Mobile and Cyber-Physical Systems Project

Team 9
Tupputi Domenico - d.tupputi@studenti.unipi.it - 585794
Elia Piccoli - e.piccoli1@studenti.unipi.it - 621332

May 9, 2022

Abstract

This paper presents the problem of managing temperature and electricity consumption inside a house. We will describe how to implement a system of sensors that using MQTT communicates and store generated data, to then be processed and managed. Temperature, electricity consumption data will be used to optimize the functioning of a ventilation system through Artificial Intelligence. It will be possible also to monitor the current temperature and its behaviour through time both past and future.

Contents

1 Problem Description

With the increase in electricity consumption, many people are wondering how to optimize consumption by obtaining a desired temperature inside their home. In fact, in homes, about 80% of consumption is due to heating or cooling, for this reason Enea recommends carrying out proper maintenance and renovation of the systems in order to easily control the temperature of the rooms. Balancing temperatures allows you to save from 5% to 10% on fuel consumption.

This project aims to develop an automatic temperature monitoring system inside a house, which will be exploited to balance temperatures while minimizing consumption or the times to reach it.

In an increasingly smart world where everything is accessible via smartphone, tablet and PC, the temperatures in the various rooms will be available to the user through a graphic interface that will illustrate the current situation, but also the past and future trends of the temperatures in the house. An example of the UI is reported in *Figure 1*.

2 Use Cases

In the example addressed in this project, the house consists of three bedrooms, a large open space and a bathroom. In each of them is installed both a ventilation duct and a temperature sensor. These sensors will perform surveys every predetermined period of time, which will be saved in a database.

The user can make different choices:

- Monitor current situation inside the house.
- Show trends for the temperatures in the various rooms.
- Activate the ventilation system which balances temperatures among the rooms and at the same time minimizes electricity consumption and time.

The data saved in the database will be shown to the user, who will be able to monitor the temperatures inside the house through a user interface. Also he can access a history section, which will indicate how the temperatures behaved and how they will behave over time using artificial intelligence

to predict the possible trends based on the past. The ventilation system is programmed to reach the same temperature in each of the rooms of the house.

3 Requirements

As far as concerns the requirements of the implementation, they can be divided into two different sections.

Hardware In this implementation of the project the sensors are simulated. This is due to the necessity to interface with the ventilation system which had to be simulated. Nevertheless, with a real ventilation system that can be controlled the functioning of the project still remains valid and the sensor scripts can be replaced with a script that access real data.

While using a real sensor, you should setup a Raspberry Pi - one for each room - each one it will be connected to a temperature sensor, and it will run the script to read data and send it via MQTT.

Software In order to implement the broker node for the MQTT protocol we used the one provided by **HiveMQ Cloud** setting up a cluster provided by Microsoft Azure cloud. To create and train the neural networks both **PyTorch** and **Keras** are used, one can easily choose one or the other. The relational database is implemented using **SQLite3**.

All the various scripts are written using Python. The code can be found at the following Github repository: https://github.com/EliaPiccoli/MCPS-Project.

4 Solution

In this section all the various elements of the project will be analyzed. The project architecture is reported in *Figure 2*.

Starting from the sensors, as already mentioned, they are simulated using a script. In this case the sensor connects to the broker using the *paho-mqtt* library and publishes to a topic called "*temperature/device_name*" with *qos*

1. The rate is set up using a parameter that the user can enter while launching the sensor. In order to generate data we used a Gaussian function that shifts its mean value based on the current time, this to simulate different temperatures through the day. The server creates a mqtt client that subscribes to the topic "*temperature/#*" with *qos 2*, and in this way it receives data from all the sensors. Once the server receives some data it stores it in the database adding a timestamp in order to track the time of the temperature. Both the sensors and the server connect to the broker node using TLS, providing username and password and accessing port 8883. The database used to store data is accessed using *SQLite3* and it has only one single table that contains all the data from all the sensors. The table is defined with the following structure:

Attribute	*Type*
id	INTEGER
device	VARCHAR
value	FLOAT
time	DATETIME

Table 1: Database *temp* table

In order to develop all the applications offered by the proposed solution we developed different scripts.

The first application - which is the one that handles the real-time UI - it simply access the most recent data in the database and updates the house map with it.

The second application offers the possibility to monitor the trends of the temperatures inside a room. The plot that is shown is divided into two different part: the first section reports data collected by the sensors and stored in the database while the second one is the forecast of the temperatures in the near future. In order to obtain the future data an Artificial Intelligence model is exploited. In this case we collected data for each room through different days. Then for each area we trained a recurrent model, in particular a LSTM model, that receives as input the past 10 temperatures and it predicts as output the following temperature.

Finally, the last scenario concerns the use of the ventilation system. In this case when the ventilation system is activated it will start redistribute the temperatures inside the house in order to balance all the rooms. To achieve this state and at the same time minimize the energy consumption and time

the system is controlled by an Artificial Intelligence model. To create such model we applied Reinforcement Learning. In order to use this approach, the problem was structured as a Markov Decision Problem in the following way:

- *State*: is the current temperatures in the house and the ventilation force
- *Actions*: the ventilation system can perform three different actions
  - From hottest room move air to the coldest one
  - From hottest room move air to colder rooms
  - From hottest room move air to all other rooms
- *Transition System*: is obtained by using the ventilation system
- *Reward Function*: the reward function is exploited in order to create a policy that minimize the number of steps and the consume by the air ventilation system.
  $R_i = -(step\_cost + \sum \Delta temp_i + ventilation\_force * electicity\_cost)$

The RL agent will interact with the environment reading the current state and it will start to learn which action to take in order to maximize the final reward. Performing an action will lead the system in a new state, given by the new temperatures stored in the database. The procedure will be repeated until the temperature inside the house is not balanced. At the end of the training process the agent will have created a policy that maximizes the expected reward, hence minimizing the number of steps and the electricity consumption. We implemented from scratch the RL agent with memory replay and the interaction of the ventilation system with the simulated sensors.

5 Demo

The project is structured in order to provide to the user three different functionalities that will be shown as demo.

The user can enter the system and monitor it through a user interface that will show the map of the house with the current temperatures.

Then, the user can ask for the plots for the trends of temperatures of a particular room. The chart will show the past and current trend of the temperature and a prediction over the near future.

Ultimately, the user can activate the ventilation system which will balance the temperatures inside the house using a certain threshold, during the process the user can appreciate the changes through the interface provided by the application.

6 Figures

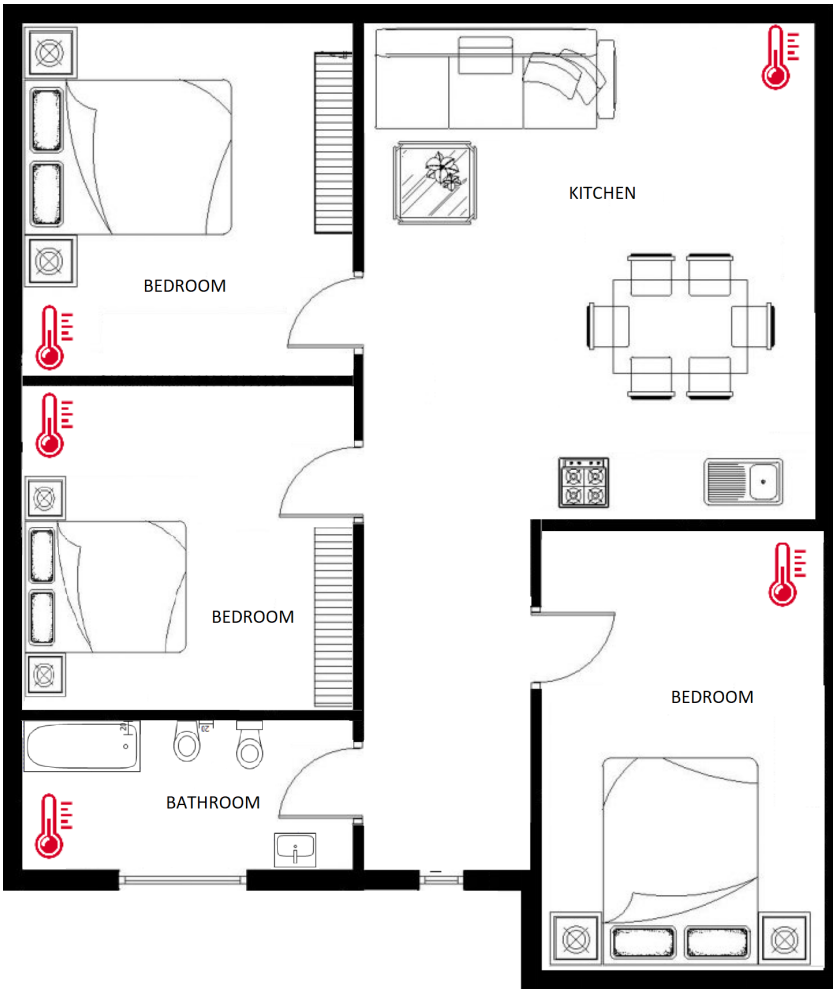

Figure 1: Map of the house.

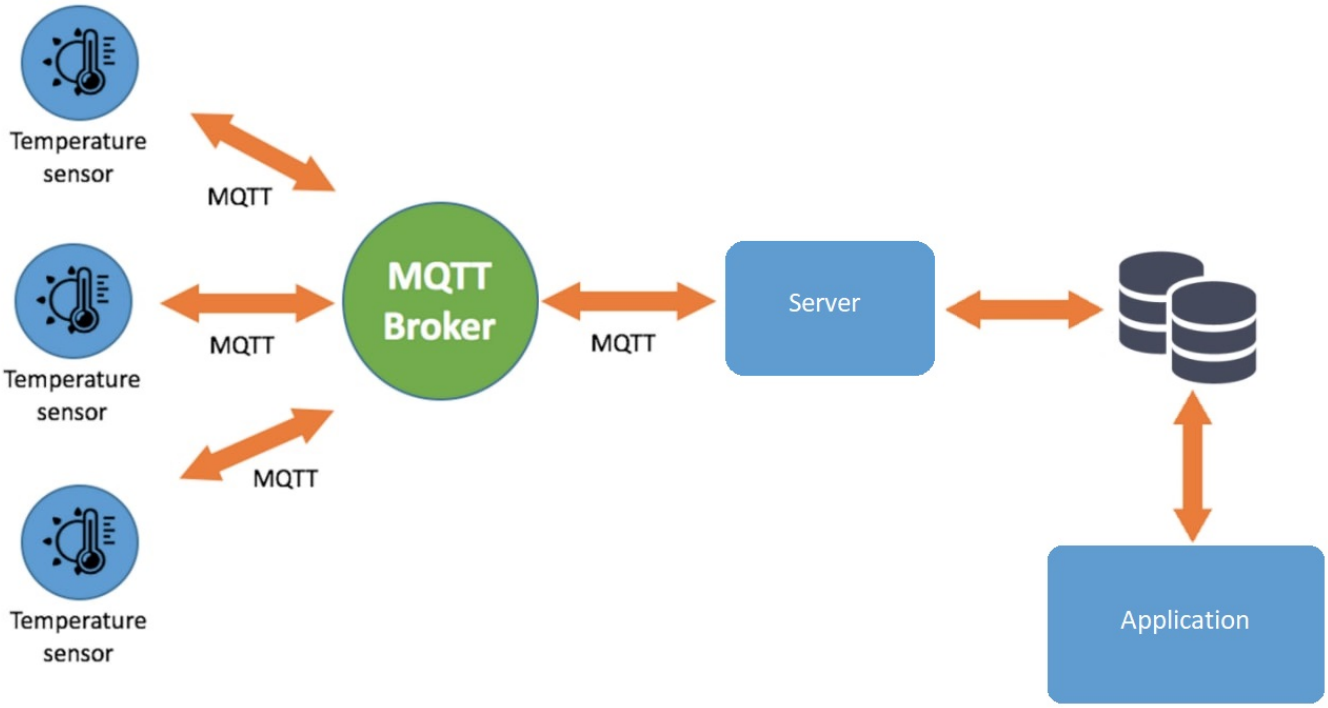

Figure 2: Structure of the project