DESIGNING A CONTROL SYSTEM FOR SMART OUTDOOR STREET LIGHTING USING ADVANCED COMMUNICATION TECHNOLOGIES

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Abstract. ***The paper proposes the design of hardware and software solutions for public street lighting with LEDs, using elements of the communication protocol interface like 485 and wireless transmission via ZigBee and GSM networks. The control is accomplished by sending commands toward slaves. The slave sites have the MCU support plate like PIC16F887 or PIC18F8520 and the software routines are written in MikroC. The data are shipped in the standard frame structure inspired from MBUS. The Desktop application for dispatcher allows to view the status of each controller involved, in this case the PWM value. Both dispatching JSE and JME with access to a MySQL database and simulations in ISIS environment have been used.***

Keywords: street lighting control, RS485, ZigBee, GPRS, JSE, JME, PHP, MySQL, MBUS, PWM, LED panel

1. INTRODUCTION

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, combined to an intelligent management of the lamp posts derived by a control system switching on the light only when is necessary, increasing the lifetime of lamps [1].

The street lights are controlled either individually or in group. In group based control, several lights are jointly connected to mains, decreasing wiring cost. The group based control system is simple in its functionality but disconnects all street lights within group due to maintenance and troubleshooting. However, in individual control, the lamps are independently connected to mains at the expense of additional wiring and labour costs. Numerous lighting control systems have been proposed to reduce energy consumption, using occupancy sensing approach, and light level tuning [2].

GSM/GPRS based on street light monitoring & control system is an automated system designed to increase the efficiency and accuracy of an industry by automatically timed controlled switching of street lights. It consists of a microcontroller which on the time setting delays OFF/ON switches the street lights and sends the update through a phone to the specified phone number. This is a smart way of managing street lighting systems. There are basically two modules which include the client side and the server side. The client side consists of the GSM/GPRS modem which is further connected to the microcontroller. The server side consists of the JSE Java based on the web server and has a core engine which interacts with the user, database and the GSM/GPRS communication manager [3].

The smart metering can be considered as one of the fundamental parts of the Smart Grid, which are the complex system in which many subsystems coexist and interact to handle the flows of energy, the loads, and the entire grid of energy distribution. The Smart Grid is one of the components of the new concept of Smart City: a city where all participants (citizens, governance, infrastructure and services) aim to reach a sustainable economic development and a high quality of life. The public lighting systems are typical examples of a smart city application: the trade-off between the energy saving and the users' comfort can be achieved by means of smart control and supervision of the state of the system. The communication system which can be applied to lighting grid is very similar to the Advanced Metering Infrastructure system [4].

The street lighting networks have a large number of devices connected and have irregular routes and areas which greatly increase the complexity of data managing. Among the technologies used as the communication protocol for public lighting *Power Line Communication* and *wireless network* communication can be highlighted. For example, [5] describes the PLC communication by ST7538 power line modem, [6] presents the same technology with three power Line Transceivers based on 8051 architecture, one for each phase, [7] shows the Candelon module equipped with a Neuron Chip processor 31xx series with PL transceivers and [8] describes an ATmega8 single-chip systems with the current sensors, Media Converter, SSS (silicon symmetrical switch), communication module, and other peripherals. The PLC technology has also some disadvantages, e.g:adding nodes to the same network requires that the nodes are plugged on the same power line trunk and the repeaters are needed for reaching the farther nodes. Moreover, the PLC technology has some constraints principally due to noise and variations in the impedance of the medium.

According with [9], the wireless networks can be classified into cellular networks like GPRS, GSM and 3G technologies, and *ad hoc* networks, which can be the Wireless Mesh Networks (WMN) and the Wireless Sensor Networks (WSN). The paper is focused on the development and performance assessment of the infrastructure for remote control of the system using IEEE 802.15.4 standard. A similar approach is presented in [10] and [11] where the WSN sensor node has both sensing and communication capabilities and can work as a transmitter node, a receiver node, or a relay node. The single chip microcomputer unit (MCU) type, radio transceiver should be carefully selected to meet the low cost, high capability in designing node hardware. There are many MCUs and radio transceivers which can be chosen in the commercial market. The available MCU includes ATmega 128, PIC16F8X and ARM 7/9 etc. The available single chip radio transceiver includes nRF903, nRF2401, CC1000, CC2420 etc. The determination of chips should be considered features, price, peripheral extend capability and so on.

2. SYSTEM ARCHITECTURE

The solution proposed in this paper presents a case study for a network with 10 pylons with LED lamps and divided into four zones with 3, 3, 3, 1 pylons. The solution for data transmission is hybrid including GSM, GPRS, RS485 interfaces and ZigBee devices.

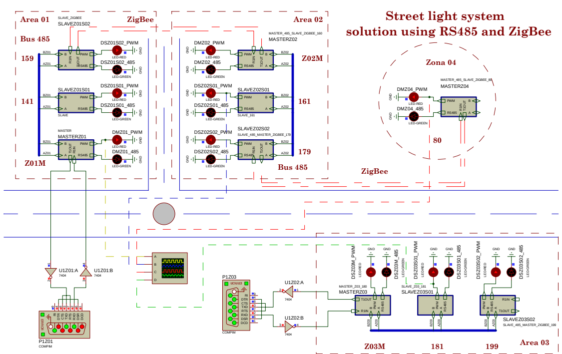


Figure 1. Case study

Figure 1 presents the case study where the four areas are observed. There is just one pylon located at distance in the fourth area, and whose action is produced through the ZigBee wireless transmission. Inside of a zone, a cable transmission by 485 interfaces is used. Between the first communication device of each zone and the dispatching centre, the transmission is achieved by a communication using the GSM system.

The transmission is achieved by ZigBee among the adjacent zones, as is shown in Figure 1, the links between link 1 and link 2, as well as between link 2 and link 4. Therefore, the control area is extended without using a wired solution on 485 interfaces, and the identification of destination is performed by the distribution of information like in computer networks towards the gateway.

The proposed solution was tested by simulation in ISIS Proteus as well as in laboratory using BIGPIC5 and PICPLC8A, development boards, and also GM862 and EasyBee devices. More specifically, three modules have been designed.

2.1 Master module

In the application with the addresses 140, 180, the module is connected by GSM to PC and by ADM485 to the slaves. The module (Figure 2) is located in the zones 1 and 3 which are continued by extension, using ZigBee, with zones 2 and 4.

The application of MCU (microcontroller) must receive data from PC to interpret frame structure (unicast, multicast, broadcast) in order to identify the necessity of PWM trigger and finally, to form the frame towards the slaves.

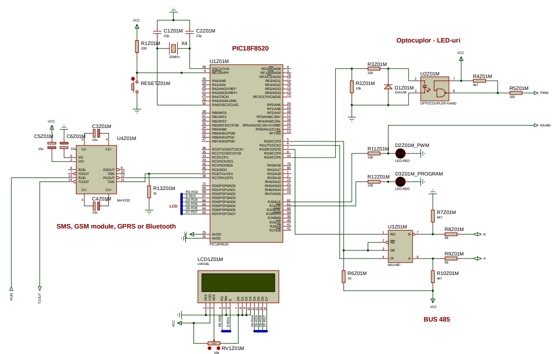


Figure 2. Master module

2.2 Slave module

In application with the addresses 141, 161 and 181, this module is connected by ADM485 to master. The module is located in zones 1, 2 and 4.

Slave modules in application addresses 141, 161 and 181. This module (Figure 3) is connected via ADM485 to master. It is found in zones 1, 2 and 4. The application of MCU must receive data from master in order to identify if the data belong to it, and if the answer is affirmative, the application must read the PWM value which will be sent to the LED module.

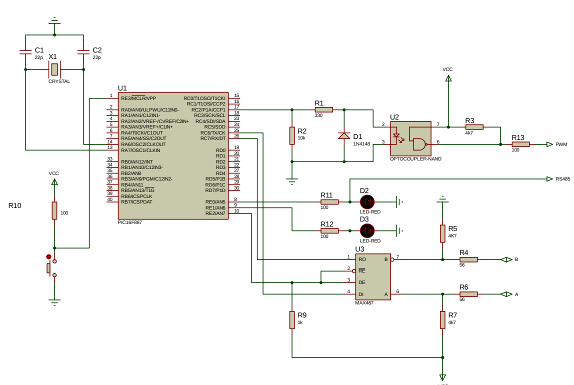


Figure 3. Slave module

2.3 Interconnection module

The module (Figure 4) is sandwiched between the networks 485 and uses the transmission by ZigBee. There are two types of modules with interconnection functions:

- Slave_485_Master_ZigBee is the module that receives data from the network 485, interprets them in order to see if this must start PWM (unicast) or whether this must send them forward (broadcast reception), case in which the module acts like a gateway equipment in a computer network. The module must send the configuration commands for ZigBee in order to forward data by ZigBee. If these commands are exceeded, these allow the remote communication with another ZigBee module.

- Slave_ZigBee_Master_485, is the module that receives data by ZigBee device, read them in order to see if must start PWM (unicast) or if send them forward (broadcast reception) by 485 network in one of the three possible formats. To achieve reception of data by ZigBee, the MCU module must launch the configuration commands for ZigBee device, which once exceeded allow the remote communication with another ZigBee module.

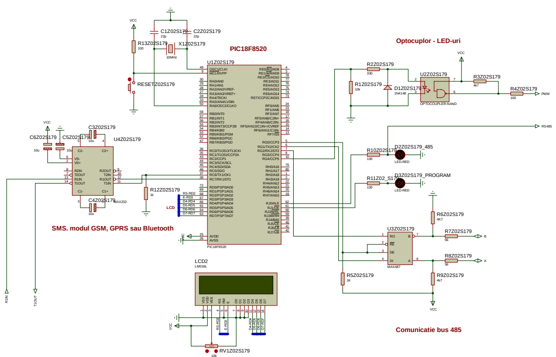


Figure 4. Interconnection module (Gateway)

2.4 LED Lamp module

The module is based on the ACS 1404, a chip manufactured by Altoran. ACS 1404 has the ability to supply LEDs systems directly from AC power and order their intensity through PWM.

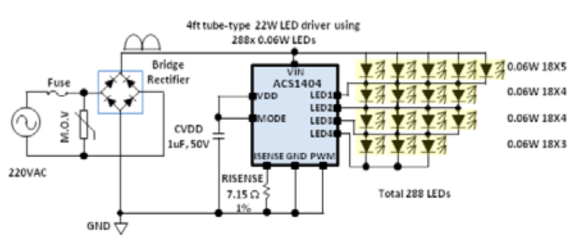


Figure 5. LED systems controled by ACS1404

ACS1404 can be used with different types of switches controlled by the TRIAC. The output signal depends on the rising front, the substracter front or the AC level value of the input signal. At the same time, ACS1404 may be controlled by PWM signal provided by a microcontroller (this solution is used in application of the paper).

Multiple ACS1404 circuits can be used together to control applications with a large number of LEDs. Figure 5 shows the case of the test for a number of 288 LEDs of 0.06W.

3. FRAME STRUCTURE

The protocol implemented for communication between the hardware application and the JSE application is derived from MBUS protocol. The structure of telegrams (Figure 6) begins with a **Start** character 0x68 ("h"), continues with a **Area** field (1 byte, in application “1”,”2”,”3” or “4”), **Pylon no** filed (1 byte) which refers to the number of pylons which receive information (0 for all, 1 for one pylon, 2 for two pylons), the **Destination Addr** field which includes the logical address for pylon (ex. 50 for broadcast, size depend of value of “*Pylon no*“ field), **PWM value** field which includes values of PWM for LED lamp modules (size depend of value of “*Pylon no*“ field) and finally **Stop** with 0x16 value.

START 0x68	Area (1 Byte, 256 areas)	Pylon no. (1 Byte, 256 pylons)	Destination Addr (1 Byte x val pylon)	PWM value (1 Byte x val pylon)	STOP 0x16

Figure 6. Data frame

The ZigBee device must be configured using the AT messages sent by MCU, before sending or receiving the data. MCU sends commands and the ZigBee device confirm them with OK, if the message was correctly received. MCU waits for OK (using a software state machine) and send the following AT command. After the configuration phase, the ZigBee device waits for the data from MCU for sending them or the messages from another ZigBee device for sending towards MCU. If the ZigBee device sends signals, the messages have the following structure (Figure 7):

ATD	55	13	date	13

DATA	:	date	13

Figure 7. ZigBee frame

A transmission from MCU UART1 to ZigBee device, with 38,400 bauds is presented here. The ZigBee device located remotely, receives data and sends them to own MCU encapsulating information between **DATA:** and **13**. At reception, MCU uses a software state machine, which traces **DATE:** and **13**. What is found between these two fields represents the useful information that is interpreted and processed.

4. SYSTEM IMPLEMENTATION

The tests were performed in ISIS Proteus and on developing boards, by sending all type of designed commands. The commands are send from the USART terminal of mikroC Pro for PIC or from JSE interface, as for example:

" h1Œ2h2¡ h41P»h31µð"

In this telegram, the PWM values of 50, 127, 240 and 187 were sent towards the addresses 140, 161, 181 and 80.

Figure 8 and Figure 9 present the effect of these commands sent from JSE interface towards area 1, with the addresses 140, 141 and 159 and the address 160 towards area 2. The PWM values were: 50, 10, 127 and 250.

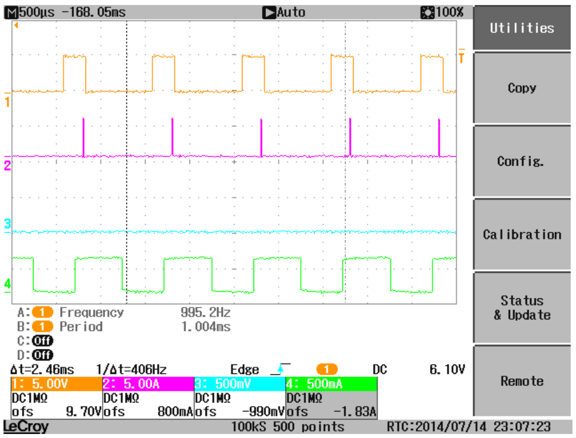


Figure 8. PWM signals for 140, 141 and 159 address

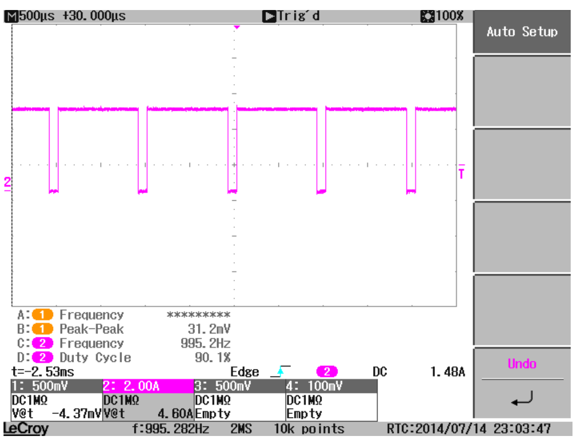


Figure 9. PWM signal for 160 address

Figure 10 presents the designed system. On the screen of the oscilloscopes, the PWM signals are observed for the addresses 140 141 159 (the oscilloscope from the foreground) respectively, for the address 160 (second oscilloscope from the distant background). The transmission is here performed by ZigBee device for zone 2 (160) and for zone 1 through 485. At the same time, the LEDs are ON, PWM value being of the slave 141, i.e. 10%.

JSE interface (Java) is interconnected with ISIS-Proteus application through using VSPK (Virtual Serial Port Kit), which create virtual connections between COM6 (hardware PC) and COM1 (in Proteus) and also for COM3 (hardware PC) and COM2 (in Proteus).

Control system for Acriche LEDs MJT 4040 have been used, where two ACS1404 chips controls 16 LEDs (Figure 11). The structure includes a radiator for heat dissipation, a bridge rectifier to supply ACS and some elements to protect the circuit.

Figure 10. Test system

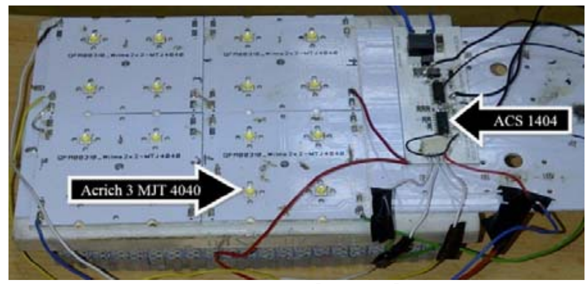


Figure 11. LED lamp pylon

Control interface involves technologies such as Java SDK Standard Edition and JME through NetBeans 3.4. The application done can send unicast, multicast and broadcast commands after a connection to a COM port and also we can write received information in a database (Figure 12 left). J2ME offers an application that reads, using a PHP script, the last record from MySQL database (Figure 12 right).

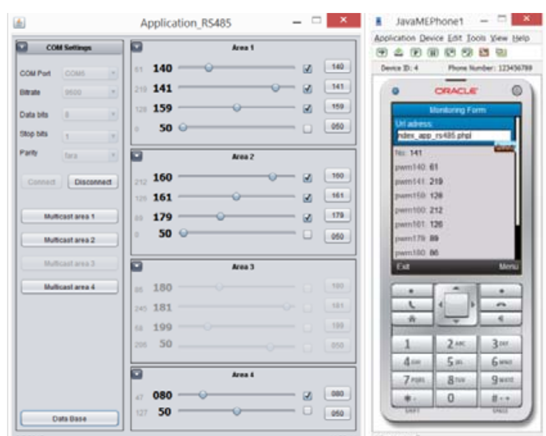
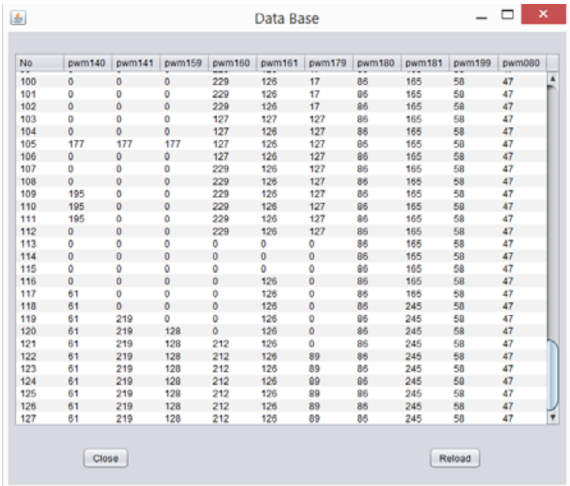


Figure 12. Control interfaces for PC and mobile phone

The database structure (Figure 13) include, for this example, 11 fields being used here as XAMPP.



No	pwm140	pwm141	pwm159	pwm160	pwm161	pwm179	pwm180	pwm181	pwm199	pwm080
100	0	0	0	229	126	17	86	165	58	47
101	0	0	0	229	126	17	86	165	58	47
102	0	0	0	229	126	17	86	165	58	47
103	0	0	0	127	127	127	86	165	58	47
104	0	0	0	127	126	127	86	165	58	47
105	177	177	177	127	126	127	86	165	58	47
106	0	0	0	127	126	127	86	165	58	47
107	0	0	0	229	126	127	86	165	58	47
108	0	0	0	229	126	127	86	165	58	47
109	195	0	0	229	126	127	86	165	58	47
110	195	0	0	229	126	127	86	165	58	47
111	195	0	0	229	126	127	86	165	58	47
112	0	0	0	229	126	127	86	165	58	47
113	0	0	0	0	0	0	86	165	58	47
114	0	0	0	0	0	0	86	165	58	47
115	0	0	0	0	0	0	86	165	58	47
116	0	0	0	0	126	0	86	165	58	47
117	61	0	0	0	126	0	86	165	58	47
118	61	0	0	0	126	0	86	245	58	47
119	61	219	0	0	126	0	86	245	58	47
120	61	219	128	0	126	0	86	245	58	47
121	61	219	128	212	126	0	86	245	58	47
122	61	219	128	212	126	89	86	245	58	47
123	61	219	128	212	126	89	86	245	58	47
124	61	219	128	212	126	89	86	245	58	47
125	61	219	128	212	126	89	86	245	58	47
126	61	219	128	212	126	89	86	245	58	47
127	61	219	128	212	126	89	86	245	58	47

Figure 13. Data base

Interconnecting the application in Proteus ISIS application through VSPK enables us sending multicast commands, e.g. for zone 3, as shown in Figure 14.

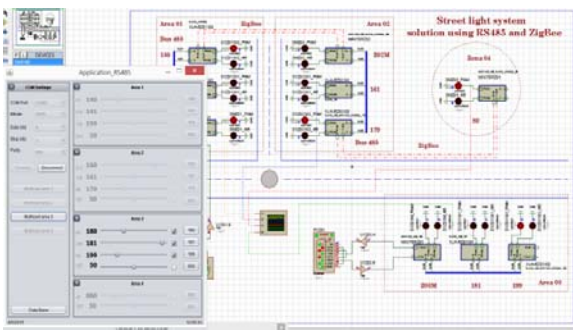


Figure 14. ISIS – Proteus simulation

Signals previous active for addresses 140, 161 and 080, are added on the address signal 181 (the lowest on the oscilloscope in Figure 15).

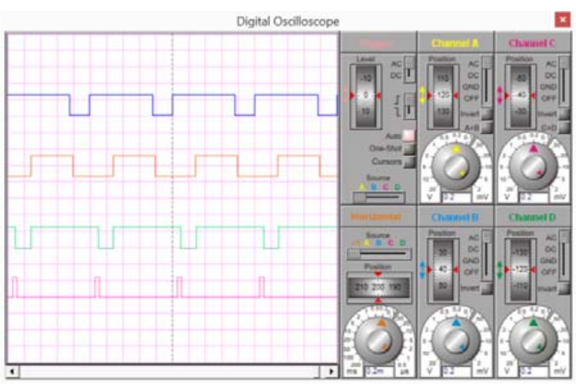


Figure 15. Simulation results

The JAVA interface is shown in Figure 16. We used Java Swing, so using appropriate controls were made:

- one module to connect GSM device through serial port COM;
- one module to setup PWM value for each element of the system;
- one module to unicast data transfer for a selected device by the interface;
- one module to multicast data transfer for a group of devices, all of them selected by user interface;
- one module to broadcast data transfer for all devices that are in designed area of the system;
- one module for reading data from Datbase and for writing PWM values selected for each LED lamp.

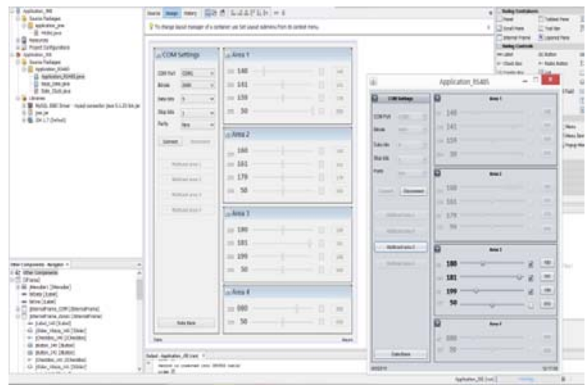


Figure 16. JSE control interface

5. CONCLUSIONS AND FUTURE WORK

This paper proposes a system of public lighting control, based on a hybrid communication solution GSM – RS485 – ZigBee. The proposed system is particularly suitable for street lighting in urban and rural areas where the traffic is light 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. In this regard, Java and Proteus ISIS (Figure 17), have allowed us to demonstrate the value of IT and hardware technologies chosen to implement such a system. The solution is based on the paper [12], which introduced the GSM communication by replacing Bluetooth solution.

To widespread the deployment of the system it is necessary to replace the development boards used with the designed systems proposed in the paper, adding components such as real time clock, light sensor, electronic components to identify energy consumption, while to transfer data it is necessary to design an improved protocol that includes feedback response message and field for errors detection in data transfer.

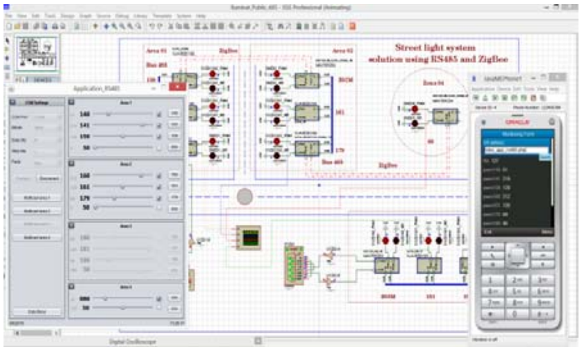


Figure 17. System control

Working options that we address in our research concern GSM - CAN - ZigBee technologies or an integral wireless solution GSM with nRF24L01 devices.

The purpose of implementing a remote control makes sense and also for idea that, using a system of videocameras, the motion recognition, shapes and textures analysis [13] or face detection, we can appreciate the need for progressive ignition - extinction of light at night when a vehicle is moving in that area or a pedestrian want to cross the road. Implementation of detection algorithms in DSP systems to control the street lighting, for example in the proposed system, is under study.

6. ACKNOWLEDGMENTS

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