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An Improved Population Based Automatic Appliance Control System for Effective Energy Management

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ABSTRACT:

In this work, a population-based energy management system was developed to control the switching of electrical appliances in a building based on the number of persons available in the building in order to reduce the amount and cost of energy consumed. This was achieved through the use of an Arduino Nano controller board, RCWL-0516 microwave motion sensor, two ultrasonic distance sensors, a switching relay, 16x2 LCD and a 12V DC power supply. The Microwave motion sensor was used in determining human motion and as such initiated counting by the ultrasonic sensors. The ultrasonic sensors were placed at the exit and entry points. Counting by the ultrasonic sensor was determined by the direction of passage. The resultant population present was displayed on the LCD. When tested, the system was observed to switch off all electrical appliances when population count was at zero, signifying no one present in the building, and appliances turned on when a human entry was detected. Thus, this system was able to effectively manage energy, reducing the cost of energy consumption, and also prevents damage to electrical appliances as no appliance was left ON when no one was present.

Keywords: Arduino Nano, Electrical appliances, Energy, Microwave, RCWL-0516, Ultrasonic Sensor.

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1. INTRODUCTION:

Energy is one of the most important factors for human survival apart from food and water. Energy efficiency is the optimization of energy that is available. The need for energy efficiency as part of our everyday life is a necessary objective from both an economic and environmental point of view (Olayinka *et al*., 2016).

Considering the high cost incurred daily as a result of unnecessary and uncontrolled energy consumption, there is a need for some form of energy management and regulation system for buildings such as homes and offices (Vijay & Nithya, 2017).

Energy management as defined by Beuth (2007)

> *"is the proactive, organized and systematic coordination of procurement, conversion, distribution and use of energy to meet the requirements, taking into account environmental and economic objectives".*

The governments of various countries over time have implemented several policies; all in a bid to efficiently and effectively manage the energy (electrical energy) available. Considering Nigeria as a case study, different administrations have enacted different energy management laws such as the National Energy Policy of 2003, the Electric Power Sector Reform Act of 2005 and the Nigerian Electricity Regulatory Commission Regulation for Mini-Grids of 2016. These policies were mainly aimed at increasing the power generating capacity of the country, thereby making energy available to all Nigerians. They also failed to address

challenges such as; excessive electricity bills, damage to appliances of consumer's resulting from the effect sudden restoration of power.

Rahul *et al*. (2014) developed a cellphone based home appliance control system using the CD4017 IC, IRF530 MOSFETs, relays and a cell phone. The CD4017 served as the main processing unit of the system. When a call is made to the cell phone on the system, a pulse is generated in the speaker of the cell phone. This pulse is used in controlling devices through the use of DTMF tones.

Ajinkya and Sanket (2015) developed a home appliance control system based on a smartphone. Commands were sent via Bluetooth from the smartphone to an ARM9 processor board which had a Bluetooth module interfaced with it. The ARM processor based on the commands received controls relays which switch ON or OFF electrical appliances in the home. In the work of Undavalli *et al*. (2015), a home automation system was designed with the use of a microcontroller, an LCD screen and IR sensors. A major drawback of this system was that Data was lost whenever there was an interruption in power supply to the system.

In the work of Chintha *et al.* (2017), an electrical home appliance control device was developed using an IR remote. This work was based on a Sony IR remote which uses 12-bit SIRC protocol and thus had a limited range of 10 meters. An IR transmitter led and a TSOP-1738 receiver module was used to receive the IR signals sent by the transmitter. The microcontroller interprets and matches this received signal which was a bit pattern and compares it to that already programmed in the microcontroller. The received signal was used in controlling the switching of relays controlling home appliances.

An Arduino home appliance control system was developed by Pramod *et al.* (2017). This system consisted of four units, a D.C power supply, a controlling unit which was the Arduino Nano, a receiver IR module and the switching section which was connected to home loads. When a button on the NEC remote control is pressed, a preprogrammed infrared signal was sent. This signal was received by the TSOP1838 IR Receiver sensor at a frequency of 38 KHz and transferred to the Arduino via digital pins. This signal received by the Arduino was compared against signal values already stored in the controller's memory and appropriate switching carried out. This system required direct human interaction to function and did not take into consideration the number of persons in the home. Also, its functioning was based on an NEC remote control and so had its range limited to the range of the remote.

Orike and Enoch (2019) developed a smart microcomputer-based controlled device for electrically powered gadgets. The device was able to control appliances in the home automatically according to the specified instructions given to it.

This current work is centered on the use of ultrasonic sensors in the development of a digital counter or counting system. It also focuses on electrical appliance control based on the result from the ultrasonic digital counter as a measure to address energy management. The design and implementation of this system will greatly assist in proffering solution to the various challenges resulting from poor energy management in Nigeria. Effective implementation of this system will aid in reducing the amount of energy consumed by ensuring that electrical appliances are turned OFF when no one is present in the building where this device/system is installed. Thus, providing an affordable means for efficient energy management in a country such as Nigeria where electrical power generation is inadequate.

Successful implementation of this system will ensure that the number of persons present in a building at any point in time is known, thereby serving as an attendance counter.

2. MATERIALS AND METHODS:

The population-based appliance control system designed in this work comprises of the digital

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counter unit and the switching unit. The Counter unit consists of the Arduino Nano, the RCWL-0516 microwave motion sensor, the ULTRASONIC sensors which are to be placed at entry and exit point and the liquid crystal display.

2.1 System Description

Each component part of the presence based automatic appliance control system developed in this work performs a distinct function in the overall operation of the system. Fig. 1 illustrates the flow of data and operation of the system.

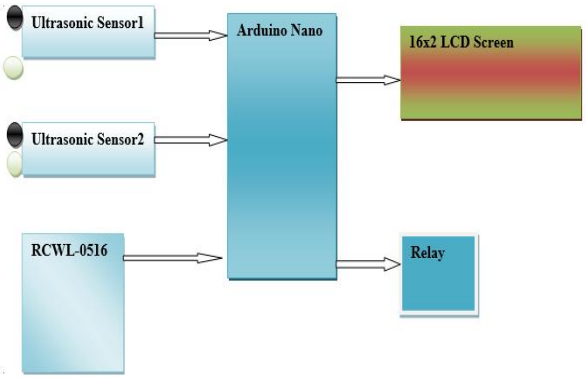

Fig 1: System Component Interaction.

Arduino Nano

The Arduino Nano development board is chosen as the microcontroller board in this work. This board is chosen because of its size (1.7 by 0.73inches), mounting headers for PCB application, and its onboard ATMegat328p. The Arduino Nano board controls all other components and houses the source code which governs the operations of the system.

In this work, the Arduino Nano receives the corresponding HIGH and LOW signals from the ultrasonic sensors, interprets this signal based on the source code stored in its memory thus, controlling the switching of the relay and the LCD display.

RCWL-0516

The RCWL-0516 is a Doppler radar microwave motion sensor module equipped to function with a voltage range of 4-28V DC, which can act as an alternative to a PIR motion sensor. This sensor has a RCWL-9196 chip embedded on it. The operation of this sensor is based on Doppler microwave induction technology which can be mathematically expressed as a Doppler shift for moving observer and a stationary source or medium, where the RCWL-0516 is the source medium and the human within the sensor range as the observer. In this reference frame, the source which is the sensor is approached at speed V_0 the speed with which the wave approaches is *vo + v*. The time interval between the arrival of the first and the $(n+1)^{th}$ crests is given as:

$$t_{n+1}, t_1, nT_0, \frac{nv_0T_0}{v_0\,v} \quad (1)$$

Thus, the period of the wave can be measured as

$$T = T_0[1 - \frac{v_0}{v_0 - v}] \quad (2)$$

$$T = T_0[1 - \frac{v_0}{v}]^{-1} \quad (3)$$

The RCWL-0516 is capable of sensing human motion in 360 degrees with no blind spot and has a maximum sensing range of 7000mm (7meters) with adjustable time delay and sensitivity. The microwave oscillator generates an oscillation signal having a frequency of 5.8 GHZ, and the oscillation signal is output to the microwave transmitting/receiving rectangular antenna; the microwave transmitting/receiving rectangular antenna transmits a microwave signal having a frequency of 5.8 GHZ, and when a moving human body is detected, the microwave transmitting/receiving rectangular antenna receives an echo signal having a reflection frequency. The reflection of this frequency by only human body is as a result of the temperature of human body which ranges from 36.1-37.2ºC and the penetration of human skin by microwaves within 5.2-5.9GHz. After this oscillation signal has been generated by the microwave oscillator, and an echo signal is output to the microwave, schottky diode are used as double balanced mixer for differential-frequency processing. Here, the RCWL-0516 is connected to digital pin 6 of the Arduino Nano

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board. It is used to control the operation of the IR Sensors. When human motion is present, which signifies the presence of a human close to the door, a HIH signal is sent by the sensor to the Arduino pin 6. Thus, when this HIGH signal is present signifying human presence, counting can be carried out by the ultrasonic sensors else, no counting is performed.

Ultrasonic Sensor

Ultrasonic detection is based on the principle of sound wave propagation and the Huygens-Fresnel principle. It is commonly used industrially to detect hidden tracks, discontinuities in metals, composites, plastics, ceramics, and for water level detection.

Sound is a pressure perturbation that travels as a wave. This can be expressed mathematically by the wave equation.

$$\nabla^2 \Phi - \frac{1}{c^2}\frac{d^2\Phi}{dt^2} = 0 \qquad (4)$$

Where:

∇^2 is the Laplace operator.

p = acoustic pressure.

c = speed of sound.

The pulse emitted by the ultrasonic sensor is based on the Huygens-Fresnel principle which states "that every point on a wave front is a source of wavelets. These wavelets spread out in the forward direction, at the same speed as the source wave. The new wave front is a line tangent to all of the wavelets". This can be expressed mathematically as

$$U(r_0) = \frac{U_0 e^{ikr_0}}{r_0} \qquad (5)$$

Where:

U_0 is known as the complex amplitude which produces a spherical wave with wavelength λ, wave number $k = 2\pi/\lambda$.

The Ultrasonic sensors convert electrical energy to mechanical energy in the form of sound waves. When an electrical pulse or signal usually 5V is applied on the ultrasonic transceiver, it oscillates across a specific range of frequencies, generating a bust of acoustic waves. This acoustic wave is reflected back to the sensor in form of echo whenever an object is placed in front of the sensor. This echo is received as electrical pulse by the sensor and the time-difference between the when the pulse is emitted and the echo signal received is computed as the distance of the object or medium from the sensor. The expression in (7) is employed in the program governing the entire device in calculating this distance.

$$distance, R = \frac{c\tau}{2} \qquad (6)$$

$$distance, R = \frac{duration \times 0.034}{2} \qquad (7)$$

Where:

R = Distance of object from the sensor.

C = Time of taken to send and receive pulse

$\tau = 0.034$=Pulse Length

LCD

The LCD is a digital display screen used to display alphanumeric characters and some special symbols. LCDs are categorized according to their screen resolution. The 16x2 LCD screen is used in this design and is capable of displaying characters on 16 columns and 2 rows. The LCD is interfaced to the Arduino Nano as shown in Table 1.

Table 1: Pin specification for the LCD

LCD PIN	ARDUINO NANO PIN
Pin1	Controller's ground
Pin2	5v dc
Pin3	Potentiometer for contrast variation
Pin4/RS	Controller's pin 12
Pin5/RW	Controller's ground
Pin6/Enable	Controller's pin 11
D4	Controller's pin 5
D5	Controller's pin4

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D6	Controller's pin3
D7	Controller's pin2
Pin 15	5v dc
Pin16	Controller's ground

Relay

The switching unit consists of a contact relay which is connected to the load to be controlled. In this work, a single channel 5V relay is used to control the switching of an electrical appliance. The relay is controlled by a digital pin on the microcontroller via a 2N3904 transistor. The relay and its driver circuit is interfaced to the Arduino Nano as shown in Fig 2.

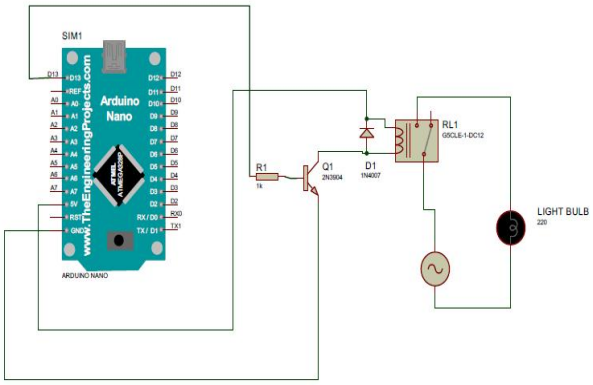

Fig 2: Relay switching Circuit.

2.2 Hardware Design

The hardware of this system comprises all electronic components used in building the circuit. The entire design is built on a printed circuit board (PCB) with each individual component soldered to the PCB. The circuit diagram of the population-based appliance control system for energy management is illustrated in Fig. 3.

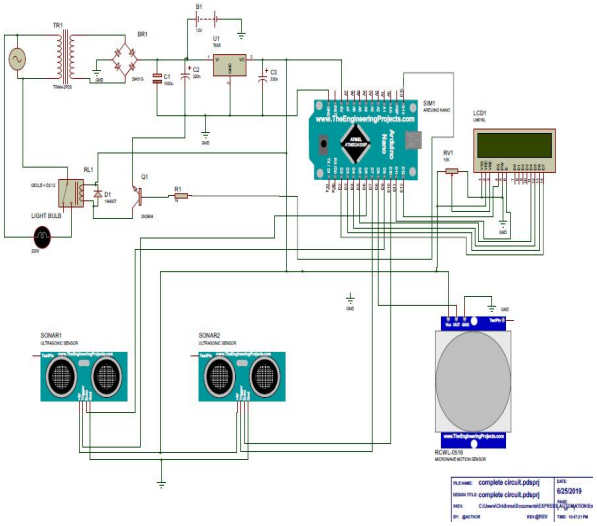

Fig 3: System Circuit Diagram.

2.3 Software Design

The source code or intelligence governing the entire system is written in C++ language using the Arduino Integrated Development Environment (IDE) which serves as the compiler, converting the C++ code to machine code which the microcontroller understands.

The source code is written such that the addition and subtraction of the sensor values are executed by the microcontroller and the result displayed on the LCD screen by switching ON/OFF the corresponding segment.

3. RESULTS AND DISCUSSION:

3.1 Counting Unit Result

The counting unit is tested to ensure proper functioning of all sensors used. These tests were also carried out to ensure that the system operates as required. The counting unit is tested using two methods. First, it was tested on the Serial monitor Interface on the Arduino IDE to check for errors and to make adjustments to the program. Hardware test was then platform to ensure proper functionality of the device before soldering on then PCB.

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Table 2: Microwave Sensor Characteristic Behavior

Object Close to the Door	Microwave Sensor S
Paper	0
Wood	0
Child	1
Moving Cloth	0
Adult Male	1
Adult Female	1
Milk Jug	0
Toy Car	0

Table 3: Characteristic behavior of the System

S/N	DOOR STATUS	POPULATION PRESENT	RELAY STATE	DISPLAY
1	Idle	0	OPEN	"BUILDING EMPTY"
2	Entry	1	CLOSED	"POPULATION = 1"
3	Entry	2	CLOSED	"POPULATION = 2"
4	Entry	3	CLOSED	"POPULATION = 3"
5	Exit	2	CLOSED	"POPULATION = 2"
6	Exit	1	CLOSED	"POPULATION = 1"
7	Exit	0	OPEN	"POPULATION = 0"

From Table 3, it can be observed that the population values on the Serial monitor and the LCD screen increases and decreases when entry and exit is detected. The increment in population counter value results from continuous entry of persons into the building this increment is detected by ultrasonic sensor1. A decrement in the population value is observed when a person exits the building. That is exit is detected by ultrasonic sensor 2. These increment and decrement only exited when a human body transverse through the doorway as shown in Table 2. From these results, the ultrasonic sensors have been used effectively in as a population counting device

Also, as shown in Fig. 5 and Table 3, when the population counter is zero "NO ONE PRESENT ALL APPLIANCES SWITCHED OFF" can be observed on the serial monitor of the Arduino IDE and "BUILDING EMPTY" can be seen on the LCD screen. Also, the population counter is observed to be zero when objects such as a wooden table, stool and a dog are place in doorway. This is due to the sensing of the IR sensors being controlled by the RCWL-0516 microwave senor which is designed to detect only human presence. Thus, the accurate number of persons present in the building can be determined per time irrespective of other inanimate and animate objects. The bulb is turned ON for values of population counter greater than zero and OFF at a population count of zero. Thus, when no one is present in the building, the switching relay automatically turns OFF all appliances connected to it. This observation shows that switching of the electrical appliances is controlled based on the population or number of persons present.

It is also observed that when there is interruption in power supply to the device, upon restoration of power, there is no loss of data as the number of persons present remains the same. This can be attributed to the use of the EEPROM of the Arduino Nano. Through the design of a presence based automatic appliance control device, developed a system where load is automatically

shut down when nobody is in a room or building, energy is managed effectively, wastage of power is minimized, fire outbreak due to electrical fault is prevented.

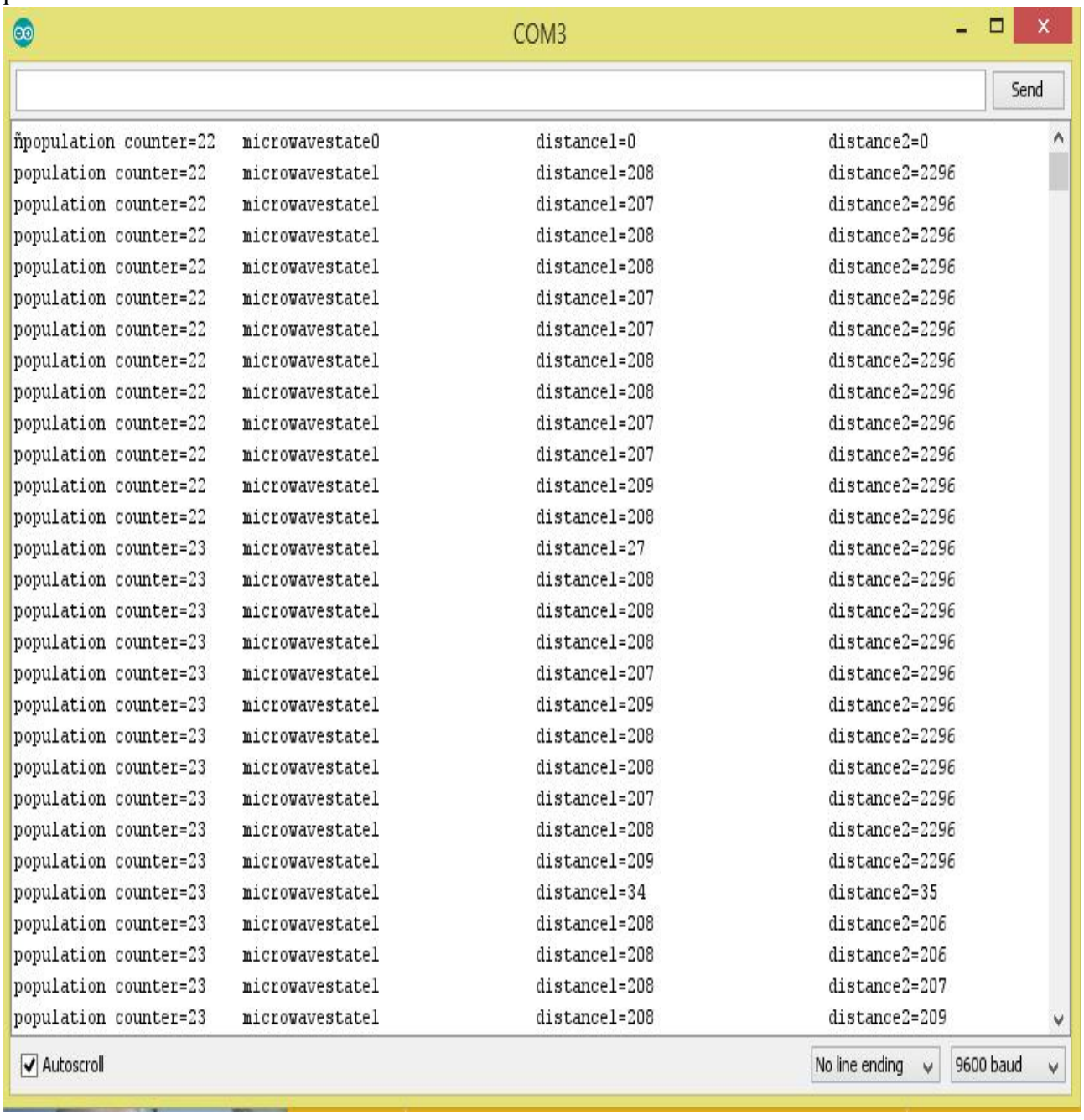

Fig 4: Serial Monitor Display of Population Counter, Microwave Sensor State and Ultrasonic Sensor1 and 2 Readings

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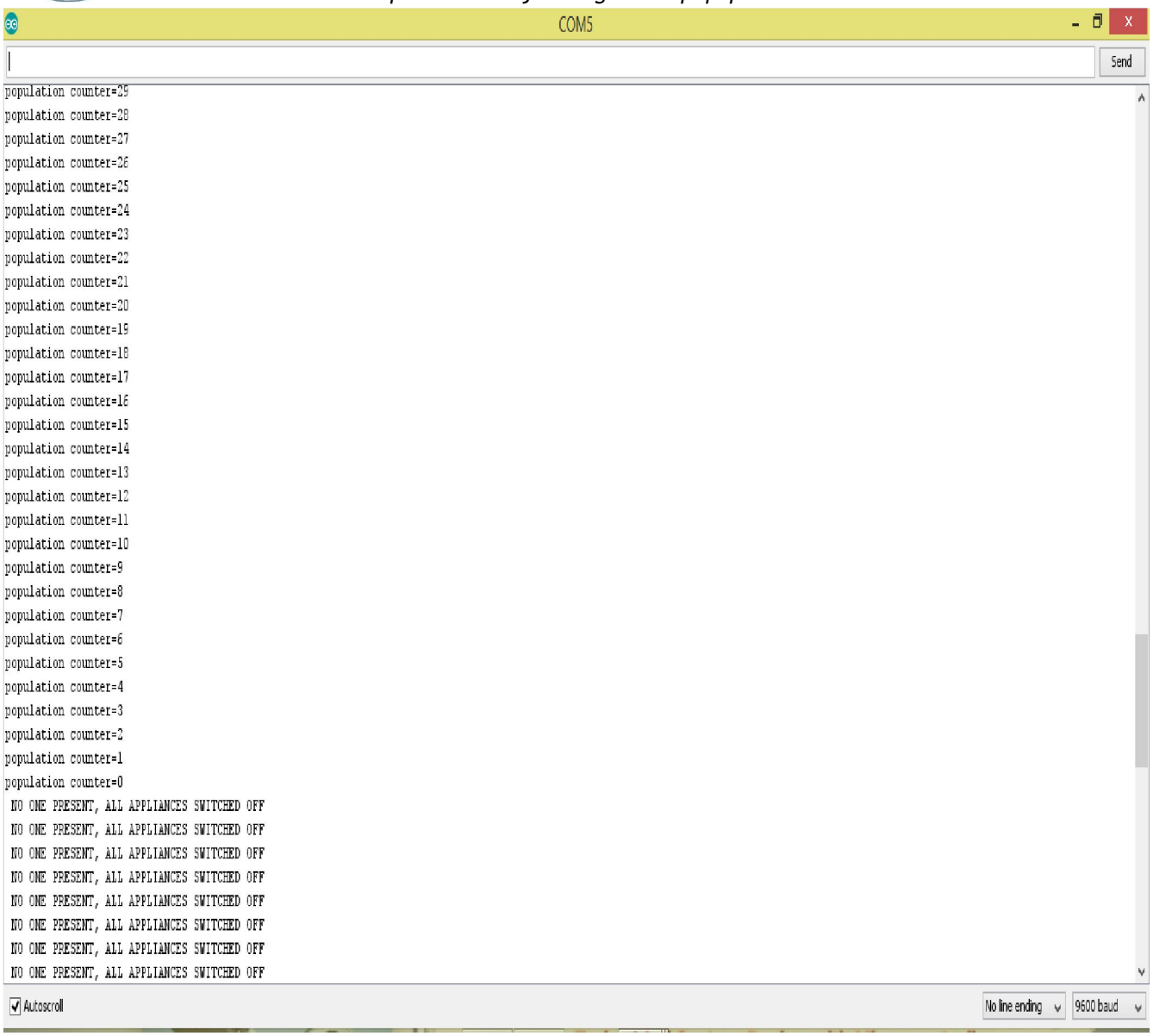

Fig 5: Serial Monitor Display Indicating the Exit of People from the Building

4. CONCLUSION:

Energy utilization and management is important in our everyday life. In this work, a population-based energy management system was designed, constructed and implemented to effectively manage the electrically energy supplied to a building. This device unlike other such devices serves as a population/attendance counter and also an automatic switch, switching off all electrical appliances when no one is present in the building.

From the results obtained during testing of this device, it was found that the system operated as desired, counting only humans and ignoring all other animate and inanimate object that enter or exit the door way where this system is installed. It is therefore important that this system be installed in every home as it could help

checkmate energy wastage, damage to electrical appliance during sudden surge of power, and electrical fire outbreak. The system designed in this work was able to meet the aim and objectives of this study.

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