Advances in Intelligent Systems and Computing 290

Sigeru Omatu · Hugues Bersini
Juan M. Corchado · Sara Rodríguez
Paweł Pawlewski · Edgardo Bucciarelli *Editors*

Distributed Computing and Artificial Intelligence, 11th International Conference

Springer

Advances in Intelligent Systems and Computing

Volume 290

Series editor

Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

For further volumes:
http://www.springer.com/series/11156

About this Series

The series “Advances in Intelligent Systems and Computing” contains publications on theory, applications, and design methods of Intelligent Systems and Intelligent Computing. Virtually all disciplines such as engineering, natural sciences, computer and information science, ICT, economics, business, e-commerce, environment, healthcare, life science are covered. The list of topics spans all the areas of modern intelligent systems and computing.

The publications within “Advances in Intelligent Systems and Computing” are primarily textbooks and proceedings of important conferences, symposia and congresses. They cover significant recent developments in the field, both of a foundational and applicable character. An important characteristic feature of the series is the short publication time and world-wide distribution. This permits a rapid and broad dissemination of research results.

Advisory Board

Sigeru Omatu · Hugues Bersini
Juan M. Corchado · Sara Rodríguez
Paweł Pawlewski · Edgardo Bucciarelli
Editors

Distributed Computing and Artificial Intelligence, 11th International Conference

Springer

Editors
Sigeru Omatu
Faculty of Engineering
Osaka Institute of Technology
Osaka
Japan

Hugues Bersini
Université Libre de Bruxelles
Brussels
Belgium

Juan M. Corchado
Faculty of Science
Department of Computing Science and Control
University of Salamanca
Salamanca
Spain

Sara Rodríguez
Faculty of Science
Department of Computing Science and Control
University of Salamanca
Salamanca
Spain

Paweł Pawlewski
Faculty of Engineering Management
Poznan University of Technology
Poznan
Poland

Edgardo Bucciarelli
Dep. PPEQS, Section of Economics and Quantitative Methods
University of Chieti-Pescara
Pescara
Italy

ISSN 2194-5357 ISSN 2194-5365 (electronic)
ISBN 978-3-319-07592-1 ISBN 978-3-319-07593-8 (eBook)
DOI 10.1007/978-3-319-07593-8
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014939945

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Contents

Artificial Intelligence Applications

Distributed, Grid, Cloud and Mobile Computing

Bioinformatics, Biomedical Systems, E-health

Data Mining, Information Extraction, Semantic, Knowledge Representation

Image Processing, Tracking, Robotic, Control and Industrial Systems

New Algorithms

Intelligent Lighting Control System

Elena García[1], Sara Rodríguez[1], Juan F. De Paz[1], and Javier Bajo[2]

[1] Computer and Automation Department, University of Salamanca, Spain
[2] Artificial Intelligence Department, Polytechnic University of Madrid, Spain
{elegar,srg,fcofds}@usal.es, jbajo@fi.upm.es

Abstract. This paper presents an adaptive architecture that allows centralized control of public lighting and intelligent management, in order to economise on lighting and maintain maximum comfort status of the illuminated areas. To carry out this management, architecture merges various techniques of artificial intelligence (AI) and statistics such as artificial neural networks (ANN), multi-agent systems (MAS), EM algorithm, methods based on ANOVA and a Service Oriented Aproach (SOA). It performs optimization both energy consumption and economically from a modular architecture and fully adaptable to the current lighting systems possible. The architecture has been tested and validated successfully and continues its development today.

Keywords: Light sensors, intelligent systems, distributed systems, Autonomous control, Street lighting.

1 Introduction

Nowadays, the concept of Smart Cities is increasingly a common trend in technological projects. The balance with the environment and natural resources is a practical and responsible key for these paradigms, which aim to achieve a state of comfort for citizens and institutions based on sustainable development. In this respect, talk about energy efficiency is paramount, not only to reduce energy costs, but also to promote environmental and economic sustainability.

One of the main costs faced by councils in towns and cities is the lighting bill. According IDEA [1], throughout the 2010 in Spain there were about 4,800,000 points of light with an average power of 180 W and 4,200 hours of annual use. Representing an electricity consumption of 3,630 GWh / year, this is excessive consumption. The technological advances that are experiencing external lighting installations along with its intelligent use will allow reducing that as high consumption.

This research appears from a greater project by the research group of BISITE (Bioinformatics, Intelligent Systems and Technology Education) of the University of Salamanca, which is to build a system that allows centralized control street lighting as well as an intelligent management, in order to economize on illumination and maintain maximum comfort status of the illuminated areas. This is to avoid excessive illumination of areas, as there are many times that it is not necessary to maintain maximum light intensity for an optimal service.

S. Omatu et al. (eds.), *Distributed Computing and Artificial Intelligence, 11th International Conference*, Advances in Intelligent Systems and Computing 290,
DOI: 10.1007/978-3-319-07593-8_24,

To validate the system in an experimental research level, a small test case is available, consisting of a portable installation of 5 luminaires with specific hardware. The functionality to be achieved is divided into two modules.

One module shall be responsible for the direct management of the various installations and control panels and will serve as a communication layer with each site, so as to allow as much control and monitoring in almost real-time of each facility and even luminaire. In this sense, the system must provide a service interface that can be accessed for each installation using a standardized interface independent of the underlying technology and hardware of each installation.

The other module, explained in this article, will have as its main objective the management of the lighting schedule for each installation, consumption management, and prediction. In this regard, a light planning is defined as light output level for each installation offered hourly. This light planning must be possible by programming user preferences, or by observing different decisive environment factors in determining the appropriate level of brightness for each site at each time. Thus, different factors come into play: astronomical clock, weather and traffic and pedestrian flow. Moreover, it will be interesting to make a prediction of consumption by the light patterns assigned to each zone, depending on its economic rate.

To carry out this management, the built system combines different statistics and artificial intelligence (AI) techniques such as artificial neural networks (ANN), multi-agent systems (MAS), EM algorithm, methods based on ANOVA and a Service Oriented Approach (SOA) [5].

The article is structured as follows: Section 2 shows a state of the art concerning projects and research conducted in the field of Smart cities and light control, showing the most commonly used techniques in this field and carry out a comparison between them and the system presented. Section 3 shows the presented system, its operation and details of the techniques used. Section 4 describes the case study developed for system validation and finally, Section 5 some results and conclusions of this work.

2 Background

The concept of smart cities, smart environments, or smart homes [2] itself is still emerging in our society. Make a "smart" city is one of the objectives currently most often heard at the research as a strategy to mitigate the problems caused by the rapid growth of the urban population. Problems such as lack of resources, pollution, traffic congestion and deteriorating infrastructure are some of the many problems that increasingly large urban populations face [3].

One of the many definitions of Smart Cities is: "*The use of smart computing technologies to make city services more intelligent, interconnected and efficient - which includes administration, education, health care, public safety, real estate, transportation and utilities.*"[4]. It seems clear that the purpose of these is sustainable economic development, based on new technologies (ICT) to provide better quality of life and prudent management of natural resources through the engagement of all citizens.

Today, more and more cities around the world are committed to develop pilot projects related to this movement, some even in Spain, such as SmartSantander [1]: for now the city has a great display of parking sensors to indicate to drivers the free sites. They also have a municipal Wi-Fi network that aims to cover the entire village, and even augmented reality applications to boost tourism. Málaga Smart City[2]: the project aims at saving energy by micro power management: energy storage in batteries for use in buildings, street lighting and electrical transport, promoting the use of electric cars, etc. Smart City Valladolid-Palencia[3]: considers two cities, adding transport between them as a problem and has smart meter network, integration of electric cars, energy efficiency in buildings, traffic organization, etc.

The current research works include the implementation and control of distributed lighting systems to facilitate the implementation of new infrastructure in a city or the optimization of existing infrastructure; further integration with other control systems and optimization of heating, cooling or controlling air quality. For instance, in [6] it presents a systematic approach to the modeling, optimization, control, and adaptation in a color-tunable LED lighting control system. Through light sensor feedback, the control system is able to achieve significant energy savings without substantially sacrificing lighting quality. The key techniques used here are an appropriate choice of cost function based on color metrics and the trade-off between quality of light and energy consumption for LED lighting systems. The authors in [7] employ formal methods for design a graph model, accompanied by means of control, including AI methods (rule-based systems, pattern matching) to design and control an outdoor lighting system. In this case, the work is focused only on the design phase and the control phase designing features such as dynamic, sensor-based control, multiple luminaire states and complex geometries. Other research on lighting control systems base their operation in image processing [8], fuzzy systems [9], cooperative methods and wireless sensor network (WSN) [10] or simulation algorithms [11] and predictive control [12] for energy optimization.

There are also some tools already developed as Lites[4], that has temperature sensors, ambient light, power, motion detection; CityLight[5], that allows remote management of lighting, fault detection and planning lighting patterns manually or Tvilight[6] that regulates the lighting based on presence sensors and maintains minimum brightness in inactive hours.

---

1 http://www.smartsantander.eu/

2 http://www.lacatedralonline.es/innova/system/Document/attachments/12351/original/IDCCiudadesinteligentes.pdf

3 http://www.valladolidadelante.es/lang/modulo/?refbol=adelante-futuro&refsec=smart-city-vyp&idarticulo=79302

4 http://www.lites-project.eu/lites-led-based-intelligent-street-lighting-energy-saving

5 Teliko http://www.teliko.com/en/

6 http://www.tvilight.com/

This paper presents an adaptive architecture that allows centralized control of numerous public lighting installations. Specifically, it allows distributed and real-time intelligent control based on prediction and analysis techniques of lighting, one of the main shortcomings of the systems listed above. From a modular architecture fully adaptable to the current lighting systems possible, an energetic and economic optimization is possible. The architecture has been tested and validated successfully and continues its development today. The following sections describe the operation and technologies used in it and the results currently obtained.

3 Proposed Architecture

The system presented aims to frame the intelligent management of all public lighting, including monitoring and real-time control of the lights, and the establishment of lighting patterns that fit with the use of the public highway installations.

The following figure shows the context of the system, mainly composed of the control software (Intelligent Street Lighting Software) and the set of public-lighting installations, accessible via the internet. Facilities include special hardware for global and individual control of each luminary, while communication between devices is done by PLC. The control software is composed of three modules:

- The hardware abstraction layer allows communication with facilities regardless of the underlying hardware.
- The management server contains both device management and intelligent algorithms for efficient energy management. The "*Data sources*" module captures information related to pedestrian and traffic flow, weather data, and data about the monitoring of the facility. The "*Data analysis*" module deals with the study of information collected for the detection of foot traffic patterns, management of neural networks to predict consumption from light intensities, and estimates of consumption online. Finally, the "*Luminosity patterns generator*" module allows the creation of adequate light planning suitable for the specific facility lighting depending on the standards of pedestrian flow and weather conditions of each case.
- The web application provides access to all functionality for configuring lighting schedules, monitoring and control of facilities.

The ideal goal of the street lighting architecture design is that it can work well and provide safe and stable street lighting control for our daily life without human intervention. But human users should know whether the system is working normally or not. So the interaction between the system and human users is necessary. The system should also be controlled by human users manually in some particular situations. The system includes the ability to automatically interact ("smartly") or manually according to the lighting used and the needs of the specific case study.

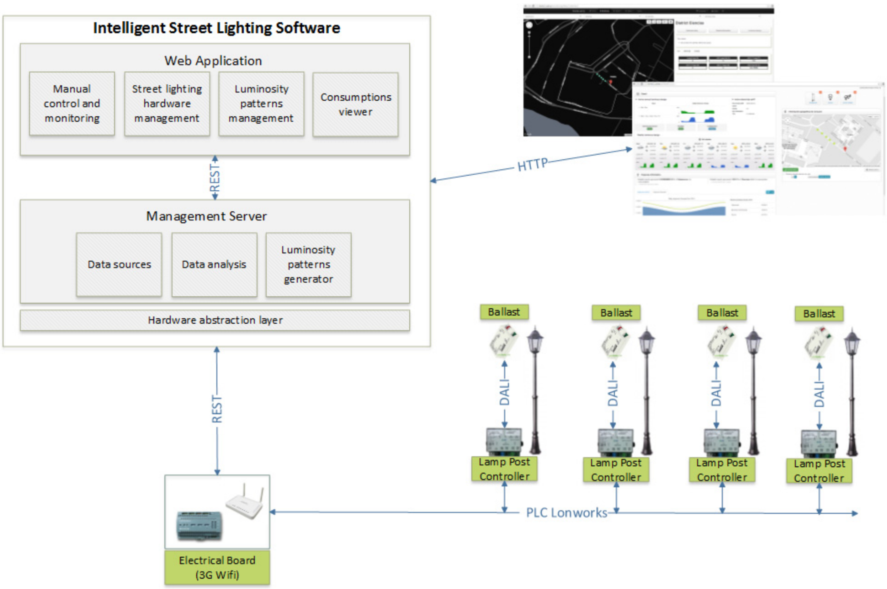

Fig. 1. Main system components

3.1 Work Flow

The establishment of adequate lighting configuration for each environment is one of the objectives of this project, meaning light configuration like a set of times at which the area is illuminated and the brightness levels associated with each time. This will save on lighting consumption, maintaining the state of maximum comfort in the lighted areas, as there are many occasions where it is not necessary to maintain a maximum level of light intensity to provide optimal service to the area, causing excessive consumption.

In the presented system the light designs can be set in a manual or smart way. In the first, the user is encouraged to plan the time slots (in hours) and the luminous flux of each time slot. In the second way, we proceed to the observation of different environmental factors that may be influential in determining adequate lighting for the particular area, such as flow or pedestrian traffic, or weather conditions each time, which influence the level of ambient light, especially near the hours of sunrise and sunset times.

The flow diagram of Figure 2 shows the procedures to complete the light patterns depending on ambient factors and the different user preferences. It is possible to observe, with common parts, two different workflows, which correspond to the process of generating light patterns for a given period of time. One of the flows can generate patterns without establishing a maximum estimated expenditure, and the other, setting it. Maximum expenditure means the maximum amount to spend on lighting bill for the period over which the light patterns are concluded.

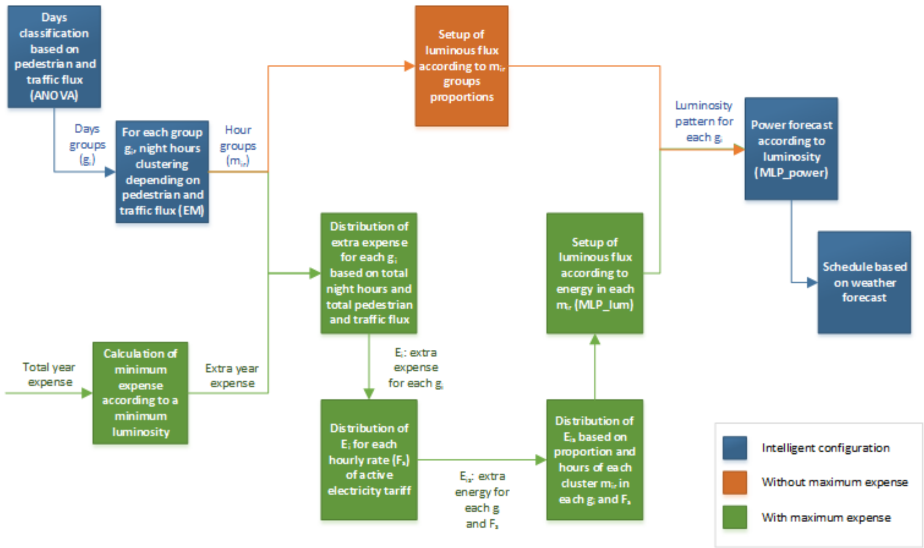

Fig. 2. Workflow procedures followed for lighting

Both processes share the initial logic. As a first step, historical data of pedestrian and traffic flow of several weeks are taken. Subsequently, a classification is performed by analysis of variance (ANOVA) [13] to determine what day of the week patterns share pedestrian and traffic flow according to the different hours of the period.

The periods (days) that share the same characteristics, according to this analysis, also will share luminous pattern. To determine the set of similar days is necessary to take into account different variables such as day of the week, time of day and the volume of people / traffic that is located in that time slot and day of the week. Not being quantitative variables is necessary to apply cluster techniques such as ANOVA to draw similarity between groups. Here is to be applied two-way ANOVA with repetition. The factors are the day of the week and the time slot, the time slot is considered factor group.

After obtaining the groups of days, for each group is applied a clustering algorithm (Expectation-maximization EM) [14][15] to determine at what time of night usually spend a similar number of pedestrians or traffic. These clusters of hours generated for each group of days will result in different light levels appropriate to pedestrian or traffic flow.

After these two steps, the flowchart shows a bifurcation. The left branch corresponds to the process to follow if you do not set a maximum expenditure, which mainly follows a simple process of adjusting lighting levels based on the proportion of generated clusters after EM technique for each group of days. Moreover, the right branch serves logic followed when a maximum flow is established. The steps followed in this last branch focus primarily on optimal distribution of the amount with which it has to provide the same light levels in scenarios with similar environmental characteristics. At all times a minimum configurable brightness is guaranteed, because in order to comply with the appropriate legislation, the area will not be left with insufficient lighting although the amount entered by the user is less than the cost of this. The distribution amount is performed based on features such as hourly rate, with or without time restrictions, the evening hours that can affect and the proportion of clusters based on traffic and pedestrian flows.

The two branches obtain different light patterns depending on the groups of days generated with the ANOVA technique. The penultimate step in the flowchart is shared and consists of the prediction of the spending of the lighting design completed, which in the case of the branch with maximum expenditure, will coincide with a small margin of error depending on the expenditure estimation technique used. The estimate of expenditure is performed by a neural network MLP (Multi-Layer Perceptron) [16][17] that predicts power level in function of lumens and is trained with historical data of the luminaire type used in each installation.

The other shared step in the workflow, optional for users, is a replanning that is performed periodically to adjust light patterns established previously to climatic conditions. This process consists in checking the prediction of the weather to advance or delay the time on and off lights in the hours of dawn and sunset. This is for that the lighting design conforms to the lighting conditions of the place in which the system is installed. In this way, for any day in which bad weather (rain, fog, etc.) is expected, the system will turn off the luminaries sooner or later that the usual hours, coinciding with the hours of dawn and sunset each day. This process is repeated weekly, so that the light patterns are sent weekly to the control node of the area.

3.2 Distribution of Expenditure

To calculate the distribution of the maximum E_T in Z time entered by the user is first necessary to calculate the minimum amount of expenditure E_{min} to a minimum brightness L_{min}. This time period has Nh overnight hours. One MLP network is used to predict the spending power of the luminaires used depending on the required level of brightness. The additional expenditure E will be distributed for generating light patterns.

$$L_{min} \rightarrow RNA_{pow} \rightarrow Pow_{min}$$
$$E_{min} = Pow_{min}\, Nh \tag{1}$$
$$E = E_T - E_{min}$$

The first step taken is to distribute the amount E between groups of days gi generated in the ANOVA process. This distribution is based on the number of hours of night Nhi of each group i and pedestrian and traffic flow P_i that exists in that group.

The calculation of traffic and pedestrian flow P_i of each g_i is done by average people who go through every night $\overline{Pd_\iota}$ and the number of days D_i that belongs to g_i, taken the average of the historical data used before (Fig 1). The number of people is limited, and is equal to the upper bound in case of exceeding this bound.

$$P_i = \overline{Pd_\iota}\, D_i$$
$$\overline{Pd_\iota} = \frac{1}{JK}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} y_{ijk} \;/\; \mathrm{j} \in \mathrm{g}_i \tag{2}$$

Both Nh and P variables can have different degrees of influence ρ at the time of allocation of the amount E. The extra expense of each group gi is given by equation (3).

$$E_i = \frac{Nh_i}{Nh} E\, \rho_{Nh} + \frac{P_i}{P} E\, \rho_P \tag{3}$$

Where:

$$Nh = \sum_{i=1}^{I} Nh_i \;\; ; \;\; P = \sum_{i=1}^{I} P_i \tag{4}$$

$$0 \leq \rho_{Nh} \leq 1 \;\; ; \;\; 0 \leq \rho_P \leq 1 \;\; ; \;\; \rho_{Nh} + \rho_P = 1$$

Once the distribution of expenditure for each group is done, E_i, a process recurs distribution thereof, in this case between different times Fs of stating the electricity tariff associated with the area to be illuminated. To do this, we take into account the proportion (w_{ir}) and time of use in hours (n_{ir}) in each group m_{ir} (which represents the values that are classified in the EM_r cluster of each group g_i ANOVA), and the price of the energy in each time slot, L_s.

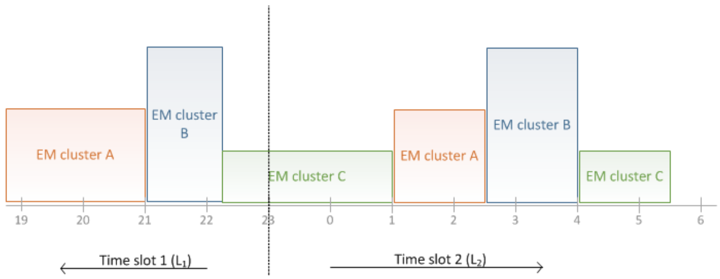

Fig. 3. Area of time slots

The figure above shows graphically a possible deployment scenario clusters m_{ir} result of the EM algorithm, where each cluster is represented by a rectangle. The x axis represents time in hours, while the y-axis represents the proportion of clusters (w_{ir}), which is determined by the average of pedestrian and traffic flow determined for each group m_{ir}. The distribution of expenditure E_i is done by calculating the total area of each time slot F_s weighted price of energy in these slots. Thus, a fair distribution of the expenditure is insured for, thus able to illuminate with the same light flow spaces schedules with similar environmental factors (3).

$$E_{is} = \left(\sum_{r=1}^{R_i} n_{ir}\, w_{ir} \right) L_s\, x \tag{5}$$

$$E_i = \sum_{s=1}^{S} E_{is}$$

$$w_{ir} = \frac{\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} y_{ijk}}{IJK} \;/\; \mathrm{j} \in \mathrm{g}_i \,, \mathrm{i} \in \mathrm{m}_{ir}$$

Once the distribution of expenditure for each time slot F_s of each group of days g_i is made, the price of energy does not vary for each slot of the group. In this step, each expendture E_{is} becomes equivalent to the energy consumed in the slot s of the days that belong to the group i during the period of time Z, that the user chose at the beginning of the process. The distribution of extra power (it will continue denoting as E_{is}) for each hour $h \in H_{irs}$ (set of hours that belong to F_s slot grouped in subgroup m_{ir} hours, of the initial group g_i) was performed similarly to the previous step manner, to continue to ensure a fair distribution. It will consider both the size of cluster w_{ir} as the number of hours used n_{ir}.

$$p_h = w_{ir}\, x \;\; / \, h \in H_{irs}$$
$$E_{is} = \left(\sum_{r=1}^{R_i} n_{ir}\, w_{ir} \right) x \qquad (6)$$

The expression (6) denotes p_h as the extra power to supply each hour $h \in H_{irs}$. In this way, the power to supply in each hour to all luminaries (p_{th}) will be the minimum power (1) of each hour more extra power calculated p_h.

$$p_{th} = \frac{Pow_{min}}{Nh} + p_h \qquad (7)$$

At this point, the power supply to each luminaire in every hour (simply dividing p_{th} by the number of luminaires) is known. For the resulting light output of the power supplied a MLP network that predicts light output from input power is utilized. The equivalence between luminous flux and power tends to be linear, so this approximation is quite accurate: in most cases, if you double the power is spent, it will get twice the luminosity. However, the use of MLP networks to predict luminosity based on power or vice versa, is performed for the sections in which it is not linear: each model of luminaire can light to a minimum power; moreover the expenditure of each luminaire can be influenced by the facility in which it is (because it is necessary more hardware, etc.). Thus, the system achieves more accurately approximate the luminosity that is going to have with a certain power. Or conversely, the cost of having the lights burning with a certain luminous flux. Knowledge of the luminous flux which has every hour for each group g_i presupposes already done the lighting pattern to be followed for each group of days. Whereupon, planning lighting design is approximated to the expenditure that the user wants to spend and to the pedestrian and traffic flow patterns in the area, depending of the desired degree of influence set.

4 Case Study

To develop the first prototype a hardware solution installed in a briefcase was purchased. Fig.4 shows a photo of the prototyping environment that emulates an installation of five street lamps with a control node. Four lamps interior and one exterior were used to test the control system while maintaining low cost hardware. Each lamp is controlled by an adjustable ballast that is behind it, hidden in the top panel. A luminaire controller regulates and monitors each ballast and liaises with the control node.

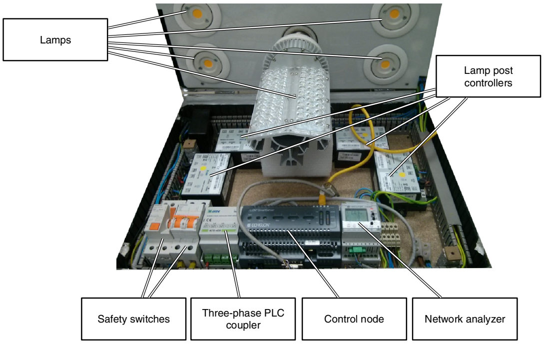

Fig. 4. Prototyping environment that simulates an installation of five streetlights

Luminaire controllers (ISDE brand ASL-510-TCH) are placed inside each lamp and communicate via PLC with the control node, but also can be placed at the beginning of a line of street lamps. These controllers interpret commands received through the line to regulate the output of the ballasts of the lamps using the DALI protocol. Also they monitor the status of the lamps, the instantaneous consumption and power supply of each lamppost.

The chosen control node is an Echelon Smart Server, a general purpose controller for automation of non-critical processes. In street lighting systems, is able to control and monitor up to 192 single or double lamps head through PLC. It offers a SOAP interface for configuration and remote management that has been used for integration with the developed system. The PLC signal injected by the control node replicates in three phases using a phase coupler [three-phase coupler PLC]. The network analyzer is the CVM-MINI brand model Circutor. It connects via a parallel port RS-485 to Echelon SmartServer, with which it communicates using the MODBUS protocol. For the prototype system for estimating pedestrian flow IP camera TP-LINK DSC-942L interior placed on a window was used.

5 Results, Conclusions and Future Work

Figure 5 shows some of the results obtained by using the system. The upper panels show data of pedestrian flow in two consecutive weeks (one week in purple and the other blue). After applying the analysis of variance traffic patterns are detected and rated day is done, resulting in two groups: green, weekdays, and blue, on weekends. The lower graphs show the generated light designs for each group of days. Using the EM algorithm, hours with similar traffic are detected, adjusting a luminosity level in each group.

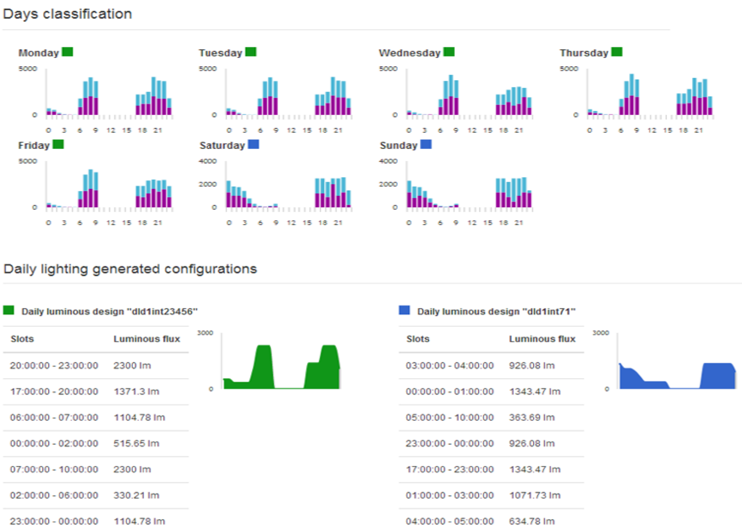

Fig. 5. Results

Figure 6 shows a prediction of both daily consumption and annual calendar designed. The green line represents the expense of having all lights full brightness during nighttime hours. The blue area represents the estimated model to the application of consumption. In this case, an approximate savings of 25% is achieved while maintaining the maximum light intensity at peak traffic and pedestrian flow.

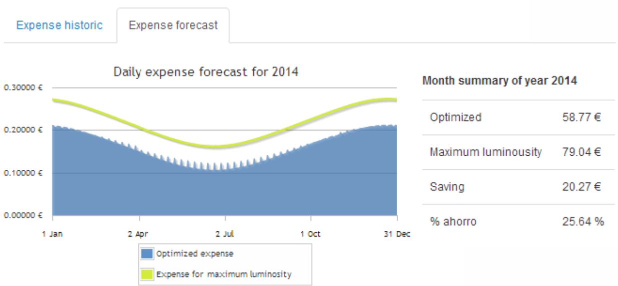

Fig. 6. Prediction of daily and annual consumption

The system is able to set lighting schedules all public lighting installations controlled and can say that this measure contributes to energy savings achieved by regulating the light intensity. The user can define their own light patterns, where lighting pattern is the hours in which the lights are on and at what level of brightness. Likewise, it is possible to assign different light patterns each day.

Furthermore, not only the lighting schedule can be established according to the user preferences, but the system has the necessary mechanisms to automatically adjust light levels based on traffic or pedestrian flow provided for each zone. To achieve this, the system is based on historical information of people flow and makes a clasification of days to find patterns of pedestrian/traffic flow. Based on these patterns, the system establishes an appropriate lighting design for each type of day. In this sense, we have applied intelligent techniques and algorithms (ANOVA, EM clustering technique, MLP) correctly and a process that fuses all together for the conclusion of the lighting schedule is made. In addition, a distribution algorithm that reduces spending and complies with the minimum luminosity and brightness levels at all times is presented. Finally, the application also allows the user to query historical data related to the luminance calendars that have been established on site, and the historical use of them.

In conclusion say that it is very difficult to find prototypes that are based on historical data of pedestrian and traffic flow to adjust the luminosity of the areas. The systems are often reactive, not predictive. The main reason for developing the system is based on the prediction of pedestrian / traffic flow is the savings in hardware. Place a camera in the area for pedestrians and vehicles spot for a while, is much cheaper than having every few luminaires a presence sensor that regulates the brightness depending on the passage of pedestrians and vehicles, in addition to the constant change light intensity emitted by the luminaires could punish excessively. Future work will focus on the following three aspects. (1) Add other sensors to the lamp member and investigate how to use sensor fusion to further improve intelligence level of the system. (2) Develop a system of alerts that happen in the real-time hardware: cast a light, overvoltage on the line, etc. (3) Develop new algorithms to make the lamp members cooperate with each other.

Acknowledgements. This work has been carried out by the project *PIRSES-GA-2012-318878*.

References

[1] IDAE, Instituto para la Diversificacion y Ahorro de la Energía, http://www.idae.es/ (last access January 12, 2014)

[2] Gómez-Romero, J., Serrano, M.A., Patricio, M.A., García, J., Molina, J.M.: Context-based Scene Recognition from Visual Data in Smart Homes: An Information Fusion approach. ACM/Springer Journal of Personal and Ubiquitous Computing. Special Issue on Sensor-driven Computing and Applications for Ambient Intelligence 16(7), 835–857 (2012)

[3] Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J.R., Mellouli, S., Nahon, K., Pardo, T.A., Scholl, H.J.: Understanding Smart Cities: An Integrative Framework. In: 45th Hawaii International Conference on System Sciences, pp. 2289–2297 (2012)

[4] Washburn, D., Sindhu, U., Balaouras, S., Dines, R.A., Hayes, N., Nelson, L.E.: Helping CIOs Understand "Smart City" Initiatives. Growth 17 (2009), http://c3328005.r5.cf0.rackcdn.com/73efa931-0fac-4e28-ae77-8e58ebf74aa6.pdf

[5] Daigneau, R.: Service Design Patterns: Fundamental Design Solutions for SOAP/WSDL and RESTful Web Services, 1st edn. Addison-Wesley Professional (2013)

[6] Afshari, S., Mishra, S., Julius, A., Lizarralde, F., Wason, J.D., Wen, J.T.: Modeling and control of color tunable lighting systems. Energy and Buildings 68(Pt. A), 242–253 (2014)
[7] Wojnicki, I., Ernst, S., Kotulski, L., Se¸dziwy, A.: Advanced street lighting control. Expert Systems with Applications 41(4 Pt. 1), 999–1005 (2014)
[8] Carrillo, C., Diaz-Dorado, E., Cidrás, J., Bouza-Pregal, A., Falcón, P., Fernández, A., Álvarez-Sánchez, A.: Lighting control system based on digital camera for energy saving in shop windows. Energy and Buildings 59, 143–151 (2013)
[9] Yang, C., Fan, S., Wang, Z., Li, W.: Application of fuzzy control method in a tunnel lighting system. Mathematical and Computer Modelling 54(3-4), 931–937 (2011)
[10] Zhang, J., Qiao, G., Song, G., Sun, H., Ge, J.: Group decision making based autonomous control system for street lighting. Measurement 46(1), 108–116 (2013)
[11] Bourgeois, D., Reinhart, C., Macdonald, I.: Adding advanced behavioural models in whole building energy simulation: A study on the total energy impact of manual and automated lighting control. Energy and Buildings 38(7), 814–823 (2006)
[12] Barra, K., Rahem, D.: Predictive direct power control for photovoltaic grid connected system: An approach based on multilevel converters. Energy Conversion and Management 78, 825–834 (2014)
[13] Miller Jr., R.G.: Beyond ANOVA: basics of applied statistics. CRC Press (1997)
[14] Dempster, A.P., Laird, N.M., Rubin, D.B.: Maximum Likelihood from Incomplete Data Via the EM Algorithm. Journal of the Royal Statistical 39, 1–38 (1977)
[15] Little, R., Rubin, D.: Statistical Analysis with Missing Data. Wiley & Son, New York (2002)
[16] Haykin, S.: Neural Networks: A Comprehensive Foundation, 2nd edn. Prentice Hall (1998) ISBN 0-13-273350-1
[17] Collobert, R., Bengio, S.: Links between Perceptrons, MLPs and SVMs. In: Proc. Int'l Conf. on Machine Learning, ICML (2004)