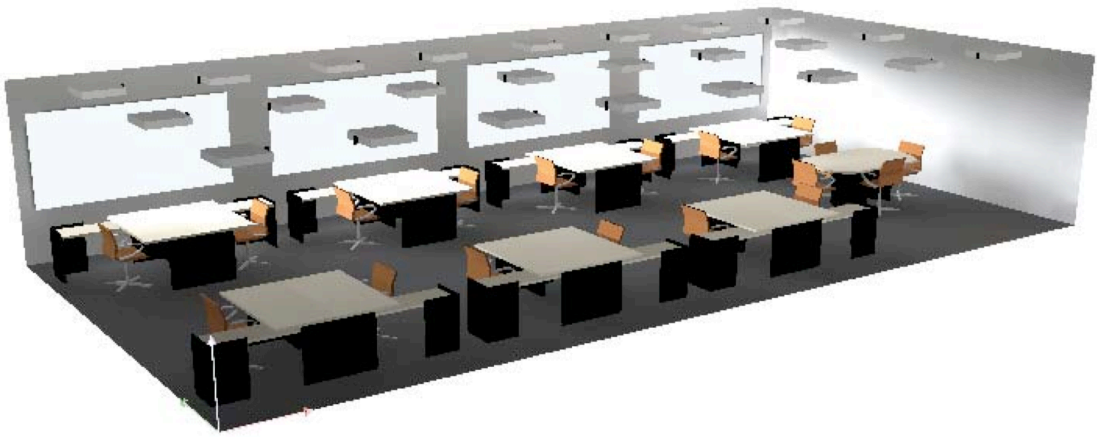
*Master Degree in Electrical and Computer Engineering*
**2015/2016 – Winter Semester**

# Distributed Real-Time Control Systems
# (Sistemas de Controlo Distribuído em Tempo-Real)

**PROJECT**

## *Distributed Lighting Control*




Prepared by

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## Instructions for the project

The students must form groups of three to execute the project. There are weekly laboratory sessions of 1.5hr each where the students will access the relevant equipment to progress in the execution of the project and receive guidance from the teaching staff. Some equipment is available for students to take home in order to experiment and advance on points not requiring lab access.

The students have to perform two demonstrations of the project: one in the middle of the semester ($30^{th}$ October, 2015) showing the progress of the first stage, and one in the end of the semester to show the full project ($18^{th}$ December, 2015). Then the group has to write a report to be delivered a couple of weeks after the last demonstration ($3^{rd}$ January, 2016).

The report must be direct, concise and short but insightful. Together with the report, the software, hardware schematics and other material developed to execute the project should be delivered.

Both the report and the software must be sent to the professor in charge of the laboratory within the prescribed time limits.

The reports and the software developed must be original. All forms of plagiarism or copy detected will be punished without contempt according to IST regulations and the Portuguese Law.

# Read this with attention!

## Safety warnings

- In case of gross misuse of the equipment or violation of its operational limits, the students will be liable for the replacement of the damaged equipment.

## Notice also:

- You must **always bring to the lab the equipment taken home** since this is required for the lab sessions.
- You must **always bring to the lab a flash drive** to store the results obtained during the class;
- When using the lab computers make sure that you are using a working folder with write permissions (can be an external flash drive).

## Take home material

Basic Kit

- 1 Arduino UNO Rev. 3
- 1 USB cable type A/B
- 1 Breadboard
- 1 Set of multicolored jumper wires.
- 1 Light Emitting Diode (LED superbright, 20mA, 3.4V)
- 1 Light Dependent Resistor (LDR GL5528)
- 1 Resistor 100 Ohm
- 1 Resistor 10 KOhm
- 1 Capacitor 1 microF

Other material that can be requested by email (if available)

- Servo Motor HITEC H-S322HD
- Micro DC motors
- Single color LED's.
- RGB LEDs
- Discrete components of varied characteristics and values (resistors, capacitors, diodes, transistors)
- 330 Ohm resistors
- 10 KOhm Potentiometers
- Push buttons
- Piezo buzzer
- Piezo knock sensor
- Temperature sensors

## 1. Introduction

With the increasing prices on electricity, large research efforts have been put in the search for efficient illumination systems during the last decade. Advances in semiconductors has brought us high power LED's that allow up to 85% saving in energy consumption and high versatility of use due to their small size and dimming ability. Additionally, improvements in technology and reductions in price are making LED the favourite illumination devices for home, automotive, office and smart building spaces (www.ledmarketresearch.com).

The flexibility of LED lighting is allowing for another recent trend in energy optimization and comfort control. Recent research is being devoted to adaptive and distributed lighting control taking into account the occupation status of spaces and the intensity of external illumination [1][2][3]. Cheap luminance and presence sensors allow controlling the power used to achieve the required comfort luminance levels for occupied spaces, and reduce the power in unoccupied spaces. Already in streets, buildings and public spaces lights are turned on and off as a function of motion detection sensors, but more versatile systems can be developed to take into account external illumination and jointly coordinate the activation multiple luminaires that interact. In this project we will consider an office-like scenario where desks have presence and luminance sensors, and luminaires have light dimming and communication abilities to synchronize with their neighbours.

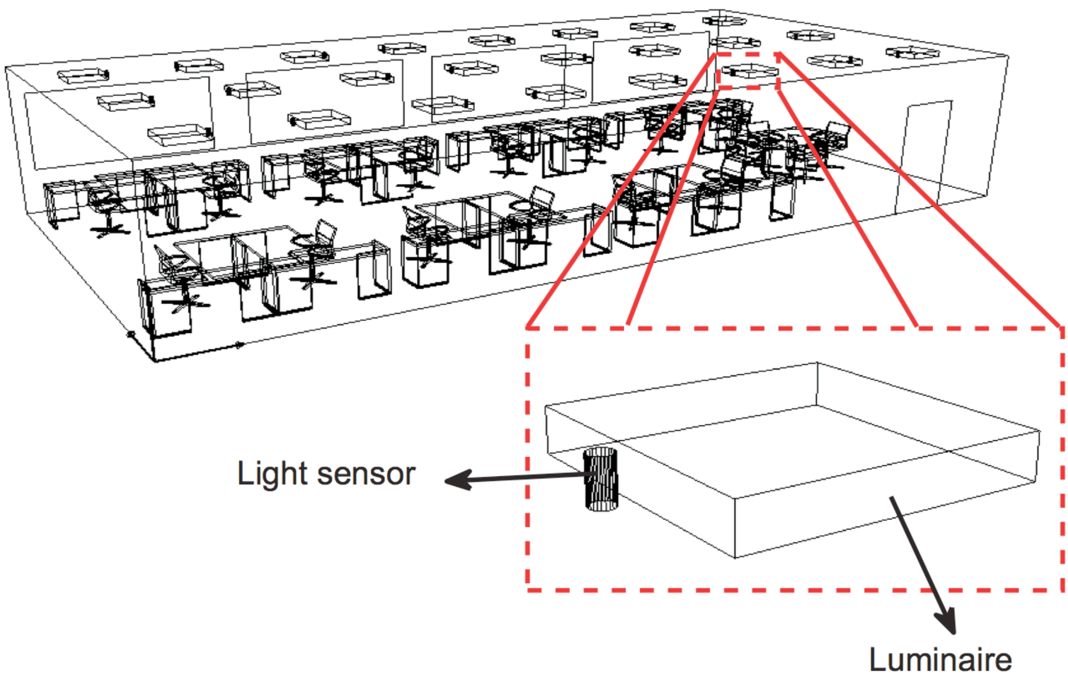



**Figure 1. Scenario envisaged in the project. Each desk is equipped with a luminaire, light sensor and presence sensor. The control of the lighting is made to keep fixed levels of illumination at the desk plane (high for occupied desks and low for unoccupied desks) while minimizing the global energy consumption and taking into account the daylight illumination and disturbances from the neighbour luminaires.**

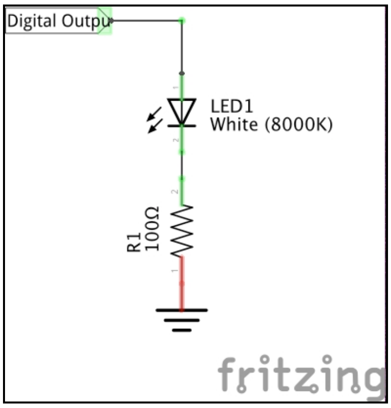
## 2. Objective

The objective of this project consists on the real-time control of a distributed illumination system in a small scale model of an office space. Consider each desk has a smart luminaire composed of a light emitting device, a luminance sensor, a presence sensor, with computational and communication elements.  In the project we will simulate the office with a small opaque car box and each luminaire consists of a breadboard with the Arduino, LED and LDR circuits. Each group will, thus, create a model of a small office with 3 luminaires. For practical reasons, the presence sensors will not be physically implemented, but instead simulated by setting variables in the microcontrollers through a computer interface or push buttons. A small window should be simulated by creating an opening in the card box, to exploit energy harvesting and simulate external disturbances.

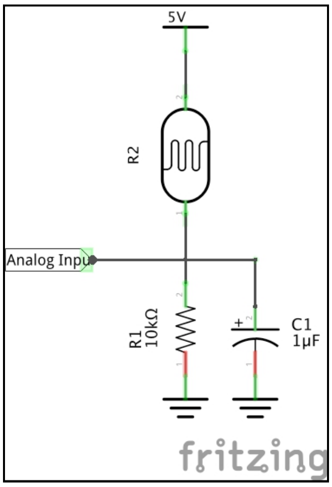
The objective is to minimize the energy consumption and user comfort. Energy minimization will be achieved by controlling the dimming level of each led such that occupied desks have luminance levels above a certain value (HIGH) and unoccupied desks have a luminance levels above a lower value (LOW). According to the European standard EN 12464-1 *"Lighting of indoor workplaces"*, April 2013, in typical office spaces during working hours occupied desks should have a minimum illuminance value of 500 lux (HIGH), whereas non-occupied desks should have illuminance above 200 lux (LOW). With the available equipment and experimental setup, these values are not achievable. Adequate values for HIGH and LOW thresholds should be defined by each group, since it will depend on the dimensions of the reduced scale model and the position of the luminaires. User comfort should be maximized by keepin the illumination always above the minimum levels, and minimizing the variations of the illuminance levels during desk occupation. These variations may be due to noise, external disturbances, or interference caused by the other luminaires in the shared space. Noise and external disturbances can be compensated by a local feedback control loop at each luminaire, but internal disturbances due to interference from other desks can be predicted and compensated through proper communication and synchronization between luminaires (global control).

## 2.Plant Description

Each luminaire will be simulated with the equipment supplied to the groups. The following diagrams illustrate a possible LED driver circuit and and an illuminance reading circuit.




a) Led driving circuit




b) Illuminance reading circuit

The LED dimming can be implemented via PWM in one of the digital output ports. The illuminance can be measured via the LDR in a voltage divider circuit. The capacitor in the voltage divider serves to reduce noise in the sensing circuit. The PWM frequency should be configured to further reduce the noise on the analog input. Both the LED and the LDR should be pointing "vertically".

The distributed illumination system should be implemented in a reduced scale model. An opaque box with a cover should be used to allow complete isolation from the external illumination. The box should be large enough to contain the 3 luminaires, but not too large. If the box is too large, the LED intensity may not be enough to provide enough power to illuminate the LDR (note that the LDR receives mostly light reflected in the box walls). To improve light reflexion, if needed, the interior of the box may be covered with white paper. Small openings in the box must be made to pass necessary cables. Try to insulate these opening as much as possible to prevent uncontrolled light entrance from the outside. A window should be simulated in the card box to test the system under controlled external light.

## 3.Work Stages

The project is divided in two major parts.

*3.1. First Stage*

During the first stage of the project, the students will implement the reduced scale office model, the luminaire actuation and sensing circuits, the actuation and sensing microcontroller code, the local feedback control, and a simple interface with a PC using the Arduino Serial Monitor. In local feedback control no explicit communication is allowed between different luminaires, and each luminaire only cares about its own desk. The local controller should be implemented as a PID controller with feedforward. The feedforward term is important to speed up the response of the system. Do not forget to implement adequate integrator anti-windup functions. To cope with LED saturation. The LDR is a non-linear element. It means that its gain (ratio of the variation of the illuminance to variation of the measurement) varies with the operating point. To implement the local controller, its characteristic should be linearized, so that the local controller has similar response in different operating points. To reduce the perception of flicker during set point transients, the LED refresh frequency should be at least 30Hz. For this purpose it also be helpful to use a high PWM duty-cycle resolution (check TIMER1 functionality). The analog input resolution can also be increased by using the AREF pin. To reduce noise in acquisition, a common strategy is to acquire many samples during one acquisition period and compute the average (or the median) of the values.

This part will be evaluated through a demonstration of the local illumination control in the middle of the semester (30$^{th}$ October). Students should demonstrate the ability to set LED dimming values, read illuminance values in Lux, define setpoints for local control, demonstrate the performance of the control system in step changes in the reference setpoint and under external disturbaces.

*3.2. Second Stage*

During the second stage the students will create a control network (I2C or SPI) to allow communication between the luminaires, define the evaluation metrics (energy consumption, user comfort), and develop the global coordinated control. When a luminaire has to change its reference value due to change in its occupation status, it should broadcast this information to the neighbour luminaires so they can compensate quickly for the change. To realize the compensation, it is necessary to model the effects of a change in one luminaire in the measured illuminance of the other. Because this interference between luminaires depends on many factors, a calibration procedure should be made at system startup. For example, turn on one luminaire at each time and measure the illuminance in all other luminaires. The global controller can use either a centralized method (basic objective) or a distributed method (advanced objective). In centralized control, a master luminaire has access to the information of all luminaires (luminance and dimming levels), computes the global optimal compensation values, and forwards to the other luminaires. In decentralized/distributed control, each luminaire can communicate only with its neighbours but no central master exists. A PC will be connected via serial port to one of the luminaires. This luminaire will operate as a router of information between the PC and the other luminaires, coordinate the calibration procedure, and serve as master controller in the centralized control mode. A C++ server with serial and socket communications will run on this PC to allow remote access by a client PC to the state of the system. The client PC should be able to read the state of any luminaire (occupation, led dimming level, illuminance level), set values to the system (occupancy, led dimming level, redefine the reference levels HIGH and LOW), and access system statistics (energy consumption, comfort metrics). The information can be requested in three different modes: actual values, last minute history or real-time stream.

This part will be evaluated through a demonstration of the final distributed control system in the end of the semester (18$^{th}$ December).

A written report containing both parts, and associated software, will be delivered two weeks after the final demonstration until (3$^{rd}$ January, 2016).

## 4. Implementation Notes

1. Using the program "serial monitor" in the Arduino IDE, information can be received from and sent to the Arduino program. Groups should program the Arduino to send relevant information to the PC (for data plotting, diagnostics, debug, etc) and receive from the PC relevant commands (set desk occupation, set control parameters, set program configuration modes, etc).

2. Take into account that serial communications use precious microprocessor time. Choose messages with short size and a high baud rate. Compute communication delays and verify that communication time do not exceed available control loop time.

3. You can copy text from the serial monitor. Format your messages so that you can use the copied text to graphically visualize the data in Matlab or Excel.

4. Add any functionalities that facilitate development, testing, debugging, and demonstration of the applications. There are additional electronics components that you can request for such purposes.

5. Always use SI units to represent quantities. Check the electronic components datasheets to verify the conversions from electrical to physical units.

## 5. Report

Write a report describing the problem, the designed solutions and the obtained results, mentioning the positive and negative points of the applied techniques. The report must be complete but succinct, with less than 20 pages including graphics and references. Avoid redundancies and exaggerated technical content. Try to summarize as much as possible but do not miss to write the important things. The graphics must be self-contained, i.e. fully labelled and with complete captions.

## 6. References


[1] Occupancy-based illumination control of LED lighting sensors, D. Caicedo, A. Pandharipande and G. Leus, Lighting Research and Technology 43: 217, 2011.

[2] Daylight integrated illumination control of LED systems based on enhanced presence sensing, A. Pandharipande, D. Caicedo, Energy and Buildings 43, 944–950, 2011.

[3] Distributed Illumination Control With Local Sensing and Actuation in Networked Lighting Systems, A. Pandharipande, D. Caicedo, IEEE Sensorrs Journa, Vol. 13, No. 3, March 2013.


All papers available in the course web page.

– ***Enjoy the project*** –