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Research Paper

HIGH EFFICIENCY AND INTELLIGENT STREET LIGHTING USING A ZIGBEE, GSM AND SENSORS

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The proposed remote-control system can optimize management and efficiency 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, Lighting system, Sensors, Wireless networks, ZigBee

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. However, the recent increasing pressure related to the raw materialcosts and the greater social sensitivity to environmental issues are leading manufacturers to develop new techniques and technologieswhich allow significant cost savings and a greater respect for the environment. We can find three possible solutionsto these problems in the literature.The first one, and perhaps the most intuitive, is the use of newtechnologies for the sources of light. In this area, light-emittingdiode (LED) technology is the best solution because it offersmany benefits. Researchers [1][4] have already considered this Possibility, designing an advanced street lighting system basedon LEDs.The second possible solution, and perhaps the most revolutionary,is the use of a remote-control system based onintelligent lamp posts that send information to a central controlsystem, thus simplifying management and maintenance issues.Researchers [5] have developed a street lamp systemusing the general-packet radio service (GPRS), power-linecarrier, or Global Systems for Mobile Communications (GSM) transmissions.

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

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effect on the environment. Solar energy is the most important resource in this field. Our work aims at the unification of the three mentioned possibilities,

Figure 1: Schematicimage of the System

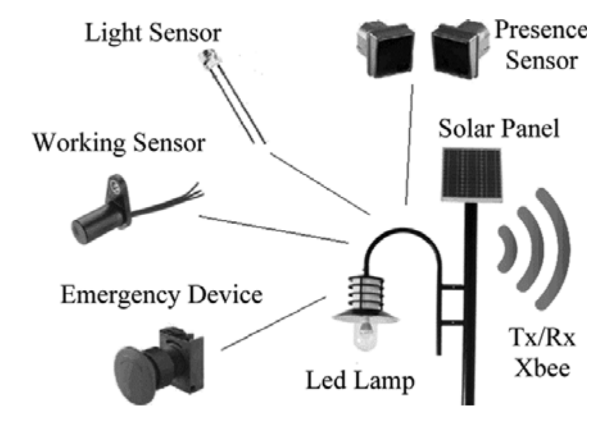
Creating an intelligent lamp post managed by a remote- controlled system which uses LED-based light sources and is powered by renewable energy (solar panel and battery). The control is implemented through a network of sensors to collect the relevant information related to the management and maintenance of the system, transferring the information via wireless using the ZigBee protocol. The field of the ZigBee remote

Sensing and control system is widely present in the literature; we can also find ZigBee systems similar to the lighting systems in structure and management. In this paper, we present our system, which is able to integrate the latest technologies, in order to describe an advanced andintelligent management and control system of the street lighting.

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 completely independent in the management of its own lighting. The on-street station also checks if the lamp is properly workingand 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. 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.

Figure 2: Schematic image of an on-street station.



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 assigned 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 crossroads, a single sensor is sufficient (or one at each end in case of a two-way street), while for a street requiring more precise control, a solution with multiple presence detectors is necessary. This feature enables switching on the lamps only when necessary, 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 enables 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 motion sensor offers good performance and is quite affordable.

2) Light Sensor

A light sensor can measure the brightnessof 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. The sensor must have high sensitivity in the visible spectrum, providing a photocurrent high enough for low light luminance 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 support to the sunlight. This mode enables saving electric powersupplied to the lamp because the lamp is regulated by the combined action of the sensor and the microcontroller to ensure the minimum illumination required.. 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

Figure 3: Control Software Flowchart

appropriate measures in case of failure.Solar energy is the most important resource in this field.

3) Operating Control

This sensor is useful to improve fault management and system maintenance. Thanks to this sensor (in this case, a hall sensor), itis possible to recognize when the lamp is switched on. The system is able to recognize false positives, because identified parameters are compared with the stored data (e.g., lamps are switched off during daylight and the sensor incorrectly detects a fault, but the microcontroller does not report the malfunction because of additional logic functions). The information is reported through the ZigBee network to the station control unit, where the operator is informed about the location of the broken-down lamp and can send a technician to replace it. The system current is 1.5 A, so a sensor suited to detect this current is necessary. An appropriate threshold value to detect the operation of the lamp has been set between 1 and 1.5 A. The chosen sensor is the ACS756 of the Allegro Microsystems, an economical and precise solution for ac or dc currentsensing, particularly suitable for communication systems. Thanks to this sensor, it is possible tostore in the microcontroller's memory the current value which flows in the LED lamp in normal operating conditions, enabling the online power consumption measurement.

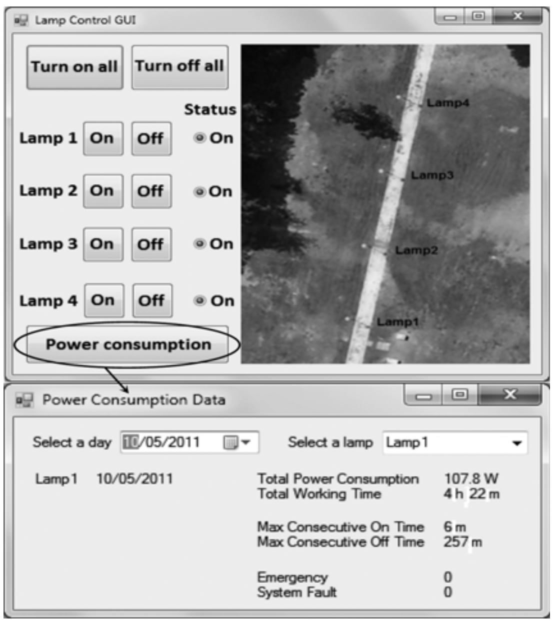
4) Emergency Device

The system has an emergency button, which can be useful in case of an emergency. This device excludes the entire sensor system with the objective to immediately turn on the lamp. The light will remain on for a pre-set time. After that, the button must be pressed again. This prevents the system from being accidentally active even when 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 information to a controller which runs the software to analyse 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 pedestrian. Once the lamp has been switched on, the operating sensor starts the monitoring and, in case of fault detection, an alarm is sent to the control center. If no fault is detected, the microcontroller measures the current flux by the Hall sensor memorizing the current values. The entire operation is regulated by a timer which

Figure 4: Lamp control system GUI and measurement of power consumption



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 themicrocontroller.

B. Base Control Station

The base control station is the hub of the system since it allowsthe visualization of the entire lighting system. The transmissionsystem consists of a ZigBee device that receives informationon the state of the lamps and sends it to a terminal.The processing unit consists of a terminal with a serial UniversalAsynchronous Receiver-Transmitter (UART) interfacewhich receives information about the state of the lamps providedby a ZigBee device. The terminal is required for a graphicaldisplay of the results. Moreover, data on lamps' operation are associated with the lamp address; consequently, all faults areeasily identified.The graphical interface enables monitoring the state of thesystem (upper section of Fig. 4) with the state of the lights andthe power consumption of each lamp (lower section of Fig. 4).The operator will have a graphical representation of the lamplocation within the area where the system is installed.Pressing the button Power Consumption Data, a secondwindow appears where power consumption and working time ofany lamp are given. The program is also equipped with a managementsystem that acts in case of no communication from thelamp posts well explained in Section III-E after the descriptionof the entire system.

C. ZigBee Network

ZigBee is a wireless communication technology based on the IEEE802.15.4 standard for communication among multiple devices in a wireless personal-area network (WPAN). ZigBee isdesigned to be more affordable than other WPANs (such as, for example, Bluetooth) in terms of costs and, above all, energy 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 created when a coordinator selects a channel and starts the communication, 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 transmission power is deliberately kept as low as possible (in the order of a few mill watts) to maintain the lowest energy consumption.In the proposed system, the network is built to transfer informationfrom the lamp posts to the base station control. Informationis transferred point by point, from one lamppost to another where each lamp post has a unique address in the system. Each lamp post can only send the information to the nearest one, until the information reaches the base station. Thus, transmission power is limited to the required low value and the signals sent by the lampposts do not interfere with each other. 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 Standard and Pro versions (pin-to-pin compatible). The Standard Xbee modules have an operation range of tens ofmeters 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 ofreceiving 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 150200 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 A. The XBee modules are distributedin three versions of antennas: with an on-chip antenna, a wire antenna, and with an integrated connector for an external antenna.

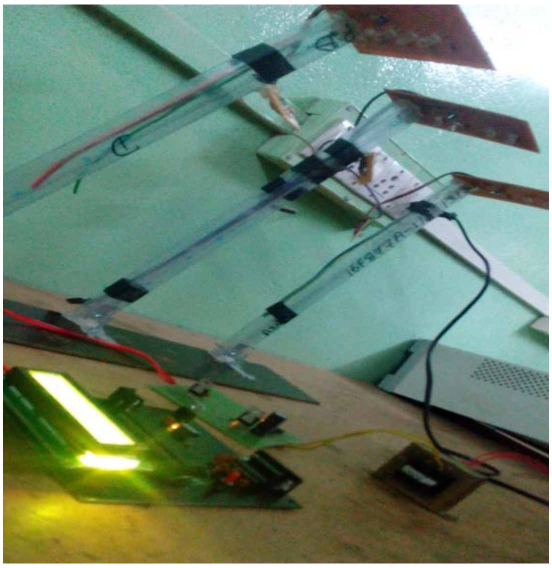
D. Details and Build up

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), whichmanages the system where the firmware is uploaded.
- Connectors for programming the pic for optionalserial transistor transistor logic (TTL), for an external reference voltage, necessary for the correct activity of the PIC analog-to-digital converter (ADC), and for the input/output (I/O) ports.

Finally, Figure 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 specificneeds 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 latitudefor thesizing of the panel, it is necessary to determine the annual energy 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:

Figure 5: Test System



- 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 providesvoltage regulation of battery charging as a function of temperatureand has built-in electronic protection to contrast overload, short circuit, and overvoltage.

TESTS AND RESULTS

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 calculatingenergy 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 atthe Electric and Electronic Measurements Laboratory of RomaTre University, to test the reliability of the communication between two or more ZigBee modules in the following environmentalconditions:

1) Open field in line of sight between modules;

2) Open field out of the line of sight where the obstacle is abig 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 ofantennas (patch, wire, external) provided by the manufacturer.To check the reliability of the Zigbee transmission, we usedthe X-CTU software, provided by Digi-MaxStream.Test cases were designed to check the network in variousreal-life operating conditions: clear weather, rain, and proximityof electrical or electronic devices possibly interfering with thetransmission (such as a WiFi access points).The indoors tests were done considering one or more wallsbetween the transmitter and the receiver, while the outdoorones were performed with one or more natural obstacles liketrees or hills. Ten-thousand transmission tests were performedfor each case, using an appropriate adapter to simulate theretransmission. The X-CTU tool, using a terminal connected to an XBeemodule, sends a packet through the network and verifies that thedata are correctly returned back from the XBee module whichhas received the packet. The obtained results, using the minimumtransmission power available, are very satisfactory: allpackets arrive to their destination and are correctly returned. Obtainedaverage reliability was 99.99%.The same tests were performed on the Xbee Pro and the percentageof reliability was 100% in each case.Positioning the lamp post at about 25 m from each other, theproposed system can reliably operate using the Xbee Standardmodules with patch antenna. These modules have a nominalrange of about 100 m outdoors and are the cheapest ones.Other functionality field tests were realized using the Xbeemodules installed in the lamp posts (at the moment, they arefour plus the remote central). A first test was to verify that thesystem is able to transfer information from any lamp post tothe control center passing data through the other lamp posts. Inthese cases, we obtained a transmission rate between 99.99%and 100% depending on the location of the sending unit.The second test verified the case of breakdown of an intermediatelamp post. At the moment, the system is not affectedby this kind of problem, considering the transmission with thesame positioning of the previously described case. The systemequipped with Xbee modules with a patch antenna becomes

Nonoperating only when four consecutive lamp posts' transmissiondevices are nonoperational. This test was performed usingtwo others Zigbee transmission stations. Placed 25 m from eachother, the lampposts chain had upstream these two stations tosimulate the other lamps.

Table 1

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%

A similar test was done with the Xbee Pro modules with an external antenna, in order not to leave anything out. It follows that the system is completely reliable also inthe case of five consecutive lamp posts broken down (the worst case in our test system). No bypass line is necessary in this case.

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.

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 byrenewable 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 controlSystem switching on the light only when necessary, increasing the lamps' lifetime.Another advantage obtained by the control system is the intelligentmanagement 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 lightingin urban and rural areas where the traffic is low at a given rangeof 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 and can be useful, for example, to preventthe system blackout. Moreover, new perspectives arise in billing and in the intelligent management of remotely controlled loads and for smart grid and smart metering applications.

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