High Efficient Automatic Solar Tracking Street Lighting System With Base Station Monitoring

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Abstract— **In this proposed system the solar panel is exactly in front of sun. Moreover the system can manage the errors and also provides the error messages on the LCD display. In manual mode, through the software (GUI) at computer, the solar panel can be rotated at any desired angle. can optimize management and effi ciency of street lighting systems. It uses ZigBee-based wireless devices which enable more efficient street lamp-system management, thanks to an advanced interface and control architecture. It uses a sensor combination to control and guarantee the desired system parameters; the information is transferred point by point using ZigBee transmitters and receivers and is sent to a control terminal used to check the state of the street lamps and to take appropriate measures in case of failure.**

Keywords- Automation, control system, Four quadrant sensor, Automatic Solar Tracking System (ASTS),lighting system, sen-sors, wireless networks, ZigBee.

I. INTRODUCTION

LIGHTING systems, especially in the public sector, are still designed according to the old standards of reliability and they often do not take advantage of the latest technological developments. In many cases, this is related to the plant administrators who have not completed the return of the expenses derived from the construction of existing facilities yet. How-ever, the recent increasing pressure related to the raw material costs and the greater social sensitivity to environmental issues are leading manufacturers to develop new techniques and technologies which allow significant cost savings and a greater respect for the environment. We can find three possible solutions to these problems in the literature.

The first one, and perhaps the most intuitive, is the use of new technologies for the sources of light. In this area, light-emitting diode (LED) technology is the best solution because it offers many benefits. Researchers [1]–[4] have already considered this possibility, designing an advanced street lighting system based on LEDs.

The second possible solution, and perhaps the most rev-olutionary, is the use of a remote-control system based on intelligent lamp posts that send information to a central control system, thus simplifying management and maintenance issues. Researchers [5]–[9] have developed a street lamp system using the general-packet radio service (GPRS), power-line carrier, or Global Systems for Mobile Communications (GSM) transmissions.

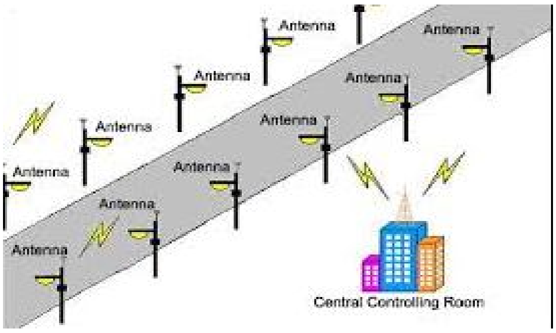


Fig. 1: Schematic image of the system

Finally, the third possibility would be the use of renewable energy sources locally available, rather than conventional power sources, with a positive effect on the environment.

Solar energy is the most important resource in this field. Our work aims at the unification of the three mentioned pos-sibilities, creating an intelligent lamp post managed by a re-mote-controlled system which uses LED-based light sources and is powered by renewable energy (solar panel and battery). The control is implemented through a network of sensors to collect the relevant information related to the management and maintenance of the system, transferring the information via wireless using the ZigBee protocol. The field of the ZigBee re-mote sensing and control system is widely present in the liter-ature; we can also fi nd ZigBee systems similar to (the) lighting systems in structure and management [10]–[18].

In this paper, we present our system, which is able to integrate the latest technologies, in order to describe an advanced and intelligent management and control system of the street lighting.

II. DEVICES AND METHODS

Fig. 1 shows the conceptual scheme of the proposed system. It consists of a group of observation stations on the street (one station for each lamp post) and a base station typically placed in a building located nearby. It is a modular system, easily extendable.

The measuring stations monitor the street conditions and the intensity of sunlight and, based on them, they decide to turn the lamps on or off . The conditions depend on the pattern of the street where the lights are located and on the solar irradiation at a given point of the street, with frequent changes, depending on weather conditions, season, geographical location, and many other factors.

For these reasons, we decided to make each lamp com-pletely independent in the management of its own lighting. The on-street station also checks if the lamp is properly working and sends the information through the wireless network to the base station for processing data. If any malfunction is detected, the service engineer is informed through a graphical interface and can perform corrective actions.

A. Monitoring Stations

The monitoring station located in each lamp post consists of several modules: the presence sensor, the light sensor, the failure sensor, and an emergency switch. These devices work together and transfer all of the information to a microcontroller which processes the data and automatically sets the appropriate course of action. A priority in the transmission of information is as-signed to each sensor, for example, the emergency switch takes precedence over any other device.

1) *Presence Sensor:* The task of the presence sensor is to identify the passage of a vehicle or pedestrian, giving an input to turn on a lamp or a group of lamps. This function depends on the pattern of the street; in case of a street without cross-roads, a single sensor is sufficient (or one at each end in case of a two-way street), while for a street requiring more precise con-trol, a solution with multiple presence detectors is necessary.

This feature enables switching on the lamps only when neces-sary, avoiding a waste of energy. The main challenge with such a sensor is its correct placement. The sensor should be placed at an optimal height, not too low (i.e., to avoid any erroneous detection of small animals) nor too high (for example, to avoid failure to detect children). A study of the sensor placement en-ables deciding the optimal height according to the user needs and considering the specific environment in which the system will work. We discovered that in field tests, the SE-10 PIR mo-tion sensor offers good performance and is quite affordable.

2) *Light Sensor:* A light sensor can measure the brightness of the sunlight and provides information. The purpose of this measurement is to ensure a minimum level of illumination of the street, as required by regulations (see CIE n°68 *et al.* [19]).

The sensor must have high sensitivity in the visible spec-trum, providing a photocurrent high enough for low light lu-minance levels. For this reason, the phototransistor TEPT5700 (by Vishay Semiconductors) has been selected.

Based on the measured luminance, the microcontroller drives the lamp in order to maintain a constant level of illumination. This action is obviously not required during daylight time, but it is desirable in the early morning and at dusk, when it is not necessary to operate the lamp at full power but simply as a "sup-port" to the sunlight. This mode enables saving electric power supplied to the lamp because the lamp is regulated by the com-bined action of the sensor and the microcontroller to ensure the minimum illumination required.

Emergency Device: The system has an emergency button, which can be useful in case of an emergency. This device ex-cludes the entire sensor system with the objective to immedi-ately turn on the lamp. The light will remain on for a preset time. After that, the button must be pressed again. This prevents the system from being accidentally active even when

4) the necessity ends. Obviously, this device does not work during the day, when there is no need for artificial light.

5) *Control Unit:* The sensors transfer the collected infor-mation to a controller which runs the software to analyze the system. Fig. 3 shows the control software flowchart. After the initial setting, the system is controlled by the light sensor which activates the microcontroller only if the sunlight illumination is lower than a fixed threshold. In this case, the system reads the state of the emergency button, and switches on the lamp if this is activated. The same happens in case of a vehicle or a pedes-trian. Once the lamp has been switched on, the operating sensor starts the monitoring and, in case of a fault detection, an alarm is sent to the control center. If no fault is detected, the microcon-troller measures the current flux by the Hall sensor memorizing the current values.

The entire operation is regulated by a timer which enables the system to work for the predetermined time. At the stop input, the lamp is turned off and the cycle restarted.

The algorithm has been written in Pic Basic and runs on the microcontroller.

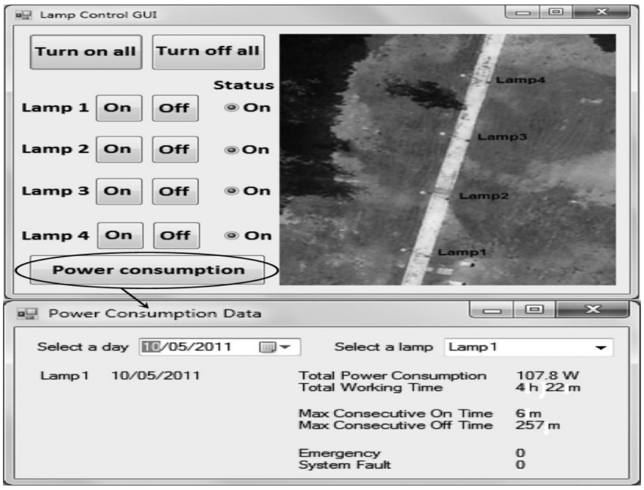


Fig. 2: Lamp control system GUI and measurement of power consumption

The base control station is the hub of the system since it al-lows the visualization of the entire lighting system. The trans-mission system consists of a ZigBee device that receives infor-mation on the state of the lamps and sends it to a terminal.

The processing unit consists of a terminal with a serial Uni-versal Asynchronous Receiver-Transmitter (UART) interface which receives information about the state of the lamps pro-vided by a ZigBee device. The terminal is required for a graph-ical display of the results. Moreover, data on lamps' operation are associated with the lamp address; consequently, all faults are easily identified.

The graphical interface enables monitoring the state of the system (upper section of Fig. 4) with the state of the lights and the power consumption of each lamp (lower section of Fig. 4). The operator will have a graphical representation of the lamp location within the area where the system is installed.

Pressing the button "Power Consumption Data," a second window appears where power consumption and working time of any lamp are given. The program is also equipped with a man-agement system that acts in case of no communication from the lamp posts well explained in Section III-E after the description of the entire system.

C. ZigBee Network

ZigBee is a wireless communication technology based on the IEEE802.15.4 standard for communication among multiple de-vices in a wireless personal-area network (WPAN). ZigBee is designed to be more affordable than other WPANs (such as, for example, Bluetooth) in terms of costs and, above all, en-ergy consumption. A ZigBee personal- area network (ZBPAN) consists of at least one coordinator, one (or more) end device(s) and, if required, one (or more) router(s). The network is cre-ated when a coordinator selects a channel and starts the com-munication, henceforth, a router or an end device can join the network. The typical distance of a ZigBee transmission range, depending on the environment conditions and the transmission power, shifts from tens to hundreds of meters, and the transmis-sion power is deliberately kept as low as possible (in the order of a few milliwatts) to maintain the lowest energy consumption [21]–[26].

In case of failure of one lamp, the chosen transmission distance between the lampposts ensures that the signal can reach the next operational lamp post without breaking the chain. The ZigBee wireless communication network has been implemented with the use of Digi-MaxStream radio-frequency modules called XBee modules, which are available in Stan-dard and Pro versions (pin-to-pin compatible) [20], [21]. The Standard Xbee modules have an operation range of tens of meters indoors and hundreds of meters outdoors, while the XBee Pro modules have a wider spread range in the order of hundreds of meters indoors and of about 1.5 km outdoors, because the Pro modules have higher transmission power, but imply higher consumption (about three times the consumption of the Standard version).

The receiver has very high sensitivity and a low probability of receiving corrupted packets (less than 1%). The modules should be supplied by 3 V from a dc source; the current consumption is in the order of 50 mA (for XBee) and 150–200 mA (for XBee PRO) in uplink and in the order of 50 mA in downlink (identical for both versions); moreover, they support a sleep mode where consumption is less than 10 μA.

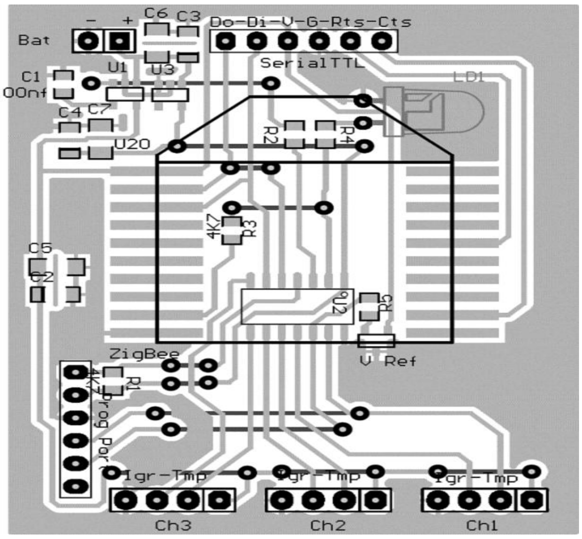


Fig. 3: Printed-circuit board.

The XBee modules are dis-tributed in three versions of antennas: with an on-chip antenna, a wire antenna, and with an integrated connector for an external antenna.

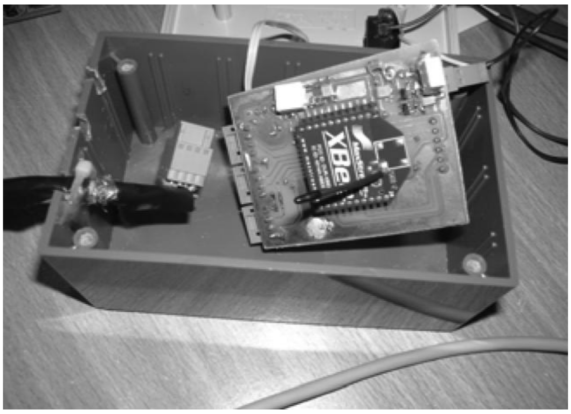


Fig. 4: Prototypes

D. Details and Buildup

In the proposed system the most important elements are:

- the voltage controllers which provide power to all other devices;
- the microcontroller (U2, Microchip PIC 16f688), which manages the system where the firmware is uploaded;
- the XBee module;
- connectors for programming the pic (ProgPort), for op-tional serial transistor transistor logic (TTL), for an ex-ternal reference voltage, necessary for the correct activity of the PIC analog-to-digital converter (ADC), and for the input/output (I/O) ports.

Fig. 3 shows the printed -circuit board (PCB) of the mon-itoring station circuit. The circuit has been realized in sur-face-mount device (SMD) technology to reduce the overall

Fig. 4 shows the realized prototype allocated in its box ready for tests. This is the prototype tested in real-life conditions.

Fig. 5: Test system

Finally, Fig. 5 shows the operational test system working in real conditions. It is visible that the proposed systems can also be used for upgrading existing conventional lamp posts.

Power is supplied by a battery recharged by a solar panel during the daytime. The capacity of the battery depends on the specific needs of the final application.

The irradiation curves of the site have been studied during a project about making a photovoltaic system, in order to determine the right inclination and orientation of the solar panels to enable the best outcome of the operation. It is possible to refer to publications which provide precise data as a function of latitude (referring to UNI 10349 data obtained by PVGIS [27]). For the sizing of the panel, it is necessary to determine the annual en-ergy required to power the lighting system under analysis. The project data here below are necessary to determine the energy produced annually by a photovoltaic panel:

• location of the installed panel;

• inclination of the absorbing surface;

• orientation of the absorbing surface;

• ground-level reflection;

• nominal power of the panel;

• losses of the solar panel;

• efficiency of the charger controller.

The charge controller manages the processes of the battery charge and power supply. Electric power generated by photovoltaic panels is handled by the controller to provide an output current for the battery charge. The charging process must be conducted according to the battery features (capacity, voltage, chemistry, etc.), providing current until the battery has been completely charged, and then switching to a standby current to compensate the battery self -discharge. The selected model (CMP12 JUTA of HARBIN Hopeful STAR [28]) provides voltage regulation of battery charging as a function of temperature and has built -in electronic protection to contrast overload, short circuit, and overvoltage.

III. PROPOSED SYSTEM TO ACHIEVE PERFORMANCE

In remote areas the sun is a cheap source of electricity because instead of hydraulic generators it uses solar cells to produce electricity. While the output of solar cells depends on the intensity of sunlight and the angle of incidence. It means to get maximum efficiency; the solar panels1 must remain in front of sun during the whole day. But due to rotation of earth those panels can't maintain their position always in front of sun. This problem results in decrease of their efficiency. Thus to get a constant output, an automated system is required which should be capable to constantly rotate the solar panel. The Automatic Solar Tracking System (ASTS) was made as a prototype to solve the problem, mentioned above. It is completely automatic and keeps the panel in front of sun until that is visible. The unique feature of this system is that instead of take the earth as in its reference, it takes the sun as a guiding source. Its active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximum.

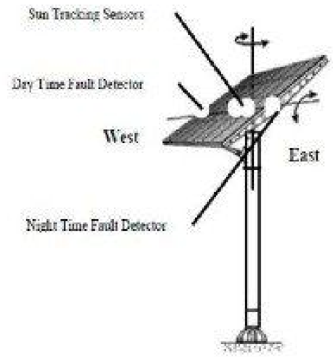


Fig. 6: Solar Tracker

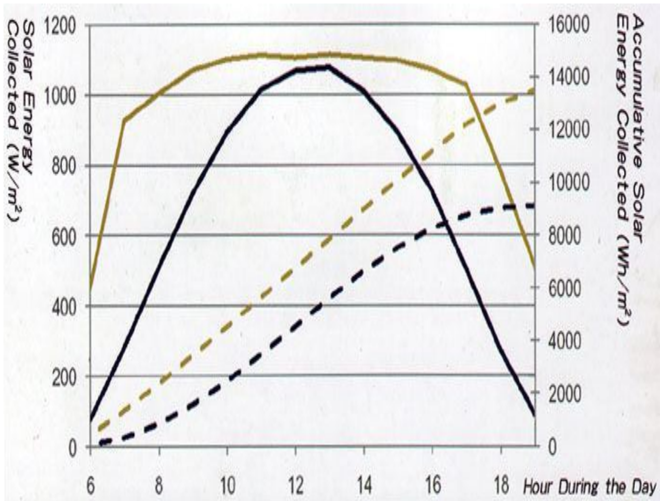


Fig. 7: Energy Consumption

In case the sun gets invisible e.g. in cloudy weather, then without tracking the sun the ASTS keeps rotating the solar panel in opposite direction to the rotation of earth. But its speed of rotation is same as that of earth's rotation2. Due to this property when after some time e.g. half an hour when the sun again gets visible.

Solar panels are usually set up to be in full direct sunlight at the middle of the day, facing south in the Northern Hemisphere, or facing north in the Southern Hemisphere. Therefore morning and evening sunlight hits the panels at an acute angle and reduces the total amount of electricity which can be generated each day.

A solar tracker is a device onto which solar panels are fitted which tracks the motion of the sun across the sky, thus ensuring that the maximum amount of sunlight strikes the panels throughout the day.

When compared to the price of the PV solar panels, the cost of a solar tracker is relatively low. We provide highly efficient, proprietary single and dual axis solar tracking systems. Our single-axis solar trackers can typically increase electricity generation by 30%, while our dual-axis trackers can boost electricity generation by up to 40%.

The benefits of solar tracker are provided below:. Solar tracking systems are utilized to continually orient photovoltaic panels to the sun and can help make best use of the investment in PV system.

They are useful as the sun's position in the sky will alter gradually during a day and over the seasons throughout the year.

Advantages to utilizing a tracker system like this will depend mostly on it's positioning in determining exactly how well it will enhance the effectiveness of the panels.

Energy manufacturing is at an optimum and energy output is enhanced year round. This is particularly significant through out the summer season with its long days of sunshine readily available to capture and no energy will be lost.

For those with limited area this suggests that a smaller sized range only needs to be installed, a substantial advantage for those smaller sites with only a small location to put solar tracker. Contrast in between taken care of and with-tracking solar PV system.

IV. Block Diagram

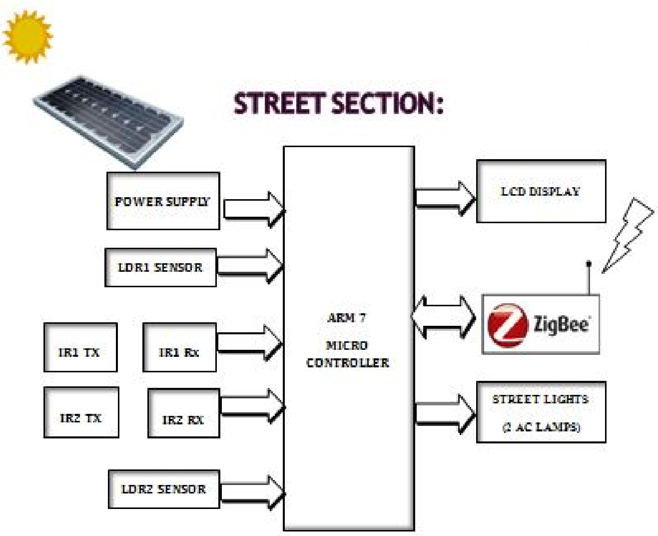
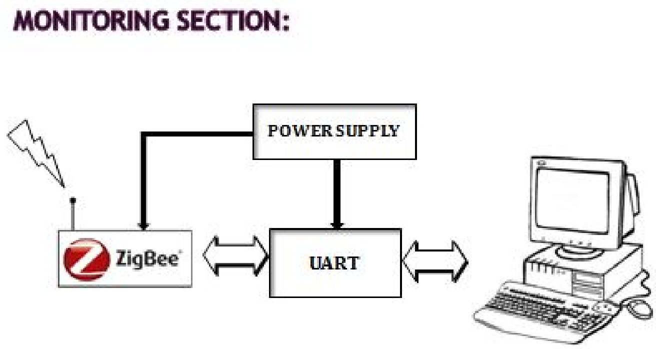


Fig. 8: Street Section



The prototype has been tested in variable real-life conditions to verify the overall functionality and seek better performance.

The measurements collected during the test phase allow calculating energy savings so that it is possible to estimate cost savings also for larger systems using approximations.

A. Range Tests

The first tests on the Xbee modules performance were done at the Electric and Electronic Measurements Laboratory of Roma Tre University, to test the reliability of the communication between two or more ZigBee modules in the following environmental conditions:

1) open field in line of sight between modules;
2) open field out of the line of sight where the obstacle is a big tree or a hill;
3) indoor test.

The tests were carried out using different types of Xbee modules, Standard and Pro, each one with three different types of antennas (patch, wire, external) provided by the manufacturer. To check the reliability of the Zigbee transmission, we used the X-CTU software, provided by Digi-MaxStream.

Test cases were designed to check the network in various real-life operating conditions: clear weather, rain, and proximity of electrical or electronic devices possibly interfering with the transmission (such as a WiFi access points).

The indoors tests were done considering one or more walls between the transmitter and the receiver, while the outdoor ones were performed with one or more natural obstacles like trees or hills. Ten-thousand transmission tests were performed for each case, using an appropriate adapter to simulate the retransmission.

TABLE I
ZIGBEE RELIABILITY TESTS

XBEE STANDARD - Patch Antenna - Outdoors				
	Sunny		Rainy	
	50m	100m	50m	100m
No obstacles	100%	99,99%	99,98%	99,97%
Tree	99,97%	99,96%	99,98%	99,96%
Hill	99,97%	99,95%	99,97%	99,94%

XBEE STANDARD - Wire Antenna - Outdoors				
	Sunny		Rainy	
	50m	100m	50m	100m
No obstacles	100%	100%	100%	100%
Tree	100%	99,99%	99,99%	99,98%
Hill	100%	99,99%	99,98%	99,96%

XBEE STANDARD - External Antenna - Outdoors				
	Sunny		Rainy	
	50m	100m	50m	100m
No obstacles	100%	100%	100%	100%
Tree	100%	100%	100%	100%
Hill	99,99%	99,99%	99,98%	99,97%

XBEE STANDARD – Indoors – more than 10 m from WiFi AP			
	1 Wall	2 Walls	3 Walls
Patch Antenna	100%	99,98%	99,96%
Wire Antenna	100%	100%	99,98%
External Antenna	100%	100%	100%

XBEE STANDARD - Indoors – 5 m from WiFi AP			
	1 Wall	2 Walls	3 Walls
Patch Antenna	99,98%	99,88%	99,96%
Wired Antenna	100%	99,95%	99,87%
External Antenna	100%	100%	99,98%

B. Power Management

The system was designed to be stand alone, supplied by solar panel energy, with relevant advantages resulting from this kind of power supply. It is possible to avoid the tedious and expensive wiring of the supply power network, with considerable savings and ease of implementation. The control circuit is designed to consume the lowest possible power, minimizing the battery capacity and the energy supplied by the solar panel. These goals were achieved through the use of the XBee module for transmitting and receiving information, using LED lamps as a replacement for standard lamps and using special power-saving solutions for microcontrollers and radio modules. The program, which controls the system, is designed primarily to save energy. First, since the system only works at night, avoiding wasting energy during daylight hours occurs when the only active device is the solar panel recharging the battery. Second, various sensors allow the system to work only when necessary. Third, the system implies highly efficient LEDs to ensure proper illumination and ensure energy savings. For our work, a 84-lm/W LED was used. Finally, when the system is disabled, all devices (XBee and microcontrollers) are in the sleep mode, which allows negligible power consumption. The wakeup is triggered by the change of conditions (emergency device, presence sensor, etc.). The management of the sleep mode is crucial, because we must ensure that the system quickly responds to interruptions. The choice of the battery depends on the conditions where the system is installed. For example, in case of a busy street at night, it is better to use a battery of higher capacity rather than the one in use for a street without traffic at night. We must also consider natural and weather conditions; in fact, we have to choose a larger battery which can compensate low sunlight for several days. In the worst case, the system needs a battery that is able to power the LEDs until 12 h (from 7:00 P.M. to 7:00 A.M.) at 1.5 A, with a total capacity of at least 18 Ah. A 5-Ah battery was chosen in the test case because the test street is not a busy one (the cost of a 5-Ah battery is almost 70%. lower than 18 Ah one). Finally, a solar panel capable of providing 1.5-A charging current at 12 V with 19-W maximum power was selected.

Table II. CURRENT CONSUMPTION AND OPERATING TIME OF LAMPPOSTS

Lamp ID	*March*		*April*	
	Time (h)	*I (A)*	*Time (h)*	*I (A)*
Lamp 1	108.14	1.47	87	1.44
Lamp 2	108.33	1.51	87	1.50
Lamp 3	108.14	1.48	86.64	1.47
Lamp 4	108.14	1.53	87	1.44

C. Measurements

The system provides an accurate reading of the switch-on times of the street lamps and of the absorbed currents. Both are stored in the memory of the microcontroller and are sent to the control center once a day. The transmission of a big frame of data could lead to the collision between data and to memory management issues. This case occurs when two or more lamp posts send quite a large amount of information simultaneously.

This matter can be solved using the transmission method that sends data from the farthest lamp post to another and, hence, down to the control center, storing all of the cumulated data in each lamp post. The high capacity memory needs would be incompatible with the components and devices chosen for the system, resulting in higher hardware costs and software complexity.

To solve this issue, data were sent from a given lamppost only when asked by the control center.

A more accurate analysis of power consumption is shown in Table II, based on the data collected throughout the months of March and April 2011.

The average consumptions of current (I) are represented in Table III; switch-on time differences are due to the test of emergency conditions on the second lamp post in March, while in April, a failure was simulated to verify the third street light maintenance conditions. Given the time, the current, and the cost of a kWh of energy, different for each provider, it is possible to determine the real energy cost savings versus other systems. For instance, lamp posts installed with a classical system are active for about 10 h/day during March and April, with a total of about 300 monthly working hours, versus the expected 108 h in March and 87 h in April for the proposed system, with a savings of about 66% of the time in the first month and 71% in the second. Table III shows the new processed data for May and June 2011. As we can see, the current consumption decreases in sunny months.

D. Comparison With a Classic Lamp Post

To make a quantitative test of the advantages available by our system in comparison with a classical lamp post, three other lamp posts were added in parallel to the others. Their switching on is controlled only buy a crepuscular sensor which keeps the lamp posts on during dark hours.Wemade this test on July 2011, and the new lamp posts had these characteristics: 1) 18-W LED lamp with 1550 lumen (84 lm/W luminous flux), powered by a solar panel and a battery;

2) 18-W LED lamp with 1550 lumen (84 lm/W luminous flux), supplied by mains through an ac/dc converter to have 12 V; 3) 50-W mercury-vapor lamp by the OSRAM model HQL50 [29] with 1800 lm (36 lm/W luminous flux), supplied by mains through an HV starter and a reactor.

We have chosen this mercury-vapor lamp because its emissions are comparable to the LED one. A shunt resistor of 10 was placed on the third lamp post for current measuring. The obtained results are in Table IV.

Table III. CURRENT CONSUMPTION AND OPERATING TIME OF LAMP POSTS

Lamp ID	*May*		*June*	
	Time (h)	*I (A)*	*Time (h)*	*I (A)*
Lamp 1	80.14	1.48	77.02	1.45
Lamp 2	80.14	1.50	77.02	1.50
Lamp 3	80.14	1.48	77.02	1.47
Lamp 4	80.14	1.51	77.02	1.49

Table. IV: REQUESTED TIME TO REACH THE BREAK-EVEN POINT BETWEEN THE DIFFERENT SOLUTIONS

	L1	L2	L3	L4
L1	-	Always more convenient	After 53 months	After 19 months
L2	Never more convenient	-	After 250 months	After 87 months
L3	Before 53 months	Before 250 months	-	After 2 months
L4	Before 19 months	Before 87 months	Before 2 months	-

It is possible to consider the price of kWh constant. Considering a particular month like July, when the amount of kWh is low and so the savings are even lower, Table V shows the break-even time between the different choices. It is possible to note as the solution L1 is obviously always more convenient than L2 and reaches the break even against the L4 with classical technology in only 19 months, it also becomes more convenient than the third solutions after 53 months.

Obviously, using a month more convenient for the calculus, the break-even can be quickly reached. That is, between the analyzed months,March is themost convenient. For it, L1 is always more convenient than L2, reaches the break-even against L4 in only 10 months and becomes more convenient than the third solutions after 29 months.

E. Management of Lamp Post Fault

One of the purposes of our work was to make the system available to inform the remote central in case of a lamp post fault so that a restore operation would be quickly possible.

In case of the ZigBee communication fault, if the n-ism lamp post does not react to the inquiry of the central, the program sends a notification of a breakdown to the graphics interface.

In this case, the system goes on measuring and storing data into the EEPROM and random-access memory (RAM) (with a capacity of 512 B) of the microcontroller. So if we consider a sampling every 5 min and a lamp post switching on for 8 h/day (as a particularly demanding case), the system will store data for about three days consecutively. But if the system is not restored within three days and we want to know the consumption information, a PIC with higher storage capacity, or even an SIM card, is necessary. If the PIC is not powered by the battery of the system anymore, a 4.5-V backup battery is integrated in the box and provides the necessary energy. The next release of the system will be modified in the firmware, providing the reading of the voltage of the battery on the microcontroller pin, so if thevoltage is zero, a battery fault signal will be sent to the remote central.

V. Conclusion

This paper describes a new intelligent street lighting system which integrates new technologies available on the market to offer higher efficiency and considerable savings. This can be achieved using the highly efficient LED technology supplied by renewable energy of solar panels, for which the cost of energy is independent from the power supplier prices, combined to an intelligent management of the lamp posts derived by a control system switching on the light only when necessary, increasing the lamps' lifetime.

Another advantage obtained by the control system is the intelligent management of the lamp posts by sending data to a central station by ZigBee wireless communication. The system maintenance can be easily and efficiently planned from the central station, allowing additional savings.

The proposed system is particularly suitable for street lighting in urban and rural areas where the traffic is lowat a given range of time. The independent nature of the power-supply network enables implementing the system in remote areas where the classical installations are prohibitively expensive. The system is always flexible, extendable, and fully adaptable to user needs. The simplicity of ZigBee, the reliability of electronic components, the feature of the sensor network, the processing speed the reduced costs, and the ease of installation are the features that characterize the proposed system, which presents itself as an interesting engineering and commercial solution as the comparison with other technologies demonstrated. The system can be adopted in the future for loads supplied by the power system, which enables the monitoring of energy consumption. This situation is particularly interesting in the case of economic incentives offered to clients that enable remote control of their loads [31] and can be useful, for example, to prevent the system blackout. Moreover, new perspectives arise in billing and in the intelligent management of remotely controlled load and for smart grid and smart metering applications.

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