Design of Embedded Systems

ESSTA, Energy Saving Smart-home distributed Temperature control Application

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Contents

1 Introduction

The purpose of this project is to realize a smart-home application to control the heating system of a building based on the temperature of each room, in order to minimize the consumption of the building each room apply an energy saving function reducing the desired temperature when it is not needed. The system is composed by two differ modules

- central unit module
- room module

1.1 Central Unit

The *Central Unit* has the role of coordinator that retrieve the status of each room and compute the average values for the builng. Using a graphical User Interface the module represents the average values of the building and the values for each room, the graphical User Interface is composed by:

- Main page to represent the overview of the building
- Room page to represent the status of each room
- Setting page to set the desired temperature

In the Settings page the module shall allow the user to set the desired temperature shared with the rooms. The minimum and maximum allowed temperatures are 15 C°and 30 C°.

1.2 Room Module

The purpose of this module is to control the temperature of the room acting on a valve in order to reach and mantain the *GoalTemperature*.

1.2.1 Energy Saving mode

In order to minimize the consumpion the module keep tracks of the presence of motion inside the room using a motion sensor.
If the number of motions detected in the last 30s is greater then a predefined threshold, the module shall set the *GoalTemperature* to the one set by the user.
If the number of motions detected in the last 30s is less then a predefined threshold the module shall set the *GoalTemperature* to:

$$GoalTemperature = DesiredTemperature - EnergySavingTemperatureOffset \quad (1)$$

1.2.2 Valve control

In order to control the heating of the room the valve is moved to different positions based on the temperature error (*ActualTemperature* - *GoalThemperature*) as in the following table, whenever one of these rules is valid the mosule shall move the valve in the correspondant position described in the third column of the table as percentage of maximum flow.

rule	**valve position**	**Flow in %**
$error < -WARM$	OPEN_POSITION	100
$error \in [-WARM, -APPROCHING)$	HIGH_POSITION	75
$error \in [-APPROCHING, +APPROCHING]$	MIDDLE_POSITION	50
$error \in (APPROCHING, WARM]$	LOW_POSITION	25
error $>$ WARM	CLOSED_POSITION	0

In the following table are reported the temperature thresholds:

WARM	2 C°
APPROCHING	1 C°

2 SySML Functional model

In the picture 1 is reported the functional Block Definition Diagram that describes the composition of the system, composed by one Central Unit and up to eight Rooms, the two modules are connected via two FlowPort as shown in 2. The Central Unit send a *RoomRequest* message composed as follows:

parameter	**type**	**[Min,Max]**
Id	Natural	[1,8]
DesiredTemperature	Float	[15.00, 30.00]

The Room module send a *RoomStatus* message composed as follow:

parameter	**type**	**[Min,Max]**
Id	Integer	[1,8]
Eco	Boolean	[0, 1]
Temperature	Float	[15.00, 30.00]
Humidity	Floar	[0.00, 100.00]
Valve	Integer	[0, 100]

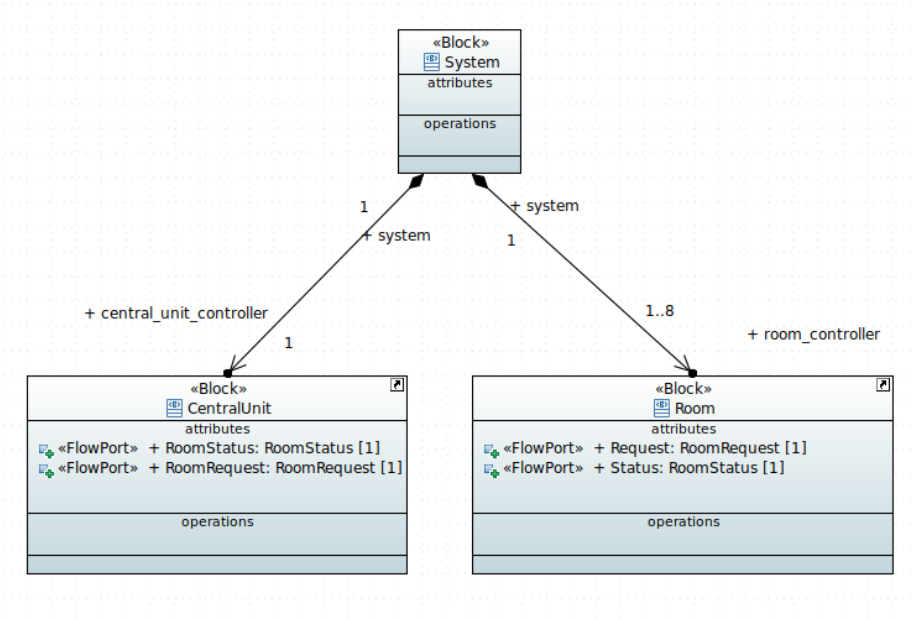


Figure 1: System Components

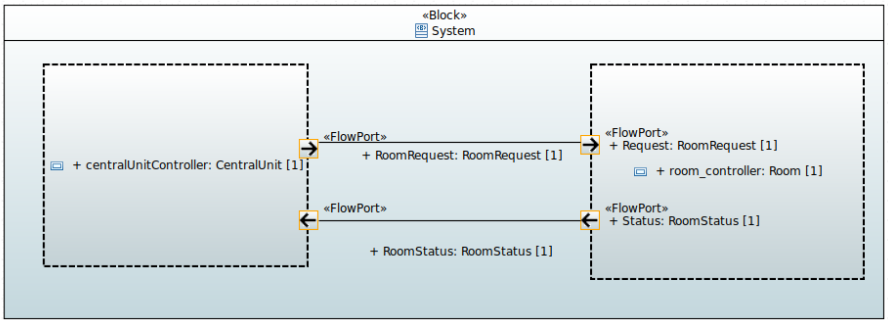


Figure 2: System Internals

2.1 Central Unit

The *Central Unit* is composed by two modules, the *RoomsManager* and the *UserInterfaceManager*. The *RoomsManager* implemnets the functionalities related to the status of each room. The *UserInterfaceManager* that implements the functionalities related to represent the status of the system. The two components exchange data as shown in 4.

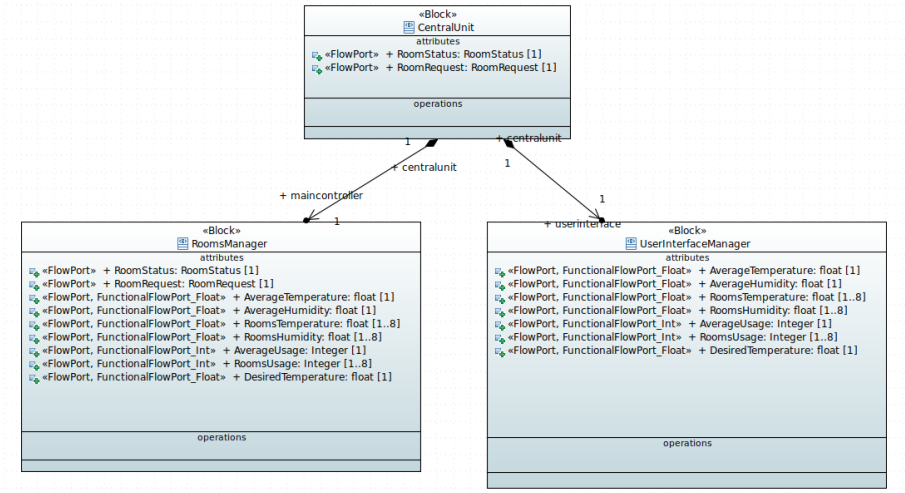


Figure 3: Central Unit components

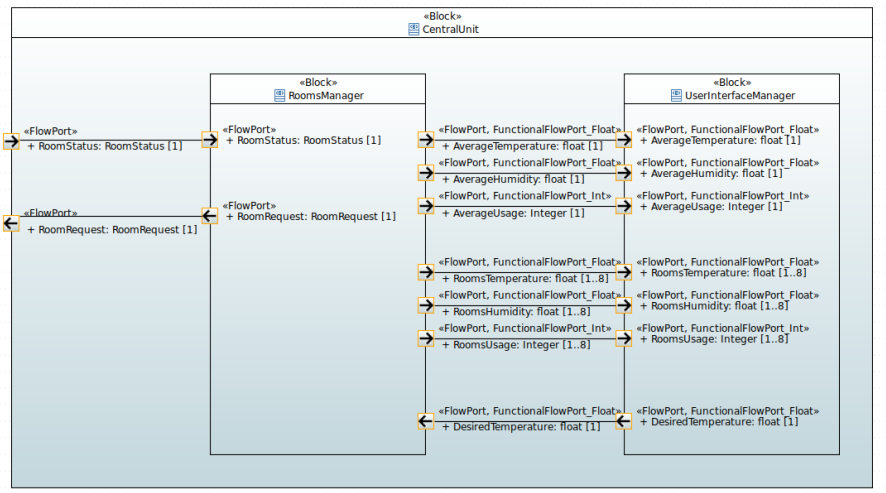


Figure 4: Central Unit internals

2.2 Room module

The main component of this module is the *MainController* composed by different funcionts as shown in 6.

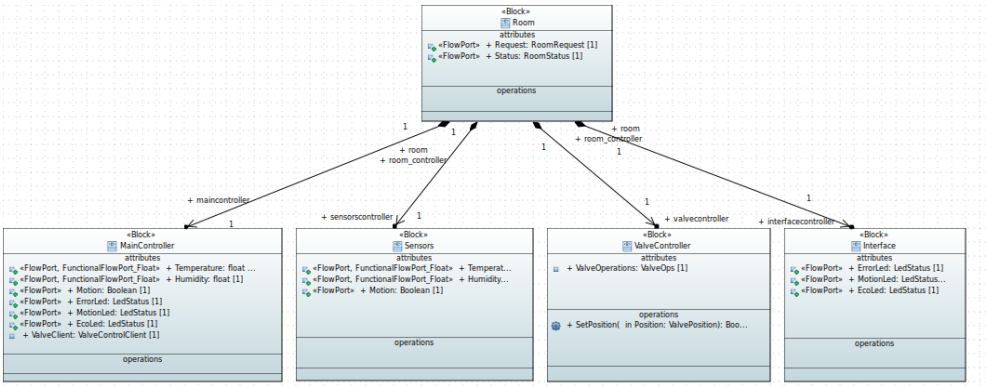


Figure 5: Room Components

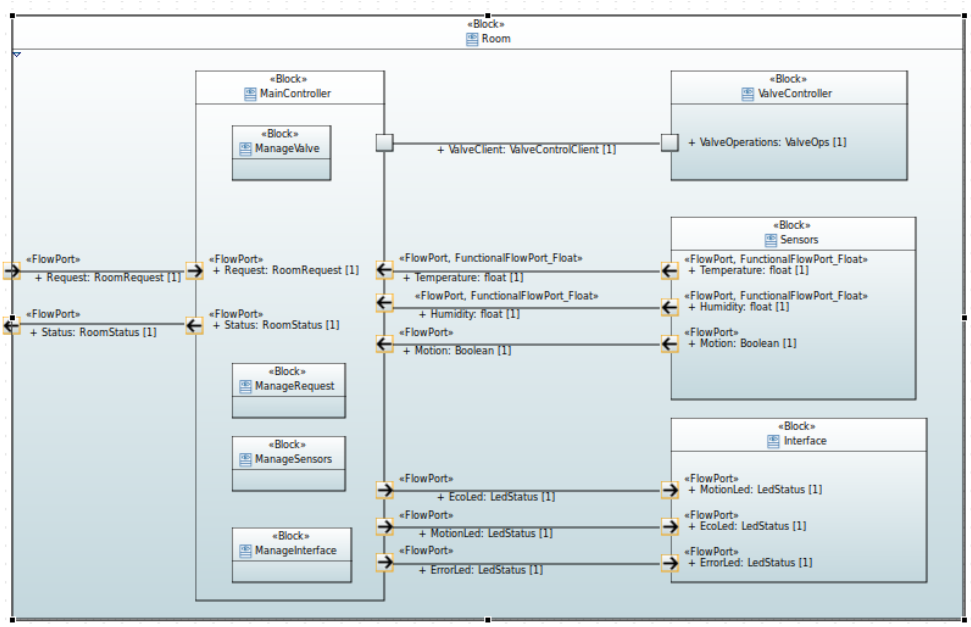


Figure 6: Room Internals

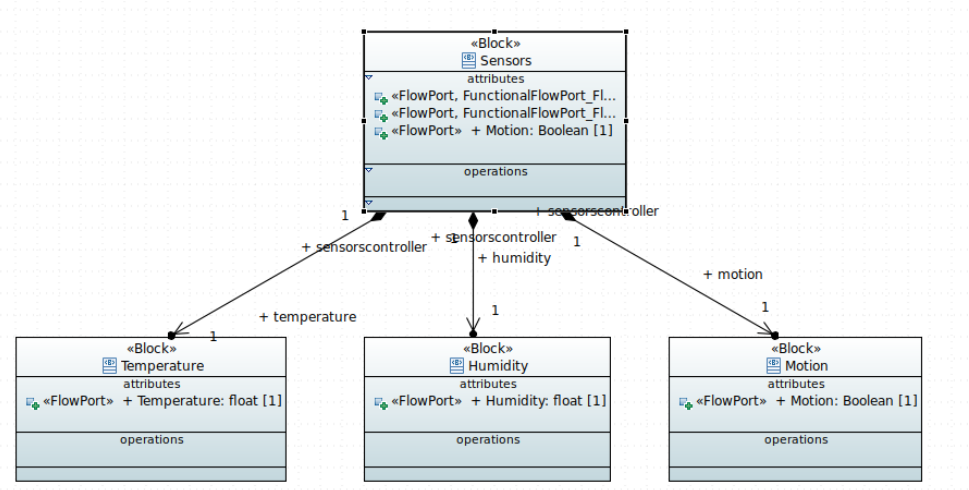


Figure 7: Room sensors components

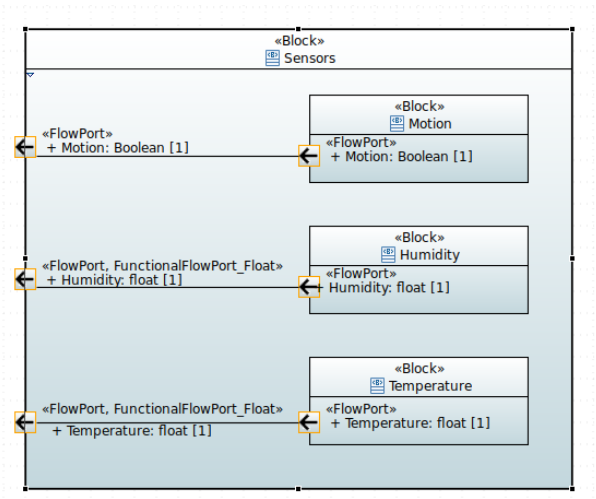


Figure 8: Room sensors internals

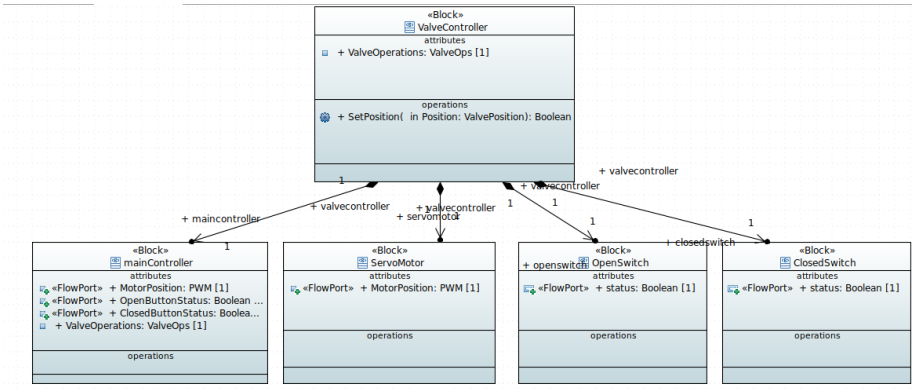


Figure 9: Valve Controller components

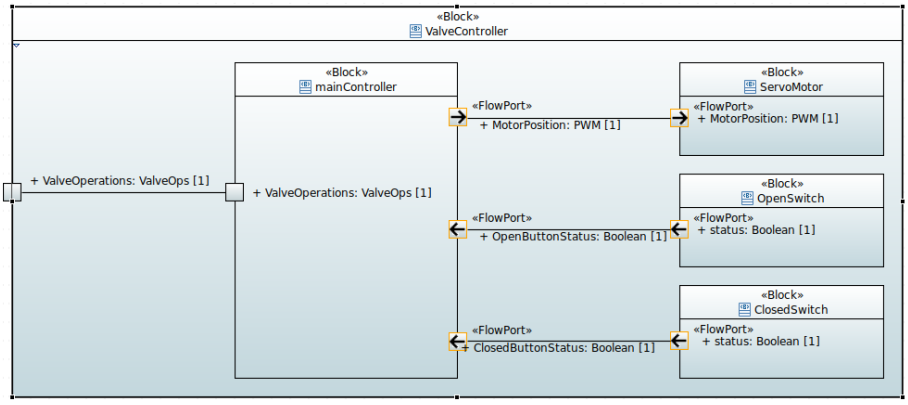


Figure 10: Valve Controller internals

3 Implementation, Central Unit module

Figure 11: Central Unit module

The module is composed by:

- STM32F407VG DISCOVERY powered by ARM Cortex-M4 32-bit
- LCD board Touchscreen 3"5

In the discovery board are running the *CentralUnit's* tasks on top of Erika RTOS, the systen is composed by three different tasks reported in the table 3.
Whenever a *RoomStatus* message arrives through the *USART* interface, the *CheckMessage* aperiodic task is activated in order to check the message and execute the *RoomManager's* functionalities.
The *CheckMessage* task apply a simple JSON compliance test and check each field name and value of the message, then the message is converted in a *RoomStrunct* and the Room's status and *Building* status are updated.
While the *CheckMessage* task has the role of processing the incoming *RoomStatus*, the *Polling* task has the role of managing the rooms sending a check message periodically one room after the other, if the response *RoomStatus* message doesn't arrive within the next task's job it's considered as an error and the same *RoomRequest* message is sent until a maximum of 3 resend, then the room is marked as crashed.
The *Graphic* task has the role to represent the data of the building and for each room depending on the selected page by the user, in the settings page the user is able to set the desired temperature that will be sent starting from the next job of the *Polling* task.

Name	Frequency	Priority
Check Message task	Aperiodic	3
Polling task	0.2Hz	2
Graphic task	10Hz	1
Receiver	USART background	/

3.1 Wiring

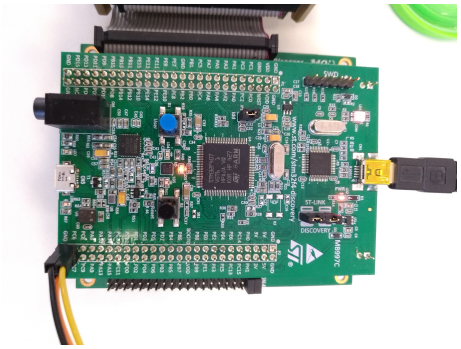


Figure 12: Discovery board wiring

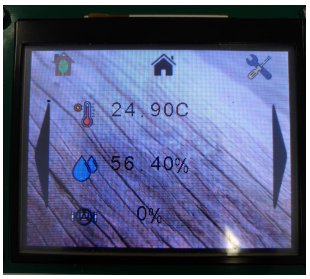
The module is using the *USART6* of the discovery board to comunicate with the *room* modules, in the following table is reported the configuration of the **USART6**

USART	TX pin	RX pin	baud-rate	Parity Bit	Stop bits	Control Flow
6	PC6	PC7	9600	No	1	No

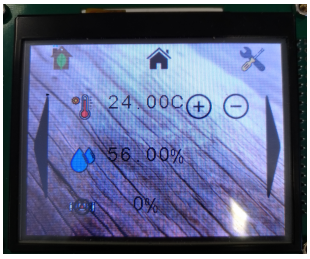
3.2 Graphic Interface

The graphic interface is compose by three different screens:

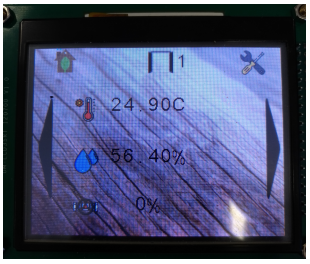
- Home screen
- Settings screen
- Room screen



(a) Home screen



(b) Settings screen



(c) Room screen

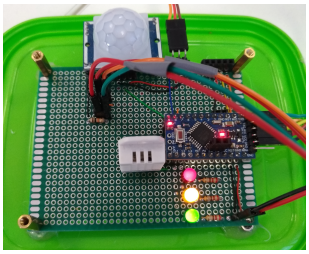
The main page is the **home screen** reported in 13a, in this page are reported the average values of the building, If at least one room is marked as *crashed* then a warning appear on the home screen. If at least one room is in *eco mode* then an *eco* icon is displayed on the home screen. If the difference between the desired temperature and the actual average temperature is less then 0.5C°, the shown termometer icon is hot otherwise cold. In the **settings screen** reported in 13b it is possible to set the desired temperature of the building that is the same for each room. In the **room screen** reported in 13c is displayed the status of the selected room, status composed by:

- Eco mode (the icon on the top-left of the screen)
- Temperature
- Humidity
- Valve position
- Warning (Warning icon between the eco icon and the icon in the top-center)

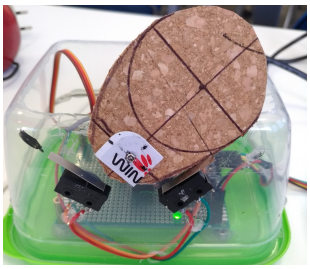
4 Implementation, Room module

The *Room* functionalities are running on a ATM328P, the tasks of the module are implemented as pseudo-periodical tasks using the *timer0* to check the activation time of each task, the tasks are reported in the following table.

Name	Frequency
Main task	0.5Hz
ControlValve task	0.25Hz



(a) Room module



(b) Valve

The module is composed by:

- Arduino pro mini, Atmega328P (8MHz, 3.3v logic)
- DHT22 Temperature and Humidity sensor
- PIR motion sensor
- Red led
- Green led
- Yellow led
- Servo Motor tower pro SG90
- 2 switch to check the open and closed position of the valve

4.1 Components description

4.1.1 ServoMotor

The chosen ServoMotor is a Tower Pro SG90 reported in 15, As reported in the 15, the signal used to move the servomotor in the correct position is a PWM and the duty-cycle describe the position that the motor has to maintain. The signal to control the motor position is managed by the Servo library using the **timer1** a 16-bit timer. The digital circuit inside the servomotor will adjust the position of the rotor using a potentiometer attached to that. In the following table are reported the characteristics of the servomotor:

Voltage(V)	4.8 - 6
Torque(Kg-cm)	2.5
Speed(sec)	0.1
Weight(g)	14.7

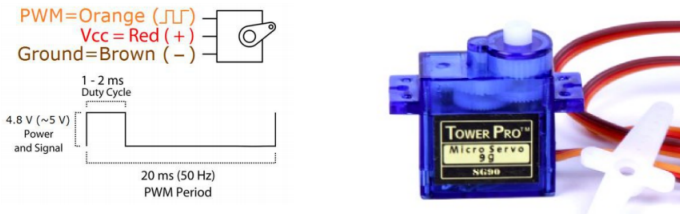


Figure 15: Servo Motor

4.1.2 Valve position switches

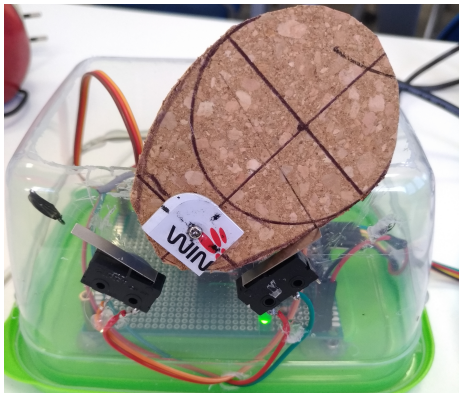


Figure 16: Discovery board wiring

In order to check the position of the valve, two switches are fixed in the open and closed position, during the *init_valve* phase the possible positions are computed starting from the open and closed position. Whenever the valve is in the open or closed position a check is done using the switches.

4.1.3 Temperature-Humidity Sensor

The sensor DHT22 have been used for the projet, in the following tables are reported the features of the sensors. The sensor has a dedicated one-wire communication protocol implemented by the DHT adafruit library, a pull-up resistor is used in order to mantain the line clear when no one is transmitting.

Voltage(V)	3 - 5
Current(mA)	2.5
Humidity(%)	0 - 100
Humidity Accuracy(%)	2 - 5
Temperature(C°)	-40 - 80
Temperature Accuracy(C°)	+/- 0.5
Sampling rate(Hz)	0.5

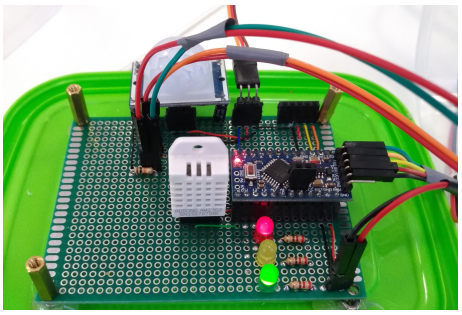


Figure 17: Room board wiring

4.2 Wiring

The board is powered by 5V external power attached to the *Raw pin*, this source is shared with the servomotor and the PIR sensor. In 17 is reported a picture of the implementation, in the following table the pins' configuration.

Red led	13	D OUTPUT
Yellow led	12	D OUTPUT
Green data	11	D OUTPUT
DHT data	10	D INPUT
PIR data	9	D INPUT
ServoMotor PWM	8	D OUTPUT
Open Switch	7	D INPUT
Closed Switch	6	D INPUT
USART TX	0	D OUTPUT
USART RX	1	D INPUT

5 JSON messages implementation

As described in the SySML internal model of the system 4, the modules exchange informations as *RoomRequest* and *RoomStatus*. These messages have been implemented using the *JSON* format, in the following are reported two messages exchanged during execution. In the following version of the project the field names and the order of the variables must follow this example otherwise the simple JSON parser will consider the message as corrupted.

5.1 Request Message

```
{
  "Id":"01",
  "DTemp":"30.00"
}
```

5.2 Status Message

```
{
  "Id":"02","Eco":"0",
  "sens":[
    {"Nm":"Tmp","Val":"23.70","Fmt":"C"},
    {"Nm":"Hum","Val":"051.90","Fmt":"\%"}
  ],
  "acts":[
    {"Nm":"Vlv","Val":"100","Fmt":"\%"}
  ]
}
```

6 CUnit tests and simulation of the system

In order to check the behaviour of the system a sequence of tests have been executed on the *ESTA_ JSON_ lib* functions, that is used to convert the incoming JSON string from the module *Room*.

6.1 Variables tests

For each variable present in the JSON message a boundary test is exeuted.

Variable	Min	Max	1°	2°	3°	4°	5°	6°	7°
Id	1	2	0	1	2	3	/	/	/
Eco	0	1	-1	0	1	2	/		/
Temperature	15.0	30.0	14.99	15.0	15.01	29.99	30.00	30.01	22.5
Humidity	0.0	100.0	-0.01	0.0	0.01	99.99	100.00	100.01	50.00
Valve	0	100	-1	0	1	99	100	101	50

6.2 JSON Compliance tests

In order to check the *JSON compliance code checker* the following tests are applied modifying a correct message.

Number	Description
1	Missing odd number of *{*
2	Missing odd number of *"*
3	Missing odd number of *[*
4	Check field name *Id*
5	Check field name *Eco*
6	Check field name *Nm*
7	Check field name *Val*
8	Check field name *Fmt*
9	Check field name *Tmp*
10	Check field name *Hum*
11	Check field name *Vlv*
12	Check Temperature format value *C*
13	Check Humidity format value *%*
14	Check Valve format value *%*

In the following picture 18 is reported the result of the tests executed using the framework *CUnit* Version 2.1-3.

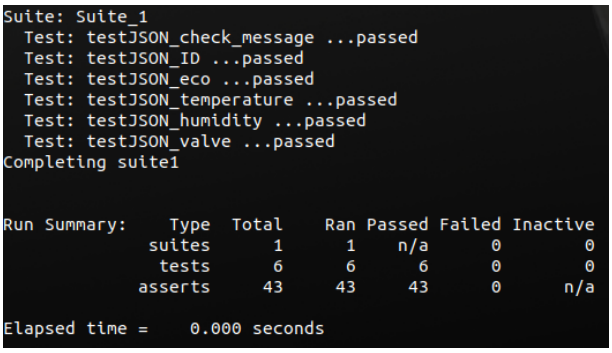


Figure 18: CUnit results

6.3 Network noise tests

In order to check the correctness behaviour of the *Central Unit* module a python conde that simulates the rooms has been created and used to test the module simulating two different rooms. The **Room simulator** creates the correct JSON string and send it, in order to simulate the **noise** of the network this cases have been considered:

Number	Description	Probability
1	Message lost, the resoinse message is discarded	0.1
2	Message corrupted, 3 random characters are replaced with *?*	0.1

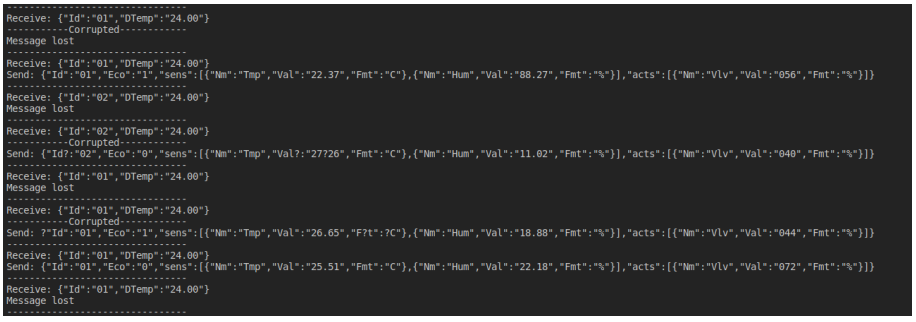


Figure 19: Room simulator

7 Future Work

This kind of **energy saving** application strictly depends on the usage of the building and the building itself.
In order to maximize the effectiviness of the heating system and minimize the consumption, different prameters play an important role, I report some of them in the following list

- room characteristicts (dimension, orientation, furnitures, etc.)
- usage of the room strictly depends on the users' life style
- external weather condition
- period of the year

These parameters have to be taken in consideration to compute the **energy threshold** of each room in such a way that the single room can reach the desired temperature in the shortest time.

One of the possible future work could be to integrate a *Machine Learning* functionality in order to adjust this *energy threshold* parameter considering all the informations related to the construction of the building and the usage coming from the sensors in the rooms.