



# UNIVERSITÀ DI PISA

Artificial Intelligence and Data Engineering

Internet of Things

## *IoT Smart Irrigation System*

Project Documentation

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# 1 — Introduction

Agriculture is one of the most fundamental resource of food production and also plays a vital role in keeping the economy running of every nation by contributing to the Gross Domestic Production. But there are several issues related to traditional methods of agriculture such as excessive wastage of water during field irrigation, dependency on non-renewable power source, time, money, human resource etc. Since every activity now a days is becoming smart, it needs to smartly develop agriculture sector for growth of country. Our project aims at developing a Smart Irrigation System using IoT Technology with the objective of automating the total job, providing adequate water required by crop by monitoring the moisture of soil and climate condition in order to prevent the wastage of water resources, resulting in many advantages for farmers. The irrigation at remote location from home will become easy and more comfortable. In addition, it will not only protect farmers from scorching heat and severe cold but also save their time otherwise required by the to-and-from journey to the field.

## 1.1 Proposed Solution

Modern agricultural methods propose an alternative way of water provisioning: instead of a daily/weekly irrigation, high-tech agricultural farms are moving towards slow, constant and lossless techniques that allow for water saving and a better quality of irrigation. In this optic, we decided to implement a smart system that is capable to compute real time the water need of the field and so to continuously adjust the water output that will be provisioned to plants. Of course, the success of this requires the water to be always available, but we all know that the seasons in which the need is higher are the ones with the lowest availability of natural water resources and vice versa: traditional irrigation methods tend to waste water abundance during wet periods and to overexploit aquifers during dry periods. In order to avoid that, the smart system makes use of a reservoir, i.e. a big container that collects water from the aquifer when the availability of it is much higher than the actual need, to be used as backup resource when aquifers are not enough. So, more precisely, the system uses provided sensors to determine the exact water output needed by plants; once this value has been computed, the system select from where to take the water and how to handle the reservoir, according to the water policy presented in the next indentation. Finally it communicates output level and selected source to the tap actuator that handles the actual irrigation, and a new iteration will be performed very soon in order to guarantee the small but almost constant output. **WATER POLICY:** if the aquifer flow is enough to cover needs, the source is the aquifer and the water excess is stored in the reservoir unless it is full. If it rains, no artificial irrigation is needed, so we turn-off the system in order to save energy and to allow the aquifer to grow again. If the aquifer is not enough to cover needs, the water will be entirely fetched from the reservoir, in order not to drain the aquifer; of course if the reservoir runs out of water the aquifer will be needed again. If the level detection system goes down, the water is taken from the aquifer.

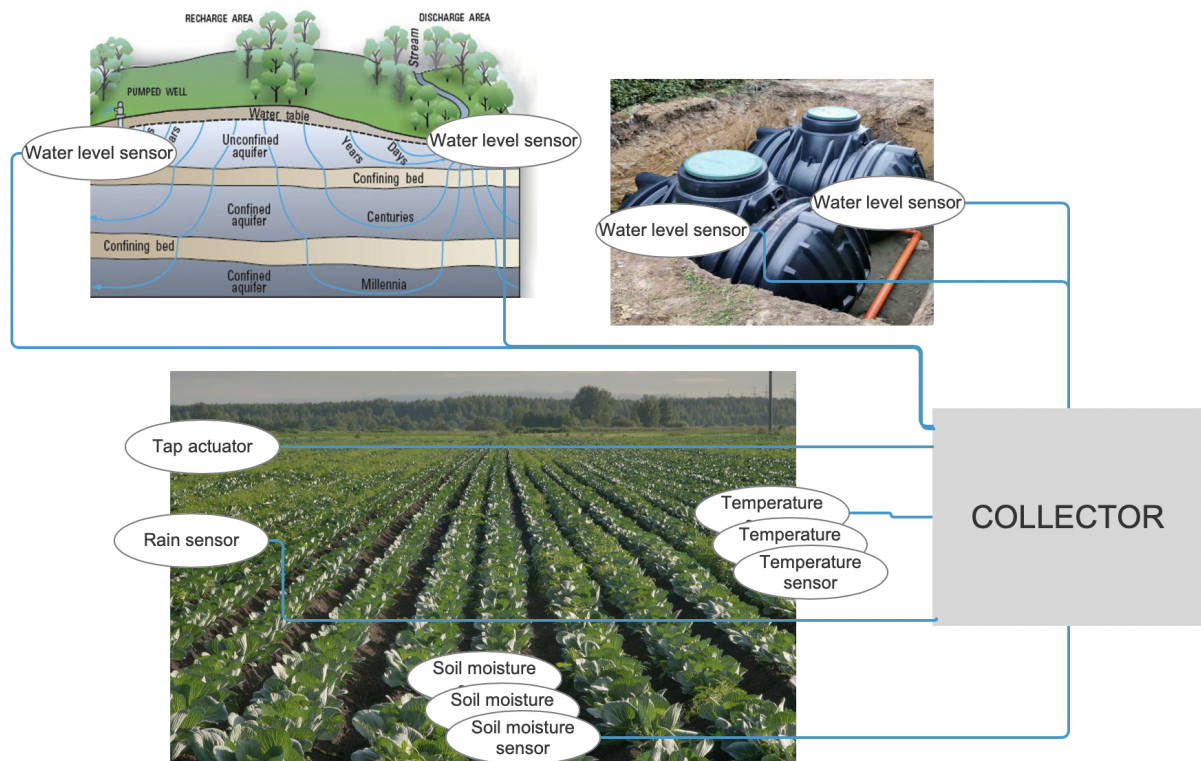
## 1.2 Deployment Structure

The objective of this project is to adopt a smart irrigation system to water cultivated fields making use of the local water resources, such as aquifers and reservoirs, in the way of using the water resources as more eco-friendly as possible (e.g., without disrupting aquifers). Thus, we can consider two different locations to takes care: the **field** and the **water provisioning site**,

For what concern the *water provisioning site*, it is composed of sensors which have the mean of monitoring the water level both of the aquifers and reservoirs. In this way, the system and the user can know where to take water (by default the aquifer). Although, a single device for source may be enough, we decided to deploy multiple water level sensors in the same source in

order to avoid errors in the monitoring (e.g., in the case of a single device if it is detected that the reservoir is empty, but it is not, the irrigation system will use the water from the aquifer pointlessly). All water level sensors will make use of *MQTT* as explained in the "MQTT Network" chapter.

The *field site* is more articulated and will exploit multiple types of sensors and a single type of actuator. The actuator needed is the one capable of providing the water to the plants, which we called "tap actuator". This will be used in conjunction with the other sensors presents in the fields that will monitor the environment, specifically there will be temperature sensors, soil moisture sensors and a rain sensor. All these sensors and the tap actuator will exploit *CoAP* as explained in the "CoAP Network" chapter.



### 1.3 Implementation Choices

Before starting explaining the implementation of the application, it is important to list here some implementation choices that we made:

- We decided to implement the **Collector** and the *control logic* using Java.
- Regarding the *data encoding*, we opted for **JSON** since our devices are very constrained devices which can fail without putting at risk the system (e.g., the farmer can check the situation on site without any problem). Our application is not a critical application, thus a data encoding language such as XML is not needed. Anyway, the best solution would be CBOR, but because it is not mature on contiki we did not use it.

## 2 — CoAP Network

### 2.1 Temperature Sensor

The temperature sensor measures the local temperature in Celsius (at the Collector level will be given the possibility to display the results in Fahrenheit, see the Collector chapter for further details). The goal of this sensors is to quantify and schedule the water provisioning.

#### 2.1.1 Resources

The temperature sensor exposes two resources: the *temperature\_sensor* and the *temperature\_switch* resources.

The **temperature\_sensor** resource is an observable resource that provides to the clients the temperature acquired by the sensor. The resource not only provides the mere temperature to the clients, but it informs if the temperature is lower or greater than a certain threshold. Hence, the sensor exposes a *PUT* method, in order to set up the lower or the upper bound for the temperature.

The change of the bounds is done at step, the user will specify the threshold that he/she wants to change through the CLI: upper or lower. At the server side the request will be processed checking if the value arrived is consistent (e.g., the new value for the lower bound is not greater than the upper bound actual value), after those controls the parameter is updated.

The **temperature\_switch** resource is connected to the *isActive* boolean variable, which indicates if the sensor is operating or not. This is done for turning off the temperature sensor when it is raining in order to save energy, since we do not perform any analysis for irrigating when the weather does that for us. For the reason that we want to change the status of the resources based on the rain sensor, it is implemented a *PUT* method for changing the value of the *isActive* variable.

#### 2.1.2 Data Generation

Data is generated every  $8 \times \text{CLOCK\_SECOND}$  in order to have a smooth simulation (i.e., without too many records in the Cooja's Log that let the simulation being difficult to understand). The value for the temperature is updated using the following algorithm:

```
1 static void temperature_event_handler(void)
2 {
3     if (!isActive) {
4         return; // DOES NOTHING SINCE IT IS TURNED OFF
5     }
6
7     // estimate new temperature
8     srand(time(NULL));
9     int new_temp = temperature;
10    int random = rand() % 8; // generate 0, 1, 2, 3, 4, 5, 6, 7
11
12    if (random < 2) { // 25% of changing the value
13        if (random == 0) // decrease
14            new_temp -= VARIATION;
15        else // increase
16            new_temp += VARIATION;
17    }
18
19    // if not equal
20    if (new_temp != temperature)
21    {
22        temperature = new_temp;
```

```

23     coap_notify_observers(&temperature_sensor);
24 }
25 }

```

## 2.2 Soil Moisture Sensor

Soil moisture sensors measure the water content in the soil and can be used to estimate the amount of stored water in the soil horizon. Soil moisture sensors do not measure water in the soil directly. Instead, they measure changes in some other soil property that is related to water content in a predictable way. Checking the different technologies used for measure soil moisture content, we decide to exploit the *soil water potential*<sup>1</sup>.

### 2.2.1 Resources

The soil moisture sensor exposes two resources: the *soil\_moisture\_sensor* and the *soil\_moisture\_switch* resources.

The **soil\_moisture\_sensor** resource is an observable resource that provides to the clients the soil moisture tension acquired by the sensor. The resource not only provides the mere tension to the clients, but it informs if the value is lower or greater than a certain threshold. Hence, the sensor exposes a *PUT* method, in order to set up the lower or the upper bound for the tension<sup>2</sup>.

The change of the bounds is done at step, the user will specify the threshold that he/she wants to change through the CLI: upper or lower. At the server side the request will be processed checking if the value arrived is consistent (e.g., the new value for the lower bound is not greater than the upper bound actual value), after those controls the parameter is updated.

The **soil\_moisture\_switch** resource is connected to the *isActive* boolean variable, which indicates if the sensor is operating or not. This is done for turning off the temperature sensor when it is raining in order to save energy, since we do not perform any analysis for irrigating when the weather does that for us. For the reason that we want to change the status of the resources based on the rain sensor, it is implemented a *PUT* method for changing the value of the *isActive* variable.

### 2.2.2 Data Generation

Data is generated every  $8 \times CLOCK\_SECOND$  in order to have a smooth simulation. The value for the tension is updated using the following algorithm (the same of to the one used for the temperature):

```

1 static void soil_moisture_event_handler(void)
2 {
3     if (!isActive) {
4         return; // DOES NOTHING SINCE IT IS TURNED OFF
5     }
6
7     // estimate new tension
8     srand(time(NULL));
9     double new_soilTension = soilTension;
10    int random = rand() % 8; // generate 0, 1, 2, 3, 4, 5, 6, 7
11
12    if (random < 2) { // 25% of changing the value
13        if (random == 0) // decrease

```

<sup>1</sup>*Soil water potential* or *soil moisture tension* is a measurement of how tightly water clings to the soil and is expressed in units of pressure called bars. Generally, the drier the soil, the greater the soil water potential and the harder a plant must work to draw water from the soil.

<sup>2</sup>For the default range value we used the ones indicated here: <https://www.metergroup.com/environment/articles/defining-water-potential/>

```

14         new_soilTension -= VARIATION;
15     else // increase
16         new_soilTension += VARIATION;
17     }
18
19     // if not equal
20     if (new_soilTension != soilTension)
21     {
22         soilTension = new_soilTension;
23         coap_notify_observers(&soil_moisture_sensor);
24     }
25 }

```

## 2.3 Rain Sensor

Rain sensor or rain switch is a switching device activated by rainfall. It is used for water conservation since it is connected to the automatic irrigation system, which will cause the system to shut down in the event of rainfall in order to do not waste water and to reduce energy consumption.

### 2.3.1 Resource

The only resource provided by the rain sensor is a value indicating if it is raining or not, named **isRaining** and stored as a boolean. Since we are only interested when the status of the variable change, we opt to use the observable pattern provided by CoAP in order to minimize the number of interactions with the sensor.

The only possible action is the **GET** method, which will respond with a text saying *"raining"* or *"not raining"* based on the status of *isRaining*.

### 2.3.2 Data Generation

Data is generated every  $50 \times \text{CLOCK\_SECOND}$  in order to have a slow simulation, helpful to see all the possible scenarios the our application can offer. The value of **isRaining** flips (i.e., if it was indicating raining it turns to not raining, and vice versa) with a probability of 50%. This is done in the *rain\_event\_handler* function in the following way:

```

1 static void rain_event_handler(void)
2 {
3     // check if raining
4     srand(time(NULL));
5     int random = rand() % 2; // generate 0, 1
6
7     bool new_isRaining = isRaining;
8     if (random == 0) // 50% of changing the value
9         new_isRaining = !isRaining;
10
11     // if not equal, notify
12     if (new_isRaining != isRaining) {
13         isRaining = new_isRaining;
14         coap_notify_observers(&rain_sensor);
15     }
16 }

```

In case the value changes, this is notified to all the subscribers.

## 2.4 Tap Actuator

The tap actuator is the device aim at irrigating the fields.

### 2.4.1 Resources

The tap actuator should be had four resources: the *tap\_intensity*, the *tap\_interval*, *tap\_where\_water* and the *tap\_switch*. However, Cooja does not permit that, limiting the maximum number of resources to two. Thus, we united the resources making just two: the *tap\_intensity* (which include *tap\_intensity*, *tap\_where\_water* and the *tap\_switch*) and the *tap\_interval*.

The **tap\_intensity** resource is mainly related to the *intensity* variable, which indicates the volume of water to provide at each simulation. Since we want to pull water from the aquifer or the reservoir, we made this resource observable in the way of better controlling the *water level sensors* in the simulation. The method implemented for this resource are the *GET* and *PUT* methods. The *GET* method respond to the user with a string containing the value of the intensity. On the other hand, the *PUT* method gives to the user the possibility to set up the intensity value updating the current one and to update where to take the water. The message received for the request is in the form of: *A/R* (indicating the aquifer or the reservoir), space, new value for the intensity.

Since we needed to include *tap\_switch* in the resource, and since the *PUT* method was already implemented, we added a *POST* method for updating the switch status. This was the only possible solution for limiting the number of resources to two and we are full aware of the fact that the *POST* method should be used for creating new elements and not for updating variables, but we could not do otherwise.

The **tap\_interval** resource indicates the period of time (expressed in *CLOCK\_SECOND*) between two activations of the tap. This resource can be retrieved using the *GET* method associated to it, and it can be updated using the *PUT* method. The *PUT* method does not only update the value, but it updates also the intensity based on the following formula.

$$\text{intensity} = \text{intensity} * \frac{\text{new\_interval\_value}}{\text{old\_interval\_value}} \quad (1)$$



## 3 — MQTT Network

### 3.1 Devices

The MQTT Network will be deployed in the water provisioning site and it is formed by 4 nodes (2 Aquifer Level Detectors and 2 Reservoirs Level Detectors and Actuators). The role of those devices is to monitor the water level in the two sources, in order to always have it enough for the irrigation needs but without the spoil of natural resources. Each pair of devices communicates the sensed levels to the Collector, which will compute the mean of the values to more precisely estimate the actual aquifer and reservoir level.

### 3.2 Aquifer Level Detector

The Aquifer Level Detector senses the level of water in the Aquifer, in order to estimate the availability. This device senses the height of the water flow in cm and based on that computes the volume of water that is available at each iteration, known the dimensions of the aquifer and the speed of the flow. The user can retrieve at any time the last measurement (the system will do it automatically) and the sensing interval is the same of the **tap\_interval**.

#### 3.2.1 Topics

This device is subscribed to the **interval** topic used to change the sensing interval (to adapt it to the tap\_interval) and publishes measurements on the **aquifer\_level** MQTT topic. The device acts as a MQTT client and handles its connection with the broker.

#### 3.2.2 Data Generation

Data is generated every *interval*, every time the system must decide from where to fetch water. The value for the aquifer sensor is updated according to the following idea: during rainy seasons, the level will be enough to cover the average water need, on the contrary during summer there can be risk of insufficient water coverage. The simulated value is then published as a MQTT message on the **aquifer\_level** topic.

```
1 #define WATER_SPEED 0.0005 /* 0.0005cm/s https://www.arpa.vda.it/it/acqua/
   acque-sotterranee/cosa-sono-le-acque-sotterranee */
2 #define SECTION 200 //2m
3 #define MAX_LEVEL 60 //60cm
4
5 static double simulate_level(){
6     boolean summer = false;
7     time_t t = time(NULL);
8     struct tm tm = *localtime(&t);
9     int month = tm.tm_mon;
10    if (month >=5 && month<8) //between June and August
11        summer = true;
12    srand(time(NULL));
13    double availability; // cm^3
14    if (summer)
15        availability = rand()%MEDIUM_NEED;
16    else
17        availability = MEDIUM_NEED + rand()%(VERY_HIGH_NEED - MEDIUM_NEED);
18
19    //Assuming rectangular aquifer, available water is given by LEVEL * SECTION
20    * WATER_SPEED * INTERVAL
21    double level = ((availability/WATER_SPEED)/SECTION)/PUBLISH_INTERVAL; //
    cm
21    return level<MAX_LEVEL ? level : MAX_LEVEL;
```

```

22 }
23
24 sensed_level = simulate_level();
25 sprintf(pub_topic, "aquifer_level");
26 //Assuming rectangular aquifer, available water is given by LEVEL * SECTION *
    WATER_SPEED * INTERVAL
27 available = sensed_level*SECTION*WATER_SPEED*PUBLISH_INTERVAL;
28 sprintf(app_buffer, "{\"node\": %d, \"aquifer_availability\": %.2f, \"unit\":
    \"cm^3\"}", node_id, available);
29 mqtt_publish(&conn, NULL, pub_topic, (uint8_t *)app_buffer, strlen(app_buffer),
    MQTT_QOS_LEVEL_0, MQTT_RETAIN_OFF);
30 printf("Sensed water level is: %.2f cm, aquifer water availability is %.2f cm
    ^3\n", sensed_level, available);

```

### 3.3 Reservoir Level Detector and Actuator

The Reservoir Level Detector senses the level of water in the Reservoir, in order to estimate the availability. This device senses the height of the water storage in cm and based on that computes the volume of water that is available at each iteration, known the dimensions of the reservoir. The user can retrieve at any time the last measurement (the system will do it automatically) and the sensing interval is the same of the **tap\_interval**. The Reservoir Actuator instead puts or fetches water according to the decisions taken by the controller: if there is water abundance the actuator is asked to store the excess, when water lacks it is asked to fetch from the reservoir.

#### 3.3.1 Topics

This device is subscribed to the **interval** topic used to change the sensing interval (to adapt it to the tap\_interval) and publishes measurements on the **reservoir\_level** MQTT topic. The device acts as a MQTT client and handles its connection with the broker.

#### 3.3.2 Data Generation and Actuation Mechanism

Data is generated every *interval*, every time the system must decide from where to fetch water. The value for the reservoir level could be determined mathematically, but the deployment of a sensor allows to deal with possible phenomena like evaporation or breaks. The simulated value however is generated leaving out those phenomena, so it is always equal to the level that was present during the last actuation. The value is then published as a MQTT message on the **aquifer\_level** topic. The actuator instead receives commands from the controller through MQTT subscription and adds/removes the quantity of water indicated by the controller.

```

1 //assuming rectangular reservoirs of capacity 1000 litres
2 #define WIDTH 200           //2m = 200cm
3 #define DEPTH 100           //1m = 100cm
4 #define MAX_LEVEL 50        //50 cm
5 //Total capacity is 200*100*50 = 1e6 cm^3 = 1000 l
6
7 static double sensed_level=MAX_LEVEL;
8
9 static double simulate_level(){
10     return sensed_level;
11 }
12
13 static void put_get_water(double quantity){
14 //assuming rectangular reservoir
15     sensed_level += (quantity/WIDTH)/DEPTH;
16     if (sensed_level>MAX_LEVEL)
17         sensed_level = MAX_LEVEL;
18     else if (sensed_level<0)

```

```

19     sensed_level = 0;
20 }
21
22 int level = simulate_level();
23 sprintf(pub_topic, "reservoir_level");
24 //assuming rectangular reservoir, quantity (volume) is given by level*WIDTH*
    DEPTH
25 available = sensed_level*WIDTH*DEPTH;
26 sprintf(app_buffer, "{\"node\": %d, \"reservoir_availability\": %.2f, \"unit\":
    \"cm^3\"}", node_id, available);
27 mqtt_publish(&conn, NULL, pub_topic, (uint8_t *)app_buffer, strlen(app_buffer),
    MQTT_QOS_LEVEL_0, MQTT_RETAIN_OFF);
28 printf("Sensed water level is: %.2f cm, reservoir water availability is %.2f cm
    ^3\n", sensed_level, available);
29
30
31 static void pub_handler(const char *topic, uint16_t topic_len, const uint8_t *
    chunk, uint16_t chunk_len) {
32
33     if(strcmp(topic, "interval") == 0) {
34         printf("Changing detection interval to: ");
35
36         long interval = atol(const char*)chunk;
37         printf("%d\n", interval);
38         PUBLISH_INTERVAL = interval;
39     }
40     else if(strcmp(topic, "set_level") == 0){
41         char value[10];
42         char *eptr;
43         double quantity;
44         strcpy(value, (const char*)chunk);
45         quantity = strtod(value, &eptr);
46         if (result == 0){
47             /* If the value provided was out of range, display a warning message */
48             if (errno == ERANGE)
49                 printf("The value provided was out of range\n");
50             return;
51         }
52         printf("Changing reservoir water level by: %f\n", quantity);
53         put_get_water(quantity);
54     }
55     else {
56         printf("Topic not recognized!\n");
57     }
58     return;
59 }

```

## 4 — Collector

4.1 MQTT Side

4.2 CoAP Side

4.3 Database And Data Visualization