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GENERAL PURPOSE CARD FOR IoT APPLICATIONS

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ABSTRACT

This document presents the design and implementation of a general-purpose card model, which integrates nine sensors, seven actuators and four communication interfaces, all included on the same card. This board model is conceived as a hardware tool for the development of prototype nodes for sensors and actuators, becoming a platform for the development of a wide variety of projects in IoT, focused to be used in Arduino's development ecosystem. The design requirements of a printed circuit board are established, compatible with the dimensions, physical structure and distribution of the connections of the board module of the Arduino UNO platform, then the most suitable electronic components in the market were determined, which are adapted to the designed printed circuit board.

Keywords: sensors, actuators, prototype, printed circuit board - PCB, internet of things (IoT).

1. INTRODUCTION

In the environment of the deployment of infrastructure for IoT applications, the sensor nodes play a fundamental role in the structure of the Internet of Things IoT, since they fulfill the function of monitoring a specific environment, through the specific tasks of "collection, processing, analysis and transmission of acquired information, collected in different environments" [1]. To fulfill its objective, the device is composed of different elements such as sensor interface, processing unit, transceiver unit and power supply. Modern sensors include multiple A/D conversion units for sensor interfaces, as well as communication modules that operate in specific frequency bands that improve communication needs [1].

Another type of devices used in this large infrastructure are the actuating nodes, which perform intervention work in the environment in which they are located, as a response to indications or stimuli generated by a processing and control unit, in this way triggering devices or initiating external processes, and that according to the logical distribution of the nodes, perform specific functions, both the sensor nodes, and the actuating nodes, being part of a technology called Wireless Network of Sensors and Actuators (WNSA).

Given the importance of mentioned devices, with respect to their design concept to operate autonomous, integrating themselves into the environment without affecting or disturbing a given environment [2], their operation is limited by certain design restrictions, limitations basically referred to the hardware of the components, which are intended for specific application, which prevents the use of the same hardware module for different tasks in terms of multiple use, which is why it is important to consider the design and implementation of hardware modules focused on multipurpose [3].

The interest of this project, focused on proposing and designing a multipurpose printed circuit module, which integrates in the same circuit plane, various electronic components essential in the IoT environment, such as sensors, actuators, external storage modules and wireless communication modules, adaptable for various sockets of processing units with particular conditions, and which in turn facilitates the construction of prototypes according to the need.

In this way, the hardware tool designed facilitates the development of rapid prototypes, for projects focused on networks of sensors and actuators in IoT, taking advantage of the capabilities of the system to which it adapts, and those of the same card designed, under the considerations described in this document.

2. ANALYSIS OF THE IoT DEVICE MARKET

The Internet of Things revolution has stimulated the growth of directly related technology markets, such as the sensor market, which has grown considerably in recent years worldwide, because sensors are the basic input in the development of any IoT device [4-5]. The increasing demand for IoT sensors in the industrial sectors and in the burgeoning Industrial Internet of Things market is driving the growth of the IoT sensor market [6].

In order to have a clear idea of the different types of elements that are normally incorporated when implementing an IoT project, a simple study was carried out on the base hardware platforms, sensors, actuators and communication modules of 100 projects already implemented between 2010 and 2019 [7-13].

The first analysis was made based on the development platform used for the execution and implementation of the project. Figure-1 shows the results of this study, resulting in five main platforms: first the Raspberry Pi, followed by the Arduino system, thirdly the ESP8266 board, fourthly the Waspmode board and finally the Intel Edison system, the latter three designed specifically for the development of IoT applications.

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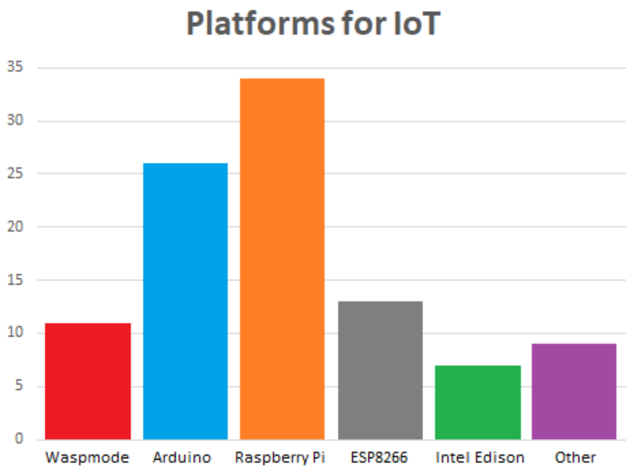

Figure-1. Most widely used IoT development boards.

Figure-2 shows the results obtained from the same study carried out but now for the most used sensors in the development of IoT devices, showing that the most used sensor is the temperature one, including also other types of sensors such as infrared, light, humidity, movement among the main ones.

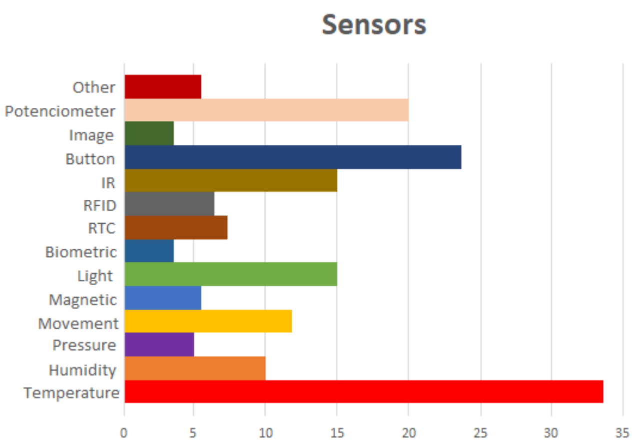

Figure-2. Most used sensors in IoT applications.

To determine the most commonly used actuators in IoT projects we proceeded in the same manner, finding that the most commonly used actuator is an LED type output (used 52 times), followed by the relay type output (used 35 times), the DC motor type actuator, the Buzzer, the servo motor and LCD display have a similar use of approximately 20 times.

Finally, Figure-3 shows the result of the analysis carried out on the types of communication module used in each of the implementations consulted, showing that the communication module using the WiFi standard is the most widely used. The remaining communication modules are generally used to interconnect with other devices, such as Bluetooth, which is an ideal interface for communicating with a smartphone, as well as ZigBee and LoRa type devices.

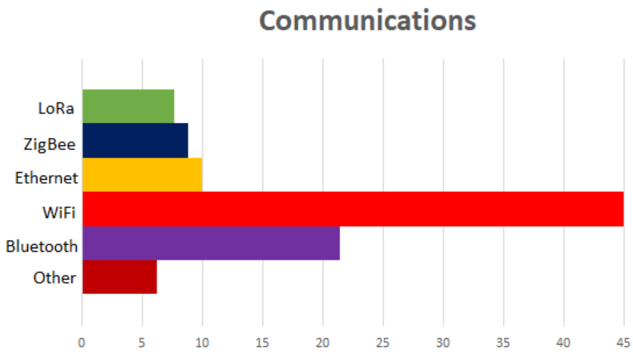

Figure-3. Communications systems used in IoT applications.

3. THEORETICAL FRAMEWORK

3.1 Basic Aspects of a Sensor Node

A sensor node consists of four basic components, a sensor system, a processing unit, a communications unit and a power unit. They may also have additional elements depending on the application, such as a location system, a power generator and a mobilization unit, as shown in Figure-4 [2].

The sensor units are composed of two subunits: sensors and digital analog converters (ADC). The analog signals produced by the sensor in the observation of a variable are converted to digital by the ADC, and directed to the processing unit. This processing unit, usually associated with a small storage unit, manages the processes that allow mutual collaboration between sensors to perform the required monitoring tasks. A transceiver unit connects the node to a network. One of the most important components of the sensor node is the power unit. The energy units are supported by devices such as solar panels. There are also other subunits, which are of specific use depending on the application [2].

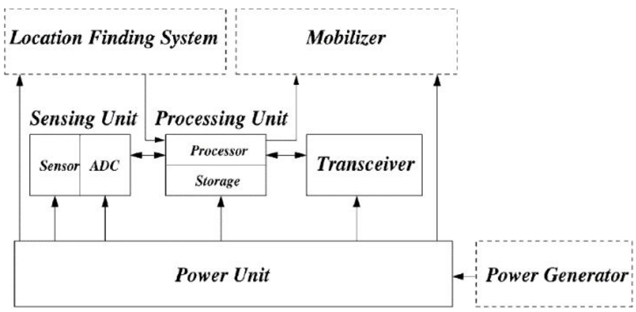

Figure-4. Typical components of a sensor node [2].

All these subunits need to be coupled to a box module of certain dimensions [14]. In addition to size, there are other restrictions for the sensor nodes, such as:

- Very low energy consumption
- Operate in high volume spaces
- Low production costs and be dispensable
- Be autonomous and operate in an unattended manner
- Be adaptive to the environment [15].

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3.2 Applications of Sensor Nodes

Sensor networks are composed of many sensors of different types, such as seismic, magnetic, low sampling rate, thermal, visual, infrared, acoustic and radar, which are able to monitor a wide variety of environmental conditions such as following:

- Temperature
- Humidity
- Vehicular movement
- Light conditions
- Pressure
- Noise levels
- Object detection
- Speed, direction and size of an object [16].

3.3 Wireless Sensor and Actuator Networks (WSAN)

A Wireless Sensor and Actuator Network (WSAN) is a group of sensors that collect information about the environment and actuators, such as servos or motors that interact with them. All the elements communicate wirelessly, and this interaction can be autonomous and controlled by humans.

WSAN is sometimes referred to as wireless sensor and actuator networks because more than one actuator can be found in an actuator point in the same network. An actuator point can refer to a combination of servo and geared electric motors organized for complex tasks. The sensors in a distributed WSAN are enabled for measurements and automatic sensing of environmental variables and control of certain parameters of the environment through the actuators and sensors controlled directly or autonomously.

WSANs are composed of multiple nodes in numbers approaching thousands, each node connected to nearby ones by means of sensor hubs just like an actuator or several. These devices are located in places where measurement and control of variables in the environment is required. In this scenario, automatic data processing and CPU control allow the actuator to modify its behavior immediately.

The initial development of WSAN was motivated by the interest of US military and government agencies to perform more effective monitoring tasks in the battlefield, and follow-up on objectives as well. Today, WSANs became popular for applications and commercial uses, such as monitoring and control of industrial parameters, telemedicine or scientific development [17].

Sensors and sensor hubs implemented in smartphones can be used to improve consumer services through location detection. The accuracy of this smartphone service will increase to such an extent that the precision error will be centimeters even in indoor environments. This precision capability will be achieved thanks to the joint use of sensors in the device. The applications of this function can be varied, for example, to determine entire populations from the knowledge of their location.

One of the most notorious differences between WSN wireless sensor networks and WSAN wireless sensor and actuator networks is that while a sensor node is very small in size, low cost, with limited sensing capabilities, computing limited computing capabilities and wireless communication, the actuators are devices that have great data processing capacity, higher transmission power of the communication modules and a longer battery life.

In the WSANs, depending on the specific application, there is a need to obtain a rapid response to the detection at the input of a sensor, therefore, the sensor data must be valid when actuating the actuator, therefore, the Real-time response is very important in WSANs since actions must be executed in the environment right after the event is detected [18].

4. DESIGN RECOMMENDATIONS FOR PRINTED CIRCUIT BOARDS

When starting the process of designing a system for IoT, a lot of time is spent on circuit design and component selection. However, at the end of the process, time and attention are not devoted to design aspects focused on the characteristics of the Printed Circuit Boards (PCBs), resulting in a design whose outcome may be very poor, since it does not meet the performance expectations that were assumed in the design stages [19]. For this reason, to obtain a PCB that achieves a great similarity between digital design and physical construction, these design parameters are proposed, which will allow a reliable, functional and suitable design for the construction of a printed circuit board according to the needs of the problem.

The task of optimizing the location of components on a PCB requires strategic considerations in terms of the physical space available on the board. This process also determines how easy the board can be made, and how it will perform once it is built. While a general design guide indicates the location of the components in the order of the connectors, the distribution of the power pins, etc., a specific guide recommends taking the following into account:

- **Orientation:** Be sure to orient similar components in the same direction and this will help with an efficient welding process and avoid mistakes.
- **Location:** Avoid locating components on the face where the components are welded likewise taking into account the elements that are located with the trough-hole method.
- **Organization:** It is recommended to locate the components that are surface on the same side of the card, and the trough-hole components on the upper side of the card, to minimize the welding steps required.

With the components located, it is necessary to establish the energy routes, ground and signal inputs to ensure that the signals have an unobstructed path. The following is recommended:

- **Orient ground and polarization planes:** It is always recommended to locate the polarization and earth

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planes in the internal view of the card, in the same way with centered location and in symmetrical points, this will help to protect the card from being bent; which will affect the components if they are not properly positioned. To energize the components of the card, it is recommended to use common lines for each source, making sure to use solid and wide lines, and avoiding connecting lines in series with power lines (Figure-5).

- **Connecting signal paths:** It is important to trace the signal paths as short as possible and direct between components. If the general location of components requires placing a horizontal cut on one side of the card, always locate a vertical path on the opposite stroke.
- **Define the thicknesses of the roads:** The design will require different networks that will transport different magnitudes of current, which determines the thickness required for the roads. With this basic requirement in mind, it is recommended to use a thickness of 0.001"or inches for low current analog and digital signals. If the required roads will carry a value greater than 0.3 Amperes, the road should be wider.

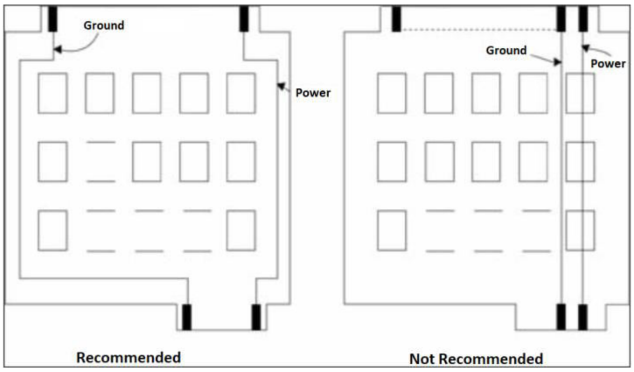

Figure-5. Proper placement of polarization signals [19].

The effects of high voltages on power circuits can be experienced, which can alter the operation of control circuits, which operate at low voltages and currents. To minimize this interference conditioning, it is recommended:

- **Separation:** It must be ensured that the control circuit ground and the power circuit ground must be separated for each section of the circuit power source.
- **Location:** If the ground plane is in the middle layer, it must be ensured that a small impedance is in the path, in order to reduce the flow of interference and protect the control circuit signals. The same indication must be followed to separate the analog and digital grounds.
- **Coupling:** To reduce capacitive coupling due to the location of a large ground plane and the paths drawn above and below that plane, it is necessary to cross over the layers, the analog ground with analog lines or paths only.

The heating problem that affects the operation of the card by degradation and deterioration of the card, when measures to dissipate heat are not used. The following indications allow to counteract the effects of the heating of the card:

- **Identify the components that affect:** It is necessary to consider which components will dissipate the most heat on the card. This can be done by verifying the information corresponding to the "thermal resistance" and by complying with the recommendations in the component specification sheets to divert the heat generated by the use of the component.
- **Adding a thermal compensation:** The applied thermal compensations are quite useful with the disadvantages of temperature, it is recommended to use them in the components with through holes to facilitate the welding and decrease the heating of the components.

A thermal compensation pattern should be used on tracks or holes that are connected to a ground or polarization plane, as shown in Figure-6.

Figure-6. Thermal compensation on a PCB pad [20].

Finally, several processes are required, among which are the verification of track widths, diameters and hole conditions in the case of through holes, the location of components on the board, the distribution of circuit groups, among other sensitive parameters at the time of manufacture of the board, as well as among the final tasks, it is recommended to verify the signal routes.

5. DESIGN AND IMPLEMENTATION

5.1 Circuit Implemented

Figure-7 shows the electronic circuit that interconnects all the chosen components to the standard Arduino UNO connector, taking into account the type of signals that each of the elements handle.

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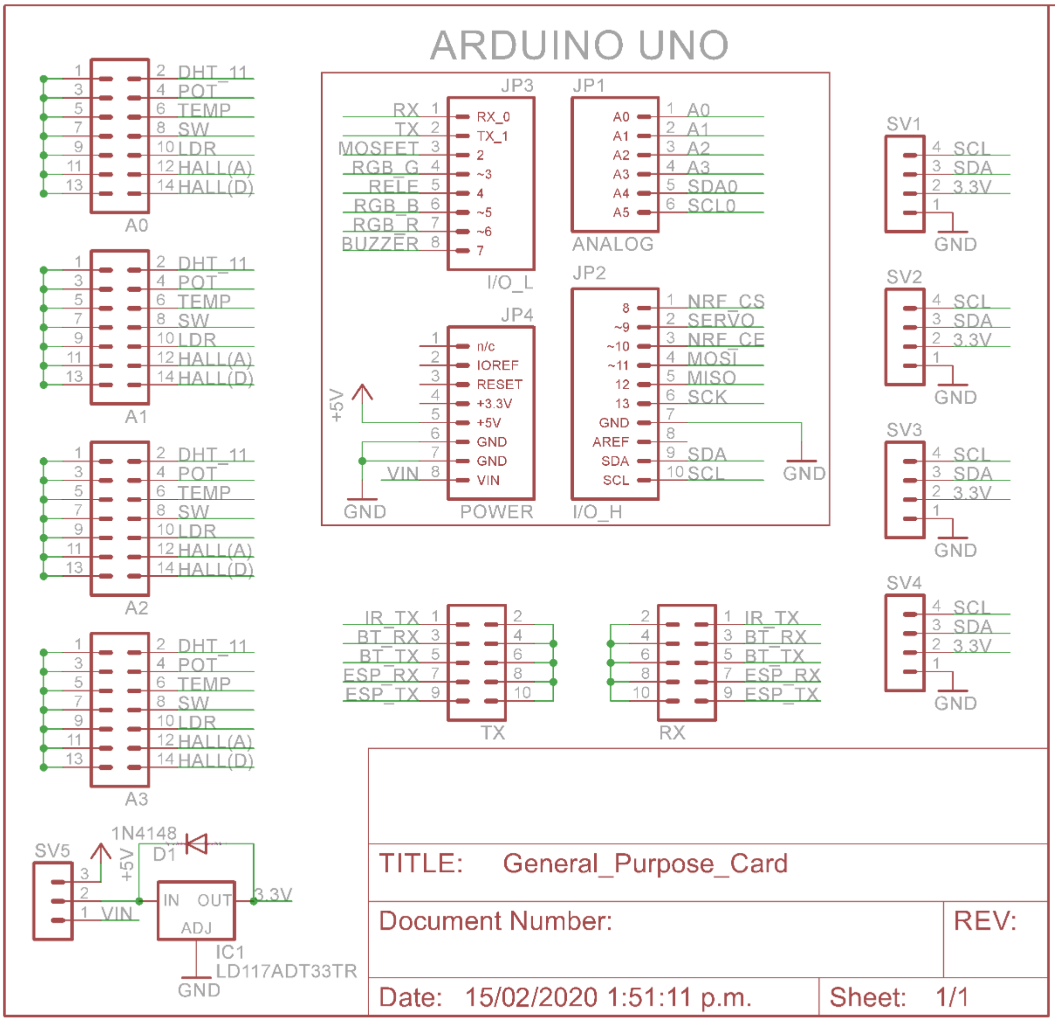

Figure-7. Schematic diagram of the general purpose card connected to the Arduino UNO.

The Arduino connector has six analog inputs (A0 ... A5), with inputs A4 and A5 shared with the I^2C protocol, so only four analog inputs are available, which is why four sensors were selected for implementation (temperature, light, potentiometer and magnetic), in addition two sensors with digital signals are used (humidity and the button) and due to the limitation of pins that the standard connector has, it was decided to implement a signal switch by means of jumpers, so that the four inputs for sensors (A0 . . A3) can be multiplexed between the six signals present. These pins can also handle digital signals. Pins A4 and A5, which refer to the I^2C bus, are connected to the motion sensor, the RTC and the LCD.

In addition, a 3.3V regulator was incorporated into the design, as several of the built-in components operate at this voltage, as well as the communication modules, so as not to overload the 3.3V output of Arduino's standard connector which can handle up to a maximum of 50 mA.

5.2 Card Obtained

The general purpose board for implemented IoT applications can be seen in Figure-8, its components are described in Table-1, which also summarizes the function of each of the blocks.

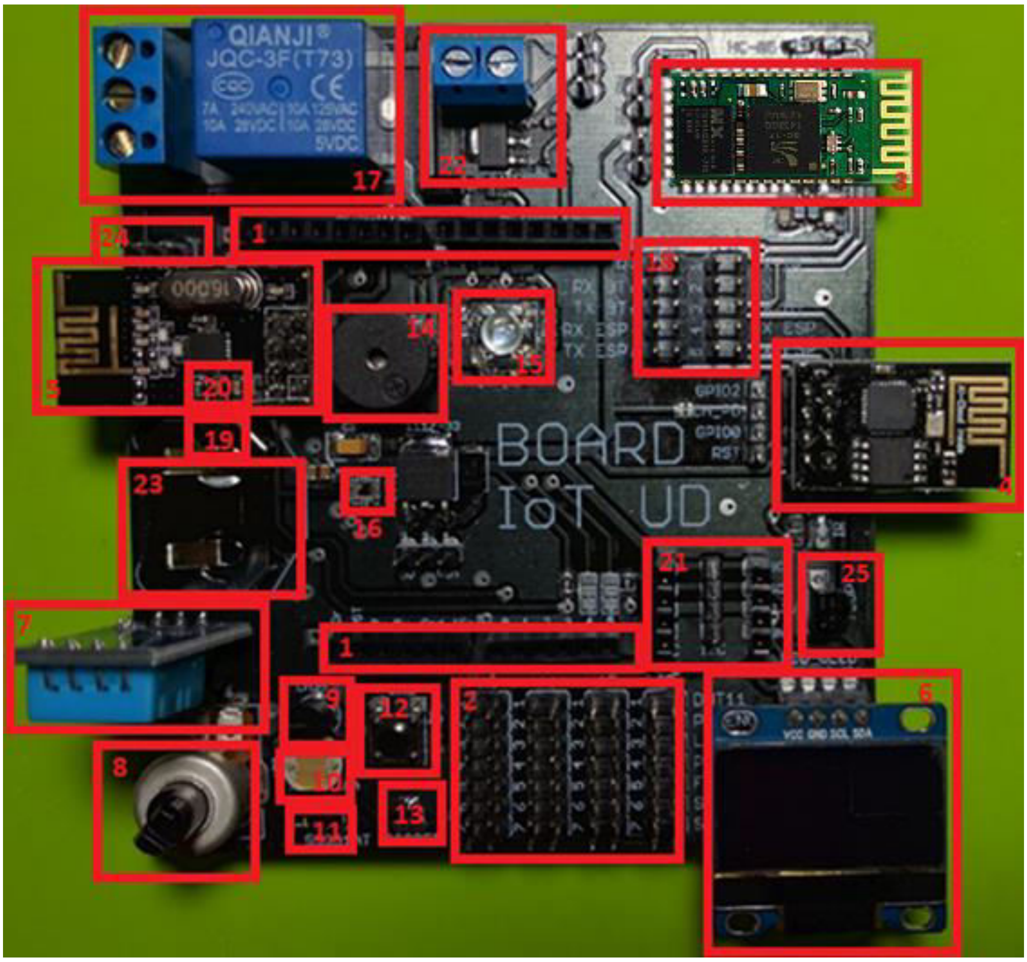

Figure-8. Location of each peripheral on the card.

The final size of the implemented board, compared to a conventional Arduino UNO that has a size of 53 mm x 75 mm (2.1" x 2.95"), is only a few centimeters larger, being able to incorporate a total of 21 components commonly used in IoT projects.

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Table-1. Components of the implemented general purpose card.

No.	Component	Function	Peripheral type
1	Arduino UNO Connector	Make the physical connection between the Arduino UNO card and the multipurpose card implemented	-
2	Sensor input connector	Allows the selection of the input pin used for the sensor connection	-
3	Bluetooth module ref. HC-05	Bluetooth communication with other devices of the same type	Communications
4	Wi-Fi module ref. ESP-01	WiFi communication with other devices of the same type	Communications
5	RF module ref. nRF24L01	RF communication with other devices of the same type	Communications
6	LCD OLED 0.96” I^2C	Used for information visualization	Actuator
7	Humidity sensor ref. DHT11	Humidity measurement	Digital Sensor
8	Potentiometer 5kΩ	Used for analog input tests	Analog “Sensor”
9	Temperature sensor ref. LM35	Temperature measurement	Analog Sensor
10	Light sensor (photocell)	Measurement of light intensity	Analog Sensor
11	Digital Magnetic sensor ref. SS351AT	Measurement of magnetic fields	Digital Sensor
12	Push-button N.A.	Inputs tests on/off	Digital “Sensor”
13	Analog Magnetic sensor ref. SS39ET	Measurement of magnetic fields	Analog Sensor
14	Buzzer 5v	Generation of sounds	Actuator
15	LED RGB	Display	Actuator
16	Accelerometer ref. MMA8452Q	Acceleration measurement	Digital Sensor
17	Relé	Handling high power AC loads	Actuator
18	Communications connector	Connector to multi-purpose card communications lines	-
19	RTC ref. DS1307	Real time measurement	IC
20	EEPROM memory ref. 24LC256	Data storage permanently	IC
21	I^2C connector	Connector to I^2C bus signals	-
22	MosFet ref. NDT2955	For DC motor power handling	Actuator
23	Battery CR2032	Battery to retain RTC information	-
24	Servomotor connector	Servomotor connector	-
25	Infrared	Infrared communication	Communications

5.3 Connection and Operation of the Card

The Arduino UNO card includes its own input for its power supply that can be taken from the USB port of the PC where the application to be implemented is developed, as well as the standard connector that was included in the multipurpose card has a direct connection to said source of power, which implies that an additional source is not required to put the implemented IoT card to work.

For the connection of the Arduino UNO to the board, a connector was included that is identical (both physically and in the pin layout) to the one on the device, which means that the Arduino should simply be located on the connector numbered 1 on the general purpose board.

The connection mentioned in the previous paragraph implies that when polarizing the Arduino UNO card all the peripherals of the general purpose card will also be polarized to the voltage required by each of them (to ensure this, a regulator was included) of 3.3v for those peripherals that require this polarization voltage).

6. CONCLUSIONS

As a main result, a hardware module has been designed, which allows to take advantage of the functionalities of an Arduino UNO development general purpose system, for applications where the design of sensor and actuator node prototypes is required.

The obtained design was adjusted to the use of specific sensors according to an initial planning looking for compatibility with the distribution of the connections of the Arduino UNO module, which limits its immediate use for other modules available in the market, since this adaptation would require modifications in the proposed design.

The design and implementation obtained for the general purpose printed circuit board, despite the basic conditions and needs established, applies recommendations for the design of this type of printed circuit board, such as isolation of the power sections of the system, recommendations on track width, and ease of maintenance of the board through the use of power outlets.

The designed hardware tool provides important features such as adaptability and versatility in the integration with an Arduino UNO module for the development of prototypes, so it is considered a very useful tool in the development of Internet of Things (IoT) projects.

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