Embedded platforms and communications for IoT

Official master degree Internet of Things

Final project

Implementation of the embedded platform for plant monitoring IoT system using the B-L072Z-LRWAN1 ARM mbed-based platform

v.2.1

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1 INTRODUCTION

1.1 Document Overview

This document describes the objectives and the specifications of the final IoT system to be developed during the course "Embedded platforms and communications for IoT".

1.2 Final Project Objectives

The main goal of this project is to develop an IoT system allowing environmental conditions and the health of a plant throughout its life. For example, this will enable vendors to adjust the final price of unique plants, like bonsais or very delicate plants, for which the environmental conditions they have suffered throughout their lives are crucial. The system could also be useful as a monitoring system in greenhouses by monitoring several plants randomly.

In this course, only the hardware and the software of the final system will be developed, while the wireless communication modules will be developed during the "Sensor Networks" course next bimester.

The system should continuously monitor basic environmental parameters, such as temperature, relative humidity, and ambient light, directly affecting the plants' health. Additionally, the soil moisture in which the plant is growing must also be recorded periodically. Even to offer more information, the system will also monitor the colour of the plant, to have information about its evolution over time. Other essential aspects of the plants' health are the possible issues they have to suffer during storage or transport, such as sudden movements, falls, hits, overturns, and base unevenness. All these parameters should also be monitored. Finally, the IoT system should provide continuous information about the plant's global location using GPS. Figure 1 shows a picture of a possible implementation of the whole system.

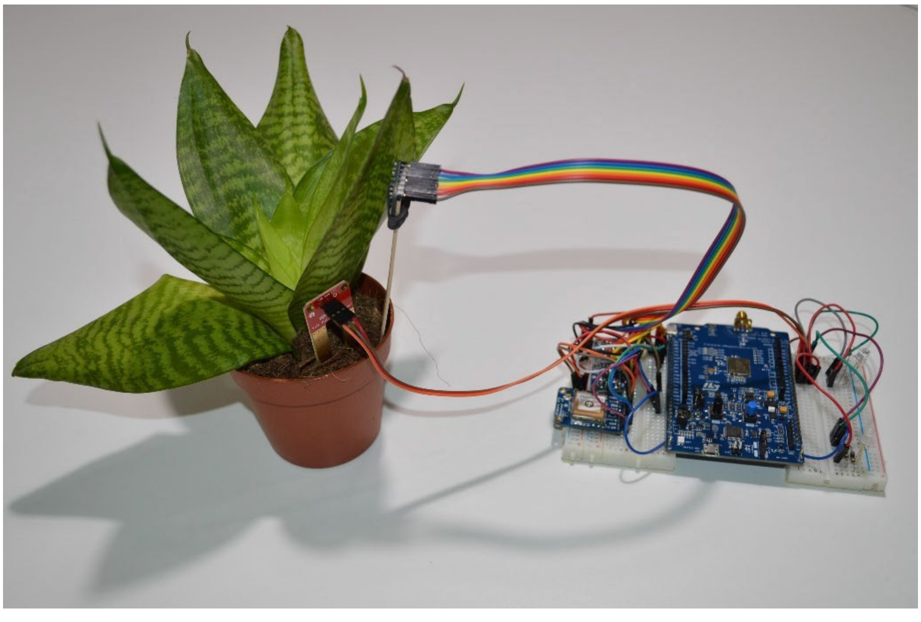

Figure 1. Final implementation of the IoT system.

1.3 Acronyms

ADC	Analog to Digital Converter
COM	Communication port (serial)
EEPROM	Electrical Erasable Programmable Read-Only Memory
FSK	Frequency Shift Keying
GPIO	General Purpose Input Output
GPS	Global Positioning System
I/O	Input / Output
I2C	Inter-Integrated Circuit
IDE	Integrated Development Environment
IoT	Internet of Things
LED	Light Emitting Diode
MDK	Microcontroller Development Kit
OOK	On-off keying
OS	Operating system
OTG	On-The-Go
PWM	Pulse-width modulation
RGB	Red-Green-Blue
SPI	Serial Peripheral Interface
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus

1.4 References

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2 PROJECT SPECIFICATIONS

2.1 Hardware and software elements

2.1.1 Hardware.

This section describes the microcontroller board and the sensors needed for the project implementation. Every group of students (ideally each student) will receive on loan a box containing all the material (see Figure 2). Of course, students are free to use other sensors to meet the design requirements or add additional hardware to improve the system.

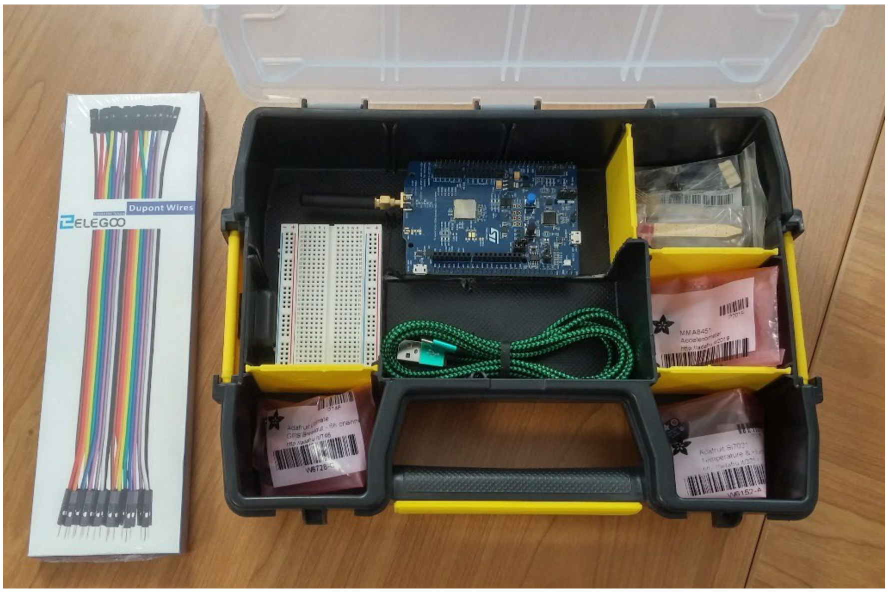


Figure 2. Loan material to implement the final IoT system.

The final project for this course is based on the *B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery kit* [1] (Figure 3) and several sensors for monitoring all the required parameters.

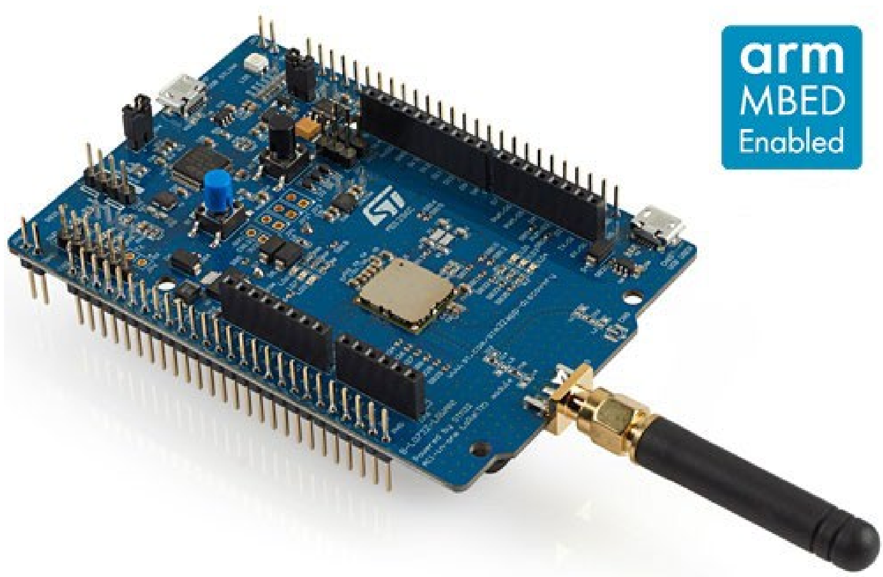


Figure 3. B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery kit.

The B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery kit is a development tool to learn and develop solutions based on LoRa®, Sigfox™, and FSK/OOK technologies. This Discovery kit features an all-in-one open module CMWX1ZZABZ-091 (by Murata). The module is powered by an STM32L072CZ (based on Arm® Cortex® -M0+ core, with 192 Kbytes of Flash memory, 20 Kbytes of RAM, 20 Kbytes of EEPROM) and an SX1276 transceiver. The transceiver features the LoRa® long-range modem, providing ultra-long-range spread spectrum communication and high interference immunity, minimising current consumption. Since CMWX1ZZABZ-091 is an open module, the user has access to all STM32L072 peripherals such as ADC, 16-bit timer, LP-UART, I2C, SPI and USB 2.0. In addition, B-L072Z-LRWAN1 Discovery kit includes an ST-LINK/V2-1 embedded debug tool interface, LEDs, push-buttons, antenna, Arduino™ Uno V3 compatible connectors and USB OTG connector in Micro-B format [2].

The suggested sensors to measure each parameter are the following:

- **Temperature and relative humidity**: The Si7021 digital relative humidity and temperature sensor [3] integrates humidity and temperature sensor measurement, an ADC converter, signal processing and an I2C interface in a single chip (Figure 4). The Si7021 has a temperature accuracy of ±0.4 °C in the range of -10 °C to +85 °C, and a relative humidity accuracy of ±3% with a range of 0–80 %RH. The *Adafruit Si7021 Temperature & Humidity Sensor Breakout Board* [4] is suggested (Figure 5) to ease the sensor connections to the rest of the system.

Figure 4. Temperature and humidity sensor Si7021.

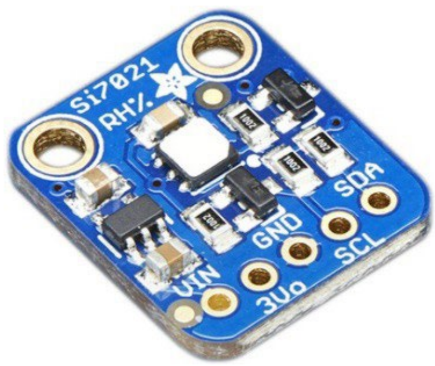


Figure 5. Adafruit Si7021 Temperature & Humidity Sensor Breakout Board.

- **Ambient light**: The *Photo Transistor Light Sensor HW5P-1* [5] is a simple sensor that detects ambient light (Figure 6). It provides an analog output voltage proportional to the light detected by the sensor.

Figure 6. Light sensor HW5P-1.

- **Soil moisture**: The *SparkFun Soil Moisture Sensor* is a simple breakout for measuring the moisture in the soil and similar materials [6]. The two large, exposed pads function as probes for the sensor, acting as a variable resistor. The more water that is in the soil, the better the conductivity between the pads will be, resulting in lower resistance and a higher voltage in SIG out pin (Figure 7). Therefore, it provides an analog output voltage proportional to the soil moisture detected by the sensor.

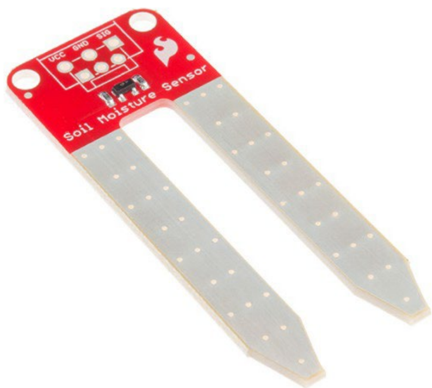


Figure 7. SparkFun soil moisture sensor.

- **Leaf colour**: The TCS3472 device [7] provides a digital return of red, green, blue (RGB), and clear light sensing values. The TCS3472 light-to-digital converter contains a 3 × 4 photodiode array, four analog- to-digital converters (ADC) that integrate the photodiode current, data registers, a state machine, and an I2C interface. It is recommended to use the *Adafruit RGB Color Sensor with IR filter and White LED - TCS34725 Breakout Board* [8] (Figure 8) to ease the sensor connections with the rest of the system. In addition to the colour sensor, this breakout board incorporates a LED onboard to illuminate the object to be sensed. The LED can be easily turned on or off by any logic level output.

Figure 8. Adafruit RGB Color Sensor with IR filter and White LED - TCS34725 Breakout Board.

- **Storage and transport issues**: To have information about possible issues during plant storage, grow or transport, such as sudden movements, falls, hits, overturns, and base unevenness, the accelerometer MMA8451Q is suggested (Figure 9). The MMA8451Q device [9] is a smart, low-power, three-axis, capacitive accelerometer with 14 bits of resolution and an I2C interface. It is recommended to use the *Adafruit Triple-Axis Accelerometer - ±2/4/8g @ 14-bit - MMA8451 Breakout Board* [10] (Figure 10) to ease the accelerometer connections with the rest of the system.

Figure 9. MMA8451Q, 3-axis, 14-bit/8-bit digital accelerometer

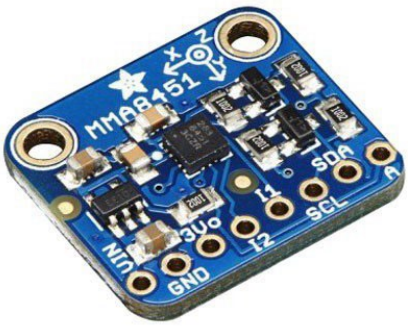


Figure 10. Adafruit Triple-Axis Accelerometer - ±2/4/8g @ 14-bit - MMA8451 Breakout Board

- **Global location**: The *Adafruit Ultimate GPS Breakout Board (version 3)* is suggested [11] (Figure 11) to track the global location of the plant. This board integrates the FGPMMOPA6H module [12], which utilises the MediaTek new generation GPS Chipset MT3339 [13] that achieves the industry's highest level of sensitivity (-165dBm). The device provides an excellent Time-to-First-Fix (TTFF) time with the lowest power consumption for accurate GPS signal processing to give the ultra-precise positioning under low receptive and high-velocity conditions. The GPS module provides the collected information periodically through a serial line. This module also provides GPS current time (UTC). A CR1220 coin cell battery should be installed in the breakout board to maintain the time even without a power supply.

Figure 11. Adafruit Ultimate GPS Breakout Board- 66 channel w/10 Hz updates - Version 3.

- **Global Status of the plant**: To inform about the global status of the plant, considering all the previous parameters collected from different sensors, an RGB LED could be used [14] (Figure 12). The RGB LED should be connected to the microcontroller board using three digital lines, using resistors to limit the current through the LEDs. Ideally, these lines should be controlled with PWM (Pulse Width Modulation) signals to achieve any colour combination in the RGB LED.

Figure 12. Common cathode RGB LED

Figure 13 depicts the suggested block diagram for the final IoT system. Note that the colour sensor, the temperature and relative humidity sensor, and the accelerometer share the same I2C bus. Blue signals are optional and should be used only after completing the basic requirements for the IoT system.

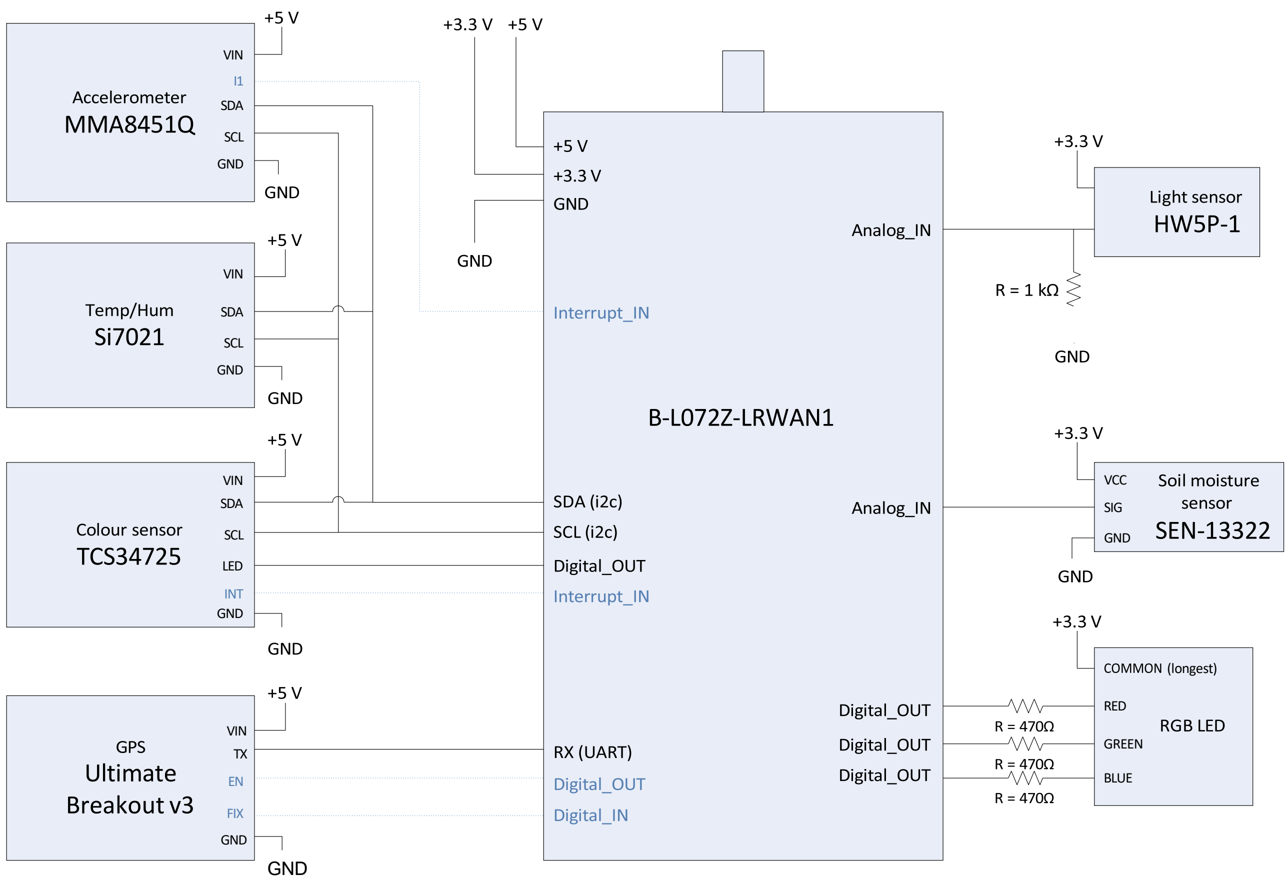


Figure 13. Block diagram of the suggested IoT system for plant monitoring.

Table 1 summarises the hardware suggested for implementing the whole IoT system, including the connection between the sensors and the microcontroller board, and the approximate price of every element.

Table 1. Summary of suggested hardware for the IoT system

Parameter	Sensor/module and complexity	Connection	Approx. price (€)
	B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery kit		39.5
Temperature/Humidity	Si7021	I2C	5.9
Ambient light	HW5P-1	Analog	0.8
Soil moisture	SEN-13322	Analog	4.2
Leaf colour	TCS34725 (*Complex*)	I2C / digital	6.8
Storage and transport issues	MMA8451Q (*Complex*)	I2C / digital	6.8
Global location	FGPMMOPA6H (*Complex*)	Serial / digital	34.0
Status	RGB LED	Digital	0.1
TOTAL price (approx.)			98.1

2.1.2 Software

This section describes the software development platform selected for the IoT project implementation. Every computer in the classroom will be equipped with all the required software modules. Additionally, students can use the same configuration in their personal computers or laptops using the university licenses.

The development of the software application for the project requires:

1. Mbed OS. Arm Mbed OS is a free, open-source embedded operating system designed specifically for the "things" in the Internet of Things. It includes all the features you need to develop a connected product based on an Arm Cortex-M microcontroller, including security, connectivity, an RTOS, and drivers for sensors and I/O devices [17]. The mbed-os version used for the project implementation will be above 6.14.0.
2. Keil Studio Cloud and mbed studio are, respectively, free browser-based and desktop IDEs for the evaluation and development of embedded and IoT software Cortex-M devices [15].
3. SVN and TortoiseSVN or Git and git-tortoise clients for Windows. Git is a free and open-source distributed version control system designed to handle projects with speed and efficiency [18]. TortoiseGit is a Windows shell interface to Git. It is open-source and can fully be built with freely available software [19]. An example of an SVN online hosting free service is https://riouxsvn.com/.
4. TeraTerm or Putty, terminal emulator programs, installed in the personal computers to manage the USB virtual COM port to communicate with the B-L072Z-LRWAN1 board [20] [16].

2.2 System requirements

The final IoT system for this course has to meet the following requirements:

- The system should measure some physical variables in the environment of the plant. The physical variables to be measured are the following:

- [SR1] The temperature in the range of -10ºC to 50ºC. Accuracy to one tenth of a degree.
- [SR2] The relative humidity in the range of 25%HR to 75%HR. Accuracy to one tenth of a percent.
- [SR3] Ambient light in %, corresponding 0% to total darkness and 100% to maximum light. Accuracy to one tenth of a percent.
- [SR4] Soil moisture in %, corresponding 0% to total dryness and 100% to maximum moisture. Accuracy to one tenth of a percent.
- [SR5] Colour of one leaf of the plant. The four associated parameters are clear, red, green, and blue values.
- [SR6] The global location of the plant should be registered. The GPS module also offers the current time (only time, the date is optional), that will be used to timestamp all the measurements taken by the system. Accuracy as shown in Fig. 14.
- [SR7] The acceleration of the plant. At least the three axes (X, Y and Z) values should be monitored. Formatted as shown in Fig. 14.

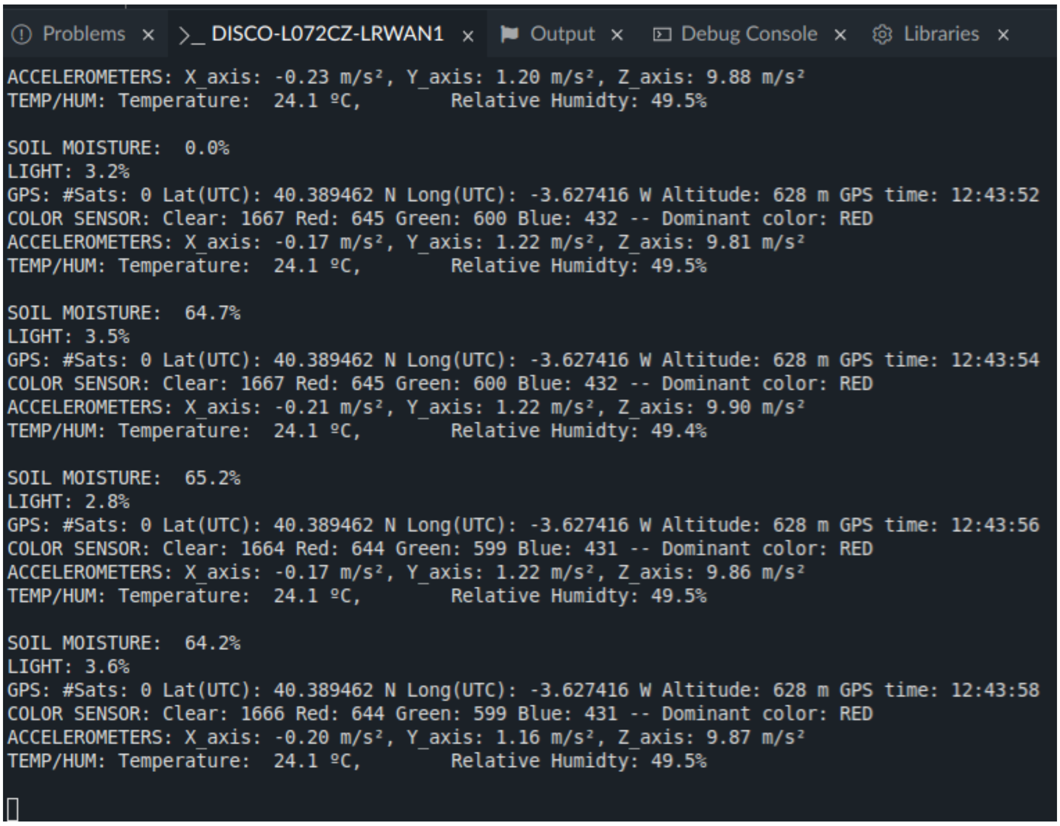
- [GR1] The system must be robust and stable.
- [GR2] Task partitioning and threads management should be stablished according to the requirements.

- The system will have three operating modes:

1. TEST MODE

- [TM1] Check connections and sensor management.
- [TM2] All of the required variables should be monitored every 2 seconds.
- [TM3] The system sends every 2 seconds all the measured values to the computer (using the USB virtual COM port of the B-L072Z-LRWAN1 board).
- [TM4] The RGB LED should be coloured in the dominant colour detected by the colour sensor.
- [TM5] In this mode, the LED1 of the B-L072Z-LRWAN1 board should be ON.

This mode allows the user to check if all elements in the system are working correctly. Figure 14 depicts a possible output for an application running in TEST MODE.



```
Problems × >_ DISCO-L072CZ-LRWAN1 × Output × Debug Console × Libraries ×
ACCELEROMETERS: X_axis: -0.23 m/s², Y_axis: 1.20 m/s², Z_axis: 9.88 m/s²
TEMP/HUM: Temperature:  24.1 ºC,       Relative Humidty: 49.5%

SOIL MOISTURE:  0.0%
LIGHT: 3.2%
GPS: #Sats: 0 Lat(UTC): 40.389462 N Long(UTC): -3.627416 W Altitude: 628 m GPS time: 12:43:52
COLOR SENSOR: Clear: 1667 Red: 645 Green: 600 Blue: 432 -- Dominant color: RED
ACCELEROMETERS: X_axis: -0.17 m/s², Y_axis: 1.22 m/s², Z_axis: 9.81 m/s²
TEMP/HUM: Temperature:  24.1 ºC,       Relative Humidty: 49.5%

SOIL MOISTURE:  64.7%
LIGHT: 3.5%
GPS: #Sats: 0 Lat(UTC): 40.389462 N Long(UTC): -3.627416 W Altitude: 628 m GPS time: 12:43:54
COLOR SENSOR: Clear: 1667 Red: 645 Green: 600 Blue: 432 -- Dominant color: RED
ACCELEROMETERS: X_axis: -0.21 m/s², Y_axis: 1.22 m/s², Z_axis: 9.90 m/s²
TEMP/HUM: Temperature:  24.1 ºC,       Relative Humidty: 49.4%

SOIL MOISTURE:  65.2%
LIGHT: 2.8%
GPS: #Sats: 0 Lat(UTC): 40.389462 N Long(UTC): -3.627416 W Altitude: 628 m GPS time: 12:43:56
COLOR SENSOR: Clear: 1664 Red: 644 Green: 599 Blue: 431 -- Dominant color: RED
ACCELEROMETERS: X_axis: -0.17 m/s², Y_axis: 1.22 m/s², Z_axis: 9.86 m/s²
TEMP/HUM: Temperature:  24.1 ºC,       Relative Humidty: 49.5%

SOIL MOISTURE:  64.2%
LIGHT: 3.6%
GPS: #Sats: 0 Lat(UTC): 40.389462 N Long(UTC): -3.627416 W Altitude: 628 m GPS time: 12:43:58
COLOR SENSOR: Clear: 1666 Red: 644 Green: 599 Blue: 431 -- Dominant color: RED
ACCELEROMETERS: X_axis: -0.20 m/s², Y_axis: 1.16 m/s², Z_axis: 9.87 m/s²
TEMP/HUM: Temperature:  24.1 ºC,       Relative Humidty: 49.5%
```

Figure 14. Example of possible output of the system in TEST MODE.

2. NORMAL MODE:

- [NM1] All the required variables should be monitored with a cadence of 30s.
- [NM2] The system sends every 30 seconds all the measured values to the computer (using the USB virtual COM port of the B-L072Z-LRWAN1 board).
- [NM3] The system calculates the mean, maximum and minimum values of temperature, relative humidity, ambient light and soil moisture every hour. These values are sent to the computer when calculated.
- [NM4] The system calculates the dominant colour of the leave every hour. This means to calculate which colour has appeared as dominant more times during the last hour. This value is sent to the computer when calculated.
- [NM5] The system calculates the maximum and minimum values of the three axes (X, y and Z) of the accelerometer every hour. These values are sent to the computer when calculated.
- [NM6] The global location of the plant (coordinates) is sent to the computer every 30 seconds. This should include the GPS time (UTC) converted to local time.
- [NM7] Limits for every measured variable (temperature, humidity, ambient light, soil moisture, colour and acceleration) should be fixed. If the current values of the measured parameters are outside the limits, the RGB LED should indicate this situation using a different colour for every parameter.
- [NM8] In this mode, the LED2 of the B-L072Z-LRWAN1 board should be ON.

3. ADVANCED MODE (OPTIONAL):

- This operating mode is optional.
- The requirements for this mode will be different for each group of students and will be provided during the validation assessment in the third week of the project's development.
- In this mode, the LED3 of the B-L072Z-LRWAN1 board should be ON.

The system starts in TEST MODE and changes from one operating mode to the next one (TEST – NORMAL – ADVANCED - TEST…) by pressing the blue button B1 on the B-L072Z-LRWAN1 board in a circular way.

2.3 Main project tasks

The main foreseen tasks that students should complete to develop the final project are summarised in Table 2. Most of the tasks will be developed individually, while other tasks will be developed by a pair or a group of students.

Table 2. Summary of the project tasks

Task	Subtask	Comments	Type
Analysis	Analysis of the final project specifications	This document	Individually
	Read of the technical documentation of the different sensors	See references (section 1.4) of this document	Individually/ Pair
	Search in mbed repository for examples of C++ programming using the sensors	mbed website	Individually/ Pair
Hardware	Identify the connections needed to interface the Si7021 with the B-L072Z-LRWAN1	I2C interface	Individually/ Pair
	Make the connections	Use the provided cables and the breadboard to connect all sensors to the LRWAN1 board	Pair
Software	Download/log in the Mbed OS Cloud and test some examples	Course website	Individually
	Decide the threads to be implemented		Individually
	Implement simple test programs for the sensors to validate the physical connection and the basic functionality	Search for examples in mbed website	Individually
	(optional) Save your project software versions in your own GitHub repository		Individually
Debugging	Test the functionality of the different threads and the main application	Verify that no memory stack corruption appears in the application. Debug always using the serial line connected to your computer (Serial prompt will display messages with an error if any)	Individually
	Test the functionality of every thread and every sensor using the debugger		Individually
	Test all modes of the project		Individually
	Ask for *Advanced mode* specifications to instructors		Individually/ Pair
Documentation	Develop the technical documentation of the final project	Download the template from the course website	Individually/ Pair

2.4 Tentative Final-project schedule

Table 4 indicates the foreseen schedule for the classroom activities of the final project.

Table 4. Tentative Project Schedule (subject to modifications)

1	October 7th	Release of project specifications. Distribution in workgroups. Collaborative work in couples (analog sensors, RGB, software, etc.).
2	October 28th	*Group presentations (**10+5 min.**)*
3	October 21th, November 4th and 11th	Collaborative work in couples
4	November 8th	Verification of the design and optional's proposal (depending on the verification).
5	November 18th	Project final assessment
6	December 1st	(not class) Documentation upload to Moodle

2.5 Final consideration

The use of complex libraries that encapsulate the management of the sensors included in the design should be avoided. One of the purposes of the proposed design is precisely to learn how to generate such resources and to be able to explain the details of how the sensors and the peripherals that govern them work. Doing this demonstration with a library in between that masks the complexity of the system is certainly difficult.

It is allowed, and even encouraged, to use these libraries to test whether a sensor is properly connected and working correctly. But beyond that, students should be able to build such functionality themselves.

In any case, no matter what resources are used in the final version to be assessed, it should be demonstrated with sufficient proficiency that the details of implementing, configuring, reading and writing to the sensors are known. In the case of using libraries that mask these aspects and not being able to respond or demonstrate the required level of detail, the corresponding part will be graded with a zero.