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Design and Implementation of a Microcontroller Based Embedded Real Time Motion-controlled Room Lighting System for Smart Homes

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Abstract

At this crucial age of technological revolution, there is a widespread transition from the use of manually operated electronic devices to fully automatic electronic system. The concept of miniaturization has gained a broad scope of applications in the field of electronic engineering as high power gigantic gadgets and components are greatly diminished to a very small size with reduced power consumptions. The microcontroller which lies in the heart of the embedded system is a single chip computer which performs various control functions as required. This paper comprehensively explores the application of a PIC microcontroller in the continuous control of a room lighting system, by enhancing house owners with the ability to automatically control the Switch ON and Switch OFF actions of light in the room or apartment, when the movement of an occupant is electronically sensed. The sensor circuits effectively utilize the advancement in photonics to detect the presence of an occupant and responds in prominent manner. The design setup was simulated using the ISIS Proteus 8.0 simulation package and the installation recommendations were given in detail.

Keywords - *Automation, Control, Computer, Embedded System, Microcontroller, Miniaturization, PIC, Photonics, Simulation.*

I. INTRODUCTION

The advancement in technology in the 21st century has brought about invaluable increase in the effective management of energy in homes and industries. The act of implementing control of equipment with advanced technology; usually involving electronic hardware is defined as automation. These has enhanced automatic control of equipment, thereby reducing stress of operation, increasing efficiency and as well reducing human-machine interface risks or dangers.

Knowing quite well that 19% of energy use in Africa is used for lighting, and 6% of greenhouse emission in the world derive from this energy used for lighting. In Nigeria, 65% of energy consumption is used by commercial and industrial sectors, and 22% of this is used for lighting [1]. Hence, there is an important need to enable householders to minimize and save light energy by automatically controlling the room-lighting system and other associated accessories. This can mainly be achieved by incorporating the concept of smart lighting which involves light turning ON when people (i.e. occupant) enter into a room and turning OFF light when they leave a room. This also involves a real time monitoring and counting of occupants (increments and decrements) are they cross the sensor path.

The motion controlled room lighting system is a sub module of the Home Energy Management System which enhances house owners with the ability to control the Switching ON-and-OFF actions of lights in the room or apartment when the movement of an occupant is electronically sensed. This documentation explains the stepwise approach in the simulation and design of motion sensors for room lighting control. This can be utilized in private offices, classrooms, conference rooms, restrooms, corridors, storage areas etc.

II. DESIGN METHODOLOGY

Principally, the entire system utilizes the advancement in photonics at the signal sensing region of the design, by having an infra-red transmitter which transmits invisible radiation at the infra-red region of light spectrum. This signal is received (or sensed) by a Passive Infra-Red (PIR) Sensor positioned directly opposite the transmitter, to obtain maximum reception of the radiation. The design project only incorporates two input sensors which will be located within the room after opening the door.
Note: The number of sensor circuit may be increased in real-life implementation.

In this project, a PIC18F4550 MCU (a small computer on a single chip [2]) continuously monitors the output from the sensor module and turns the lights on when it goes active. It also produces the number of occupants with the room per time as displayed on the LCD display. The sensor circuit requires 5V supply.

The schematic diagram of the motion controlled room lighting system is given in the figure below.

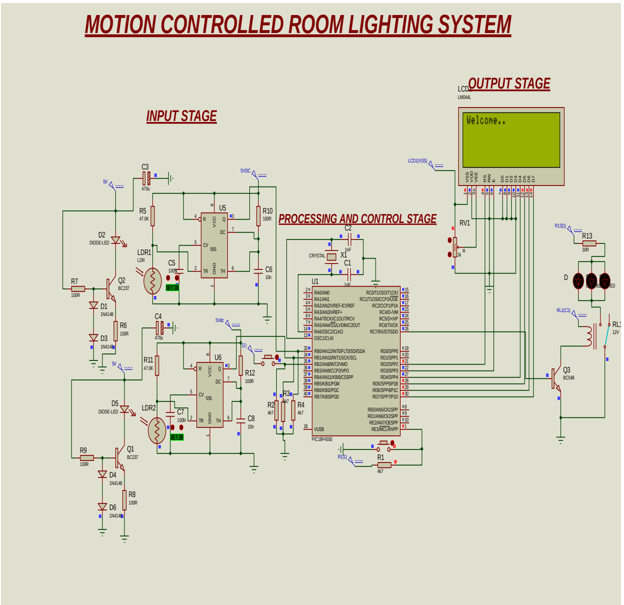

Fig. 1: Schematics of the Motion Controlled Room Lighting System

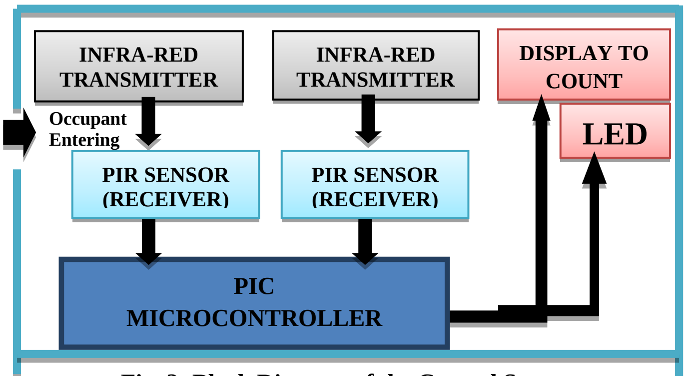

Fig. 2: Block Diagram of the Control System

The complete design circuit comprises of three main stages which are:

- *The Input Stage*
- *The Processing and Control Stage*
- *The Output Stage*

A. *The Input Stage*

This comprises of the Infra-red transmitter and Passive Infra-Red receiver circuit. The transmitter circuit is at a specific distance from the Infra-red receiver (or sensor) as determined by the frequency of radiation and the manufacturer. The major sub- section of this stage involves the transmitter and the receiver.

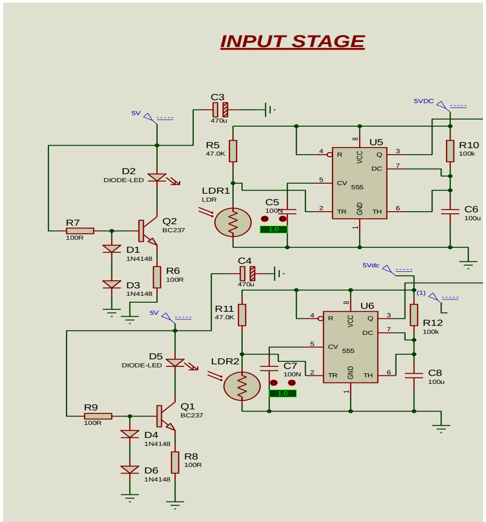

Fig. 3: The Input Stage

1) *The Transmitter*

The transmitter is designed using a non-illuminating Light Emitting Diode (LEDs) which give off invisible light rays in the infra-red spectrum of radiation frequency. The input supply to the two transmitter circuit is 5V each. The components are:

1. Non-illuminating LED as the IR transmitter
2. An n-p-n transistor for signal amplification
3. 100Ω resistors for current limiting functions
4. Diodes.
5. 470µF capacitor
6. The ground.

The transmitter circuit is designed to always give off invisible light which would be received by the PIR sensor, unless it is being switched off. You can be rest assured that the energy consumed by leaving the transmitter LED permanently ON in highly negligible because the current drawn by the LED is very small (with a saturation current of 1E-38).

2) *The PIR Sensors (Receiver)*

The PIR sensors stand for Passive Infra-Red sensors. They have a single output that goes high (or low, based on the circuit connection) when motion is detected. They are passive because they are not self-generating, but rather dependent on external source of triggering for them to work. The sensor circuits enables the entire setup to sense motion, almost always used to detect whether a human has crossed the sensor range. This sensor circuit is small, inexpensive (considering the components used), low-power, easy to use, pretty rugged and are easy to interface with.

a) *Light Sensors*

Generally, Light sensors (commonly referred to as photoelectric devices or Photo sensors) are transducers that generate output signals indicating the intensity of light received, by measuring the radiant energy (photons) present in a very narrow range of frequencies called 'light'. The ranges in frequencies are from the 'Infra-red' to the 'Visible' up to the 'Ultra-violet' range of the light spectrum. They are passive devices which convert light energy (in the visible or infra-red range) into an electrical signal output. Photoelectric devices can be classified into two categories:

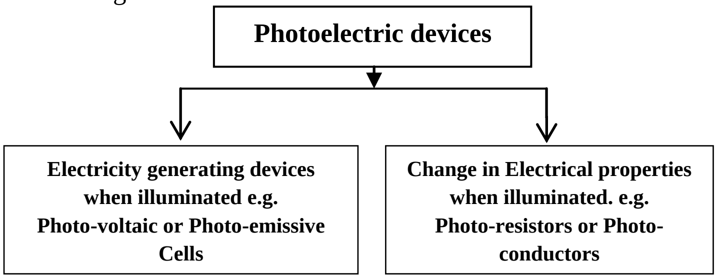

Fig 4: Classification of Photoelectric Devices

b) Light Dependent Resistor (LDR)

Light Dependent Resistor (LDR) or photo resistor is a device that acts like a resistance and its resistance varies with the intensity of light incident on it [3]. In this device, if photons of sufficient energy fall on it, the resistance drops drastically as the electrons in the semiconductor are able to jump from the valence band to the conduction band and are available for conduction. The resistance might drop from as high as 1MΩ in the dark to 1 k Ω in bright light. In this project, the LDR is configured to sense darkness, that is, once an occupant crosses the light path from the transmitter, the LDR becomes active and gives a high input to the MCU. The LDR used in the simulation Schematics is set to an intensity sensitivity of 1.0. The LDR and the resistor form a voltage divider circuit. The output from this voltage divider is the value of the voltage across the LDR and is connected to the TR input terminal of the 555 Timer. The voltage across the LDR is obtained using the voltage divider rule:

$$V2 = \frac{R1}{R1+R2}V \quad ,$$

Where V2 is the voltage across the LDR while V1 the source voltage.

R1 and R2 are the voltage divider resistors, where R2 is the LDR's resistor.

For simulation purpose the input circuit is as shown below:

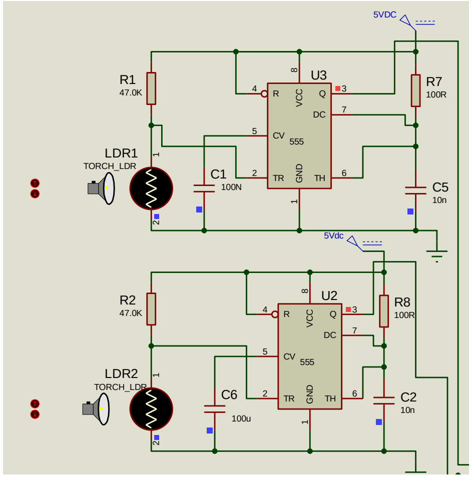

Fig. 5: The Input Stage

The 555 timer receives the analogue input signal from the voltage divider connection when the LDR is blocked. It converts this signal to an oscillating signal. The timer gives the instantaneous response of the LDR to an input from the LDR as it goes high when blocked. The oscillating output signal from the 555 timer is obtained at terminal Q, which is the input given to the MCU.

To determine the instantaneous time required by the timer to switch,

$$\tau = 1.1 * R * C$$

Where τ is the switching time in seconds.
R is the resistance (R7 and R8 in this case).
C is the capacitance (of C5 and C2).

$$\therefore \qquad \tau = 100 * 10 * 10^{-9}$$

$$\tau = 0.000001s2$$

Therefore the time response of the system to a change in the input circuit or stage is *0.000001s*.

B. The Processing and Control Stage

The major component representing this stage is the PIC18F4550 microcontroller. The PIC18F4550 MCU is a single chip computer, and is used in the design and implementation of the motion controlled room lighting system. It helps in making decisions about the input signals received from the input stage of the design circuit. It is well known that MCU is digital in nature, that is, it can only recognize a HIGH or LOW level on the input pin. When an occupant passes through the sensor path, the darkness is sensed and it initiates a HIGH input level in the MCU input port. The MCU Analogue to Digital Converter (ADC) unit converts the input oscillating signal for the sensor into a digital signal (High and Low). Therefore, it is said that the MCU monitors the voltage (High or Low) at the output of the 555 timer. The MCU is programmed to switch ON the lights in the room when a HIGH input signal is received from the input stage. Another basic function carried out by the microcontroller is to count the number of persons that cross the sensor region and produce the numbers on an LCD display. The microcontroller does count incrementally or otherwise depending on whether occupants are entering or leaving the room. The RESET input introduces a low Level on the RESET pin there resetting the entire circuit. The entire circuit can as well be switched on or off as desired by the user, by pressing the push button connected to pin RB2/AN8. When switched off, the entire circuit will be on standby until the push button is pressed.

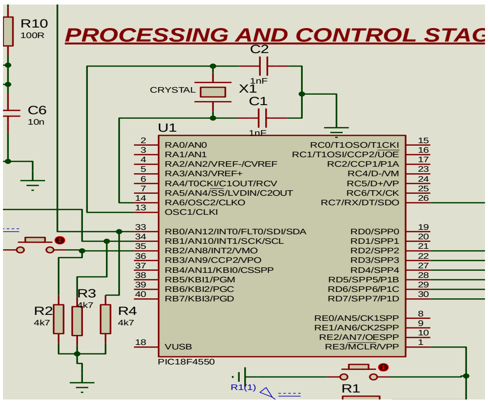

Fig. 6: The Processing and Control Stage

C. The Output Stage

The output stage reveals the outcome of the two preceding stages. The two major components of this stage in the simulation circuit are the Liquid Crystal Display (LCD) and the Light Emitting Diodes (LED). An LM044L (having 3-visible display rows) is used to display the status of the system and as well indicate the number of occupants in the room. The LEDs represents the lights present in the room. The light goes on when there is an occupant in the room and goes off when the occupant leaves the room.

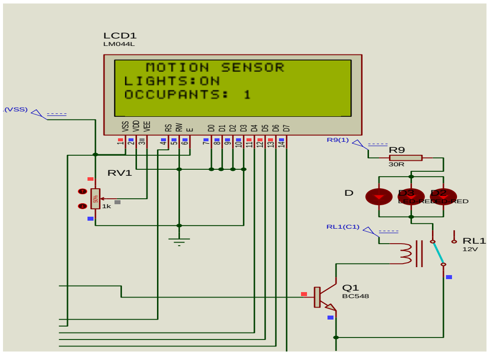

Fig. 7: The Output Stage

III. OPERATION PRINCIPLES

The overall control operation of the Motion controlled room lighting system is shown in the figure below.

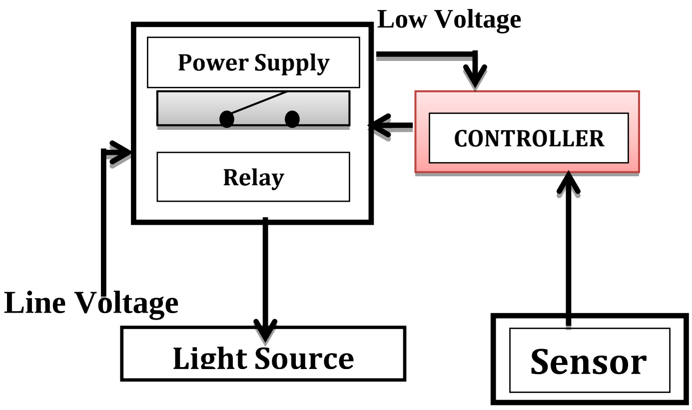

Fig. 8: Control Diagram of the Simulation circuit

The simulation circuit uses a Torch-LDR as the source of light rays to the LDR. The torch is configured to be permanently switched ON to represent the infra-red transmitter. As the torch moves far away from the LDR, the resistance of the LDR becomes high. This implies that the voltage across the LDR, which as well is the input to the MCU, becomes HIGH. The MCU performs the necessary processing actions and gives the output status on the LCD screen. The output is connected from the MCU through a relay to the LEDs (which represent the lights in the room).

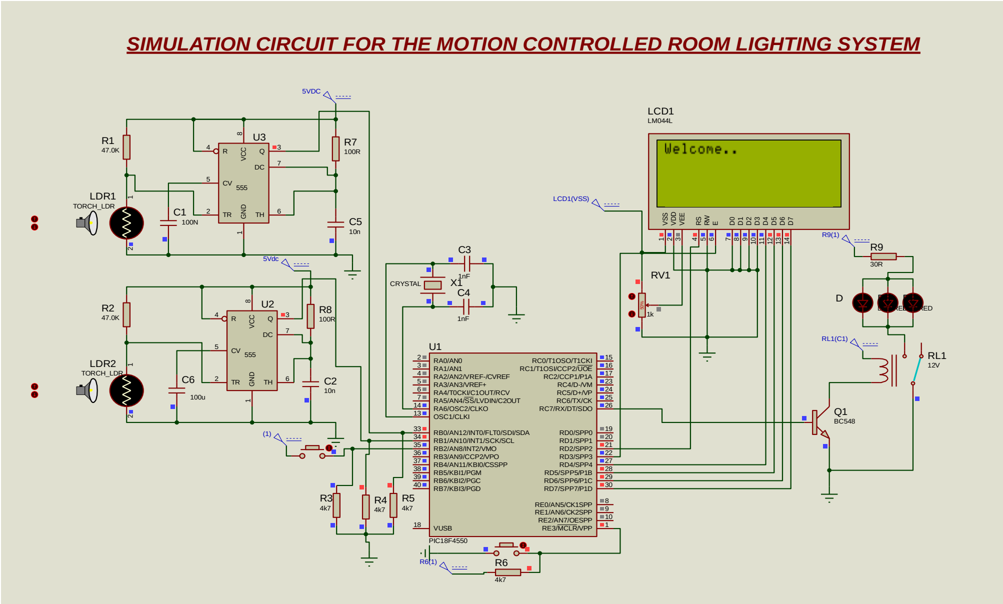

Fig. 9: Simulation Circuit Showing First Display at Switch ON or RESET

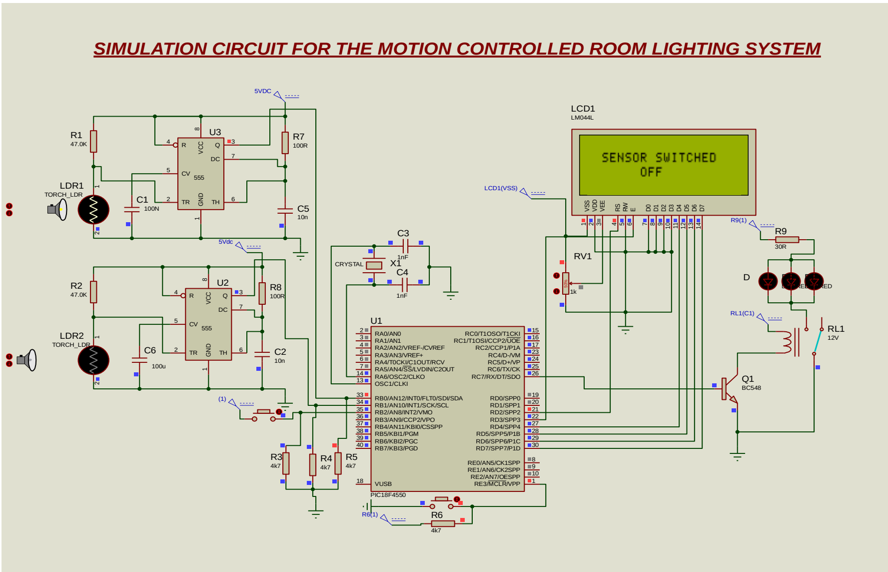

Fig. 10: Simulation Circuit Showing Display at Switch Off

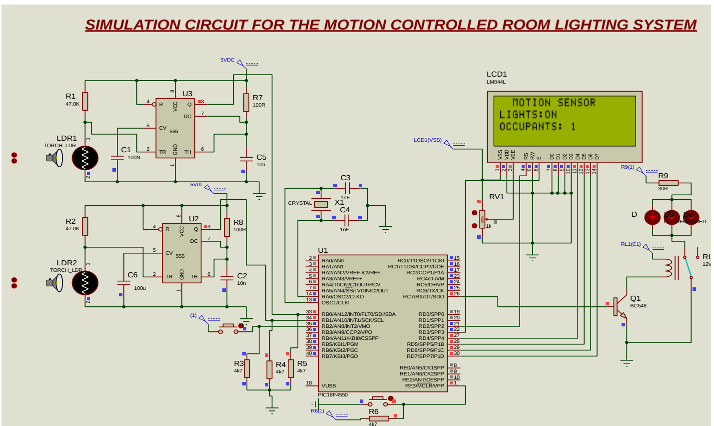

Fig. 11: Simulation circuit Counting up with Lights ON

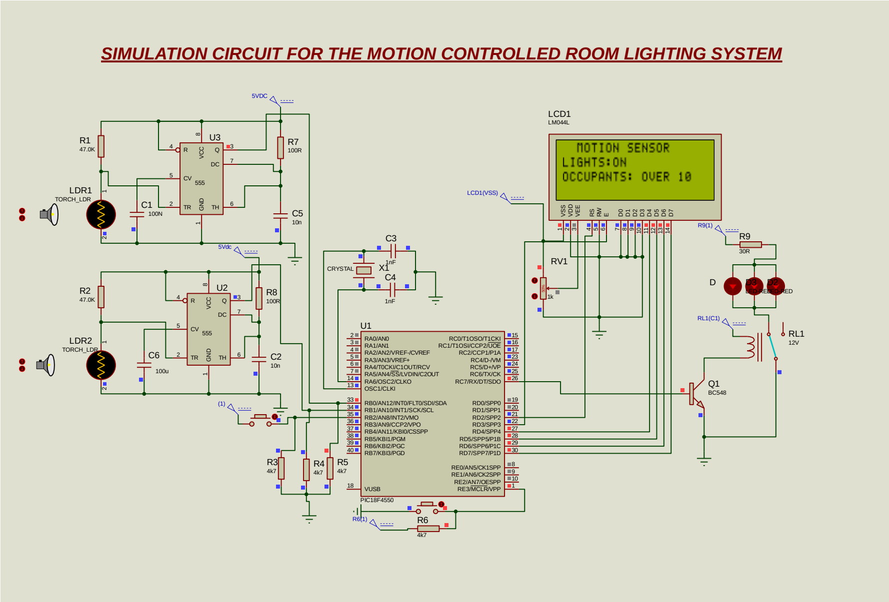

Fig. 12: Simulation Circuit Counting over 10 Occupants

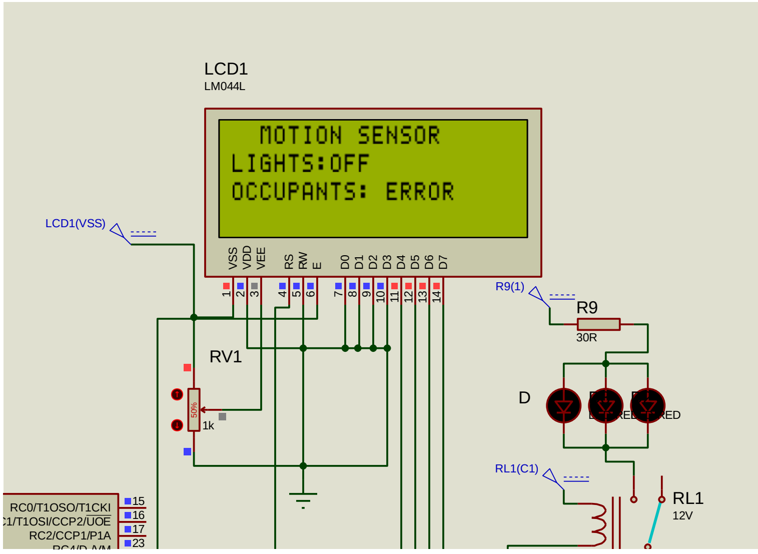

Fig.13: Simulation Circuit Showing Occupants less than 1

Installation Recommendations

1. The distance between the two transmitter-receiver circuits should not be more than two feet.
2. The circuit is highly flexible to incorporate other equipment to be controlled e.g. fans, air-conditioner, electricity-controlled digital clock etc.
3. The PIR sensors should be positioned directly opposite the source of the infra-red radiation for maximum performance.

IV. FIRMWARE CODE

The full firmware code for the PIC18F4550 Microcontroller is given below. The compiler used is the MikroC Pro Compiler, engaging the C programming language.

Code : Firmware Code for the MCU

```
#include <stdio.h>
#include <string.h>

//LCD Module Connection
sbit LCD_RS at RD2_bit;
sbit LCD_EN at RD3_bit;
sbit LCD_D4 at RD4_bit;
sbit LCD_D5 at RD5_bit;
sbit LCD_D6 at RD6_bit;
sbit LCD_D7 at RD7_bit;
sbit LCD_RS_Direction at TRISD2_bit;
sbit LCD_EN_Direction at TRISD3_bit;
sbit LCD_D4_Direction at TRISD4_bit;
sbit LCD_D5_Direction at TRISD5_bit;
```

```
sbit LCD_D6_Direction at TRISD6_bit;
sbit LCD_D7_Direction at TRISD7_bit;

//Variable Declaration
int intFlag=0, frombCounter=0,
incomingFlag=0,outgoingFlag=0;
int occupantsCounter=0, comingfromB=0; int
comingfromA=0, lightswitchFlag=0, AProcessed=0,
BProcessed=0, k=0;
int toggle=0, counter=1, counter2=0;

void interrupt(){
      if(INT1IF_bit==1){    //User just crossed Spot A
            INT1IF_bit=0;    //Reset INT1 Interrupt Flag
if(Aprocessed==1){    //For immediate reverse
movement
              comingfromB=0;
              comingfromA=1;
              outgoingFlag=1;
              incomingFlag=0;
               outgoingFlag=1;
            }
  if(comingfromB==0){
     comingfromA=1;
     outgoingFlag=1;
            }
 else if (comingfromB==1 &&
BProcessed==1){
               comingfromA=0;
               incomingFlag=1;
               outgoingFlag=0;
               occupantsCounter=occupantsCounter+1;
            }
            else{
            }
 if (incomingFlag==1 && occupantsCounter>0){
      lightswitchFlag=1;
    }
          Bprocessed=0;
          Aprocessed=1;
  }

else if(INT0IF_bit==1){   //User just crossed spot B
         INT0IF_bit=0;
 if(Bprocessed==1){    //For immediate reverse
movement
              comingfromB=1;
              comingfromA=0;
              outgoingFlag=0;
               incomingFlag=1;
            }
 if(comingfromA==0){
              comingfromB=1;
            }
 else if (comingfromA==1 && AProcessed==1){
               occupantsCounter = occupantsCounter-1;
               comingfromB=0;
               outgoingFlag=1;
                 incomingFlag=0;
           }
  else{
           }
           if(comingfromB==1){
             incomingFlag=1;
       outgoingFlag=0;
           }
  if (outgoingFlag==1 && occupantsCounter==0){
     lightswitchFlag=0;
    }
          Bprocessed=1;
          Aprocessed=0;
 }
  if(INT2IF_bit==1){
    INT2IF_bit=0;
    if(toggle==1){
       toggle=0;
      }
   else if(toggle==0){
       toggle=1;
     }

   }
  }

void initialDisplay(){
Lcd_Cmd(_LCD_CURSOR_OFF);
LCD_Out(1,1,"Welcome");

//Animate Welcome
for(k=0; k<5; k++){
          LCD_Out_Cp(".");
          delay_ms(500);
          }
          //Prepare Home Screen
          LCD_Cmd(_LCD_CLEAR);
          delay_ms(500);
           LCD_Out(1,3,"MOTION SENSOR");
           LCD_Out(2,1,"LIGHTS: ");
           LCD_Out(3,1,"OCCUPANTS: ");
        }

void main() {
TRISB = 0b00000111; //set INT 0 and 1 of PortB as
Input while the rest as output
PORTB = 0x00;   //Make PORTB initially low
LATB = 0x00;

TRISC = 0x00; //Set all pins of PORTC as OUTPUT
PORTC = 0x00;   //Make PORTC initially low
LATB = 0x00;
    CMCON = 0x07;    // Turn off comparators
   CVRCON = 0x00;
//Configure AN0:4 Pins as Analogue, but
AN12,AN11,AN10,AN9,AN8 as digital
    ADCON1 = 0b00001111;
    ADCON2 = 0x0F;
```

```
INTEDG0_bit = 0; //Interrupt happen on the falling
edge of the signal into INT0
INTEDG1_bit = 0; //Interrupt happen on the falling
edge of the signal into INT1
INTEDG2_bit = 0; //Interrupt happen on the falling
edge of the signal into INT2
INT0IE_bit = 1; //Enable interrupt which depends on
the state of the INT0 pin
INT1IE_bit = 1; //Enable interrupt which depends on
the state of the INT1 pin
INT2IE_bit = 1; //Enable interrupt which depends on
the state of the INT2 pin
INT0IF_bit = 0; //Set INT0 interrupt flag initially to 0
INT1IF_bit = 0; //Set INT1 interrupt flag initially to 0
INT2IF_bit = 0; //Set INT2 interrupt flag initially to 0
GIE_bit = 1; //Enable Global Interrupt

Lcd_Init(); // Initialize LCD
initialDisplay();
 do{
 if(toggle==1){
 if (counter2==0){
 LCD_Cmd(_LCD_CLEAR);
  }
      LCD_Out(2,3,"SENSOR SWITCHED");
      LCD_Out(3,8,"OFF");

      counter=0;
      counter2=1;
 }
 else{
       if(counter==0){
         LCD_Cmd(_LCD_CLEAR);
        initialDisplay();
          counter=counter+1;
       }
   if(lightswitchFlag==1){
    LCD_Out(2,8,"ON ");
    PORTC.F7=1;
    if(occupantsCounter>=10){
      LCD_Out(3,12,"        ");
      LCD_Out(3,12,"OVER 10");
      LCD_Out(3,12,"       ");
    }
    else if (occupantsCounter<0){
         LCD_Out(3,12,"        ");
       LCD_Out(3,12,"ERROR");
    }
    else{
    LCD_Chr(3,12,occupantsCounter+48);
    }
       }
   else if (lightswitchFlag==0){
      LCD_Out(2,8,"OFF");
       PORTC.F7=0;
      if(occupantsCounter>=10){
      LCD_Out(3,12,"        ");
         LCD_Out(3,12,"OVER 10");
     }
     else if(occupantsCounter<0){
          LCD_Out(3,12,"        ");
         LCD_Out(3,12,"ERROR");

     }
     else{
     LCD_Chr(3,12,occupantsCounter+48);
     }
    }
     counter2=0;
     }
   }while(1);
 }
```

End of Code

V. CONCLUSION

The performance of microcontroller based embedded system in the automatic control of room lighting system when the presence of an occupant is electronically sensed via a motion sensor (PIR transmitter and LDR) is comprehensively explored in this paper. Each entry into the apartment records an increase in the occupant counter and exit records a decrease. The implementation of this system totally reduce the rate at which householders interface with electrical switch to control their lighting system, thereby reducing stress and the death of people due to current shocks. This helps to minimize energy consumption as lights will automatically switch OFF when the occupant counter displays zero on the LCD, thereby saving cost and enhancing security of lives and properties. The cost of implementation when compared with the cost of incessant wastage of electrical power due to lighting is very small. Hence the crucial need to adopt smart lighting [1] system in homes, malls, offices e.t.c.

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