationary form**
- Future trend **Forecasting** using ARIMA model
- Baseline **Referencing**



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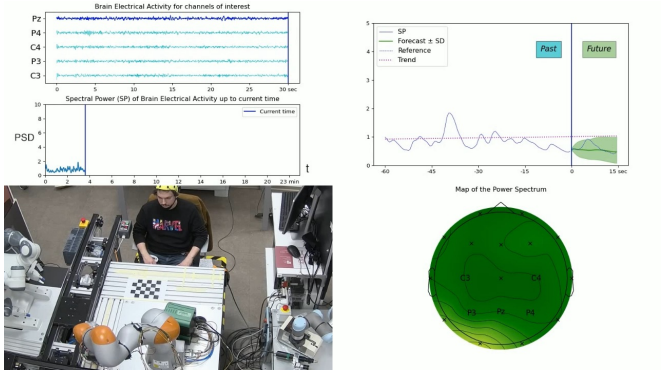
Vigilance Monitoring



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Conclusions and Future Works

- We have demonstrated the **feasibility of Vigilance monitoring** in the industrial context (biological signal acquisition and processing)
- Integrating the system on a realistic production environment can improve safety and productivity
  - **User acceptance** is required
  - **Personal data** must not be used for **secondary or discriminative purposes**

Future directions

- Development of a fully **online generalized model**
  - Improved model (RNN) + multivariate analysis
- **Dataset expansion** and introduction of **new features**

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Further Reasearch and Contributions

- BraiNAVigation Lab aim is to **enhance BCI technology** for industrial purposes by using motor-imagery (MI) based **Active** BCI systems
- Having suitable decoding algorithms is the key point for classifying or detecting specific brain patterns

State-of-the-art limitations:
Few electrodes are used to distinguish different mental tasks

Our contribution was to design, implement and test a new EEG-BCI system based on **connectivity features in a multi-class framework**

Siviero I. et al., *IEEE EMBC 2022*
Siviero I. et al., *IEEE-EMBS BHI 2022*
Siviero I. et al., *IEEE THMS (under review)*

These works stem from OPERA 4.0 project

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Role in the demo:

- assembly (phase 5)

SAFETY IN A HUMAN-MACHINE ENVIRONMENT

Techniques to Enforce Safety in a Human-Machine Environment
D.Quaglia

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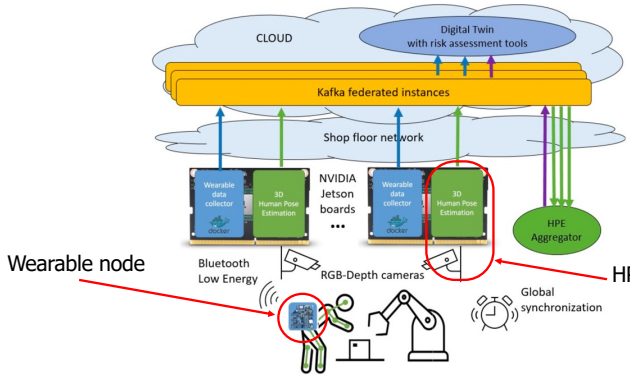
Industry 4.0-5.0 scenario

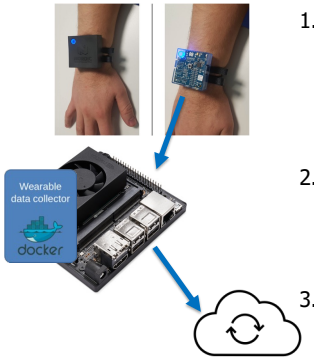
In the era of Industry 4.0, risk **prediction** and **avoidance**, where autonomous robots strongly interact with humans in smart industrial scenarios, are of utmost importance.

- Uniform and scalable **data collection infrastructure** based on **publish/subscribe paradigm** supported by Kafka
- **Wearable device** with inertial data
- 3D **Human Pose Estimation** (HPE) provided by a distributed set of smart cameras in real time (see Tech. Sess. 2)
- A set of safety assessing tools running on the cloud:
  - **Human-Robot Interaction** (HRI): necessity to predict contacts to avoid injuries in collaborative robots;
  - **Assertion Mining**: exploits formal verification techniques to monitor risky situations;

Data collection architecture in ICE Lab

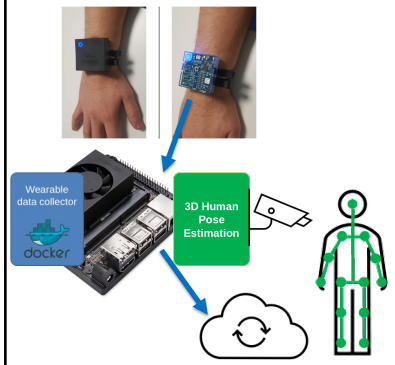


3-tier arch. for the wearable node



1. Wearable device
   - Bluetooth 5, BLE, ANT
   - 3-axis accelerometer, Gyroscope, Compass, Magnetometer
   - Sampling frequency: from 5 Hz to 200 Hz (power trade-off)
2. Edge device
   - Step count, Rotation matrix, Quaternion, Pitch, roll and yaw
   - Configure wearable sampling frequency
   - Configure transmission mode
     - Continuous vs. Event-based (power trade-off)
3. Cloud computing
   - Safety assessment tools

Integration wearable-HPE



1. The edge device runs both wearable and HPE processes to merge data
   - from the wearable
     - Worker identity
     - Inertial data
   - from HPE
     - Worker pose
2. Context can be easily detected to be sent to the safety assessment tools in the cloud
   - Approaching a dangerous machine
   - Work shift
   - Work break
   - Fire emergency

Safety tools: accuracy vs. efficiency

Accuracy and **efficiency** are conflicting requirements:

- Accuracy comes at the cost of intensive computing activities lasting for long periods;
- The cost of heavy risk prediction can affect constraint platforms system's functionality;

Several solutions have been adopted to avoid collisions and the common challenge is to implement real-time HRI framework, searching a **trade-off** between accuracy and resource efficiency.

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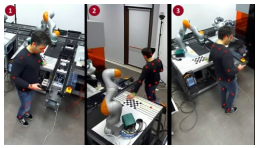
Safety tools: goals

Given an unsafe human-robot environment:

1. Predict the risk of **collisions**;
2. Explain the **causes** leading to such a risk;
3. Achieve accuracy and efficiency at the same time;



To achieve a trade off between accuracy and resource cost, the approach combines two software platforms:

- HARM: a **lightweight** assertion miner, but less accurate;
- OPERA: a **heavier** collision prediction tool, more accurate;

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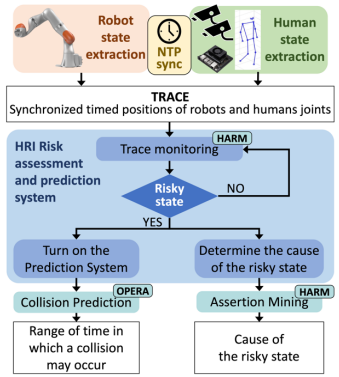
Safety tools: methodology



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Safety tools: HARM*

The HARM[1] assertion miner is used to **detect** the occurrences of unsafe states and to **explain** their causes on robot and human behaviour traces.

Always active task that performs the following steps:

1. Monitors the human-robot traces searching for occurrences of unsafe states through the verification of Linear Time Logic (LTL) formulas;
2. When the LTL fires, the system enters into a risky situation;
3. Activates the Opera collision prediction module and in parallel computes the causes that led to the unsafe state;

*) https://github.com/SamueleGerminiani/harm

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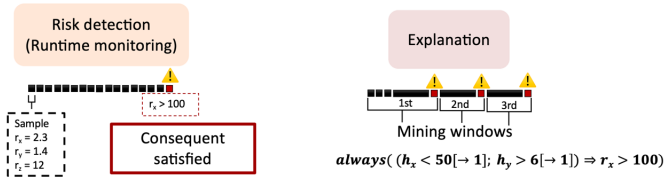
Details of HARM

Each unsafe state is expressed as a user-defined logic formula (named consequent), while its cause is represented by logic formula that is automatically mined by HARM (named antecedent).



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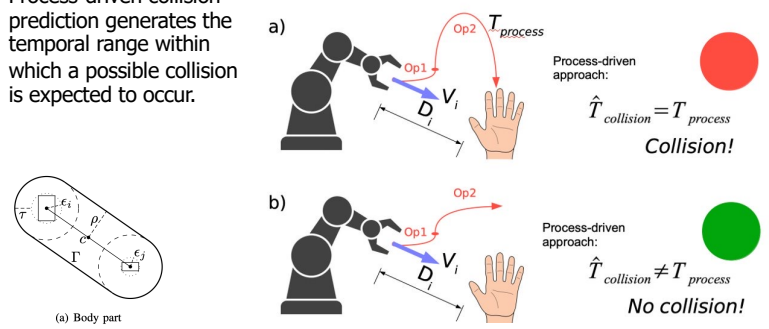
Safety tools: OPERA*

Process-driven collision prediction generates the temporal range within which a possible collision is expected to occur.

Process = (Op1, Op2, ...)

Geometrical approach: $\hat{T}_{collision} = D_i / V_i$



(a) Body part

*) https://github.com/ariadne-cps/opera

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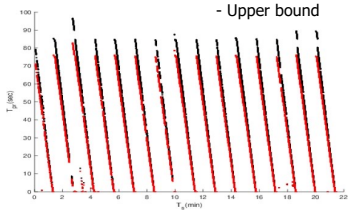
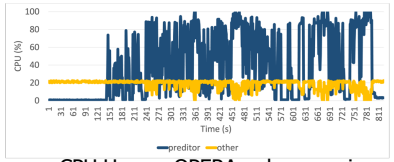
Safety tools: experimental Results

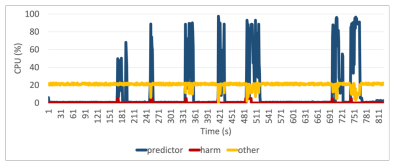
Prediction time T_{pr}

- Lower bound
- Upper bound





CPU Usage: OPERA-only scenario



CPU Usage: hybrid scenario

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Future work

- Add other wearable nodes to enhance human activity recognition
- Use data from the wearable system to cope HPE limitations and vice versa
- Human pose forecasting techniques to predict the operator behavior

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Role in the demo:

- gadget delivery (phase 6)

SECURITY & PRIVACY

Context-aware Privacy in Emergency Situations
F.Paci – E.Quintarelli

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Workplace Surveillance vs Privacy

- Employers today are increasingly using technologies to control employees
  - facial analytics,
  - keystroke monitoring, workstation screenshots
  - cameras, GPS on vehicles
- The use of the technologies is justified to enhance productivity, ensure safety, and provide security
- Workers are exposed to privacy risks such as data misuse and abuse

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Research Problem

Is it possible to use of workplace surveillance technologies while respecting workers' privacy?

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Framework for privacy in the workplace

- Implement the notion of privacy as contextual integrity
- Privacy is about the appropriateness of an information flow within a particular context
- Privacy policies specify what information is appropriate to share in a given context

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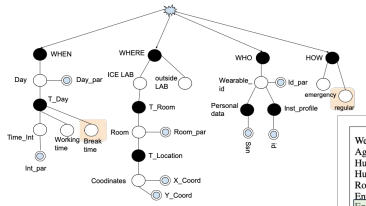
Context Modeling

- What does the notion of context represent?
  - different perspectives useful to enforce the privacy in the data flow
- What is the context useful for?
  - To tailor views of data and protect sensitive information



Wearable_dev(wID, timestamp, x_accelerometer, x_accelerometer, x_accelerometer, . . .)
AggregatedWerable_dev(devID, timestamp, orientation, fall, activity, shake, in_use)
HumanTracking(bodyID, timestamp, x_pos, y_pos, room)
HumanPoseEstimation(cameraID, timestamp, bodyID, x_leg, y_leg, . . .)
RobotTracking(cameraID, timestamp, robotID, x_pos, y_pos, . . .)
EnvironmentalSensor(sensorID, type, um, . . .)
EnvironmentalSensorMeasurement(sensorID, timestamp, value, . . .)
Shift(day, operatorID, from, to, break_from, break_to)
HealthInfo(operatorID, Status, Description, LifeSavingDrugs)
. . .

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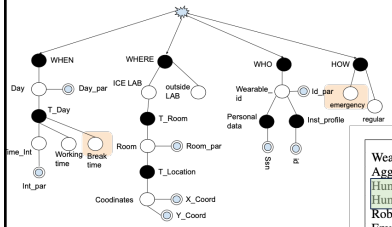
An emergency context

- During emergency situations some sensitive information are relevant



Wearable_dev(wID, timestamp, x_accelerometer, x_accelerometer, x_accelerometer, . . .)
AggregatedWerable_dev(devID, timestamp, orientation, fall, activity, shake, in_use)
HumanTracking(bodyID, timestamp, x_pos, y_pos, room)
HumanPoseEstimation(cameraID, timestamp, bodyID, x_leg, y_leg, . . .)
RobotTracking(cameraID, timestamp, robotID, x_pos, y_pos, . . .)
EnvironmentalSensor(sensorID, type, um, . . .)
EnvironmentalSensorMeasurement(sensorID, timestamp, value, . . .)
Shift(day, operatorID, from, to, break_from, break_to)
HealthInfo(operatorID, Status, Description, LifeSavingDrugs)
. . .

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Privacy Policies Modeling

- We formalize privacy policies as IF-THEN rules

location(s1)<- InDangerousArea(s1)

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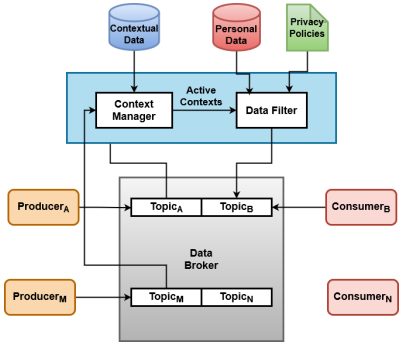
System Overview



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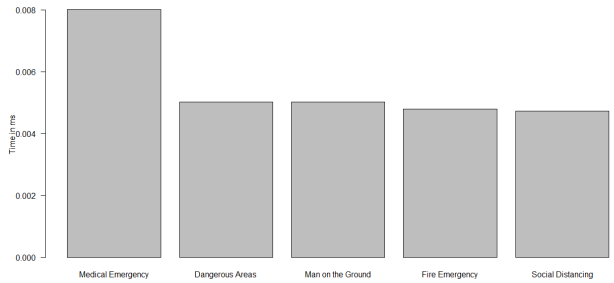
Performance



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Future Work

- Extend the framework to support complex privacy policies
  - e.g., apply data anonymization and masking techniques before they are consumed by an application
- Apply the framework to other surveillance technologies
  - e.g., workstation monitoring, cameras with facial recognition

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