

Energy-efficiency improvement on roadway lighting using wireless sensor networks

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Abstract

The concept of energy from public utilities like roadway lighting was extensively and critically discussed in this paper. The world is facing energy crisis both in supply and cost. The model for energy efficiency in public roadway lighting was developed using wireless sensor networks to monitor the environment and to take real-time decision on lighting, whether to be in off, dimming or full bright light state. The work was simulated and compared with two traditional pattern namely: roadway lighting with incandescent lamps and other high energy consuming devices; roadway lighting with energy saving lamps. The results shows that much energy were conserved when the smart networks is in use than other technologies which waste energy as a result of insensitivity to environmental response.

Keywords: energy efficiency, smart network, sensor, roadway, incandescent lamp

1. Introduction

Wireless sensor networks (WSNs), which are multi-hop self-organized networks with wireless communication, are used to achieve information collection and processing by deploying a large number of tiny sensor nodes in a surveillance area and lighting zones. One of the fundamental functions in a wireless sensor network is to acquire environmental information, as the effectiveness of sensor monitoring depends mostly on whether the environmental information is accurate or not [1].



Fig 1: Aerial view of Roadway Lighting

The operation of outdoor lighting is a complex, labour intensive and responsible technical and social task. Outdoor lighting covers the biggest areas, consumes significant amounts of energy, and requires availability of smart network and other equipment to reduce the energy consumption. Proper operation of the lighting systems is a precondition for quality lighting services and, hence – for safer vehicle traffic, decrease of criminal acts and a guarantee of the civil safety, creation of harmonious and aesthetic environment.

This could be achieved only if the operation is well organized, purposeful and uses up-to-date equipment based on the principles of the sustainable development, i.e.: energy saving; durable elements of lighting systems; improved effectiveness of operation; and at the same time improved quality of the outdoor

lighting. The sensors are deployed to monitor the environment (visibility) of the area, hence an intelligence communications among the nodes and both the outdoor control and indoor control board via the wireless connection. The illumination of the area depends on the outward weather of the immediate environment. Solid State Lighting (SSL) technology, which Light-Emitting Diode (LED) is the focus for energy reduction, is crucial for our purposes because it enables a dynamic control of illuminance level. Current SSL market penetration in African is very low. The replacement of the incandescent lamps with the energy saving lamps was also one of the measures used to control the dissipation of energy from the street or roadway lightning. The smart and energy efficient roadway lighting as shown in figure (2) is equipped with web application for remote monitoring. For energy saving measures suitable dimming equipment is used as illustrated in the diagram.

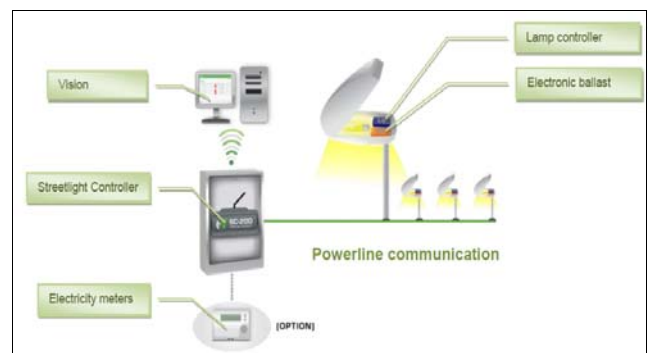


Fig 2: Different Modules of the Energy-Efficiency Lighting

Owing to improvements of the lighting system components based on LED technology, retrofitting allows us to reduce the energy consumption by at least 40% [2]. Due to the extremely low onset time of LEDs and the flexibility of photometric solid shaping, they are perfectly suited for a lighting design and for building advanced control systems, contrary to high intensity discharge (HID) light sources. In particular, LEDs

can be dimmed so an applied power level can be adjusted precisely to the actual needs determined by a state of an environment (traffic level, outdoor lighting and so on) and constrained by mandatory lighting standards^[3] (a luminous flux intensity is nearly linearly dependent on the power being applied (Some side effects of a fixture's high dimming is growth of a reactive power.). A dimming level depends weather condition and the road classification (highway, residential area, bike lane) which can additionally change due to the variable traffic intensity.

Another factor influencing this classification is the ambient light level. An intelligent system which controls and optimizes a lighting installation's behavior is, in a natural way, the element of a distributed electricity smart grid^[4] which can reduce the energy consumption by several percent. Technical problems with lighting design preparation such as a real-time control system has been considered in^[6], but the basic issue is the preparation of multiple variants (practically counted by hundreds) of each lighting scene, corresponding to different predefined environment conditions. Unfortunately, designers using, for example, the popular DIALux software (or other, similar programs), prepare a project containing 1000 lamps in one week of time. It becomes obvious that creating 100 additional variants of this project is infeasible due to the expected cost and preparation time. Thus, it is crucial to support a designer by providing an AI (Artificial Intelligence) system capable of building such a project in a reasonable time.

One of the first non-standard attempts of making a lighting design [8] does not consider luminous flux dimming and still has a limitation of high execution time. The niche methods such as increasing reflectance of a road surface in tunnels^[9] will not be discussed here either due to their limited area of application. Instead, the focus will be put on design methods which are not so common as retrofit and control, which is caused by their computational complexity. An interesting approach to improving energy efficiency is based on rules of thumb giving relations among configuration parameters of an optimal installation such as spacing, fixture inclination angle or mounting height^[10]. For now, however, this approach is intended for discharge lamps only.

In other climate, as a rule of thumb, it can produce suboptimal solutions instead of optimal ones. In this article, the new, smart or intelligence-based approach is proposed: it is assumed that lighting system components and their relationships are represented in some formal way so that the computing systems can solve a design problem fully automatically using exact coordinates of luminaires and illuminated areas (roadways, squares, etc.). Thanks to this, a lighting installation being designed is characterized by the high power efficiency (over-illumination is minimized) and, on the other side, all standard-based performance requirements are met. The presented idea is based on the following requirements: The proposed formalism has to have the sufficient expressive power to describe all analyzed objects and relationships among them. It will be possible to build either exact or effective heuristic algorithms capable of finding the best (local) solutions.

2. Literature Review

Some important and relevant related research works were reviewed in this paper. The energy efficiency roadway lighting anchored by sensor network were discussed in terms of power management communication throughputs and real time delivery.

Galperti^[11] in his quest for energy efficient lighting, proposed Maximum Power Point Tracker (MPPT) circuit that is specifically designed for wireless sensor network. MPPT is a power transferring circuit that conveys solar energy into rechargeable batteries for the network. Therefore, wireless sensor network that deploys MPPT no longer rely on battery (which is a finite resources) as energy supply. An ad hoc adaptive algorithm is introduced to maximize energy transfer from the solar cell to the batteries, thus keeping the MPPT electronics in optimal working point and achieve high efficiency. The implementation is particularly effective even in critical weather conditions. As MPPT is designed for low power operations, experimental results showed that high energy transfer rate is generated when the cell is in shadow or the weather is cloudy, where existing solutions for wireless sensor network nodes do not produce energy in such situations. GSM based autonomous road illumination system for efficient power management GSM is used as the communication medium between the concentrator and control center. Microcontroller is installed on each road light to control various sensors and GSM module is installed for wireless communication. The main challenge of hardware is to produce low cost and tiny sensor nodes. Power theft control was also proposed to be added into the system.

In 2013 there was a research proposal that the wireless roadway light control system with Jennic Wireless Microcontroller which is an IEEE802.15.4 based wireless microcontroller as communication between road lights and monitoring software. The duration of the operation of road lights is taken into concern. The project also aimed to increase frequency band for network nodes to get maximum possible data rate. Results showed that the duration of road lights operation can be monitored through implementing light dependent sensors. The life of lamps is extended due to efficient control of duration of operation.

De Dominicis^[12] proposed an intelligent road lighting and monitoring system can maximizes energy saving and minimizes light pollution as well as taking account of the environment and safety standards needed in all traffic condition. Energy saving is achieved making light source into minimum illumination. Settings can be adjusted to suit various environmental conditions. Light level can be predefined according to requirement provide. Mohammaddoust R *et al*^[13] proposed a dynamically lighted roadway in which lighting can be adjusted to any three levels (0.2cd/m², 1cd/m², and 2.0cd/m²) depending on the amount of traffic, time of day, and weather conditions. 900MHz is used as frequency band of the system wireless communication. This results is lower in data communication rate. Riener,^[14] mentioned that the conventional road light system is installed in places where no passerby available during night time therefore it is a waste of electricity power. Introducing flexible lighting system like light emitting diode with wireless internet connection availability solves the issue of wasting energy unnecessarily.

3. Method and Material

The 'Smart' Roadway Lighting Systems (SRLS) are a combination of three systems (parts), according to the functions and the technical performance of its elements;

- Lighting subsystem;
- Power supply subsystem;

▪ Subsystem for adaptive control of roadway.
The modernization of the roadway lighting is characterized by

“adaptive management”, which brings the need of telecommunication experts.

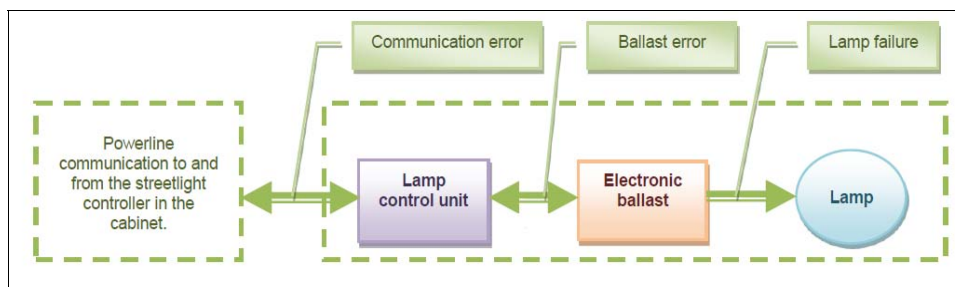


Fig 3: Segmentation of the Smart Roadway Lighting System

According to the diagram above the system is of three segment

a) Lighting subsystem or module

The lighting module comprises the lamps used. A brief overview of a roadway lighting design process is given to define the context for future considerations. The designer’s objectives are threefold: ensuring compliance with mandatory standards, good practices and recommendations [15], optimizing a design with respect to some measurable criteria like energy-efficiency, investment costs, and real-time response of the system to the remote station. Note that those three objectives have to be achieved jointly.

Usually, a human-made preparation of a project is supported by some photometric verification capable software like DIALux. The loop execution is continued until three objectives defined previously are achieved.

Due to the great number of available variants corresponding to such factors as positioning of objects, material selection and so on (see the example shown in Table (1), a designer has to use, besides his expert knowledge, the trial-and-error design method. Even assuming that the experience in a domain allows for reducing a number of possible scenarios, the search space size and design time still remain large. It also has to be mentioned that lighting situations are simplified in the practice to accelerate the design process. This simplification is achieved by averaging luminaire spacing, road widths, pole setbacks, and so on. In addition, the presence of buildings, trees and other similar objects is neglected.

The schema presented above is characterized by the high work overhead, especially for restrictive optimization criteria, e.g., related to the power consumption (exploitation costs) and a human performance is a bottleneck of this process.

Table 1: Parameters of the lighting design process.

parameter	Range	Step	No of variants
Pole height	7m -12m	0.5m	9
Arm length	0.7m – 2m	0.4m	5
Dimming level	0% - 70%	0.5%	80
Fixture inclination	0% - 15%	3%	5

The core requirement which has to be addressed in lighting

design is the compliance of a project with mandatory standards for illumination, defined for various areas such as roadways, driveways, intersections, sidewalks etc. For each of them, an appropriate lighting class is assigned [16] depending on the traffic characteristics: dominant user types, traffic flow intensity, average speed of vehicles etc.

b) Power subsystem

The system was designed to have less energy dissipation, according the literature reviewed above, one of the contributors proposed that it was a waste of power to keep the roadway ‘ON’ when noting was making use of the energy. The energy modulation was proposed with the help of the sensors embedded in the system. The proposed work assume constant public power supply.

c) Adaptive control

The software development stages consist in developing the local area communication software by means of a wireless sensor network, followed by the software needed for the remote transmission of the data. The coordinator is linked to the e-Box through a USB/RS232 communication interface. This is an essential network node, performing the following tasks: it selects the radio channel that will support the communication, initializes the network and allows the nodes to join the network. The coordinator enables the transfer of data from the WSN network to the control device where the client application is installed through the USB/RS 232 interface. The data consists of details about the status of each node. Moreover, the coordinator transfers the commands initiated by the user from the server to the WSN network. Figure (5) presents the general logic diagram of a node within the proposed roadway lighting control system. Thus, should the network experience any kind of malfunction, the integrity of the system is not compromised. The on/off lamp switch command is performed depending on the luminosity level of the environment. If the network is operating within normal parameters, each node will monitor the received messages/commands (Message Control). After a pre- defined period of time, the node reads the sensor values, checks the lamp status in order to detect any possible malfunctions and then forwards this information to the coordinator.

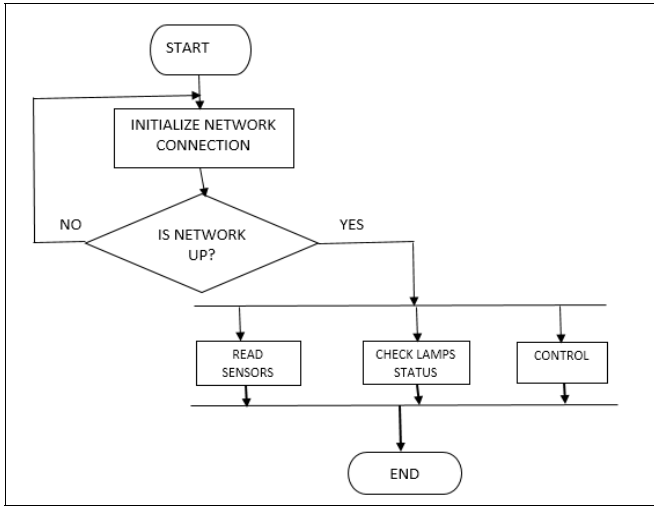


Fig 5: Network Flowchart

4. Result and Evaluation

The desired method for assessing real energy savings is to

compare actual consumption data with the corresponding consumption data prior to the introduction of intelligent control systems. It was however difficult to evaluate in this way since the historical consumption data we had access to be not sufficiently clear to enable a reliable comparison. The method we used was to calculate the consumption of the plant assuming a conventional ON/OFF system without dimming, i.e. multiply the burning time with the lamp power. This has been compared to the actual consumption data each lamp controller has reported to the Vision server. In the data we used, we have taken into account losses in the control gear according to the specifications provided by the supplier of the electronic ballasts. We have also calculated with an overvoltage of about 1%. Normally, this would result in both increased energy consumption and reduced lamp life. An electronic ballast keeps a constant voltage to the lamp so that the negative effect of the overvoltage disappears.

In order to verify collected measurement data from the lamp control units, we also calculated an expected annual consumption using the following formula: *burning hours x lamp power x power reduction factor (%)*.

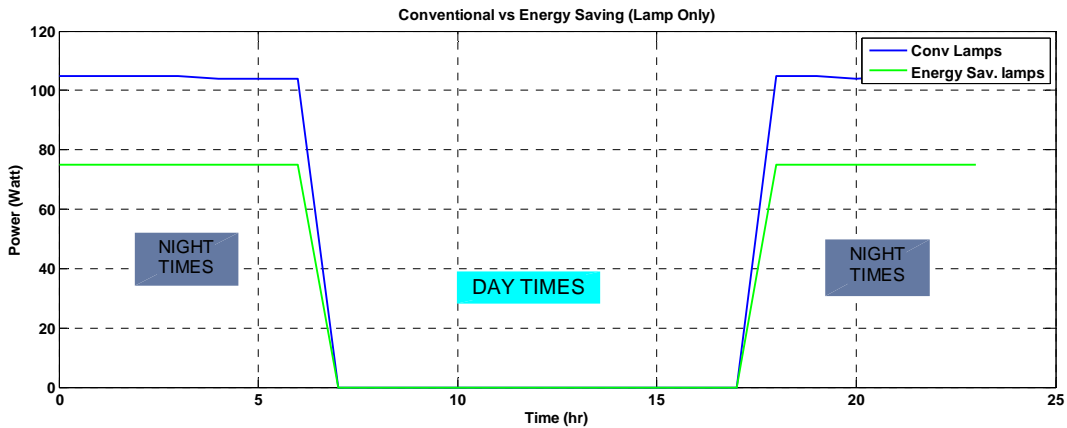


Fig 6: Conventional lighting with change of lamps

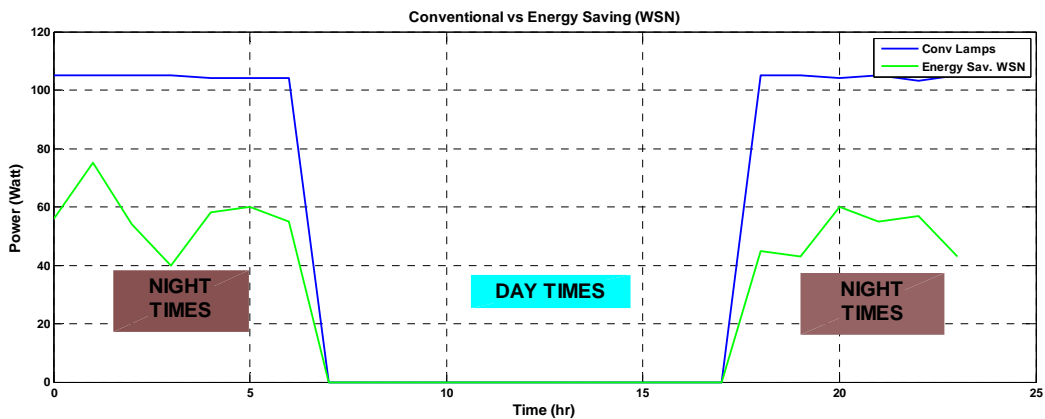


Fig 7: Conventional lighting with smart network

The figure (6) shows that energy is saved as a result of replacement of incandescent lamps to less energy consumption outfit. Hence energy was saved but not compared to intelligent or smart sensor technology or network in figure (7) which works with the environment to know when to be at full flash or illumination otherwise dimming or off state will be activated.

5. Conclusions

The main advantages of this system consist in a significant reduction of the costs related to energy consumption and maintenance services, through the adjustment of the light intensity (dimming) after processing the information received from the sensors: light intensity monitoring and vehicle

detection. Moreover, the proposed system significantly lowers the implementation costs by integrating a WSN communication protocol in the system. In conclusion, the advantages brought about by the implementation of this system are: the automated periodic reports on the events that may occur (lamp malfunctioning communication errors within the network), the implementation of the on/off switch command depending on the time of day or changes in the environment, or by developing a flexible operating schedule. The main contribution of this system consists in its decentralized implementation, thus allowing it to operate when errors occur along the communication lines. The introduction of a vehicle detection algorithm further reduces the power consumption costs.

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