Pós-Graduação em Ciência da Computação

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AN IOT ARCHITECTURE FOR COUNTING PEOPLE

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AN IOT ARCHITECTURE FOR COUNTING PEOPLE

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AN IOT ARCHITECTURE FOR COUNTING PEOPLE

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I dedicate this dissertation to all my family, friends and professors who gave me the necessary support to get here.

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Abstract

Knowing whether a room is occupied or not is crucial for improving electrical energy efficiency. For instance, if a given room is empty there is usually no need for the lights to be turned on. Usually in small spaces such as elevator halls, a Passive Infrared (PIR) sensor is used together with the lighting, but as it lacks accuracy, people often are left in the dark after a few minutes. Another factor that deteriorates energy efficiency is that these sensors are seldom connected to a network, limiting the application scenarios to simple tasks, such as controlling lamps. The same data could be used to improve other services such as adjusting the temperature of an air conditioner, which usually has a high impact on energy costs in countries with warm weather. In the present dissertation a wireless device capable of counting people in a room is implemented using Infrared (IR) Light Emitting Diode (LED)s. The implemented device is analyzed regarding energy consumption, cost, error count and installation time. It is also compared to other existing solutions. An architecture for interfacing this device with the Internet of Things (IoT) is provided as well as some of its applications in real scenarios. The results show that the architecture provided as well as the device implemented are useful in the presented scenarios, presenting a distance range of up to 30cm, a false negatives percentual error around 4% and an energy consumption of 1.519W.

Keywords: Presence Sensors. Smart Lighting. Counting People. Occupancy Sensors. IoT.

Resumo

Saber se um cômodo está ocupado ou não é crucial para melhorar a eficiência de energia elétrica. Por exemplo, se um quarto está desocupado, geralmente, não há necessidade de as lâmpadas estarem ligadas. Geralmente, em ambientes pequenos como em halls de elevador, um sensor Infravermelho Passivo (PIR) é usado em conjunto com as lâmpadas, mas como estes sensores não são precisos, as pessoas são frequentemente deixadas no escuro após alguns minutos. Outro fator que prejudica a eficiência energética é que raramente estes sensores estão conectados a uma rede, limitando os cenários de aplicação a tarefas simples, como controlar lâmpadas, enquanto os dados do sensor poderiam ser utilizados para melhorar outros serviços, como ajustar a temperatura de um aparelho de ar condicionado, que geralmente tem um alto impacto nas contas de energia, em países quentes. Nesta dissertação, um dispositivo sem fio capaz de contar pessoas em um quarto é implementado utilizando Diodos Emissores de Luz (LED)s Infravermelhos (IR). O dispositivo implementado é analisado nos seguintes aspectos: consumo de energia, custo, contagem de erros e tempo de instalação. Este também é comparado a outras soluções existentes. Uma arquitetura para fazer a interface entre este dispositivo e a Internet das Coisas (IoT) é fornecida, assim como alguns cenários em que esta pode ser aplicada. Os resultados mostram que a arquitetura, assim como o dispositivo implementado são úteis nos cenários apresentados, apresentando um alcance de 30cm, um percentual de erros do tipo falso negativo da ordem de 4% e um consumo de energia de 1.519W.

Palavras-chave: Sensores de presença. Iluminação inteligente. Contagem de pessoas. Sensores de ocupação. Internet das coisas.

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List of Acronyms

PIR	Passive Infrared	6
IR	Infrared	6
HVAC	Heat Ventilation and Air Conditioning	13
PC	Personal Computers	13
IoT	Internet of Things	6
PCB	Printed Circuit Boards	5
DFHP	Device Free Human Presence	17
RSSI	Received Signal Strength Indicator	17
STP	Spatio-Temporal	18
BLE	Bluetooth Low-Energy	21
MQTT	Message Queuing Telemetry Transport	11
DB	Database	37
GPIO	General Purpose Input/Ouput	29
FMCW	Frequency Modulated Continuous Wave	17
ADC	Analog-to-Digital Converter	20
ARM	Architectural Reference Model	22
RF	Radio Frequency	23
HTTP	Hypertext Transfer Protocol	22
TCP	Transmission Control Protocol	38
UDP	User Datagram Protocol	38
REST	Representational State Transfer	11
MOSFET	Metal-Oxide-Semiconductor Field Effect Transistor	28
LED	Light Emitting Diode	6
LASER	Light Amplification by Stimulated Emission of Radiation	26
PWM	Pulse-Width Modulation	51
SOA	Service Oriented Architecture	19

Contents

1

Introduction

Electrical energy economy is a concerning issue in most countries nowadays. According to [13], illumination was responsible for 10% of the energy consumption in buildings in 2010 in the United States and Heat Ventilation and Air Conditioning (HVAC) systems contributed with more than 40%. Other devices such as personal computers and TVs were responsible for more than 7.5%. In order to minimise the energy wasted by these devices, it is crucial to know whether a room is occupied with people or not, so that they can be turned off automatically. PIR sensors are sometimes used with lighting systems in environments such as elevator halls or public toilets. As they are not very precise, often the lights are turned off even with people still present, what makes these sensors unsuitable for application in general rooms. A big effort is being made by the scientific community to develop better ways of tracking people indoor, as we show in the Chapter 2.

1.1 Motivation

A lack of devices for counting people was identified in the market and in the literature. Among the devices found, connectivity and interfacing was not a concern. Hence, the main motivation for this dissertation is to improve (decrease) the electrical energy waste in residential spaces by creating a mechanism for counting people in rooms and interfacing it with the IoT, where in the future, most of the electrical domestic equipment will be connected to. Enabling this, it will be possible to turn lights off automatically, adjust HVACs systems properly and switch off televisions and Personal Computers (PC)s when no one is using them.

Applications of this architecture may extend to:

- The reduction of the electrical energy consumption in non-industrial environments - Usually, in industrial environments, the machinery impacts much more the energy consumption than the lighting and HVAC systems. Therefore, the solution here presented may not be much relevant in order to improve energy efficiency in this type of environment;

- human protection in industrial automated environments - In many industrial environments, robots are confined in spaces called cells. These cells may not operate when there are humans inside them, for security reasons. The most common security protocol to avoid possible incidents depends on people to mechanically block the doors of the cells before going into it. When the protocol is not respected, humans may be at risk. Hence, a device capable of counting people inside each cell may also block the cells in cases of unsafe operation;

- human detection in emergency scenarios - In situations such as a fire in a building, the knowledge about where the people are and their number may help the rescue forces;

1.2 Goals

1.2.1 General Goals

This dissertation focuses on developing an architecture which allows the monitoring of the amount of people, in general rooms, in the IoT context.

1.2.2 Specific Goals

The specific goals of the present dissertation are:

- Analysing existing solutions to count people;
- Comparing the existing methods used to count people;
- Evaluating the performance of the proposed architecture;

Some basic requirements for the system include:

- telling whether there is or there isn't someone in a given room;
- be low power;
- be low cost;
- be easy to install;
- be error-free;

1.3 Application Scenarios

The proposed architecture is capable of counting the number of people in a given room. Therefore, it is easily applicable in scenarios where the amount of people requires a different response from the environment, such as increasing the light intensity (the number of lights turned on or the intensity of a dimmer) or controlling an air-conditioner's temperature. As the count information involves the presence information [48] it could also be used in scenarios that only need to know whether there is or isn't someone in the environment such as the light control in elevator halls, where the use of PIR sensors is preferred. The crucial factors in that choice nowadays are the cost, power consumption and availability of the products. When the counter devices are integrated in a network, another information is obtained, which is the location. In rescue scenarios this can be helpful. It is important to notice that usually the term "location information" refers to the location of each individual, which will never be supplied by the counters. Furthermore, if a database is used to store all the changes of such a network, it can also be possible to infer the tracking information, which can be valuable in scenarios such accident reconstitution. Finally, higher level programs receiving the information previously stated and using machine learning techniques, can possibly associate the system changes to specific individuals, achieving the highest information level, which is the identification. For instance, imagine that a business man always wakes up at 6 a.m, goes to his kitchen to drink a coffee and logs into his personal e-mail account. This information can be valuable once it takes into account personal preferences. Some of the concepts used in this section are better explained in the next chapter.

1.4 Dissertation structure

This dissertation is organised as follows: In Chapter 2 we present some aspects regarding the history of human detection. Later, some technical papers, patents and solutions available on the market compose the Literature section, so that the reader can become familiar with the state of the art in the subject. In Chapter 3 we present the ideas and main results that came up with this dissertation: first an overview of the proposed architecture, technical information regarding the electronic circuits used, microcontrollers and network configurations. Then, we discuss the user interface, the communication between this interface and the devices and the database that stores the data. In Chapter 4, we present some quantitative results referent to the analysed devices. Finally, in Chapter 5 the author, based on the main results obtained, states his own conclusions. This work has the following contributions:

- Definition of an architecture that integrates devices capable of counting people to the IoT;
- Definition of a protocol that enables efficient communication between these devices and the actuators;
- Design and analysis of a device capable of counting people;
- Publication of the paper [5] presented at the 42nd Annual Conference of IEEE Industrial Electronics Society.

2

Background

2.1 Historical Review

The most usual presence sensors nowadays use passive infra-red (PIR) technology. According to [21] PIR sensors started being produced with good quality at the 1970's in California. These sensors detect a small variation in temperature through absorbing infra-red radiation. Berman, who was the pioneer in the area, used thermistor sensors [15]. By 1975, PIR sensors were already sold in a large scale as part of alarm systems. In 1979, a breakthrough was made with the availability of the differential pyroelectric sensor, which was much easier to use than thermistors. At this time the English sensors were much smaller than the American ones. In the 1980's, the Americans started to manufacture the sensor with Fresnel lenses in order not to infringe Berman's patent. Marcel Züblin was the pioneer in switching light with a PIR, in 1981 [29]. The idea took five years to be accepted by the market. According to [21] other applications of PIR sensors such as connecting to computers and coffee machines have been considered since then, but they seldom get realised because people do not understand the PIR sensors properly.

2.2 State of the Art

This section covers some related technical papers, patents and market solutions regarding human presence sensing. In some of the items presented in the last subsection regarding market solutions, not many details were found regarding these neither was it possible for the author to acquire and test the devices. The information presented in this dissertation about market solutions is mostly based on each manufacturer's website.

2.2.1 Technical Papers

In [37] and [38] the authors used a millimetre-wave radiometer in order to detect humans outdoor. According to them, IR sensors are affected by fog, smoke, dust and daylight and other solutions such as radars cannot locate stationary targets. The millimetre-wave has a higher contrast between people and background objects than IR.

Many solutions for presence detection also made use of image processing. For example, [10] used the skin color combined with a fuzzy approach, [20] used the skin color combined with minor motion detection, [33] used a combination of a 3D camera, a microphone array and a PIR sensor, while the work in [16] combined information from a webcam and a microphone.

In [9], [7], [8] and [40] Caicedo *et al* implemented and tested an ultrasonic presence sensor. This sensor transmits a pulsed sinusoidal wave and deducts the occupancy based on the time and power of the received echoes. They developed a statistical model to analyse different tracking algorithms for false alarm reduction. By testing the ultrasonic array sensor in a 24 m^2 room they obtained better detection results compared to state-of-art PIR sensors in detecting tiny and minor motion while they achieved similar results for major movements. In another test bed they put 4 equally spaced sensors and showed that the localization is considerably improved with the addition of the tracking algorithm. The main motivation of the authors was to develop an advanced and user-unobtrusive control system to be used in offices to provide sufficient illumination in only those spaces that are occupied. Some limitations of the sensor are the pre fixed 5m distance range and maximum people speed of 4 m/s. Cost and power consumption were not found in any of the related papers. The authors tested the sensor with 2 people in the same room, but the maximum number of people to be tracked was not informed.

In [46], Caicedo *et al* also tried combining ultrasonic data with audible data to improve the results. The authors did so by using what they called a wideband sensor capable of dealing with signals extending from the sonic until the ultrasonic frequency range. The results showed that occupancy in still presence was better detected using this method than with the ultrasonic only method. Other solutions, such as [19], used ultrasound sensors on the top of personal computer screens facing to the PC user and reached a precision of up to 98%.

In [34], [35] and [36] Mrazovac *et al*, aiming to develop a method for Device Free Human Presence (DFHP) detection, used a technique based on the Received Signal Strength Indicator (RSSI) measurements of WiFi modules to determine occupancy. The system was composed by a set of off-the-shelf smart bulbs and a controller, which they claimed to offer an advantage regarding the installation. According to the authors, in absence of people the RSSI behaves randomly and so the entropy is higher if compared to the occupied room. They made an experiment using four smart bulbs in a room, in which blind spots were detected at more distant places from the nodes. A solution pointed was to include more nodes. The authors achieved higher accuracy with this system than with PIR sensors.

In [47] and [12] Suijker *et al* developed a sensor which comprises a Frequency Modulated Continuous Wave (FMCW) radar and demonstrated it was capable to detect small movements, such as typing, in real time. Some requirements appointed by the authors for the sensor were: to be very small, low cost, low power and have low energy consumption, although they did not detail their cost. Some limitations include a maximum velocity of 6.1 m/s and a maximum range of 19.2 m.

[48] provided a survey of methods to detect presence, count, location, track and identity.

Besides some solutions that were already discussed, it included other technologies, such as pressure pads, electric field sensors, wearable inertial sensors, pressure-sensitive tiles, vibration sensors and tomographic sensors. The authors pointed out some challenges in implementing presence sensors such as sensing noise, environmental variation (which often triggers false alarm in PIR sensors), similarity between different people and active deception which takes place when someone is trying to fool the sensor. Among the 3 categories involved in human sensing which are Spatio-Temporal (STP), behavioural and physiological properties, this survey focused on the first one. The information to be extracted from the environment includes: presence, count, location, track and identity, where each one already contains the information of the former when presented in this order. The reason for this choice is that STPs are at the core of a majority of human-sensing applications. It is a consensus in the literature that the PIR sensors tend to produce bursty positive detections and a large number of false negative detections.

Other solutions for indoor location required the user to carry a wireless device or tag and were described in [26]. They could be classified based on the technology they adopted, such as WiFi or Zigbee and according to the location algorithm they executed, such as Time of Flight (TOF) which evaluates the time a probe signal takes to travel and the signal strength that tells the distance of another node based on the strength of the received signal. Three measuring principles are explained next:

- Triangulation - three different nodes compute the distance of the mobile node to be located using one of the above algorithms
- Scene analysis - fingerprints of a given room are taken *a priori* and the location is then estimated by comparing the actual fingerprint with the previous stored.
- Proximity - it uses the proximity of a mobile node to known located antennas and the user is said to be within the closest antenna range.

The following performance metrics were listed and explained: accuracy, precision, complexity, scalability, robustness and cost. According to this survey, accuracy is the most important.

Regarding IoT, the survey in [43] lists some functional blocks that can be included in IoT systems. They are:

- Device - provides sensing, actuation, control and monitoring activities;
- Communication - Perform the communication betwen the devices and remote servers;
- Services - for device control and data publishing, for instance;
- Management - provides functions to govern an IoT system;
- Security - provides functions such as authentication, authorization, etc;

- Application - provides the user interface with modules that monitor and control the system.

It also lists some key components, such as interoperable communication protocols and unique identity, that characterize an IoT system. It details some communication technologies that can be used in IoT, but none of them are low cost solutions. The 26 most popular application domains in the market are presented. Among them, the smart environment, control and location aware are strongly related to the applications described in this dissertation. In order to reduce the time of product development of IoT products, the Service Oriented Architecture (SOA) approach, which is based on systems services is being increasingly used in this domain. It uses the concept of middleware, which is a software layer between the application and the technology that abstracts unnecessary details from the developer.

Work in [11] lists a set of design goals for an ideal IoT architecture, among which there are cost-effectiveness, which determines the affordability of the architecture and efficiency, which is described in terms of the power management of the different devices connected to the architecture. Two design principles were identified in this project: a layering approach and the existence of intelligence in the network, in the core or in the end-devices. The authors identify the architecture that perfectly fits to their requirements applied to e-health. This architecture consists of 3 layers:

- Information perception layer - containing sensors;
- Network transmission layer - makes the connection of the above layer and the application;
- Application service layer - displays the information to the user.

2.2.2 Patents

Proximity sensors can be implemented in a variety of ways. In the development of this dissertation it will be shown how to use proximity sensors to build indoor people counters. In [51] a capacitive sensor was improved by adding a second conductive sheet parallel to the sensor's conductive sheet. Usually, this type of sensor is built following the principles of a parallel plate capacitor. The sensor itself consisted of one plate of the capacitor and the second one, which is grounded, was the object to be detected. The plate is often built with only one conductive sheet. According to the authors, the sensing distance was increased by a magnitude of at least 10 using this technique. The authors used this capacitive sensor to drive a variable oscillator so that when the capacitance changed, the frequency of the oscillator also changed, and the distance could be measured.

In [23], a sensor system for an automatic sliding door control was described. The system was composed by a set of identical modules of infra-red transmitters and receivers, that detected the reflected infra-red radiation. Each module defined a detection zone, and therefore, they should be mounted in such a way that at least two zones intersected. An optical barrier was positioned between the emitters and receivers in order to avoid direct light interference.

In [41] the authors developed an optical sensor consisting on two infra-red LEDs and an infra-red receiver with an electronic circuitry. The first LED emits a pulsed signal while the other emits a complementary signal with intensity proportional to the intensity of light sensed by the receiver. The electronics circuitry works by amplifying the time variant component of the received signal, which is only present when there is a moving object, thus a non-continuous signal is received by the sensor.

The invention of a resonant circuit capable of detecting the presence of an object (or person) was described in [49]. It consists of an LC oscillator with a planar inductor, followed by an amplifier, a filter and an Analog-to-Digital Converter (ADC). As an object gets near to the circuit, it changes the magnetic permeability of the medium, changing the resonance frequency of the circuit.

2.2.3 Solutions Available on the Market

LUTRON [28] is an American company existent since the 1960's. Initially, the company focused on dimmers but afterwards it included sensors to bring to the client more complete smart systems. Five solutions from this company that are related to the subject here discussed were found:

- Maestro Occupance/Vacancy Sensors - which are light switches formed by a dimmer and a proprietary presence sensor said to be capable of sensing fine motion such as fingers movements. This device is available in two different configurations, one including only a PIR sensor, specific for major motion and the one with dual-technology for rooms where tiny and major motions are possible.

- Radio Powr Savr sensors - which sensor (does not include a switch) is compatible with the LUTRON dimmers. There is a default 15-minute timeout after the last detected motion which can be changed down to 1 minute. The battery lasts approximately 10 years under normal use.

- LOS W Series Occupancy Sensor - Available in PIR only or PIR and ultrasonic. Are used in spaces with pendant fixtures, ceiling fans, or high ceilings. The PIR only version is not suitable for minor motion.

- LOS C Series Occupancy Sensor - Available in PIR only, Ultrasonic only or PIR and ultrasonic. Can control other building systems such as HVAC or security systems.

- Wired High Bay Occupancy Sensor - PIR only. Suitable for big environments such as warehouses.

The cost of a system for controlling the lights in a nine square meters room was beyond R$ 800.00 in 2016.

The ilumi Smartbulb [18] is a color-tunable LED light bulb controllable and programmable wirelessly through mobile devices using Bluetooth Low-Energy (BLE). It detects people's presence by sensing the phone proximity.

Belkin's [3] main product is a smart bulb controllable by WiFi. The company also produces a smart plug, which includes a presence sensor. The biggest advantage is the price, which was US$ 24.99 in 2016.

The Tinycount [50] developed by Eurecam is an optical people counter using infra-red horizontal beam. It has Ethernet interface and covers up to 7m wide.

Idt Electronics [17] has five solutions for counting people in a room. The simplest one counts how many times a door opens and closes and thus is not an adequate solution for the problem that this dissertation treats. The simplest solution using optical beams is the EPC-IRD1 People Counter which has a maximum sensing distance of three feet and costs US$ 174.

Table 2.1 lists advantages and disadvantages of each studied method.

Technology	References	Advantages	Disadvantages
Millimetre-Wave	[37] and [38]	Higher contrast than IR	Outdoor use
Image Processing	[10], [20], [33] and [16]	Precision	Cost and consumption
Ultrasound	[9], [7] and [8]	Location and Tracking	Cost increase with space
RSSI Based	[34], [35] and [36]	Installation	Cost
FMCW Radar	[47] and [12]	Small, low cost and low power	No exposed cost
Maestro Occupancy/ Vacancy Sensors	–	off the shelf	Cost

Table 2.1: Advantages and disadvantages of the studied methods

The previous devices and systems have not so far reached the general public (except for the PIR sensors which have limited applications). It will be shown and detailed in the next chapter an architecture capable of integrating such systems as well as another approach to count people indoor.

3

Proposed Architecture

In this chapter, an architecture that enables the communication of people counters to the IoT will be presented. It is composed by basically five modules: sensor module, actuator module, gateway, server and application.

In order to implement the sensor module, the circuit will be first implemented in breadboards until the basic parameters for the circuit are obtained. Once it is done, a Printed Circuit Board (PCB) will be developed with the KiCad [22] software. Equipment necessary to the manufacturing process include a laser toner printer, a hot press and acid for etching, all of them already available in the laboratory. The author foresees in this research the use of only off-the-shelf discrete components and regular microcontrollers and transceivers.

The actuator module will be shortly discussed and the protocol that this device uses to communicate with the sensor module will be detailed.

Next, the author will discuss some approaches used in order to enable the communication between the gateway and the application.

After, the user interface will be implemented and the device will be tested along with it. The last step is to include the database in the system and test everything together.

3.1 IoT Architectures

In order to choose the most suitable architecture for the developed system, the author researched what has been produced regarding this subject so far. An Architectural Reference Model (ARM) that can be used to derive concrete IoT architectures was developed by the IoT-A project [25] and some of its functional blocks serve as a basis to the architecture developed in this dissertation, which are the "Network Communication" and the "IoT Service" blocks, as can be seen in Figure 3.1. Its goal is to improve the alignment of the architectures and enable simpler reuse of the results, functionalities and components. Many projects involving IoT are increasingly adopting the IoT-A ARM as the starting point of their architecture design activities. In [24] an IoT architecture using the Hypertext Transfer Protocol (HTTP) is implemented. Although the authors have made it available to the public, a simpler approach is presented in this dissertation.

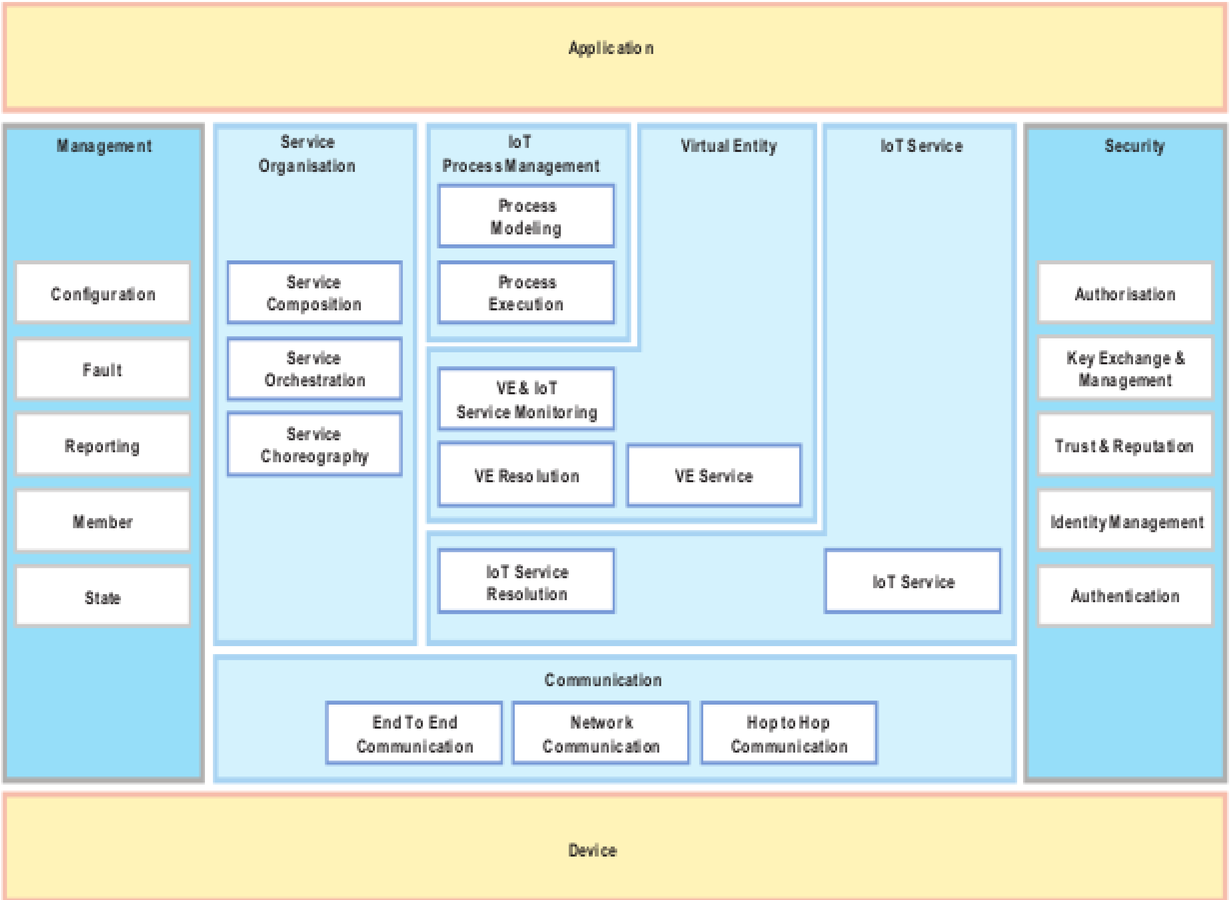


Figure 3.1: Functional view of the IoT-A ARM.

3.2 Architectural Requirements

The basic requirements for the architecture are:

- Scalability - Support a large number of sensors and actuators to be dynamically included;
- Interoperability - Include gateways in order to allow applications to communicate with devices in spite of the Radio Frequency (RF) technology they use;
- Data storage - To store all the activities in a database;
- Be low weight, low power and as quick as the network infrastructure allow it to be.

3.3 Architecture Overview

In this dissertation an architecture to integrate counter modules with the IoT is proposed. It can be seen in Figure 3.2.

Lets have a general description of each module:

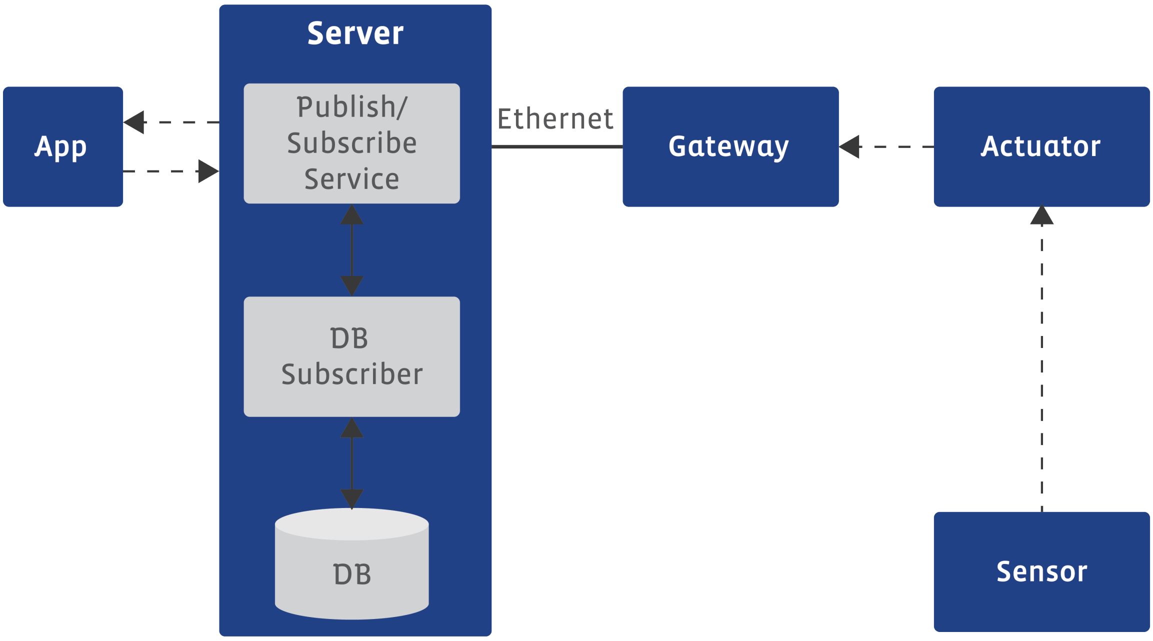


Figure 3.2: Proposed architecture to integrate counter modules with the IoT.

- Sensor - The sensors are devices positioned next to each entrance of a room that sense people going in and out of that room. Each time a person enters or leaves a room, it sends a message to its **Actuator** containing the sensor ID, which is unique for that subnetwork and the increment, which may be positive or negative, depending if the person went in or out. Please note that the sensor module does not know how many people there are in the room, if the room can have more than one entrance. The communication protocol between sensors and actuators is detailed in the protocol section. This module deployment is always the larger in quantity, as each room has at least one entrance, and it is not necessarily connected to the mains. For this reason, the devices which communicate directly with it may be located the closest as possible to it;

- Subnetwork - The devices of this architecture that are in the same room form a subnetwork;

- Actuator - Actuators are unique devices in each subnetwork. They centralize the people count in each room and forward this information to their gateway, i.e., they are between the sensors and the gateways, from the architectural point of view. In the scenario of this dissertation, the actuator turns the lights of the room off every time the people count reaches zero, and turns the lights on if it is positive. Hence, actuators are necessarily connected to the mains and can have higher transmission power than the sensors;

- Gateway - Sensor modules and actuators may not communicate using WiFi, because it implies higher component costs, energy consumption and network and processing overhead. Thus, a **gateway** is necessary. Its role is to enable the communication between the actuators and the internet. It consists of a device, cabled or not, which also has the same wireless interface as the actuators (and sensors). Only one gateway may be necessary in a house or office;

- Server - It is the information centraliser, composed of three other blocks that can optionally be executed in the same machine:
  - Publish/Subscribe Service - It pushes a message to an app every time they receive an update from a gateway. Each gateway may be associated with a specific app. MQTT is an example of such a service and is the one which will be used in this dissertation;
  - Database Subscriber - A simple module that updates the DB every time there is an update in any of the gateways;
  - Database - The module that stores all the information required.
- App - Is the application which will deliver value to the user. A specific application has been developed in this dissertation to enable the user to monitor the amount of people in each room of his house. It will be detailed in Section 3.6.

The people count could be alternatively done in the server or in the app. Nevertheless, there is an advantage in letting the actuator being responsible for counting the people, in this case, it is that part of the system, which controls the lighting system, works in the absence of connection to the server, as illustrated in Figure 3.3.

3.4 Sensor Module

Among the technologies already discussed, the IR was chosen to implement the sensor module because of its simplicity and availability of electronic components. The concept is inspired in the EPC-IRD1 people counter module developed by Idt Electronics [17], illustrated in Figure 3.4. This device does not sense the object's motion direction, but according to the manufacturer, has a range of up to 25", and can last up to 24 months when power by 2 AA industrial batteries.

It is important to notice that no such sensor was found in the literature, thus this section may serve as a guideline to future improvements in this sensor. The sensor consists of a single module containing IR emitters and receivers. The emitters send IR light which is reflected when an object comes near the module range. The receivers are components sensitive to IR light that change some property, in this case the resistance, when receiving the light. This working principle is illustrated in Figure 3.5. Infra-red light was chosen because it is not as affected by

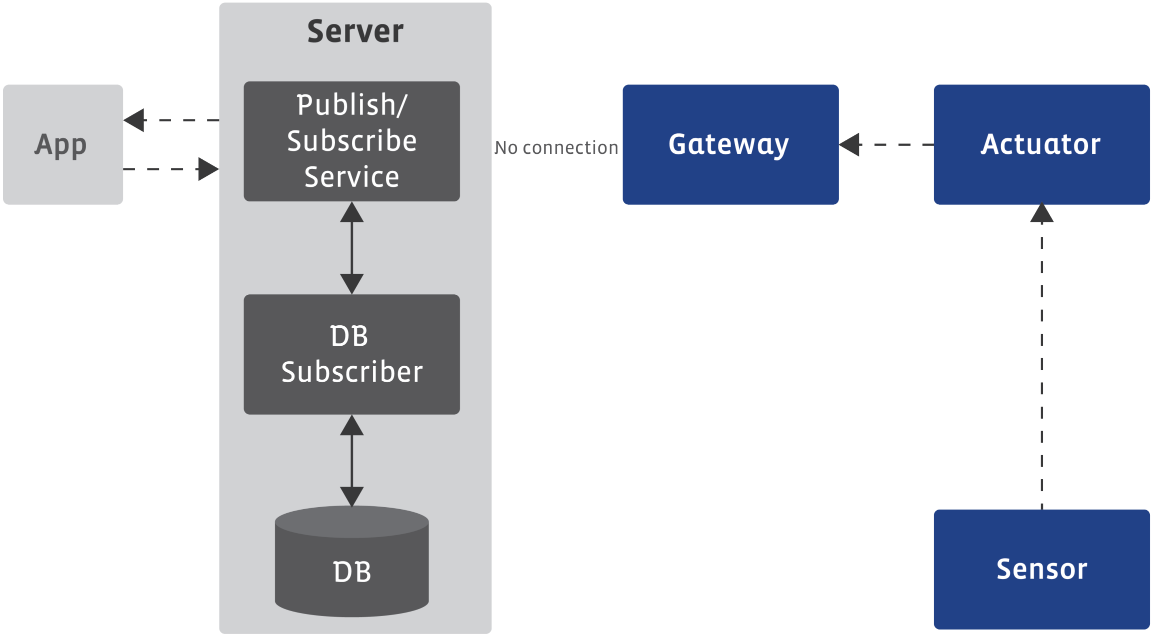


Figure 3.3: The architecture proposed allows the lighting control to work properly still in the absence of connection to the server.

visible light or sun light as visible light and most of the photodiodes include a daylight blocking filter. Hence, it is suitable for indoor use. LEDs were used as the light emitters because they are the cheapest device for this purpose. Nevertheless, Light Amplification by Stimulated Emission of Radiation (LASER) emitters could be possibly used instead.

It is simple to develop a counter by positioning two such sensors side by side and connecting both of them to a processor. The processor task is to tell whether the received sensor's sequence is an entrance, an exit, or none of them. If a sensor is first activated and then the following one is, it may mean an entrance or an exit. If only one sensor is activated then deactivated it may mean an incomplete event such as a person turning back and giving up entering a room, for example. Figure 3.6 illustrates the counter arrangement and Figure 3.7 illustrates how the resistance of the sensor should behave in this case.

3.4.1 Circuit Overview

Figure 3.8 illustrates the schematics for the counter module.

The first thing to understand in order to get a general circuit overview is the IR sensor. Its main component is a photodiode. This electronics component, when reversely biased, changes its resistance as it receives IR light. The variation of the resistance depends on the light intensity received by the photodiode, the reverse voltage applied and the intrinsic characteristics of the device, i.e., the model of the photodiode. While not receiving IR light it behaves as an open circuit, i.e., it has a very high resistance, which was measured to be around $200M\Omega$. When illuminated with IR light and reversely biased (6V applied) its resistance was measured to be

Figure 3.4: EPC-IRD1 People Counter developed by Idt Electronics.

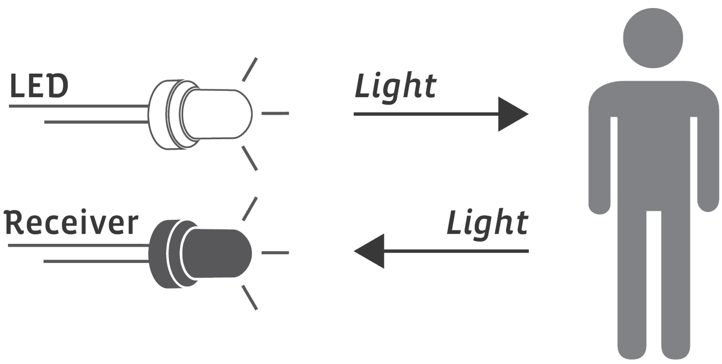


Figure 3.5: Sensor principle: the light reflects on an object and activate the receiver

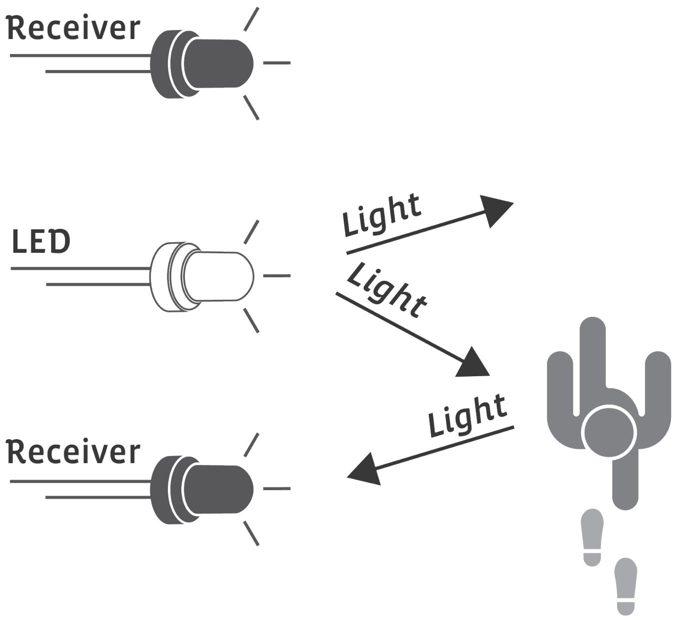


Figure 3.6: Two receivers positioned side by side with some space between to detect entrance or exit

around 10$M\Omega$ (facing a standard 940nm IR LED to it at a distance of 10cm). The photodiode used was a model BPV10NF [45], which has a bandwidth from 870nm to 950nm and a daylight blocking filter. Its falling and rising time is equal to 2.5ns. Hence, the time response is not a concern to this application. It is desirable and necessary to have the output falling within two different logic levels for each of the previous circumstances, say zero and five volts, in order to connect the output to a micro-controller. That is where the transistor, a general purpose Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) [31], comes in. It will work as a switch. As its gate input resistance is approximated to ∞ the gate voltage (in the resistive divider) is given as

$$V_{gate} = \frac{R}{R + R_{photodiode}}.V_{dd}$$

It is desirable for V_{gate} to be near zero without light and above V_{th} with light. V_{th} is the threshold

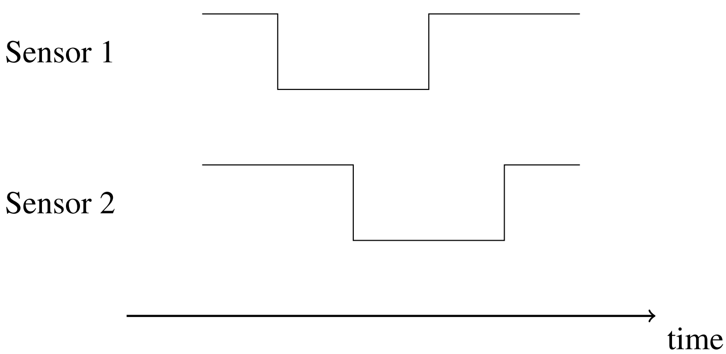


Figure 3.7: Resistance of the photodiodes as a person passes in front of the module.

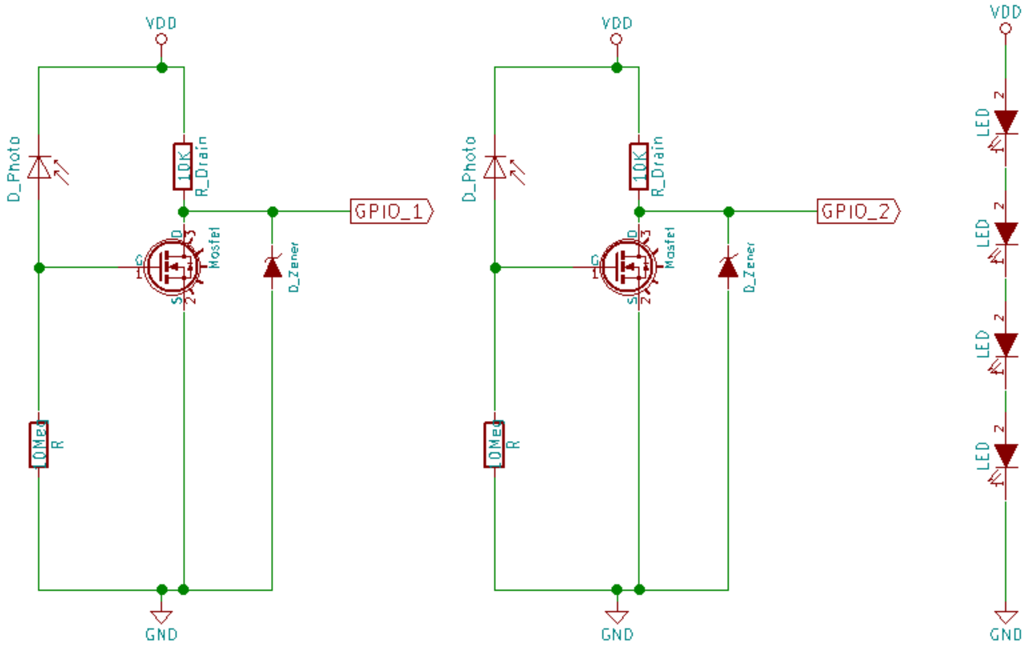


Figure 3.8: Circuit schematics

voltage, i.e, the minimum voltage needed to allow current to flow from drain to source in a field-effect transistor. According to the datasheet of the 2N7002 MOSFET [2], V_{th} is typically 2V. Thus the resistor R must be in the range of the $10'sM\Omega$. The highest value resistor available in the laboratory was a $22M\Omega$ resistor, although there are higher resistances available in the market, as can be seen in [6]. It is important to notice that the larger the resistance R, more sensitive will be the sensor, once the divider will overcome V_{th} at bigger distances (from emitter to receiver). Connected to the MOSFET drain there is a $10k\Omega$ resistor that may be only sufficient for setting the drain voltage to zero when the transistor is active/saturated, a Zener diode for stabilizing the output and a microprocessor General Purpose Input/Ouput (GPIO) [14]. The rightmost block consists of four IR LEDs connected in series. This block is responsible for emitting the IR light that should reflect on an object and reach the photodiodes. The LEDs are not polarized using a resistor in order to save energy. The distance range of the sensor may increase with the number of LEDs. The same may occur with the power consumption. Therefore, the number of LEDs may be changed in future versions of this module.

Three photographs of the implemented double sided PCB are showed in Figure 3.9. In Figure 3.9 a), it is possible to see the 4 LEDs and the 2 photodiodes and in Figure 3.9 c) it is possible to see the microcontroller and RF module.

3.4.2 Firmware

The micro-controller may have the following properties:

- low power modes

- two ports supporting change level interruptions
- CPU frequency at least 1 MHz (minimum frequency tested)

When someone passes in front of the module, say going inside a room, a signal sequence similar to the one seen in Figure 3.7 will show up to the micro-controller. The same occurs when someone leaves the room. Other sequences are also possible as illustrated in Figures 3.10, 3.11 and 3.12 and may not change the people count in the room.

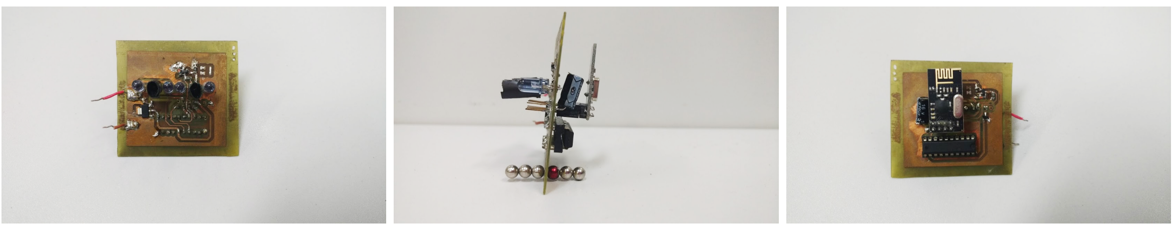
Thus, the pseudo code in Algorithm 1 was implemented for monitoring each sensor. This algorithm implements the state machine showed in Figure 3.13.

Sensor_1_Level and *Sensor_2_Level* are the variables regarding the logic levels of the GPIO ports 1 and 2 illustrated in Figure 3.8. They can assume two different values: high or low.

Interrupt	Sensor	Mode
Int_{11}	1	Rising
Int_{12}	1	Falling
Int_{21}	2	Rising
Int_{22}	2	Falling

Table 3.1: Substitutions of the transitions to properly map into the algorithm.

The state machine will be explained first: It starts at the state I, which corresponds to the two GPIO ports at logic level high. When an object passes in front of the first photodiode, the logic level of the GPIO port 1, or simply *Sensor_1_Level*, will fall down to low level, generating a falling interruption at this port (Int_{12}) and the state will change to II. At this point, there are two possible events: *Sensor_1_Level* goes up or *Sensor_2_Level* (the logic level of the GPIO port 2) goes down. If the object moves back, *Sensor_1_Level* will rise up to high again, generating a rising interruption at the port 1 (Int_{11}) which will change the state back to I again. Otherwise, *Sensor_2_Level* will fall, generating a falling interruption at the port 2, which will change the state to IV. From state IV, there are also two possibilities: the object can possibly move back getting out of sight of the second photodiode or it can move forward getting out of sight of the first photodiode. The first option will make the state of the machine go back to II and the second option will make it move forward to VI. Finally, if the machine is in the state VI and the object gets out of sight of the second photodiode, completing the entrance, the state of the machine will



(a) Front view (b) Lateral view (c) Back view

Figure 3.9: Photographs of the implemented PCB.

Algorithm 1 Verify entrance or exit

Require: Interrupt from sensor 1
  if $Sensor\_1\_Level = HIGH$ **then**
    if $(state = II)$ **then**
      $state \leftarrow I$
    else if $(state = IV)$ **then**
      $state \leftarrow VI$
    else if $(state = V)$ **then**
      $state \leftarrow III$
    else if $(stateIn = VII)$ **then**
      $state \leftarrow I$
      $local\_count \leftarrow local\_count - 1$
    end if
  else
    if $(state = I)$ **then**
      $state \leftarrow II$
    else if $(state = VI)$ **then**
      $state \leftarrow IV$
    else if $(state = III)$ **then**
      $state \leftarrow V$
    end if
  end if
Require: Interrupt from sensor 2
  if $Sensor\_2\_Level = HIGH$ **then**
    if $(state = IV)$ **then**
      $state \leftarrow II$
    else if $(state = VI)$ **then**
      $state \leftarrow I$
      $local\_count \leftarrow local\_count + 1$
    else if $(state = III)$ **then**
      $state \leftarrow I$
    else if $(state = V)$ **then**
      $state \leftarrow VII$
    end if
  else
    if $(state = II)$ **then**
      $state \leftarrow IV$
    else if $(state = I)$ **then**
      $state \leftarrow III$
    else if $(state = VII)$ **then**
      $state \leftarrow V$
    end if
  end if

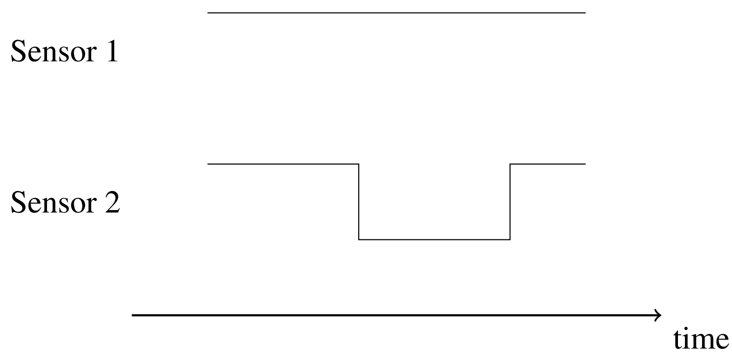


Figure 3.10: Signals sequence when one intends to enter, activate the first sensor and go back.

change to I and the *local_count*, which is the variable counting the amount of people passing through the sensor's door will be incremented.

Please note that only interruptions are able to change the state of the machine. Therefore, if the object stands still in front of the sensor it will not change to another state.

The same procedure can be used to identify objects moving in the other direction. In this case, starting from the state I again, the GPIO port 2 will be the first to have its logic level put to low and the state of the machine will change to III. The transitions to the other states work as explained in the entrance.

In order to properly map the state machine into the algorithm, the substitutions defined in Table 3.1 may be done to the transitions. Int_{11}, for instance, is the interruption raised when the signal level at GPIO port 1 (Sensor 1) changes from low to high.

One complete entrance will be identified by the algorithm as follows: both falling and rising interruptions may be enabled in both GPIO ports 1 and 2. When an interruption occurs at a given port, the microcontroller needs to check whether it was a falling or a rising interruption. In order to do so, it is sufficient to check the logic level at this port after the interruption. If it is low, it was a falling interruption, otherwise it was a rising interruption. Let's say the machine is at state I (the initial state) and a falling interruption occurs at GPIO port 1. This will cause state to change to II. In order to change state to IV from the current state, a falling interruption

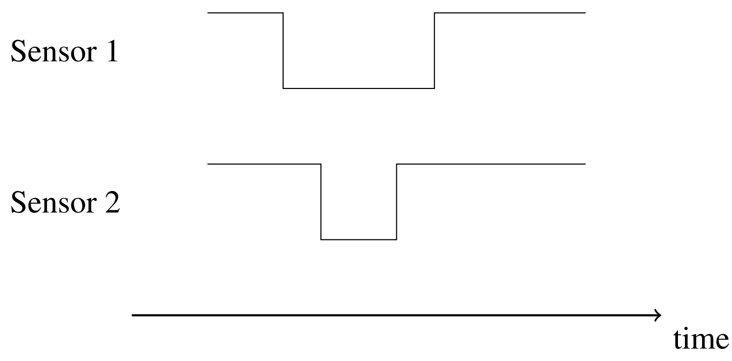


Figure 3.11: Signals sequence when one intends to enter, activate the first and the second sensor and go back.

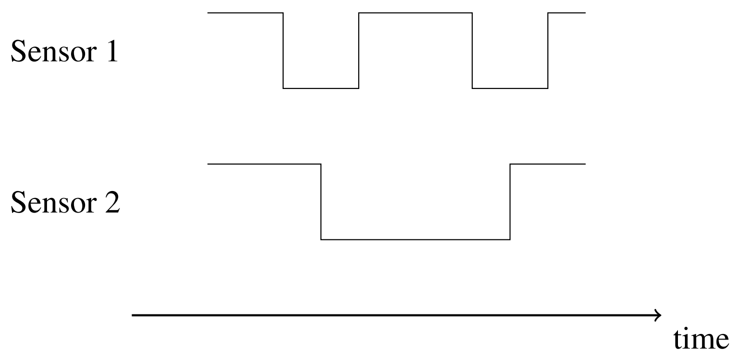


Figure 3.12: Signals sequence when one intends to enter, activate the first and the second sensor, passes the first sensor and go back.

at GPIO port 2 is necessary. From state IV, the state will change to VI if a rising interruption occurs at GPIO port 1. Finally, if a rising interruption occurs at GPIO port 2, state will go back to I and *local_count* will be incremented in one unit.

3.4.3 Network Setup

In order do control devices based on the people counting, the counter may communicate wirelessly with another device named *Actuator*. The actuator is the device that centralises the people count. The system was thought this way to allow integration in rooms with multiple doors/entrances. A set composed by an actuator and one or more counters is called a subnetwork and is identified by a natural number smaller than 256 in the first implementation, once it is improbable that a house has more than 256 rooms. In case of spaces with a larger amount of rooms, such as hotels, two possible solutions can be applied:

- increase the limit to fill 2 bytes, which will support up to 65536 rooms;
- divide the space in smaller spaces with up to 256 rooms, each one having its own gateway;

The only information that may be sent by each counter is its ID and if there is someone going inside or outside of the room. The actuator ID number, which is equal to the subnetwork ID, can also be inserted to avoid interference from one subnetwork in another. In the present case, this problem was solved by using logic pipes, which are a feature of the selected transceiver.

Packet loss was found to be a problem and a robust and efficient retransmission protocol was necessary, once just one miss in the information exchange is enough to let the system unstable in this scenario. The counter will send consecutive integers between -128 and 127 to the server starting at 0, incremented or decremented every time the counter does not receive an ACK. This variable is named *RetransmissionCount*. A *localCount* variable in the counter registers the total number of people going inside the room (counted by this module), which is the difference between people going in and outside the room. If *localCount* is positive, *retransmissionCount* will be incremented. Otherwise it will be decremented. If *localCount* is equal to zero it means

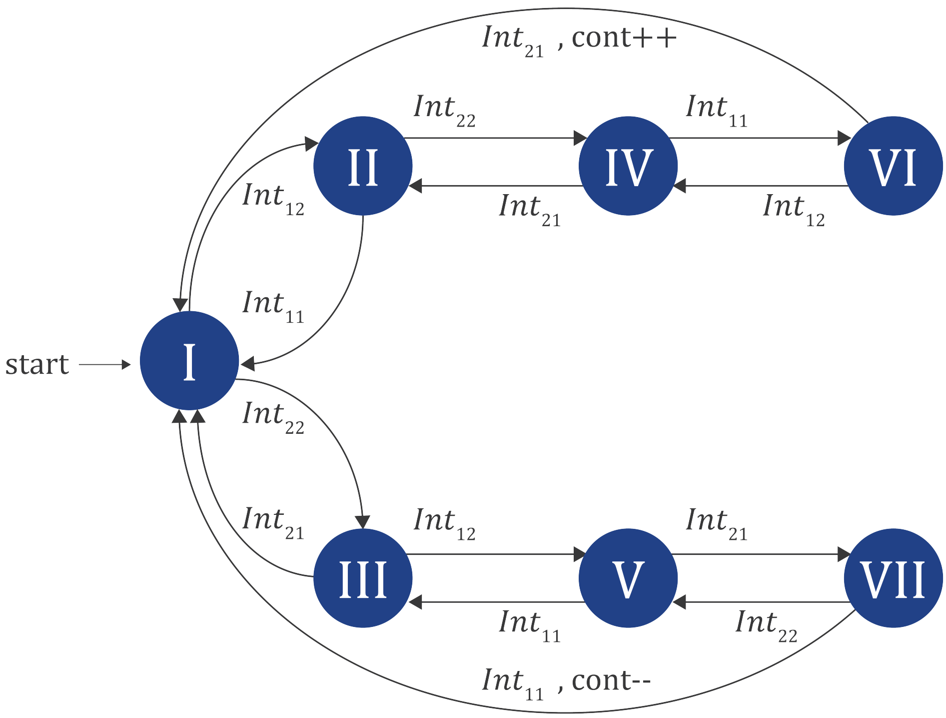


Figure 3.13: State machine relative to the algorithm executed by the microcontroller

that there is no message to be sent. As a message starts being sent, the counter decreases *localCount* and resets *RetransmissionCount* to 0. Therefore, only one field is responsible for carrying the retransmission and count information. In the actuator, a variable named *Counter*, counts the actual amount of people inside the room. It is incremented or decremented upon the successful reception of a retransmission count. After receiving the message, the actuator sends an ACK to the sensor. A maximum of 127 retransmissions is allowed, and in case of 128 loss messages the system will get unstable. The maximum loss registered so far was 3 messages when the server and the counter are positioned 2m apart. Electromagnetic interference was not controlled in this experiment and may lead to higher losses. Figure 3.14 illustrates this protocol's operation upon the entrance of one person in a room.

The system was developed in order to fulfil the following requirements:

- An actuator can have more than one counter;
- A counter from a given subnetwork cannot interfere in an actuator from a different one;
- Recover from packet losses;

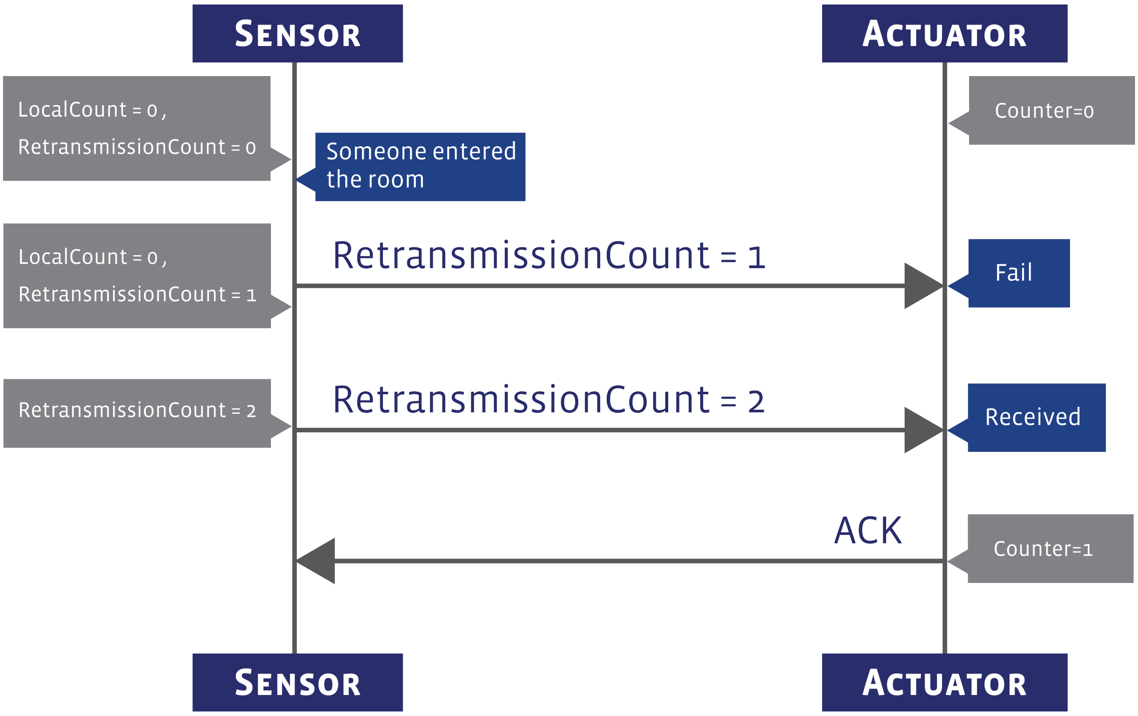


Figure 3.14: Retransmission protocol between sensors and actuators.

3.5 Actuator Module

The actuator module is, as stated in the subsection 3.4.3, the module responsible to count the amount of people in a room. Each time the people count changes, it sends a message to the gateway, which will forward the message to the server. Furthermore, it is also responsible for switching the lights of the room on and off, according to the amount of people in the room. For testing purposes, this module was also implemented in hardware, and its block diagram can be seen in Figure 3.15. It is composed basically by an RF interface module, a microcontroller and a relay. The RF interface module allows the actuator to communicate wirelessly with the other modules (sensors and gateway). The relay is directly connected to the mains.

3.6 Graphical User Interface

In this dissertation, the author developed an application that allows the user to monitor how many people there are in each room of the house. By placing a sensor module in the entrance of each room of the house, an actuator in each room and a unique gateway in the house, the user can see the quantity of people in each room, in real time. A snapshot of this interface can be seen in Figure 3.16.

Some features implemented in the interface include:

- The interface is completely customized by the user, so that he/she may arrange the rooms before using it;

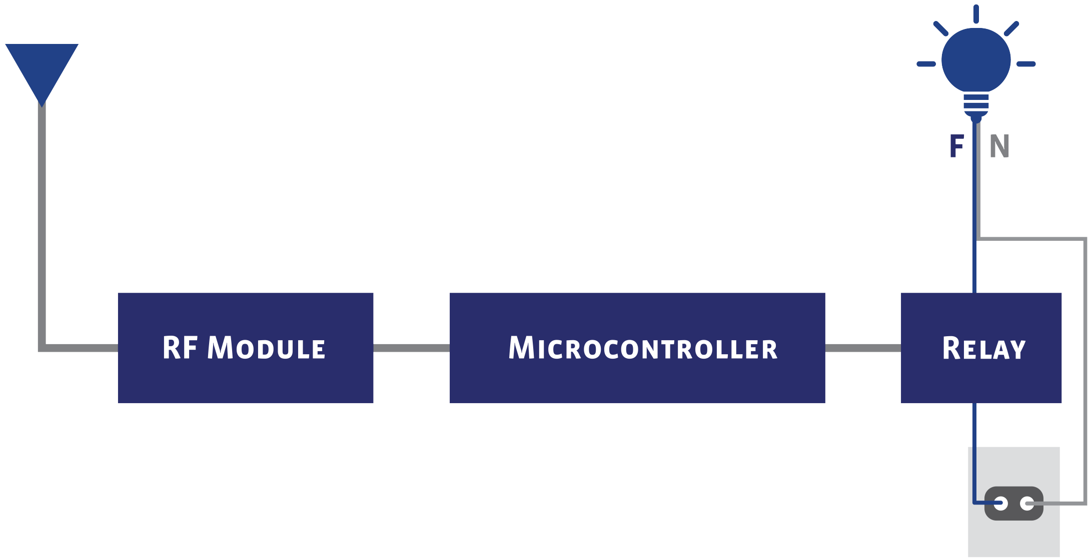


Figure 3.15: Simplified block diagram of the actuator module.

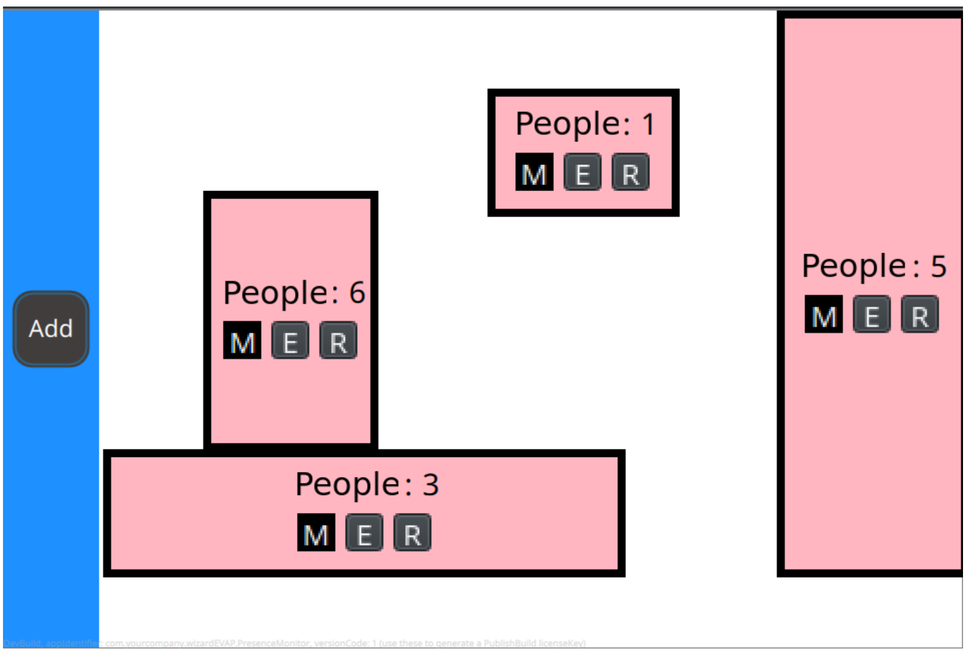


Figure 3.16: A snapshot of the Graphical User Interface.

- The sensors and actuators must be linked in the interface according to an ID printed on them;
- Rooms inside rooms are allowed (a house can be thought of as a room);
- Connected rooms require a single sensor module;

As people change the location, the interface is updated in such a way that a number in the center of each room indicates the number of people inside the room, at the moment.

3.7 Communication Between the Interface and the Devices

In order to communicate with the devices, three classical approaches were selected, which were compared according to their complexity. They are HTTP/REST, sockets and finally MQTT,.

3.7.1 REST

The REST architectural style describes six constraints [44]:

- Uniform Interface;
- Stateless;
- Cacheable;
- Client-Server;
- Layered System;
- Code on Demand.

Four commonly-used HTTP methods help to make an uniform interface. They are: POST, GET, PUT and DELETE, which correspond to the CRUD (Create, Read, Update and Delete) operations. In order to update the application every time the gateway receives a message, first it is necessary to setup a main HTTP server in the server machine (the same machine that executes the Database (DB) or in a different one dedicated only to this functionality. The following steps are also needed when using this approach:

- The gateways have to POST to the server at startup and PUT a message containing the people count every time it receives an update from an actuator;
- The application has to periodically send a GET message to the server requesting the people count of the actuator related to it.

As the HTTP protocol is not designed for IoT or lightweight applications, the message size will not be optimized in this sense.

Another disadvantage of this approach is that if the application uses big intervals to send the GET message to the server, the usability of the application will get worse, once it will not reflect the current people count in each space.

3.7.2 Sockets

Sockets are, according to [42], the endpoints of a bidirectional communications channel. Sockets may communicate within a process, between processes on the same machine, or between processes on different machines. They can communicate using different channel types, such as Transmission Control Protocol (TCP), User Datagram Protocol (UDP) and Unix domain sockets. In the present application, it is necessary to guarantee the delivery of the messages between different machines, which restrict the channel to TCP. If programming with python, this can be done by specifying the socket type *SOCK_STREAM*, upon the creation of the socket. The following steps would be necessary to send the messages to the application:

- Create a socket in the server, in the gateway and in the application;
- In the server, bind the created socket to a port and start listening at that port;
- When the gateway receives a new message, request to start a connection with the server;
- The server has to accept the connection and read the message which contains the people count and the referring actuator;
- Both server and gateway close the connection;
- Periodically, the application starts a connection with the server, requesting updates regarding its gateway;

The disadvantage of this approach is the complexity caused by the low level it reaches. The developer has a high effort just to transport the message, meanwhile the final protocol is still not defined at that level.

3.7.3 MQTT

The MQTT protocol (Message Queuing Telemetry Transport) was used in this dissertation as the publish/subscribe service. According to the MQTT web page [32], MQTT is a machine-to-machine (M2M)/"Internet of Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium.

In [4] five MQTT servers are evaluated and compared regarding their scalability with the number of clients. The test scenarios simulate a large number of devices publishing data to a command center, which is the subscriber. The scalability test starts with a minimum of 2000 publishers and 2 subscribers, and tries to reach a maximum of 100.000 publishers and 100 subscribers. The results show that, among the selected servers, *JoramMQ* has the best performance regarding CPU usage and message transmission latency in almost every situation. Despite this, the *Mosquitto* server was used in the present implementation of this architecture, as it shows to be very stable when dealing with up to 60000 publishers and has built in debug capabilities.

On a server running the Ubuntu 16-04 64-bits Linux distribution, a mosquitto instance was executed (a MQTT server, known as broker before). Always an actuator sends a message to the gateway (containing the current people count in it), the gateway publishes it in a topic of the form "`presence/<gateway_id>/<actuator_id>/<sensor_id>`". If the topic doesn't exist, it is automatically created. The application is subscribed on the set of topics "`presence/<gateway_id>/#`, and is therefore updated in every change regarding that gateway. Each room in that house, must be associated with a specific actuator and each entrance of the rooms must be associated with a sensor in the interface. The actuator sends a message to its gateway every time its people count changes, i.e when the actuator receives a message from a sensor. Each sensor is associated to a topic for storage purposes.

3.8 Database

As the architecture includes an MQTT server to interface the gateway and the application, this dissertation leverages on a database in order to facilitate data storage. In order to store the data, one MQTT client will be connected to the MQTT server and subscribed in all the topics, i.e, subscribed on the big topic "`presence/#`". Every time a message is pushed, the application executing the client will store the message in the DB, along with a time stamp.

The basic requirements for this DB are:

- Provide a Python API - Once it makes the development easier and faster;
- Be free - As long as it is for concept proof;
- Be scalable - Because the amount of clients is initially small and can increase;

MongoDB [30] is a document based database that includes all the previous features. Besides, it is possible to gather the data in collections, which suits the problem of grouping houses well. For instance, it is possible to group the gateways by neighbourhood.

In this chapter the whole system including the architecture and the sensor module was presented in order to allow other researchers interested in the subject to replicate the experiments. In the next chapter the author shows the analysis of the counter module, as well as the results obtained by the analysis.

4

Counter Validation

In this chapter the counter module is analyzed regarding its energy consumption, distance range, error count, cost and installation time.

4.1 Consumption

In order to evaluate the device energy consumption the battery was removed and a voltage generator Voltcraft LSP-1403 was applied instead, as depicted in Figure 4.1. In Figure 4.2, the real testbed is showed. It is possible to see on the voltage generator's screen the current pulled by the device (see Figure 4.3). A voltage between 4V and 10V was varied in steps of 1V and the current pulled by the module was observed. The consumption varies according to the DC voltage applied. The real power consumed by the module in Watts can be calculated as a product of the voltage and the current applied.

Another parameter that depends on the voltage applied is the sensing distance once the IR LEDs light becomes brighter as more current passes through them. This parameter was examined in the next experiment.

4.2 Distance Range

In order to analyze the relation between consumption and sensing distance, the following experiment was carried out: The module was placed facing a wall. A fixed voltage was applied and varied from 4V to 10V in steps of 1V. An oscilloscope probe was placed on the MOSFET

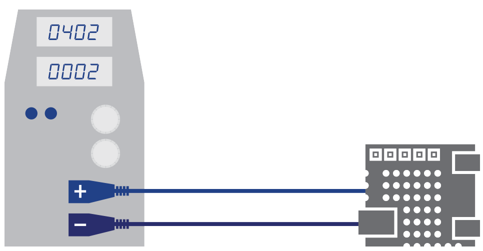


Figure 4.1: Illustration of the first experiment, regarding the energy consumption of the sensor module.

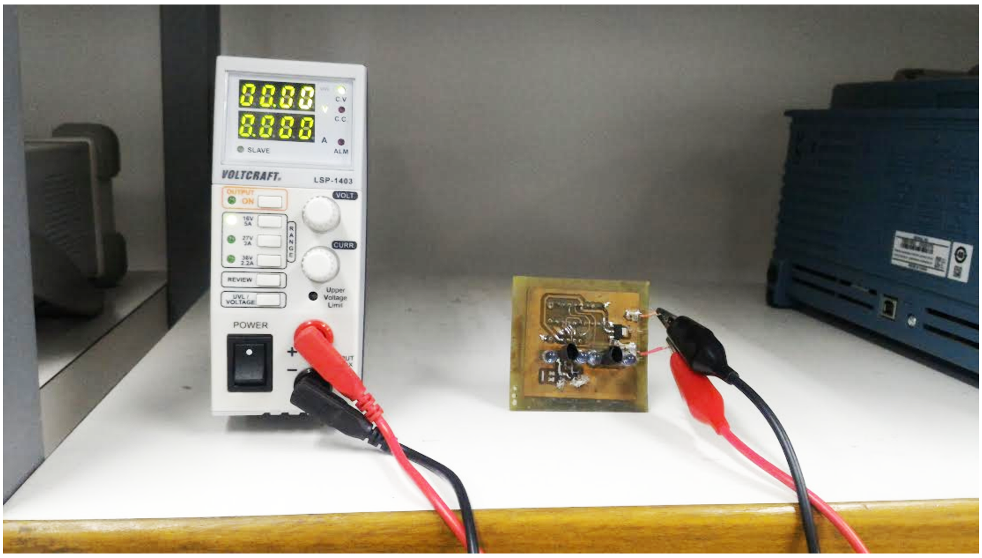


Figure 4.2: Real testbed for the consumption experiment.

Figure 4.3: Picture of the voltage generator when a load is pulling 2mA@4V.

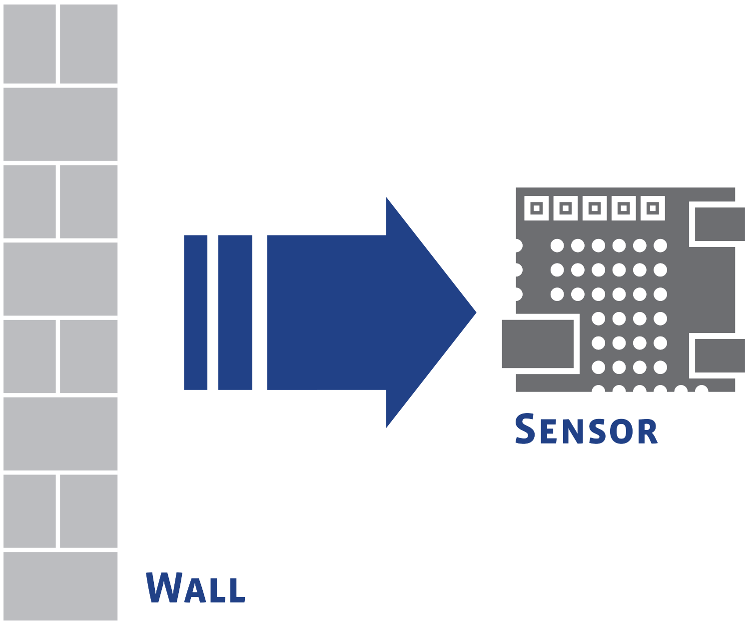


Figure 4.4: Illustration of the experiment to evaluate the sensor's distance range.

drain and the module was moved away from the wall until the drain voltage reached 3V, which guarantees that the transistor is saturated. For each voltage, the author took notes of the distance and the current pulled by the module as shown in Table 4.1. The distance was measured from the base of the PCB to the wall, where the LEDs and sensors are attached to. An illustration of the experiment can be seen in Figure 4.4.

Voltage(V)	Current(mA)	Power(mW)	Distance(m)
4	26	104	0
5	55	275	0.13
6	145	870	0.16
7	217	1519	0.29
8	253	2024	0.30
9	264	2376	0.26
10	270	2700	–

Table 4.1: Relation of current, power and distances when varying the supplied voltage.

When testing with 10V, the circuit got very unstable and it was not possible to measure the distance. The plots in Figures 4.5 and 4.6 illustrate the results obtained in the two previous experiments.

In Figure 4.5, it is possible to see that the inclination of the curve, which is directly proportional to the conductance, decreases as the voltage increases. It is a sign that the diodes are almost breaking. According to the 940nm LED datasheet [1], its maximum continuous current is 100mA and it is usually achieved when a voltage equal to 1.4V is applied to the LED (The maximum forward voltage for 100mA is 1.8V). As the LEDs are connected in series, the maximum voltage that should be applied to them is $4 * 1.4V = 5.6V$.

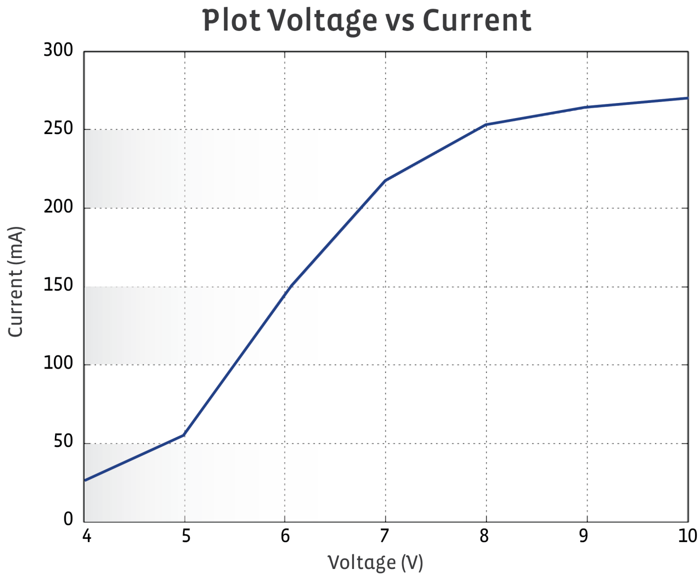


Figure 4.5: Plot of the relation voltage vs current

In Figure 4.6, it is possible to see that the distance range decreases at 9V, although the power dissipated in the diodes is increasing (as the voltage and current are both with higher values). This means that the power is being dissipated as heat, which confirms that the diodes are almost breaking.

4.3 False Count

Two possible failures are foreseen in the counter. These are also known as false positive and false negative events, which are:

- Nobody passes and the device counts as if someone had done it
- Someone goes in/out and the device misses it

The first error didn't happen during all performed experiments. The second error was encountered as in the following experiment: Five people without knowledge about the sensor's existence and usage were asked to go in and out of a room for 5 times each as the counting was being observed, in such a way that each person passed 10 times by the sensor. As the sensor performance depends on the feeding voltage, the author repeated this experiment with 6V, 7V and 8V, for each person, in such a way that a total of 150 (= 5 people X 10 passes X 3 voltage levels) experiments were observed.

The sensor was placed next to the door of a room as depicted in Figure 4.7. The distance between the actuator and the counter module is approximately 1.5m.

In order to generate these different voltages, the LM317 [27] voltage regulator was used. The circuit described in Figure 4.8 was taken from the LM317 datasheet. It was added to the original circuit as well as a 12V battery. In this circuit, the output voltage can be approximated

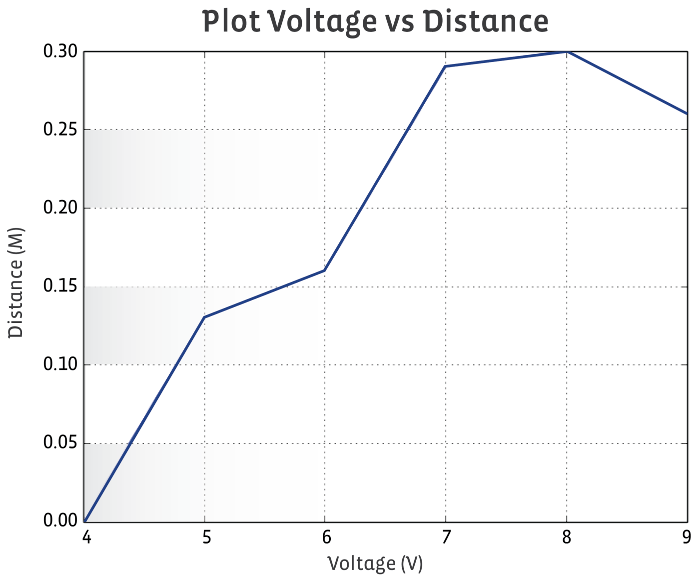


Figure 4.6: Plot of the relation voltage vs distance

by:

$$V_{out} = V_{REF} * (1 + \frac{R_2}{R_1}),$$

where $V_{REF} = 1.25V$. Thus, using $R_1 = 100\Omega$, R_2 must be:

- 380Ω, for 6V;
- 460Ω, for 7V;
- 540Ω, for 8V.

The closest available resistors were: 360Ω, 470Ω and 560Ω, which led to 5.75V, 7.125V and 8.25V, respectively. The voltage measured in the battery output was 11.72V instead of 12V. The voltages measured on the output of the regulator with the practical resistors values and battery were:

- 5.75V for the 360Ω resistor;
- 7.12V for the 470Ω resistor;
- 8.18V for the 560Ω resistor.

which should not interfere in the experiment. Figure 4.9 shows the voltage measured with the 360Ω resistor.

The individual number of fails are showed in Table 4.2 for each voltage:

It is evident that the number of fails significantly decreases when 7V and 8V are applied when compared with 6V. As explained before, the higher the voltage, higher is the current that passes through the LEDs and so will be the light intensity (or radiant intensity) and the distance range. According to Table 4.1, the distance range at 6V is 0.16m, while at 7V and 8V it is 0.29m

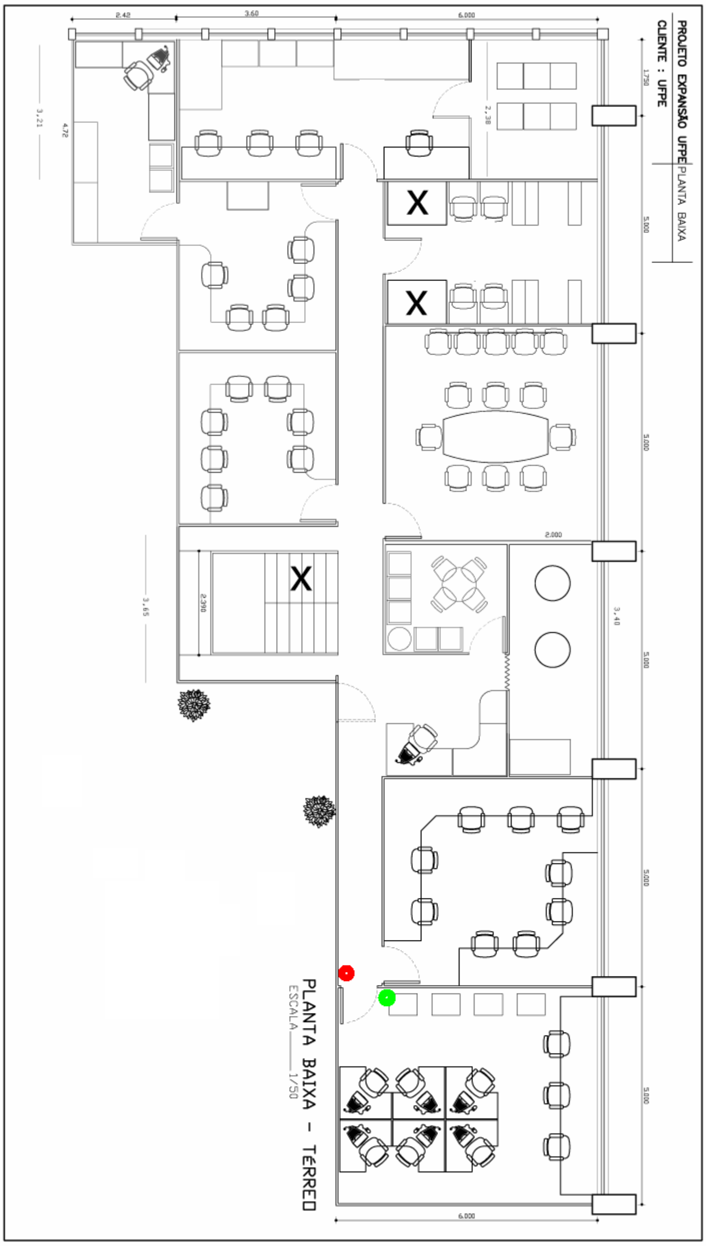


Figure 4.7: Overview of the scenario where the experiment took place. The red and green circles represent the counter module and the actuator module, respectively.

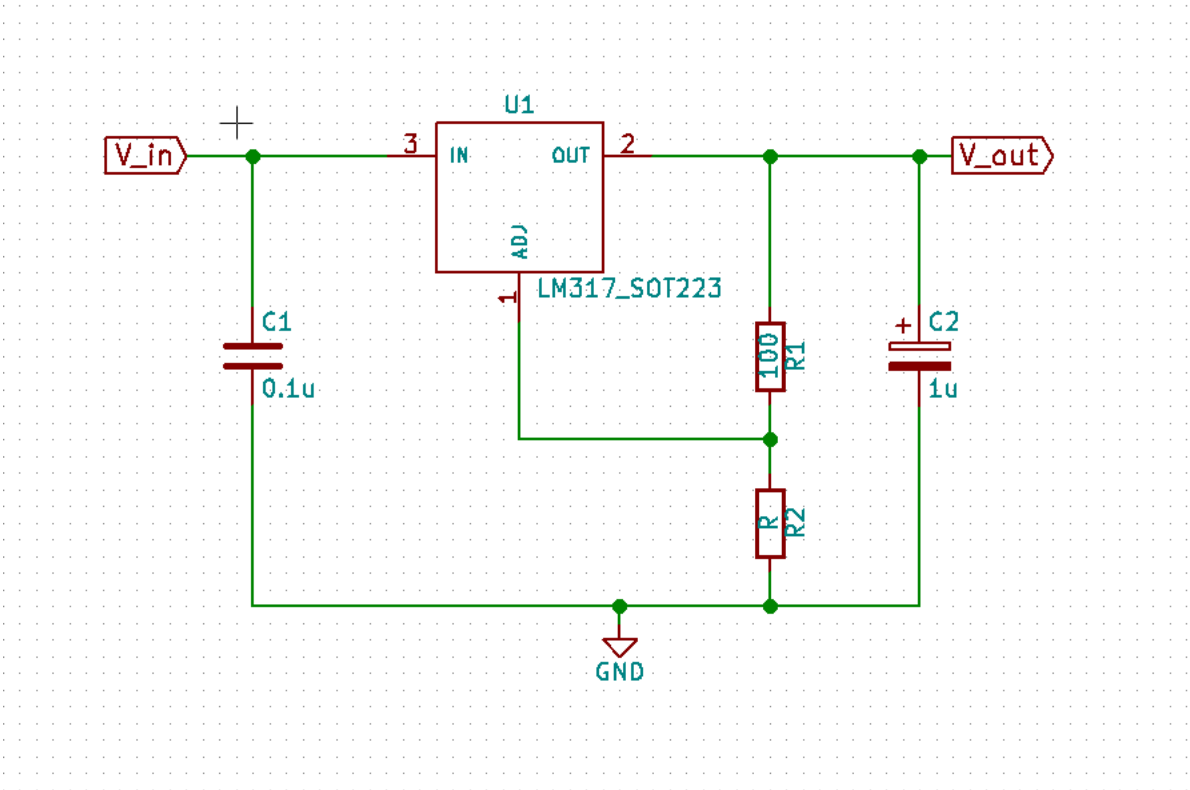


Figure 4.8: Voltage regulator circuit from the LM317 datasheet.

Figure 4.9: Voltage measured on the output of the voltage regulator with a 360Ω resistor.

Voltage	Person 1	Person 2	Person 3	Person 4	Person 5	Total
6	1	8	3	3	0	21
7	0	2	0	0	0	2
8	0	2	0	1	0	3

Table 4.2: Count of fails of the sensor for each person.

and 0.30m, respectively, which is nearly double of the value. This justifies the higher number of fails at 6V.

However, when 7V and 8V are compared one with the other, the number of fails, despite being very close, is slightly smaller at 7V, which disagrees according to the previous explanation. However, it can be explained by the fact that people walk differently every time they pass by the door. As the experiments with different voltages were repeated with the same people, a paired t-test can be done in order to evaluate if this difference is significant. For this test to be valid the differences only need to be approximately normally distributed, without extreme outliers [39], which is satisfied in the present sample. Hence, a script was implemented using the python programming language and its library named *scipy*. It provides a package for statistical analysis named *stats* which has a built in method *ttest_rel* that performs this analysis. Two arrays containing the second and the third rows of the Table 4.2 were given as the input. The result shows that the t-statistic is -1.000 and the p-value is 0.374. Therefore, it is not possible to state that there was a statistically significant change in the experiments, even if a high critical value as 0.1 is used.

4.3.1 Limitations of the Sensor

After evaluating the sensor, some comments are required in order to clarify to the reader the limitations of this technology. It is also important to present some usage guidelines to the reader interested in replicating a similar sensor.

- The sensor counts objects that pass completely in front of it. If someone passes an object, for instance a chair, in front of it, the sensor will count it;
- The limited distance range is not only a limitation, but also required for the proper operation of the sensor. It cannot be as long as the wall facing to the sensor, because the GPIO ports would be continuously in low level, as if someone was in front of the sensor;
- The gaps between two people that pass by the sensor are required for the sensor to count properly. If two people pass side-by-side, the sensor will count only one person. If two people pass hugging each other one in front of the other, the sensor may count one or two times, depending on the sensor placement and the distance between the people at its high;

- The actuator has to be configured to not allow the people count to be less than zero, so that if the light is turned off and someone goes into the room, the light turns on;
- If the last person inside a room leaves it, but the light is still turned on, it means that the people count in that room is greater than zero. This can be fixed by passing the hands in front of the sensor from inside to the outside of the room. Another approach to fix this problem is to insert a PIR sensor in the actuator with a very large timeout (for instance, 3 hours) so that if there is no wide movements in the room for this amount of time the count will be set to zero. This approach was not tested so far;
- The sensor does not count people that are standing still in front of it, once a complete passage is required to increment the count. If the room is empty and someone is going in and out repeatedly (or only moving his/her hands in and out in front of the sensor), the lighting system will be turning on and off as would occur with a common light switch. This can damage the lamps (or other devices), which is not desired. Therefore, it is important to establish a security protocol, such as a minimum timeout by firmware between consecutive commands. The same protocol can be useful in case of security attacks to the system. These protocols were not studied in this dissertation;
- If the sensor is to be placed next to stairs or ramps, it is important to leave enough space between the sensor and the stairs, so that people can see what comes next before stepping on it.

4.4 Cost

In order for the system to work within the main scenario of this dissertation, which is that of lighting control, the following items are necessary:

- One counter module for each entrance for each room;
- One actuator module for each room;
- One server for the house

Table 4.3 lists all the components used in the circuit prototype of the counter module and its costs in R$ (Brazilian Real).

The reader should notice that the battery accounts for almost 60% of the price of the counter module.

The components' cost of the actuator module prototype is around R$ 12.00. Finally, the server costs around R$ 9.00 and must be plugged to a PC.

The total costs in order to install this system in a house with: three rooms, kitchen, living room, laundry and two bathrooms is around R$ 343.64 (about US$ 110.00), considering no rooms with more than one entrance.

Component	Unitary Cost(R$)	Quantity	Total
Mosfet 2n7002	0.06	2	0.12
Resistor	0.01	5	0.05
Zener	0.05	2	0.10
IR Led	0.19	4	0.76
IR Photodiode	0.19	2	0.38
Microcontroller	2.84	1	2.84
RF Interface Module	2.34	1	2.34
6v Battery	17.24	1	17.24
Other (Board, acid, etc)			6.00
Total			29.83

Table 4.3: Components costs.

4.5 Installation Time

The counter is fed by batteries. Thus the installation of this module is as simple as fixing the device on the wall next to the room door to be monitored. Using adhesives it can be done in less than a minute. On the other hand, to control the lights, it is necessary to connect the switching module in series with a mains line. In order to do so, it is important first to turn off the circuit breaker. Then, to cut some wires and connect the module. The whole procedure from turning off and on again the circuit breaker may not take more than 10 minutes.

In the next chapter the author shows his own conclusions regarding the developed prototype.

5

Conclusions

Solutions that provide reduction of the energy consumption have been widely investigated in the last decades. In particular, many solutions were shown in order to improve the energy efficiency accounting for the people presence, but they are mostly still not feasible economically.

In this dissertation, an architecture capable of integrating counter modules to useful applications was provided. This architecture optimizes the lighting energy consumption by not requiring an external network connection to work properly, as discussed in Section 3.3. If an external network connection is present, many other applications can arise, as discussed in Section 1.1. The architecture concept was successfully proved and can lead to different architectures on the same research area. For instance, if the actuator module is replaced by a device that can control HVAC systems, a higher impact on the energy consumption is expected, as these devices consume much more electrical energy than lights. Further, a new architecture, or at least new modules for it, are needed in case both are desired: to control lighting systems and HVAC systems without the need of an external network.

A counter module prototype was implemented, with unity cost around US$ 7.60. The maximum distance range of the counter module was 30cm when supplied by 8V and 29cm when supplied by 7V, with a much smaller consumption. In order to test this module in a real scenario for 24 hours it is necessary to use a 5Ah 7V battery, which is not practical to common users. Among the requirements first stated in this work, three were accomplished and two were not, which are the low energy consumption and to be error-free. Nonetheless, it has been demonstrated that the proposed architecture is feasible.

Not only the sensor module was implemented in hardware, but also the actuator module, which enabled the architecture to be tested.

On the server side, an MQTT server, a DB subscriber and a DB were executed in the same machine, which proves that it is not necessary to have a large infrastructure to replicate the experiments for restricted scenarios. As discussed in Section 3.7, the experiments performed in [4] conclude that the MQTT server used in this dissertation can handle up to 60000 publishers simultaneously. Still, it is possible that a bottleneck exists at the actuator module. This could not be tested in laboratory due to availability limitation.

Although only one application has been exposed in this dissertation, many applications can be developed in the IoT inspired by it. This connectivity to the IoT is the main advantage of the present work. On the other hand, the disadvantages are the range and consumption of the developed sensor.

5.1 Future Work

The following main features may be added to this dissertation, which are:

- Improve the sensor consumption and range;
- Guarantee that the system can work with a single gateway in a house or office;
- Improve the GUI;
- Test the system in different and larger scenarios;
- Include protection to security attacks in the firmware;

The first can be achieved, for example, by changing the common LEDs used to a focused light beam, such as a low power LASER. This has to be tested and the cost and efficiency be evaluated. Another approach is to use Pulse-Width Modulation (PWM) in the light signal, so that the sensor will be emitting light only in a fraction of the time it is turned on. The second feature can be achieved by changing the actuators firmware to work in a mesh network topology. In the present dissertation they communicate only with sensors and a gateway, so the message from distant actuators may not reach the gateway.

Regarding the storage, another information that may be useful is the gateways' IPs, which enable it to identify the costumer location. Adding this field in the DB subscriber is also included in the future work.

5.2 Published Papers

Part of this dissertation regarding the sensor module and the actuator module was incorporated from the author's own paper entitled "A presence sensor for smart lighting systems" [5] presented at the IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society and available at the IEEE Xplore digital library.

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