Intelligence and control of a bio-adapted light

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Abstract: The aim of this project is to give intelligence to lighting systems based on LEDs. In order to optimize the outcome it is necessary to control the system and its surroundings, using electronic devices to transmit, receive and treat the data. For this purpose we use Arduino, an open-source electronics platform based on easy-to-use hardware and software. This essay explains the design and the implementation of an electronic device capable of controlling a bio-adapted lighting system with LED technology.

Keywords: Arduino, lighting control, intelligent lighting, sensors, electronics, *treball de fi de grau*, TFG

I. INTRODUCTION

The field of lighting has been revolutionized in recent years by the discovery of the blue LED, whereby Shuji Nakamura, Hiroshi Amano and Isamu Akasaki were awarded the Nobel Prize in Physics 2014 [1]. This discovery has allowed science to work on the potential this technology provides.

For lighting purposes it is needed a white light source with an emission similar to that of a black body of temperatures ranging from 2700 to 6500 K. It can be achieved by combining a blue LED (based on InGaN) covered by a luminescent phosphor emitting in the green-yellow range (one can find commercially this kind of LEDs). Nevertheless, the *Correlated Colour Temperature* (the temperature associated to an ideal blackbody radiator that radiates light of comparable hue to that light source) of white LEDs is static and their associated *Colour Rendering Index* (CRI, a quantitative measure of the ability of a light source to reveal the colours of an object that is being illuminated) is typically poor (between 75-85). The development and implementation of new lighting systems, more efficient and optimized, save both financial and human resources.

Within this framework, there is an ongoing project in the Department of Electronics at the University of Barcelona's Faculty of Physics, which aims to develop an intelligent and bio-adapted lighting based on LED technology [2]. This system acts as a variable CCT light source by mixing the light emitted by different types of LEDs (white LED of different nominal CCT plus a combination of red-green-blue LEDs). This variable source can emulate the same CCT of the Sun at a specific time and place. One of the most immediate uses of this technology is to adapt artificial lighting to biological system's biorhythms of plants, animals or humans (circadian regulation).

Once this technology has been discovered and implemented, it is crucial to take advantage of all its features. Due to the electronic nature of LED technology and its compatibility with electronic control systems, the purpose of this project is to create a system in to control and optimize the performance of this new light source.

The implementation of this device is based on the Arduino platform [3], an open-source electronics platform based on easy-to-use hardware and software. In the Fig.1 there is a picture of the PCB, which includes all the components that Arduino integrates (more details will be given in section III.A).

This platform arouses from the need of having a high performance and low cost electronic device accessible to anyone with basic knowledge of μC programming. Due to the success this platform has had in recent years, many manufacturers have designed, implemented and launched onto the market a wide range of Arduino compatible electronic devices. Some of these devices are used in this project.

By using this platform and connected to different sensors, the lighting system will have an intelligence control that will allow

1. Reducing energy consumption.
2. Automatically re-calibrating by a feedback system.
3. Having control over the spectra (CCT) depending on time.
4. A user friendly mobile and (future) voice controlling.

The design and implementation process will be described and exposed in the following sections.

II. DESIGN

The design process begins with the identification of the features we want to add to the light source and the possible ways to do it. The idea is to create an electronic device that receives inputs from its surroundings and emits the proper output to control the light source. There are many Arduino boards with different micro-controllers (μC), which have different features. I decided to use Arduino's μC in a standalone configuration, as the best option is to be implemented together with the different sensors, all of them inside a control box. This box can be placed anywhere (far from any power plug), so a battery holder has been installed with a 5V regulator. The battery will supply the power to all the sensors and actuators of the project.

One of the added features is a way to save energy. The μC will be connected to a motion sensor, which will send the instruction to the lighting system, depending if it

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detects a person nearby (lights on) or there is no one (lights off).

Another important feature is the control the light source behaviour and one of the goals of the bio-adapted light is to simulate natural light to adapt it to human circadian rhythms. The spectrum of the natural light changes during the day. A Real Time Clock (RTC) module gives the hour at any time and it allows the µC to change the CCT to the changing Sun's spectrum.

Moreover, the system includes a RBG-light sensor that gathers information regarding the CCT of the emitted light, considering the one from the surrounding. This feature is very useful for energy saving purposes, as in case there is enough natural light in the room the system lowers the artificial light intensity. Additionally, in case that one (or more) LED exhibits an efficiency reduction, it will not emit its initial spectrum, so the combined light will not present the proper CCT or CRI (more details in section III.G). Using the RGB components and a feedback routine the systems can be re-calibrated automatically.

Even though the light source can be set up and controlled only by the µC software, there is the possibility of giving a specific order to change either the CCT or the intensity. This option has been implemented in an Android application to be used in a smartphone or tablet. The CCT and the light intensity can be selected through a graphical user interface (GUI) programmed in App Inventor, a programming language for Android devices developed by the Massachusetts Institute of Technology (MIT). There is also a microphone that intends to translate sounds into an analogical µC's input signal. This feature was out of the scope of the present project and has not been implemented yet.

III. HARDWARE

A. Arduino's µC

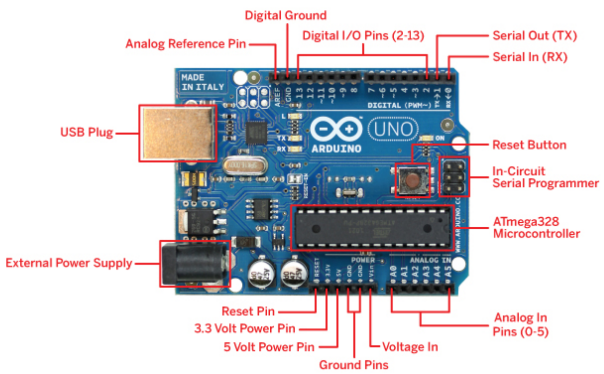

FIG. 1: Arduino UNO Rev3 [4]

The standard Arduino is basically a credit card sized board that contains all necessary components to develop electronic projects (see Fig. 1). Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators.

There are several kinds of Arduino µCs. In this case, and considering the amount of signals that have to be treated, we have chosen an ATmega328P-PU, which is an 8-bit RISC AVR µC, it has 32 Kb of flash memory and 26 input/output pins.

B. Motion sensor (PIR)

They are often referred to as PIR, "Passive Infrared", "Pyroelectric", or "IR motion" sensors and they allow to sense motion,

PIRs are basically made of pyroelectric sensors that can detect levels of infrared radiation (IR). A Fresnel lens splits this radiation in two beams. These two beams are wired up so that they cancel each other out. If one of the beams has more or less IR radiation than the other, the output will swing the PIR state.

This sensor is placed outside the box, so it can detect if there is someone in the area. This information can be used to turn on and off the luminaire to save energy, being used when necessary. Its range is between 6 and 10 meters and the sensitivity can be adjusted (for instance to avoid turning on the light when a pet is moving). The time that the PIR state remains HIGH can be adjusted, so this sensor can be directly wired to the power supply system, which saves energy automatically. In the present work, the time was fixed to 5 minutes, so after this time without detection of motion the system turns off.

C. Microphone

A microphone is an acoustic-to-electric transducer that converts sound into an electrical signal. The purpose of including this device was to have a speech recognition system to give orders by voice.

In computer science and electrical engineering, speech recognition (SR) is the translation of spoken words into text. The main problem that arises in SR systems is to make a right cooperation between parameters from different fields: acoustic, phonetic, phonological, lexical, syntactic, semantic and pragmatic.

The SR system’s accuracy lies on the algorithm used on the translation and they are usually based on the treatment of big databases that contain a lot of parametrized voices. There are many SR commercial systems but this project is intended to be built with open-source software/hardware and there are not sufficiently good open-source options. Although the microphone is placed outside the box and it is connected to the µC, its signal is not treated (the possibility of being connected to the Google Voice service is under consideration).

D. Real Time Clock (RTC)

This project is built for a light source that can change its CCT. It allows the system to adapt artificial emitted light to the natural light that the sun emits at a specific time and place. The sun rises and falls throughout the day. That implies that the CCT changes depending on the sun's altitude, which means that it depends on the time as well.

This is why the DS3132 RTC is needed. It has an integrated circuit and an independent battery so it can maintain the right date and hour. The RTC allows you to emit the right CCT, which means that the artificial light becomes “natural” light that can be adapted to human circadian rhythms.

E. RadioFrequency (RF)

The hardware can control several lights at the same time and the simplest and cheapest way to do it is with a wireless communication. The 433MHz RF module allows the communication between the hardware and the luminaire. Both of them, hardware and luminaire, have a transmitter/receiver RF modules. The hardware will send orders and it will receive the confirmation from the luminaire.

There is a protocol that maintains the integrity of the system. Any order contains a string of control characters, the order ID, the light source ID, the CCT and the light intensity. If a luminaire receives an order it changes its parameters and sends the order upside down, so the hardware can check if the order has been received and applied.

This implies that the luminaire has a µC to treat the orders and to apply the parameter changes. The RF has an ideal transmitting range of 40m indoor and 100m outdoor. The tests on these RF modules have shown that the standalone module (without antenna) has a transmitting range of few meters. With an antenna of at least 17 cm, the range increases until 15-20 meters indoor. That is enough for our purpose because the hardware will be near the luminaire, and it could act as a replicator signal.

F. Bluetooth

Another added featured is the communication between the hardware and a smartphone. The objective is to control the whole system with a smartphone or a tablet. The best way to do it is via Bluetooth, because it is one of the most extended standard communication protocols.

The smartphone will send an order to the hardware through the HC-05 Bluetooth module and it will send the order to the luminaire through the RF modules.

The reason a RF module is used between hardware and luminaire instead of Bluetooth is because it is cheaper (we need one receiver/transmitter module per light source) and it has a double/triple transmitter range.

G. Light sensor

The TCS34725 is a light sensor which has RGB and clear light sensing elements. An IR blocking filter, integrated on-chip and localized on the colour sensing photodiodes, minimizes the IR spectral component of the incoming light and allows colour measurements to be made accurately. It has one photodiode per each light component (RGB) and one photodiode sensitive to white light.

It is used to verify the light that the luminaire is emitting by the analysis of the RGB components and to measure the intensity of light arriving externally. This indicates to the µC if it can reduce or increase the light intensity in order to save energy.

This sensor is not calibrated by default. It needs to be calibrated with a real luxometer/spectrometer.

The light sensor detects when the global light intensity in the room changes. If there is low luminosity the µC increases the intensity of the light and vice versa, which also helps saving energy. It maintains a constant level of luminosity in the room.

By reading the RGB outputs it is possible to determine if the luminaire emits a right CCT or if it is any LED that does not work properly.

IV. MANUFACTURING

The hardware is placed into a small plastic box so the distribution of the devices must be precise. Due to the fact that we are manufacturing a prototype, all components are wired and/or welded to a perforated circuit board.

First of all, it is necessary to have a diagram to use it as a guide to connect everything correctly. We used an open-source program called Fritzing [5] that simulates electronic components and allows you to do quick and clean diagrams.

Second, the perforated circuit board has to be placed into the box. There are three components that have to scan the surroundings: the motion sensor, the light sensor and the microphone. The other devices including the battery holder, the µC, the RTC, the RF and the Bluetooth module are directly welded or placed to the perforated plate.

Once all the hardware is set up and well welded/wired the µC has to be programmed to control all the devices.

V. SOFTWARE

The open-source Arduino’s Integrated Development Environment (IDE) makes it easy to write code and upload it to the board. It runs on Windows, Mac OS X and Linux. The environment is written in Java and based on Processing and other open-source software.

The software can be uploaded to any Arduino board. This project requires a standalone configuration so it uses an Arduino board to program the standalone µC. The board is connected by an USB to the computer and the µC is connected to the Arduino board by their serial pins.

The µC has to control several devices, and each one has different communication protocols. Most of manufacturers provide a piece of code to facilitate the library implementation. Each library contains a set of functions that makes easy to interact with the sensor/module.

The only device that does not need a library is the PIR sensor because it only has three pins: two for the power supply and one that changes his state when detects motion.

All these libraries are included in the main program and they help controlling the CCT and the light intensity attending the specified parameters (e.g., turns off the light when there is no one in the room). The code is written in Java, compiled and uploaded to the µC. If the µC is properly programmed it is ready to work by itself. The code can be downloaded from here

VI. SMARTPHONE APP

Although the µC can be well programmed, placed on the perforated plate, wired and never touched again, the interaction of the luminaire with a smartphone improves its possibilities and it could be useful for future applications.

There are many ways to build apps on Android. For those who do not know how to program Android apps, the MIT has developed a GUI called App Inventor [7] designed to introduce children to programming. There are no code lines and the program is made by concatenating blocks, with a specific function built inside each one. A program is divided in two connected windows: the design and the blocks. The design shows a standard smartphone screen in which you can place pre-built buttons, sliders, labels, pictures, etc. It shows the graphical part of the app, what the final user will see. The block window has all the elements added in the design window and represents the functions that are behind the graphical elements. These are the blocks that are actually used when programming. For instance, it is possible to program what to do if a button is pressed or a slider changes his position. It also has specific blocks to enable Bluetooth communication. This is the main reason I choose this GUI to build a smartphone app: simplicity.

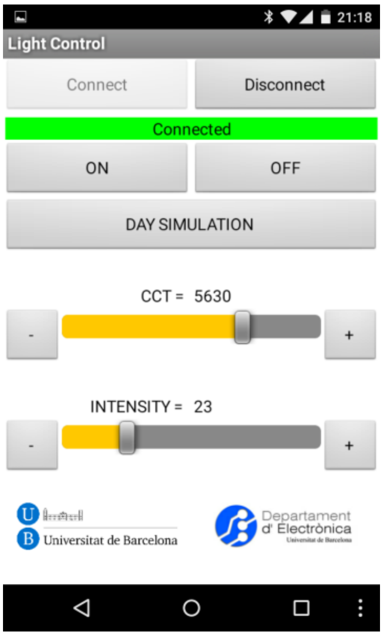

FIG. 2: Screenshot of the developed app.

The developed app has a static frame and it allows you to connect and disconnect the mobile phone to a Bluetooth device; to increase and decrease the CCT and the light intensity with buttons and sliders and to turn on and off the lights. It also has a button called "simulation" that makes the luminaire simulate its changes during a whole day in less than 30 seconds.

VII. CONCLUSIONS

Finally, the hardware is built and fully connected, the µC is correctly programmed, it does a right data treatment, it controls the devices properly and the smartphone app works efficiently.

The vast majority of initial proposals are completed. The only feature not implemented is the speech recognition. As mentioned previously, there is not open-source speech recognition software that works as well as Siri or Google Voice, because a big data base with a lot of different kind of voices is needed to improve algorithms to translate the voice into text. There are several open-source projects but they lack that extensive voice data base. I would like to highlight one of these projects that have developed phoneme recognition. It is called µSpeech and it is compatible with Arduino platform. Although it provides libraries with all the calculations to transform phonemes into letters, the calibration process is not optimized yet.

All the other features have been successfully implemented and tested.

- The PIR sensor detects motion within 6 to 10 meters, it turns the lights on when motion is detected and they remain on only for 5 minutes. This helps the device to save energy, as it changes to standby mode. It has one disadvantage: the communication between the smartphone and the hardware requires that the system is not on standby mode. So the user must be close to the device (6 to 10 meters) to establish communication. But it is reasonable to think that the user wants to control the luminaire when he is in the illuminated area, so it is not an actual problem.

- The light sensor helps changing the light intensity so there is a constant level of luminosity at the room. The µC changes the intensity of the light when it exceeds a threshold so it does not change constantly, which would be annoying. The change of intensity is progressive to avoid people noticing it.

- The Bluetooth module did not give me any problem and it stablished connexion with the smartphone from the very beginning. There is only one thing to keep in mind: it uses the serial pins of the Arduino, which means you cannot upload a sketch to the Arduino while the Bluetooth module is still connected; it creates conflicts in this serial bus.

- The RTC module was easy to install. The library given by its manufacturer implements the functions to determine the date and time and it is really easy to re-write some code lines to customize the outputs.

- The RF modules where the most difficult components to make them work properly. I used a 433MHz receiver and transmitter and their accuracy is low without an antenna. It took me many hours to discover that the problem was the antenna. Moreover, with a welded antenna, the accuracy is still unacceptable and the final solution lies on the software. The transmitter sends the message several times and the receiver sends back a confirmation. If the transmitter does not receive it, it returns an error message. Now, to succeed in the RF communication, several numbers of attempts are needed.

- As a prototype, the hardware works very well. Some connections are made by wires instead of welder but they run perfectly.

VIII. REVIEW

Before this project, I could not imagine that I would develop this kind of TFG. Normally, when people think about a TFG in Physics, they expect a project implying particles, measurements, quantum mechanics or experiments. This has been an applied project where I used all my informatics and my electronics knowledge, and the result is a hardware that, maybe, someday will be a part of a product sold in the market. But my knowledge was not enough, because I had to improve my capabilities to solve problems, and that is what a physicist does: solve problems. So I have also learnt a lot of things.

This process took me through an unknown world for me: electronics. I learnt how to build interactive projects that require electronic devices. Now, I realise electronic IDEs such as Arduino have a lot of potential. It is still a young project and it has a lot of things to improve. For sure it will grow up thanks to the people that develop compatible software/hardware Arduino devices.

I had never welded anything before this project, so I had to learn how to weld with the help of my electronics colleagues. Electronics is a part of the physics field that is studied specifically in another degree and only the basics is taught on Physics degree. But nowadays, most of the experiments in Physics need an electronic component to get and treat the data and the results. I am glad to have learnt such an applied thing such as building an electronic device that solves a real problem.

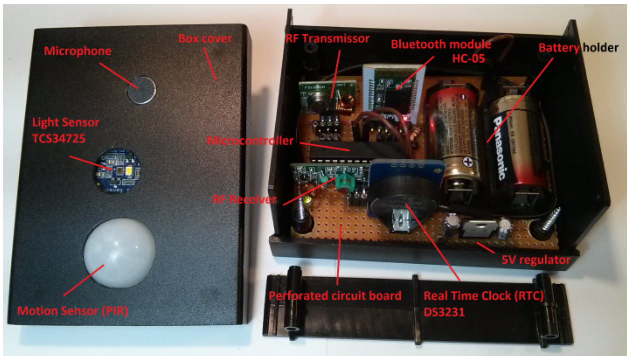

FIG. 3: the prototype

As I said before, this project is a prototype that can become a final product, but it needs to be improved. The next step is to identify if this hardware covers all the customer needs. If it does, the next step is to design and implement a Printed Circuit Board (PCB) with the hardware. If not, it is necessary to improve the prototype with the appropriate devices. Finally, if the product is going to be sold, its appearance will become one of the priorities, as long as it has to be visually attractive to be competitive in the actual market. In order to have several optional boxes, the electronics department has bought a 3D printer machine to try different shapes, sizes and configurations.

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I would like to thank Adrià Huguet Ferran, who first developed the bio-adapted luminaire as his "*Treball de Fi de Màster*" [8] and who is still working on the project. He has been always there helping me for any difficulty I had.

I also would like to thank to Fisitrónica, a student's association at the Faculty of Physics [9], for introducing me to the electronics world.

I would not want to finish without thanking my family, who have always supported and encouraged me.

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