Design and Implementation Of Smart Wireless Street Lighting System With Ad-Hoc Network Configuration

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Abstract

In this research, a smart wireless street lighting system (SWSL) based on wireless communication using ZigBee configuration is designed, implemented, and analyzed. The proposed SWSL system which is equipped with sensors (light sensor, motion sensor, current and voltage sensor), time readers and the microcontroller so that the system is able to regulate its function automatically according to the time and environmental conditions. The SWSL communication system is using ad-hoc network configuration to transmit the data information of each point of lights to the server. Ad-hoc network configuration makes the system more flexible because each node can communicate with each other directly without having to go through an access point. In addition, this system also uses LED lights and apply on-grid technology that uses the energy of sunlight as its primary power source, so it is able to save on energy consumption. It is shown from the results, the system has been able to work in accordance with designed algorithms (resources switching, work function of light and sensor, and data communication). On data communications testing for transmitting data from router node to coordinator node, is obtained data reception success rate of 82.085%. Then, from the results of the calculating simulation of the efficiency of the system obtained the total power usage of SWSL per year only amounted to 59.09 KWh / lamp. Therefore, SWSL system is much more efficient in terms of energy consumption compared to existing street lighting system

1. Introduction

Public street lighting (PSL) is a vital infrastructure required the public to light street especially at night. In addition to this, the PSL functions are also to improve security, prevent criminality and provide comfort and beauty of the environment. In every country, PSL system has enormous network with huge energy consumption levels. It is not known for certain, but it is estimated there are hundreds of millions to one billion units of existing street lights around the world [1]. In Indonesia, this system contributes to 4.95% of peak load and 2.85% consumption of electricity [2].

PSL standards commonly used today are lacking advantages of technological developments. Lighting system is less precise work and still operated manually, it causes wasteful use of energy in operation [3]. In addition, the system network is still cable-based as well as the manually monitoring and maintenance methods. It also still makes the system less effective and efficient.

Many researches have been done to design a street lighting system more flexible and efficient compared to existing conventional system. A recent research [4] had developed a remote control system for street lighting system that have been equipped with sensors and controllers as well as the usage of solar power. The controller also had the ability to transmit the information to the central control using ZigBee network, so that the network is more flexible and installable. It is known, that this system was quite efficient in terms of energy consumption, however it is still not optimal because the lamp only had on-off operation mode without being able to perform the function of the setting. The lighting intensity when the condition or state of the environment does not require full illumination intensity.

Other research [5] has also developed the control of street lamps based on ZigBee networking standards. More minimalist system developed by using only 1 (one) ZigBee module and a microcontroller to regulate some street lights. However, this system is more efficient in the initial development investment, but it has drawback because it still uses a cable network for connection between the lamps on the same cluster.

A Shiddiqui et.al. [6] had developed a complex system to monitor and control of the smart street light as well. In addition to this, turning on and off the lights, the system has also been able to adjust the lighting intensity by using ballast actuator, which is fitted with the condition of the environment. The system uses an embedded system for regulators and ZigBee module for wireless communication. It is quite complex, but the system has not been yet represented as energy efficient. Which is not because of the lack implementation on-grid technologies that use sunlight as a primary resource.

Smart wireless street lighting (SWSL) system in [3] and [7] are already using sensors that are able to make the system more efficient and reliable, because it is able to measure physical quantities and parameters that can be used to adjust to the environment. The system also uses a ZigBee module as a wireless transmission medium as well as the use of light emitting diode (LED) lighting technology and applying on-grid for its resources. The weakness of the system in this research is not yet configured and conditioned to form the actual network, the system is only configured for single peer communication (point to point).

2. Proposed SWSL

SWSL system based on wireless sensor networks will be designed and analyzed. The system is equipped with sensors (light, presence, current and voltage sensor), time readers (real time clock) and a microcontroller that used to regulate the works of system according to the state or condition of the surrounding environment. The system was designed to be able to turning on/off and dimming based on sensor measurement.

SWSL communication system uses a ZigBee module with ad-hoc network configuration to transmit information data from each node towards the server. The information data transmitted by each node is lamp energy consumption data (the current and voltage of lamp), status of lights (on, off or broken), status of sensor, status of battery, error in the system, and the time and date of data sampling. These data help in the process of monitoring and control, and will be stored in the system database as documentation.

In order to save energy consumption, this system uses LED lights and on-grid technology that uses solar cells as a main power resource. Fig.1 shows the hardware configuration of the proposed SWSL.

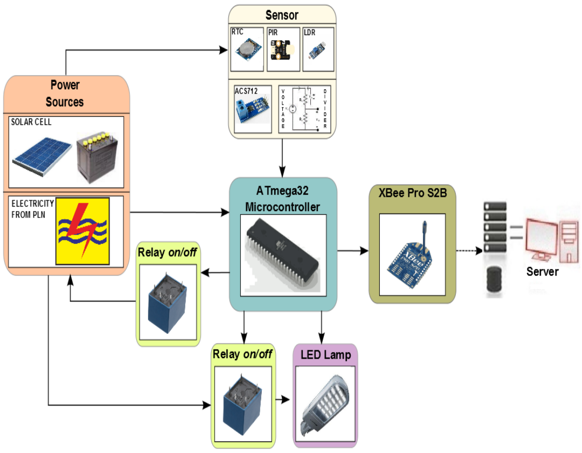

Fig. 1. Hardware configuration of SWSL

The components use for the design are as follows:

a. Light dependent resistor (LDR) is light sensor that uses to observe the brightness level around the streetlights node.
b. Passive infra-red (PIR) is presence sensor that uses to detect human presence around the streetlights node.
c. Current sensor is used to measure the current flow in the lights.
d. Voltage Sensor (voltage divider circuit) is used to measure the value of the voltage on the battery and lights.
e. Real time clock (RTC) is used as a master clock on the system for sampling of monitoring data.
f. Microcontroller is used as the controller of the entire hardware in the system.
g. XBee Pro Series 2B is used as a gateway for wireless communication between lights points (nodes) and servers.
h. Solar panel and battery

Solar panels are used to convert sunlight into electrical energy using photovoltaic effect principle. This system uses solar panels that generate power of 100 Watt peak (Wp). This system also uses a battery to store electrical energy from solar panels. The battery used has a capacity of 100 Ah with the resulting voltage of 12 volts.

3. Ad-hoc Configuration

In the implementation, the system is designed to operate on the ad-hoc network configuration, where all nodes in the system are able to communicate directly without going through the access point and serves as a router to forward the information / data from each node in order to get to the server. Data received by the server will then be stored in the form of a database.

Ad-hoc network configuration is suitable to be implemented on a SWSL because the system does not require the support of the backbone infrastructure. Ad-hoc network is also very flexible and can be reconfigured in a variety of topologies both for small and large number of node in accordance with the application and installation. Each node in an ad-hoc network must be able to maintain the performance of the data traffic by reconfigure the network. For example, if there is a faulty node, then the node which sends the data through faulty node will request the establishment of the new link route to forward the data.

The process of realization of the system is done by fabricating an embedded system which is the core of the SWSL overall. Fig.2 is a result of fabrication of SWSL.

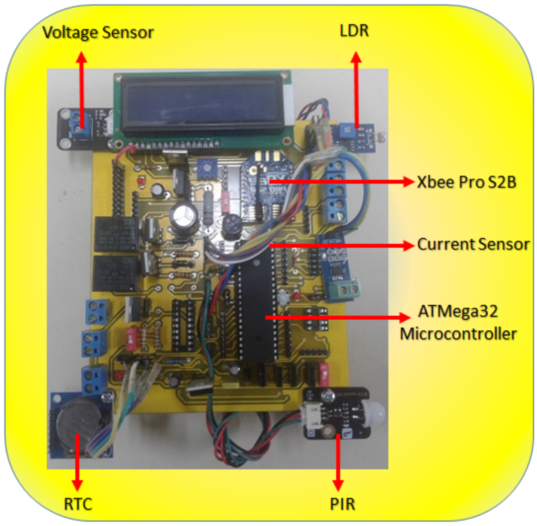

Fig. 2. The fabrication of embedded systems

4. Test and Analysis

4.1. The testing of Resources Switching Algorithm

Resources switching algorithm is designed to make the prioritizing system that use of resources from the battery (which is derived from solar panels), but it can also automatically switch to electricity grid resources when battery capacity is below the lower threshold. The mechanism of resources selection is done by utilizing the analog comparator features of the microcontroller. Analog comparator is used to compare the input voltage with an internal reference voltage of the microcontroller. The selection of system resources run based on battery capacity, if the battery capacity is less than 12 volts then the system will automatically switch the power source to the electricity grid, but if the battery capacity back to 12 volts or more then system resources will switch back to the battery. The transition of resources from the battery to the electricity grid can be seen from the data changes that read via serial monitor of Arduino IDE software, as shown in Fig. 3.

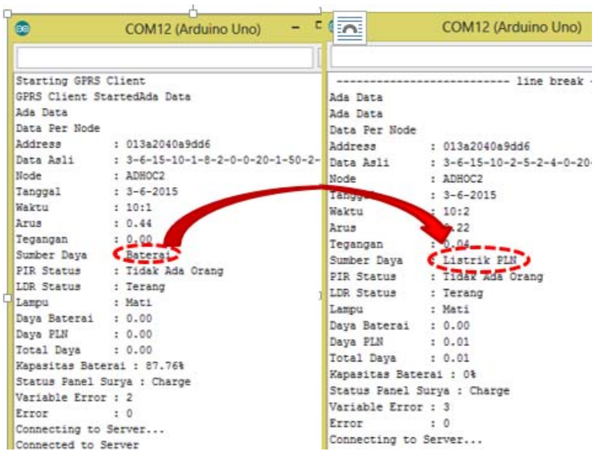

Fig. 3. Testing of resources switching algorithm via Arduino IDE software

From Fig.3, it can be seen that if the capacity of the battery is 12 volts or more, then the resources used batteries, however, if the battery capacity is below 12 volts, then the power source switch to electricity grid.

4.2. The Testing of Work Function of Lights and Sensor Algorithm

Work function of lights and sensor algorithm is shown in Fig.4.

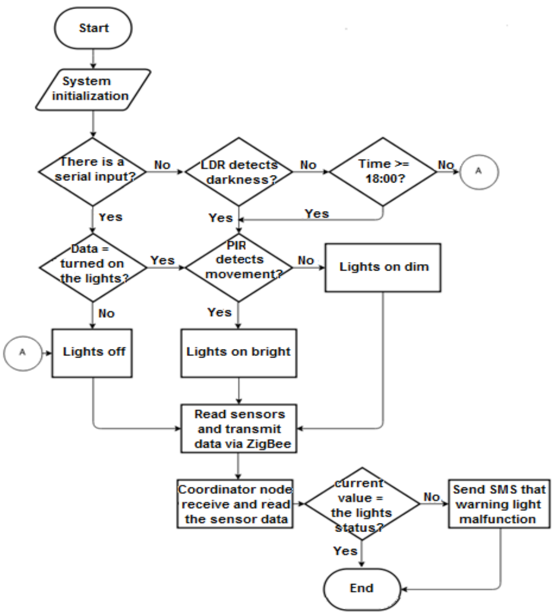

Fig. 4. Flowchart of work function of lights and sensor algorithm

The testing of lights function and sensor algorithm is accomplished to see the performance of the sensor in regulating the operation of the lights and see the difference in the parameters when the lights turn off (in the morning and afternoon) and when the lights turn on (at night). In the morning and afternoon the SWSL will be measured the performance parameters of the sensor LDR, RTC, current sensors and voltage sensors. Meanwhile at night, it will be measured by the performance parameters of the sensor LDR, PIR, RTC, current sensors and voltage sensors. Table 1 shows the data for sensor at each node.

Table 1 Test Data for Sensor at Each Node

The data taken from the hours 17:00 to 9:00									
	The number of data packets that received and uploaded to server Successfully	Status of LDR		Status of PIR		Status of Lights		Status of Resources	
		Bright	Dark	There are Activities	No Activities	On	Off	Battery	PLN Electricity
Node 1	828	175	653	12	816	653	175	828	0
Node 2	776	151	625	10	766	625	151	776	0
Node 3	774	154	620	11	763	620	154	774	0
Node 4	774	155	619	10	764	619	155	774	0

It is shown from Table 1, that the number of data packets which are successfully received and uploaded to the server is different for each node. Node 1 has the largest number of data packets that are received and uploaded successfully compared to other nodes. This can occur because of a failure during the process of uploading the data to the server. It is shown from Table 1, that the performance of LDR with the status of lights have been appropriate. This can be seen from the same amount of data between the status of the LDR and status of lights, when LDR detects dark then the lights goes on and when the LDR detects bright then the lights goes out. From the Table 1, then the data samples taken during the transition of lighting condition, which the results are shown in Table 2.

Table 2 Test Data on Transition of Lighting Conditions

	Time	Hours	LDR	I (A)	V (Volt)	Resources	Lights	Battery Capacity (%)
Node 1	Morning	05.58	dark	0.22	9.38	battery	on	55.61
		05.59	bright	0	0	battery	off	73.57
	Afternoon	17.19	bright	0	0	battery	off	97.95
		17.20	dark	0.67	7.81	battery	on	68.44
Node 2	Morning	6:01	dark	0.15	9.38	battery	on	78.7
		6:03	bright	0	0	battery	off	81.27
	Afternoon	17:14	bright	0	0	battery	off	97.95
		17:19	dark	0.81	8.69	battery	on	95.38
Node 3	Morning	6:04	dark	0.15	9.38	battery	on	77.42
		6:05	bright	0	0	battery	off	79.99
	Afternoon	17.14	bright	0	0	battery	off	94.1
		17:21	dark	0.89	7.78	battery	on	69.72
Node 4	Morning	6:02	dark	0.22	9.38	battery	on	72.29
		6:04	bright	0	0	battery	off	74.85
	Afternoon	17:20	bright	0	0	battery	off	97.95
		17:21	dark	0.22	9.38	battery	on	81.27

Table 2 shows that the transitional status of the lights on all nodes either in the morning or afternoon, happened at about the same time. It proves that the reading of the sensor parameters and the lights operating settings by the microcontroller has to function properly. It is also shown from Table 2, that in the afternoon, battery capacity is always in a full state (above 94%), which indicates that the solar panels managed to charge the battery. Then the capacity will decrease when it used for lighting. From the current and voltage measurement results, it is indicate that the value of the current and voltage are almost non-existent when the light turns off. It has a value that varies at the moment the lights on bright or dim. The value of the lights current and voltage are shown in Table 3.

Table 3 Current and Voltage Values on Different Lights Operation

Status of Lights	Voltage (V)	Current (A)	Power (W)
Lights on bright	11.78	2.07	24.38
Lights on dim	9.28	0.28	2.6
Lights off	0	0.175	0

4.3. The Testing of Data Communication Algorithm

Data communication between nodes are performed by applying the ad-hoc network configuration. In testing, use 4 nodes that are configured as a router nodes and one node as a coordinator node. Router nodes are integrated on the physical street lights, while the coordinator node is not integrated at the physical street lights but integrated with GPRS/GSM Shield module for sending data to the server or to send alert via SMS. The data communication test results data from router nodes to coordinator node is shown in Table 4.

Table 4 The Data Communications Testing Results from Router to Coordinator Nodes

The data taken from the hours 17:00 to 9:00 (16 hours)				
	The number of data packets that should be accepted	The number of data packets that can be accepted and uploaded	The number of data packets that failed to received and uploaded	The success rate of data packets that can be accepted and uploaded (%)
Node 1	960	828	132	86.25
Node 2	960	776	184	80.83
Node 3	960	774	186	80.63
Node 4	960	774	186	80.63
Average				82.085

Based on test results, it is shown from Table 4 that the average results with a success rate of 82 085%, where from the 960 sampled amount of data during 16 hours, there are 172 the amount of data that failed to be accepted and uploaded to the server. Failure reception of data can be caused due to two factors, , namely due to the failure in the process of sending data by ZigBee or because of the failure in the process of uploading the data to the server due to weak / loss of GPRS signal, so the data is not entered into the database.

4.4. Testing The Influences Of A Distance Towards Data Communication

The test is aimed to see the influences of a distance against the validity of the data received. Testing data communications are conducted from router nodes to coordinator node by sending data packets consisting of 29 bytes as many as 10 times for each distance. Testing conducted in a state of line of sight (LOS) condition. Table 5 shows the data obtained from the testing.

Table 5 Testing Data Communications with Distance Variations

No.	Distance (meter)	The amount of data sent	The amount of data received
1	20	10	10
2	40	10	10
3	60	10	10
4	80	10	10
5	100	10	10
6	120	10	10
7	140	10	10
8	160	10	10
9	165	10	9

It is shown from Table 5, that up to a distance of 160 meters, all data sent from router nodes can be entirely well received by the coordinator node. However in a distance of 165 meters, from 10 times the data transmission only 9 data can still be received well. It can be concluded that the maximum distance of system communication in a state of LOS is 160 meters. When implementing the system with ad-hoc network configuration, recommended maximum distance between nodes is ½ of the maximum distance where the node can still deliver and receive data properly, i.e. 80 meters.

4.5. Calculation of Maximum Number of Nodes

Based on the range of time required between nodes starting from the data transmitted up to received and uploaded to the server, it can be calculated the maximum number of nodes that can communicate with the coordinator node in the configuration and algorithms designed. Table 6 shows the time required between nodes to transmit data.

Table 6 The Time Required Between Nodes to Transmit Data

The data taken from the hours 17:00 to 9:00 (16 hours)	
The Turn Time Of Data Transmission	Required Time (sec)
Node 1 – *Node* 2	4.46
Node 2 – *Node* 3	4
Node 3 – *Node* 4	4.25
Average	4.23

It is shown from Table 6, that the average time required between nodes to transmit data up to received and uploaded successfully to the server is for 4.23 seconds. So in 1 minute, the maximum number of nodes which data can still be received and uploaded to the server are as many as 14 nodes. To increase the maximum capacity of the nodes that can be connected, it can be done by:

1. Adding data transmission time duration (> 1 min);
2. Uploading of data is done after several periods of data transmission (not done in every time period of data transmission). This is done to save time in the process of uploading the data to the server.

5. Conclusion

The smart wireless street lighting system (SWSL) based on smart-grid and wireless sensor network using ZigBee 2.4 GHz with ad-hoc network configuration has been designed and implemented. The system is designed to be able to perform the function of supervision (monitoring), control and data storage to make it more effective and efficient in the process of operation, control and maintenance. The design of the system is divided into two stages, namely the design of hardware and software. On testing data communications for 16 hours by using an ad-hoc network configuration, obtained a success rate of 82.085%. Data reception failure caused due to two factors, namely due to the failure in sending the data by ZigBee (11.824%) and due to failure in the process of uploading the data to the server due to weak/loss of GPRS signal (6.091 percent). From the testing data communications with the variation of the distance indicate that maximum distance communication system in a state of LOS is 160 meters. Then from the calculation of the system efficiency obtained the total power usage per year of 59.09 KWh/lights. So the smart street lighting system use energy much more efficiently than other existing street lighting system, which is about 1/15 of the energy use of conventional street lights powered by electricity grid and 1/2 of the energy use of solar-powered street lights.

6. References

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