Final course projects

ICT for Industrial Applications

Prof. Andrea Zanella

Rules

The final project assignment is a teamwork for 3 to 5 persons. The work must be completed and delivered by the first exam session. Each team can select one of the still-available proposed projects. A team can also propose its own project, which however must be preliminarily approved by the professor.

The team is required to:
- understand the problem
- look into the literature to gain knowledge of the main proposed approaches to the problem and open challenges
- get familiar with the tools used to develop/test the solution
- realize the testbed/simulation environment (or part of it)
- plan the experiments
- perform the experiments
- analyze the results

While it is not strictly mandatory to complete every part of this assignment, your final grade will increase in direct proportion to how thoroughly you fulfill its requirements. However, your actual grade will also reflect the quality of your work on the assignment.

The team is required to write a technical report of **no more than 6 pages** that briefly discusses the following aspects:
- Motivations (why the addressed problem is relevant)
- State of the art (explore the leading solutions presented in the literature and the open challenges)
- Proposed solution
- System Model or Experimental setup
- Analysis of the results

In addition, the team will present the project during an oral session, where the team members will be asked to illustrate their contribution to the project, defend their design choices, and possibly answer other questions regarding the course content.

In the following, you will find a brief description of the project proposals, along with the contact information for a reference person whom you can consult for further explanations if needed. Each team is permitted to request **a maximum of two meetings** with the contact person.

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1. *IoT-based Predictive Maintenance System for Manufacturing Equipment (andrea.zanella@unipd.it)*

Unscheduled downtime in manufacturing can lead to significant economic losses. An IoT-based predictive maintenance system, e.g., based on acoustic and vibration sensors, can help in anticipating equipment failures before they occur.
The team is required to complete as many tasks as possible (but at least the first three):

- Conduct a literature review on the latest IoT technologies and their application in predictive maintenance.
- Identify a minimum set of IoT hardware and software tools that can be used to realize a Proof of Concept (PoC).
- Implement the system in a controlled environment to simulate real-world industrial noises and record the system's response to normal and anomalous acoustic patterns.
- Design experiments to collect and analyze sensor data.
- Analyze predictive data to improve maintenance schedules.

2. *Enhancing Manufacturing Efficiency through IIoT: A Digitalization Initiative in the bakery industry (marco.pesce@smact.cc)*

The objective of collecting manufacturing data is to oversee, gauge, and enhance various aspects of the manufacturing process to improve efficiency, quality, and overall productivity. By leveraging Industrial IoT (IIoT), organizations can gain comprehensive visibility into their operations, enabling data-driven decisions and streamlining processes. In this context, the food industry is undergoing a digitalization transition, and SMACT has a brand new bread production line available for testing and developing these technologies within an authentic industrial setting!

The project is organized into sequential tasks of increasing complexity. The team must complete as many tasks as possible:

- Develop a data exchange simulator for each machine based on manufacturer specifications (Server Modbus TCP/IP).

- Design and implement a data acquisition system (Client Modbus TCP/IP) to collect real-time data from industrial equipment.
- Establish a database for storing acquired data efficiently and securely.
- Develop a visualization interface using Grafana for real-time monitoring and analysis of equipment performance.
- Design and perform data analysis for production data collected by the acquisition system

3. SVRUM: Safety systems for Vulnerable Road Users Mobility (andrea.zanella@unipd.it)

Vulnerable Road Users (VRUs), including pedestrians, cyclists, and skaters, face significant risks in urban environments due to dynamic traffic conditions and urban hazards. The SVRUM project aims to increase the safety of VRUs by enhancing context awareness and integrating diverse data sources to provide real-time warnings and recommendations. A first version of a SVRUM platform was developed in a previous course's project (see the master thesis work of Mattia Pasti: https://thesis.unipd.it/handle/20.500.12608/60408). Starting from that work, the team is required to complete as many tasks as possible (but at least the first three):

- Assemble two or more SVRUM experimental sensor platforms, each consisting of an Arduino MKR board equipped with sonar, accelerometer, GPS, and camera sensors.
- Set up a server to collect the data generated by the SVRUM sensors and combine them in a proper database.
- Design and develop data-fusion and outlier detection algorithms to enhance the quality of the dataset (according to the crowd-sensing paradigm).
- Conduct field tests to collect new data, collecting data for different vehicle speed, type of road anomaly, etc, enriching the already-existing dataset (available at: https://researchdata.cab.unipd.it/id/eprint/1207).
- Validate the accuracy and effectiveness of the context-aware safety alerts and the reliability of the urban dynamic map.
- Build a georeferenced map of the most significant irregularities detected by the system.

4. Safe Reinforcement Learning for Autonomous Systems (pietro.talli@phd.unipd.it)

Reinforcement Learning (RL) has shown promising results in areas ranging from video games to robotic control. However, deploying RL in real-world scenarios poses significant safety challenges, especially in environments where errors can be costly or dangerous. This project aims to develop methodologies for implementing Safe Reinforcement Learning (Safe RL) that ensures the safety of autonomous systems during both the training and deployment phases.

The team must complete as many tasks as possible (but at least the first three):

- Conduct a thorough review of the current state of Safe RL, focusing on techniques like risk-sensitive learning, constrained RL, and recovery policies. Explore mechanisms such as shielding (where unsafe actions are overridden) and reward shaping (modifying the reward structure to penalize unsafe actions).
- Identify a theoretical framework for Safe RL that integrates safety constraints directly into the learning process.

- Design a simulation environment tailored to test the Safe RL algorithms. This could involve an abstract model or more practical scenarios, like autonomous driving, robotic surgery, or industrial automation.
- Implement the Safe RL framework within this environment, ensuring that the model can interact with complex variables and respond to dynamic changes safely.
- Conduct experiments to evaluate the effectiveness and robustness of the Safe RL model across various scenarios.

5. Cooperative intersection crossing(muhammad.sohail@studenti.unipd.it)

In the future, autonomous driving vehicles are expected to exchange data and information to coordinate their maneuvering in order to improve traffic smoothness and fluidity while avoiding risks. One challenging target scenario is the cooperative crossing of planar road intersections, without traffic lights.

The team must complete as many tasks as possible (but at least the first three):
- analyze some papers provided by the instructors presenting solutions to the problem
- Identify the set of sensors to be used and determine the traffic profile of each sensor
- Identify the wireless technologies that can be used to exchange data and characterize their capacity
- Either perform a comparative study of different solutions taken from the literature for infrastructure-free road crossing, or propose a new solution that aims at overcoming the limitations or explore aspects not been properly covered by the current literature.

6. Remote Driving in Duckietown (federico.chiariotti@unipd.it)

Duckietown (duckietown.org) is a small-scale robot driving platform, which enables experiments and real-world AI training. The department has recently acquired a Duckietown testbed, and there is an extensive simulator that allows students and researchers to replicate the behavior of the real-world testbed before trying algorithms out in real life.

This project involves getting familiar with the **Duckietown simulator** and implementing a simple communication model to allow remote driving, which would simulate the behavior of a real-life remote control application. This is a first step towards implementing joint communication and control policies based on Deep Reinforcement Learning.

The project is organized into sequential tasks of increasing complexity. The team must complete as many tasks as possible (but at least the first three):
- Review the state-of-the-art related to effective communication in remote control tasks
- Implement a basic communication simulator in python inside the Duckietown simulator
- Set up a simulation in the Duckietown simulator and drive an autonomous car remotely with a simple or pre-defined policy
- Train a DRL agent to improve on the results obtained by the heuristic
- Implement an effective communication solution in the simulator
- Run the test in the real-life testbed, ensuring proper transfer learning

7. AURIX: Stepper Motor actuation (simone.friso@dei.unipd.it, Andrea.Cesaro@infineon.com)

Interface AURIX with a stepper motor module so as to implement at least one of the three applications listed next (or something else that you can propose):

- Torque Amplifier for an automatic door opener (as "plus" combining with project 6. To send a PASSWORD and then open the door)
- Automatic "Dog feeder", putting a spoon on it (as "plus" combining with project 6. To send a trigger to feed the dog)
- Meridiana 2.0 (as "plus" combining with project 6. sending the HOUR message and displaying it as a clock-on-hour)

Tools:

- Hardware: Control NEMA17 Stepper Motor with A4988 Stepper Motor Driver Module & Arduino
- Video Tutorial: https://youtu.be/KM-5PYfRlso

Develop a demo that shows that the device is properly working and prepare a presentation that describes the developed solution.

NOTE: mechanicals adaptations are needed, but the project can be developed in a didactical way (the idea is to sketch the mechanical part, which is not the focus of this project though)
NOTE: Basic HW background needed to setup motor and controller

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HW:
1. Delivery Modulo Driver Motore Passo-Passo A4988 Scheda Breakout with Arduino-compatible heat sink including an E-Book!
2. Nema 17 stepper Motor, Longruner stepper motor bipolar 2 to 64oz. in (45NCM) 42 x 40 mm body 4-lead W/1 m cable and connector with mounting bracket for printer 3D hobby CNC LD08
3. https://youtu.be/KM-5PYfRlso
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8. AURIX: Long distance communication (simone.friso@dei.unipd.it, Andrea.Cesaro@infineon.com)

Interface AURIX with this module to enable long-distance communication. Enable communication within AURIX board so as to exchange different data (temperature/humidity/proximity detection/etc.). Design and perform a set of experiments to characterize the performance of the connection. Prepare a presentation that describes the developed solution and reports the performance characterization of the wireless connection (e.g., maximum range, packet loss rate vs distance, etc).
Tools:

- Hardware: ARCELI HC-12 3.2-5.5V 433Mhz SI4463 Module wireless serial port 1000m

9. 12-lead ECG Reconstruction for Digital Heath (federico.mason@unipd.it)

The 12-lead electrocardiogram (ECG) is a fundamental tool for assessing myocardial infarctions (MIs) and other cardiovascular conditions. However, the 12-lead ECG requires a complex set of 8 electrodes to be placed on the patient's limbs and chest, which limits its use outside traditional clinical settings. Developing new techniques that enable the recording and processing of ECG signals with a limited number of electrodes represents a crucial step toward the diffusion of health services in remote locations.

This project involves the design of a reconstruction framework that generates a 12-lead ECG by taking a limited number of signal leads as input. The final aim is to design a new digital health device that enables the reduction of the number of electrodes necessary for signal recording, saving network resources in terms of bandwidth, energy, and computation, and making it possible to diagnose MI or other cardiovascular diseases out of clinical facilities.

The project is organized into sequential tasks of increasing complexity. The team must complete as many tasks as possible (but at least the first three):

- Review the state-of-the-art of ECG reconstruction algorithms
- Implement one or multiple algorithms for ECG reconstruction
- Analyze what are the algorithms' advantages in terms of network resource savings
- Analyze the algorithms' performance in terms of mathematical differences between the original and reconstructed signals
- Analyze the algorithms' performance in terms of accuracy in detecting myocardial infarctions or other clinical conditions
- Design a novel algorithm for ECG reconstruction and compare it with the solutions taken from the literature

10. *Meta-Learning for Dynamic Channel Prediction (federico.mason@unipd.it)*

Modern 5G/6G systems enable reliable data transmission in extreme scenarios (e.g., underwater environments or high-speed trains) where the channel conditions constantly evolve. Estimating the channel status hence becomes a fundamental task, which is often accomplished by learning-based predictors. These latter need to be periodically updated according to the evolution of the channel statistics, making it necessary to devote part of the network resources to such a goal.

This project involves the modeling and analysis of a communication scenario where the underlined channel estimation problem arises. The final aim is to design an efficient meta-learning strategy to establish the number of network resources to be used for adapting the channel prediction, trading off between the maximization of the current performance and the enhancement of the predictor's accuracy.

The project is organized into sequential tasks of increasing complexity. The team must complete as many tasks as possible (but at least the first three):

- Review the state-of-the-art related to channel prediction algorithms for 5G/6G systems
- Model the target problem from a theoretical point of view
- Describe a realistic scenario where the target problem arises
- Implement a basic simulative environment to analyze the scenario
- Implement a benchmark solution (e.g., based on the periodic update of the channel predictor) in the simulative environment
- Implement a meta-learning solution (e.g., based on a reinforcement learning agent) in the simulative environment

11. Explainable Effective Communication (federico.chiariotti@unipd.it)

The project is organized into sequential tasks of increasing complexity. The team must complete as many tasks as possible (but at least the first three):

- Review the state-of-the-art related to effective communication and AI explainability
- Implement a dynamic transmission algorithm in a robotic task, based on the work from (https://arxiv.org/abs/2301.05901)
- Analyze the resulting policy with one AI explainability algorithm (SHAP, saliency maps, abstract policy graphs)
- Apply other algorithms and compare the explanations
- Define a heuristic based on the results
- Apply the heuristic in a similar setting and verify its robustness

12. ML-based predictors for mmWave (filippo.bragato@phd.unipd.it)

Teleoperated Driving, like several 6G applications, has tight requirements in terms of latency and reliability. Respecting those requirements is fundamental to ensure the safety of the users, and to enable this use-case. Another element of complexity in this scenario is that those requirements do not have to be respected on average but in every moment of the communication.

This requires a fine granularity control of the communication that Machine Learning (ML) can be able to handle. The application of ML to this type of problem is still unclear, and in this project, you will analyze which information is more valuable to effectively introduce ML in the communication protocol. The final aim is the creation of a predictor able to approximate and forecast the end-to-end (e2e) application delay in mmWave-based communication.

The project is organized into sequential tasks of increasing complexity. The team must complete as many tasks as possible (but at least the first three):

1. Review the state-of-the-art related to Predictive Quality of Service and the documentation of the 5G protocol stack
2. Select the features of the communication that most affect the delay
3. Of the previously selected features, highlighting the ones that are available at the vehicle, and the ones available at the base station
4. Implement a basic simulative environment to analyze the scenario, and gather the data
5. Design an ML algorithm able to predict the e2e delay of the communication of the current transmission
6. Select the best subset of features needed for the prediction algorithm
7. Design an ML algorithm to forecast the delay of the following transmissions

13. GreenEdge Challenge: Project 3: Internet of Things. "Energy Efficient IoT Networks" (andrea.zanella@unipd.it)

The team is required to tackle the Challenge 3 proposed by the GreenEdge project. See the instructions here: https://greenedge-itn.eu/contest/

(Winning the contest is not required… but nice to have!)