DEVELOPMENT OF A LOW COST AUTOMATED SLIDING DOOR

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Abstract: In this work, a low cost automated sliding door system is developed. This has been occasioned by the high cost of imported automated door systems found in the country. The system employs a DC motor, PIR motion sensors and the Arduino Uno (microcontroller) programmed to automatically open and close a door upon detecting movement in its vicinity. Usually, the temperature and surface characteristics of objects cause an HC-SR5901 passive infrared sensor to detects variations in the amount of infrared radiation falling on it. Hence, a moving body such as human can distort the background radiation pre-recorded by the sensor. The resulting difference in the incoming radiation is converted to a change in output voltage which is measured by an on-board amplifier. As the ambient infrared signals change rapidly, the on-board amplifier trips the output to indicate motion. Consequently, the drive unit controlled by Arduino microcontroller is activated to drive the door open and close. A model of the system has been built and successfully tested to demonstrate the operation of the door.

Keywords: Automated door, ArduinoUno, microcontroller, passive infrared, pulse width modulation

Introduction

A door is a moving structure used to block off, and allow access to, an entrance to or within an enclosed space, such as a building or vehicle (Wikipedia, 2016). Doors normally consist of panel that swings on hinges or sometimes slides or revolves in space, and are made from wood, glass, steel or aluminium. They are used in buildings and vehicles to engender privacy, safety, convenience, protection from harsh weather conditions, barrier to noise etc. Common types of doors are hinged doors, sliding doors, rotating doors and high speed doors.

The invention of modern door automation has been credited to Lew Hewitt and Dee Horton in 1954; a technology said to have evolved from the related field of mechanisation, which has its beginnings in the Industrial Revolution (Horton, 2016; Macropaedia, 2010). Zungeru and Abraham-Attah (2013) stated that automation in electrical, electronics and computing world has grown rapidly and dates back to 1940s when the first electronic computing machine was developed. Door automation now involves advanced sensor technology and programmable logic controllers for greater efficiency and control. As a result, automation has eliminated human intervention in door access.

Foracountry like Nigeria, door automationis easilynoticed in banks, shopping malls, hotels, government offices, institutions or corporations. Beside the fact that most of these doors are imported, anotherconcern is the outrageous price they command which has peaked them beyond the reach of low income earners. Relatedly, being foreign technologies many of the automatic doors may not be readily repairable, hence a locally developed one should be much easier to maintain and repair in case of any fault.

The aim of this work is to develop a simple, affordable and yet efficient model of the automatic sliding door system. It will be a low-cost system that will bring such technology within the reach of everyone irrespective of their social class affiliations. And to achieve this, we shall integrate analogue and digital components to design the various circuit stages; simulate the system using relevant software and hardware platforms like Arduino IDE, Fritzing or Proteus 8 professional and breadboard; solder and test the performance of the system; assemble and package a model of the automated sliding door.

Related work

In Digital Automatic Sliding Door with a Room Light Control System, Zungeru and Abraham-Attah (2013) proposed an infrared-based automatic door that utilises a system of monostables to control a door. Their system consists of two transmitting infrared led and two receiving photodiodes. These were configured to sense incoming and outgoing users, respectively. When connected to comparators, low outputs signify broken transmission caused by a body while high outputs would mean continuous transmission. This is related to the work of Oladunmoye, Oluwatomi, and Obakin (2014).

Similarly, Mohapatra and Anand (2014) developed an Automatic Pneumatic Sliding Door using Infrared proximity sensors and Arduino controller. In their model, the door works on pneumatic air pressure through a retracting double acting cylinder. Upon sensing a body, the two infrared sensors transmit signals to the Arduino which then respond according to programmed instructions. This causes the pneumatic actuators to drive the door using a 24 DC supply. It is important to stress that by simply reprogramming the Arduino, the door operation can be modified without any change of hardware. Besides, it uses fewer connecting wires and is also environmental friendly.

Advancements of these works include those of Nishida *et al.* (2014) from the University of Electro-Communications, Tokyo-an Intelligent Automatic Door System that employs a three-dimensional laser scanning technology to open only for people who intend to use them and adjust the precision timing of the doors to open to match the speed of people going towards the door. This is in addition to algorithms developed to control the process. For Jie-Ci *et al.* (2013), it was 'An Intelligent Automated Door Control System Based on a Smart Camera.' This was later applied by Ahmed *et al.* (2014) in their work 'Design of an Automated Secure Garage System Using License Plate Recognition Technique.'

System Modelling and Design

In this section, the theory of some components used and design method shall be discussed.

Component theory

The basic principle of operation and how the following components are applied in this work. The components are: passive infrared (PIR) motion sensors, Arduino microcontroller, transistor, relays, and direct current (DC) motor among others.

PIR motion sensor

The operating principle of the optical motion detectors is based on the detection of light (either visible or not) emanated from the surface of a moving object into the surrounding space. Such radiation may be originated either by an external light source and then reflected by the object or it may be produced by the object itself in the form of natural emission (Fraden, 2004). The passive detectors perceive mid- and far-infrared (4 – 20 µm) emission fromobjectshavingtemperaturesthataredifferentfromthesurroundings to generate charge.

Transistor

A transistor is basically a semiconductor electronic switch that allows one to switch a larger current by applying a small current to the device. They are often used inside an audio amplifier in a home sound system, where they can be used to convert a small sound signal into a much louder one (Dossis, 2013). For proper working of a transistor, Theraja (2012) noted that it is important to apply voltages of correct polarity across its junctions. Under normal operation, the emitter-base junction is always forward-biased while the collector-base junction is always reversed-biased. As used in this work, the switched current goes between the collector and emitter; the controlling current goes between the base and emitter as shown in the Fig. 1.

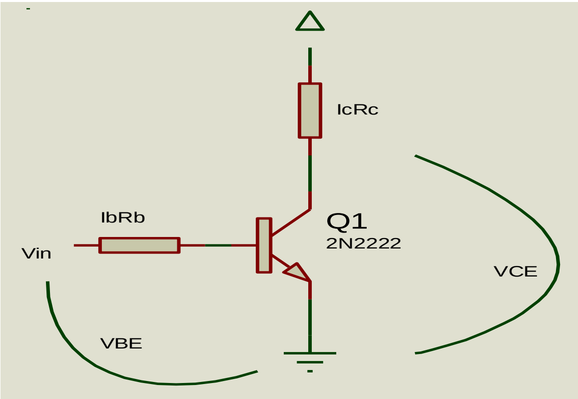

Fig. 1: Transistor as switch

In this common emitter configuration, the direct current power supply is designated by;

$$V^+ = I_C R_C + V_{CE} \qquad 1$$

Also,

$$V_{in} = I_B R_B + V_{BE} \qquad 2$$

Since the transistor is acting as a switch, $V_{CE} = 0$ at saturation (fully conducting); such that the collector has a maximum current flowing through the load.

$$I_{C(sat)} = \frac{V^+}{R_C} \qquad 3$$

The gain is denoted by;

$$h_{FE} = \frac{I_C}{I_B} \qquad 4$$

At cut-off, $I_B = 0, I_C = 0$and $V^+ = V_{CE}$. This implies that the transistor is not conducting under this condition and has turned off.

WhereI_C= collector current, I_B = base current, V_{in} = base voltage, V^+= Supplied voltage, V_{CE}= collector emitter voltage, and V_{BE}= Base emitter voltage, R_C = collector resistance, and R_B = base resistance, respectively (Theraja, 2012).

System Analysis and Design

Principle of operation

The automated sliding door is made up of power supply, two PIR motion sensing unit, display unit, switching unit and driver unit, all connected to the Arduino Uno board (Fig. 2).

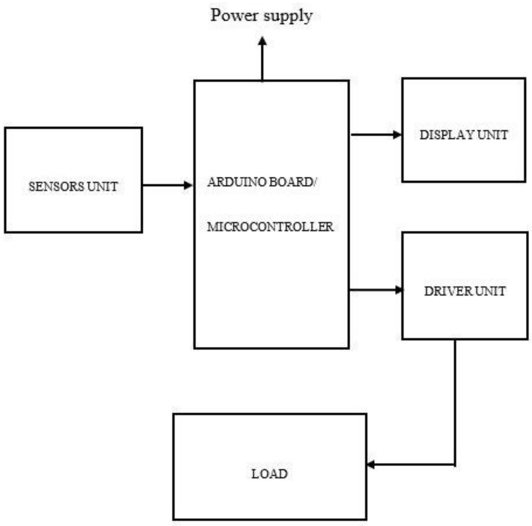

Fig. 2: System block diagram

Sensor Unit

The sensor unit consists of two HC-SR501 motion sensors mounted on both sides of the door, with a maximum range of view of about seven metres. And they are connected to the microcontroller through pins 2 and 4 of the Arduino microcontroller board as its inputs. The sensors are so placed with their sensitivity adjusted to minimise false trigger from far bodies as much as possible. Switching on the power supply causes the sensors to calibrate for about thirty minutes after which each becomes ready to read its environment. It must be noted that during the calibration process, any form of motion in the direction of these sensors must be prevented to ensure that they properly learn their environment.

When motion is sensed, a signal goes into the Arduino pins 2 and 4, causing it to respond based on specific programmed conditions written for it. The sensors present different outputs to the Arduino microcontroller depending on whether motion is in progress or has stopped.

Operation of the sensors

The sensors send high voltage level (5V) signal into the Arduino microcontroller if motion is detected. Else, a low level voltage (0V) signal is sent into the Arduino microcontroller. The program logic for these functions are found in the Appendix.

Display unit

The system's display makes use of two $20\,mA, 5V$LEDs connected through separate 220 Ω resistors. The green LED is connected to pin 7 and the other red, connected to pin 8 of the board and programmed to indicate the opening and closing cycles of the door respectively. By this, a user is prompted to wait for another person to leave before using the door.

Driver/switching unit

The driver stage consists of two 2N2222 transistors (Qs) that switch on (logic level 1) or off (logic level 0) the 12V relays (RL) that control the DC motor. Their base pins are connected to pins 9 and 11 of the Arduino through separate 15 KΩ resistor. And each of these switching transistors connects the 5V or 9V DC motor (as selected) to the 5/9V regulated supply meant for it. However, this action is never done simultaneously, but only one transistor at a time. While one transistor is written to connect the motor to positive supply, the other is kept low for the time being. This alternate switching allows for movement of the motor in dual directions.

For any motion detected, the base of the Q1 is written high. As a result, the relay (RL1) gets energised and connects the motor to the 9V. Once motion is completed, Q1 is turned off (logic level 0), while Q2 is turned on. Consequently, the

second relay (RL2) now connects the motor to the 9V again while the first relay gets it to the ground and vice versa.
The circuit diagram of the switching transistor is shown in the Fig. 3.

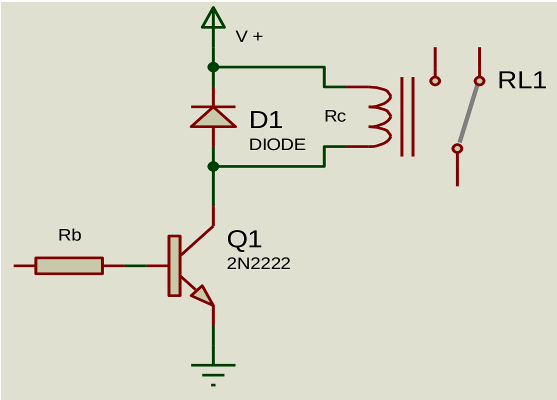

Fig. 3: Switching/control stage diagram

To design for the appropriate resistors to be used for R_B, Where R_B is the base resistor, R_C is the coil resistance of the relay, V^+ is supply voltage = 12V, V_{in} is the Arduino microcontroller output voltage = 5V.
By using common emitter PNP transistor, the collector current,

$$I_C = \frac{V^+}{R_C} \quad 5$$
$$= \frac{12}{400} (R_C is resistance of the relay coil)$$
$$= 0.03A$$

The base current of a transistor is related to its gain β, by;

$$I_B = \frac{I_C}{\beta} \quad 6$$
$$= \frac{0.03}{100} \quad (\beta is transistor gain from datasheet)$$
$$= 0.30mA$$

From;

$$V_{in} = I_B R_B + V_{BE} \quad 7$$

$$R_B = \frac{V_{in} - V_{BE}}{I_B} \quad 8$$

Therefore,

$$R_B = \frac{5V - 0.6\,V}{0.30mA}$$
$$= \frac{4.4}{0.30mA}$$
$$= 14,666.67\Omega$$

This is the current-limiting resistor connected to the base of each transistor. A preferred value of $15K\Omega$ is however used.
Where I_C= collector current, V_{in} = input voltage, V^+= Supply voltage, V_{CE}= collector emitter voltage, and V_{BE}= Base emitter voltage. The diode serves to protect the transistor against back electromotive force from the relay when turned off.
However, equation 6 does not hold good at saturation (Theraja, 2012).

Microcontroller unit/arduino board

The Arduino microcontroller board adopted in this work is the Arduino Uno, having 14 digital input/output pins based on the ATmega328P microcontroller. Six of these pins can be used as pulse width modulated (PWM) outputs, and another six for analogue inputs. The remaining two form the serial TX and TR.

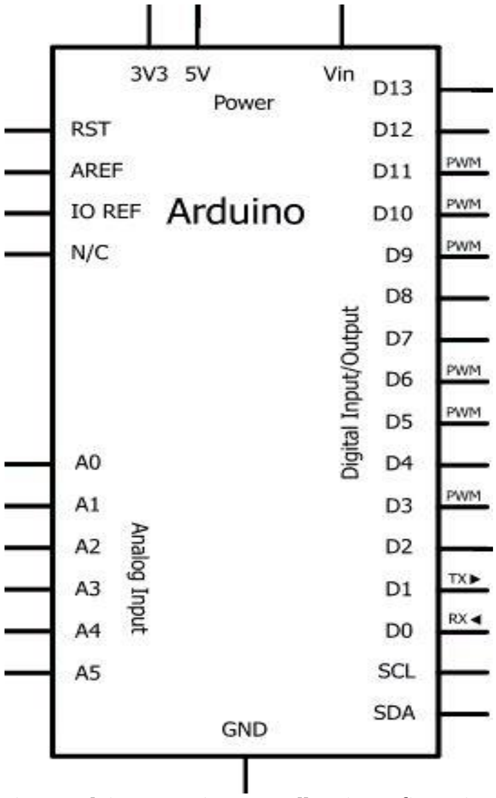

Fig. 4:Arduino Uno microcontroller pin configuration

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive 20 mA as recommended operating condition and has an internal pull-up resistor (disconnected by default) of 20-50 k ohm. A maximum of 40 mA is the value that must not be exceeded on any I/O pin to avoid permanent damage to the microcontroller.
The Uno has six analogue inputs, labelled A0 through A5, each of which provides 10 bits of resolution (i.e. 2^{10} or 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference().
For any analogue signal, the microcontroller's analogue to digital converter change a continuous analogue signal applied to one of its analogue pins into a digital integer proportional to the voltage at that pin and returns a linear value between 0 to 1024 corresponding to 0 and +5V, respectively. Hence, it can actually read voltage levels down to 4.88 millivolts per level. However, being a digital device, it can only approximate the analogue signal by quickly turning on and off at different time rates through pulse with modulation.

Power supply unit

The major power supply to this system is a linear 12 Volts direct current required by the loads (DC motor and relay). However, it has been regulated to 9 volts sufficient to power the Arduino board from which other units derived their own power. This linear power supply includes a step down transformer, rectifier, filter capacitors and voltage regulators.
Alternatively, the Arduino board can be solely powered through any of the 5 Volts USB port of a personal computer (PC). But this is just the minimum power requirement.

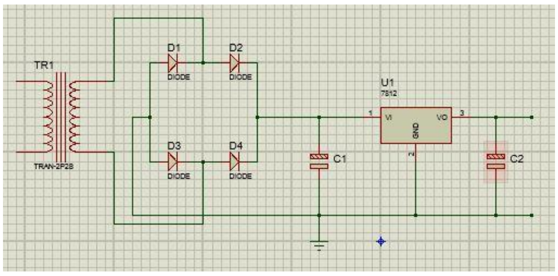

Fig. 5: Power supply stage

Figure 5 is a circuit required to rectify a 220/240 alternating voltage source to a 12-volt source of voltage. A 7812 voltage regulator gives the needed output of +12V. And it ensures that no voltage above its specified value is ever delivered.
Let the output be 12V after a ripple of about 2V. To select a suitable transformer for this power supply, 1.2V drop imposed by the silicon bridge rectifier (with 0.6Vx2 forward biased voltage) plus the 12V output brings the peak value of the total output to 13.2V. Allowing for an additional 2V bring the transformer output to about 15.20V. The root mean square value of this voltage is specified by

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}} \quad 9$$
$$= \frac{15.20}{\sqrt{2}}$$
$$= 10.74V$$

Since the voltage is stepped down from 220V to 12V, it is an indication that the primary current steps up by about eighteen times. Therefore, a transformer of 12V, was selected.

Using the fact that

$$I = C\frac{dv}{dt} \quad 10$$

Assuming that the load would draw a maximum current, I of 1A;

$$C = I\left(\frac{dt}{dv}\right) \quad 11$$

Wheredt is the time between peaks of the input waveform and is equal to;

$$dt = \frac{1}{2 \times f} \quad 12$$

And f is the frequency of the input waveform.

$$dt = \frac{1}{2 \times 50Hz}$$
$$= 0.01$$
$$C = 1\left(\frac{0.01}{2}\right) = 5000\ \mu F$$

Where$V_{rms} is the$root mean square value of the voltage, $V_{peak}$is the peak voltage, $I$is the maximum current, $C$is the capacitance of the capacitor, $dv$is the ripple voltage, dt is the time between peaks of the input AC waveform, and f is the frequency of the input waveform (Hayes and Horowitz, 2002). However, the available standard capacitor of $4700\ \mu F$ was used.
The manners in which the various components and stages are connected to the board are presented in the completed circuit (Fig. 6).

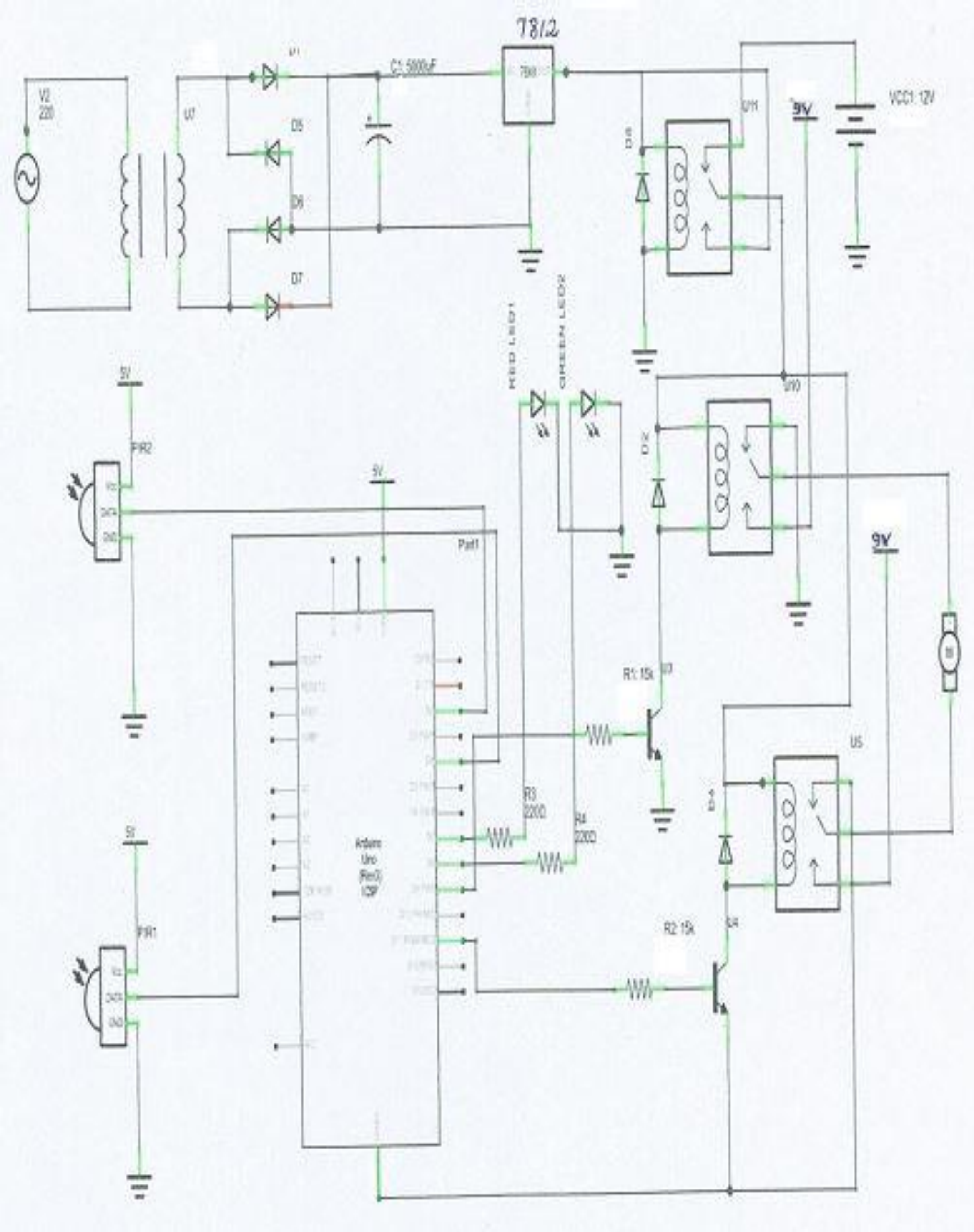

Fig. 6: Complete circuit diagram

Flow chart

The logical flow of the processes involved is illustrated in the flowchart (Fig. 7).

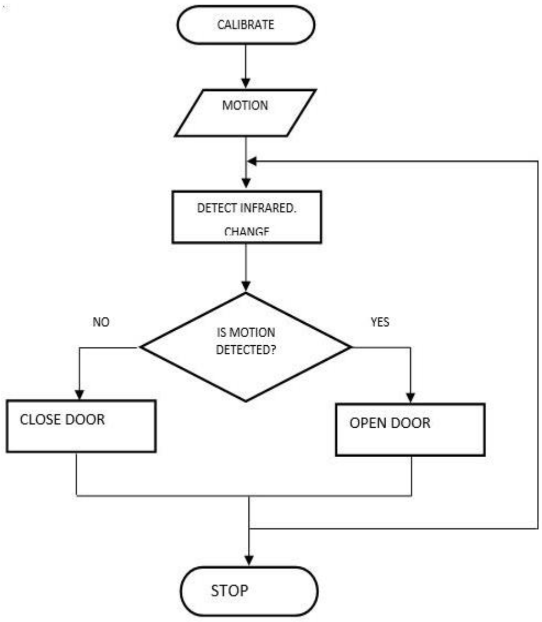

Figure 7: System logic flow

System Construction, Testing and Discussion

Construction and layout

The construction of this system was done in stages. In the first stage, the power supply unit, switching and control relays were soldered, before the Arduino board was screwed to the veroboard. At each stage of the circuit construction, continuity test with the multi-metre were done on the various components. Corrections were then made before engaging the next stage. The soldering of the circuit was done on a 9.5 by 24.5 cm Vero-board. The second stage of the system construction is the housing of the soldered circuit which was done with plywood as in Plate 1. The casing has vent to dissipate heat energy lost by components. Subsequently, the sensors were mounted above the entrance as shown in Plate 2.

Plate 1: Inner view of components

Plate 2: PIR Sensor being mounted

Testing

In order to achieve the stated aims, various programs were written to map the best behaviour of the automated doors under different operational conditions. Some of these include how the door should function if both sensors receive signal simultaneously as in Plate 3; when a user decides not to proceed on ingress or egress; delay action or remain stationary. In these cases, the door closed otherwise, it opened. To monitor these real-time conditions, vital readings were taken from the serial monitor of the Arduino IDE as in Plate 4 to observe whether or not any compliance exists. Arduino IDE displayed "motion detected" within 2.5 feet (0.76 m) and "No motion/motion ended" beyond it. However, this is adjustable.

The process of testing and implementation also involved the use of the oscilloscope to observe the rectified AC to DC voltage source and the digital multi-meter to keep track of voltage changes in the sensor states. Over all, parameters like voltages, continuity, resistance values of the components are integral part of the test.

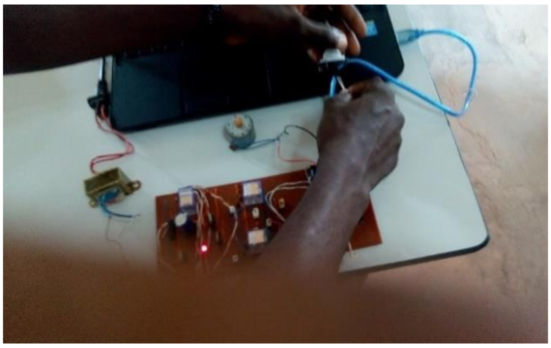

Plate 3: Testing the operation of the PIR motion sensor

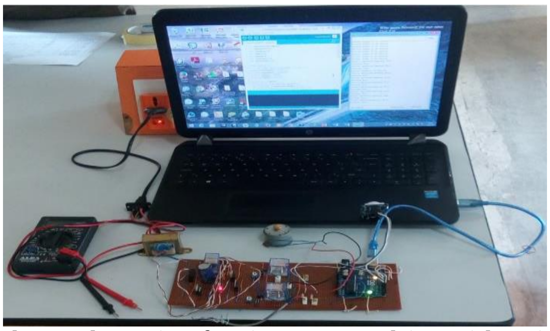

Plate 4: Observation of motion state on Arduino serial monitor

Implementation

The implementation of this system began on the breadboard as shown in Plate 5. And a PC was used to power the Arduino board while the rectified 12V DC was separately used to serve the relay and DC motor. These were done to test the performance of the circuit according to programmed instructions before the power supply stage was finally soldered. Stage by stage testing was done according to the block representation on the breadboard, before final solder of circuit commenced on the Vero board. The various circuits and stages were soldered accordingly as shown in Plate 6. The whole system is cased with dimensions 40.5 by 40 by 30 cm using plywood. This is shown in Plate 7.

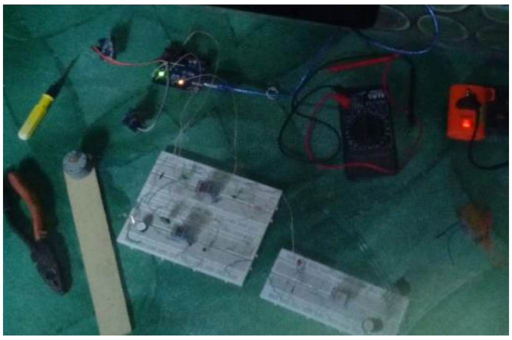

Plate 5: Breadboard simulation of the door's motor operation

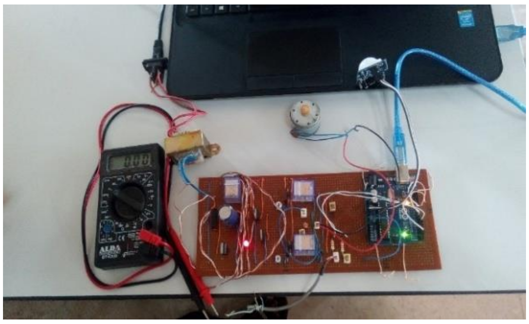

Plate 6: Completed circuit on veroboard

Plate 7: Front view of the automated slide door

Plate 8: Back view of the automated slide door

Problem encountered

As experienced, major problems are as follows: (1) Inability to get suitable software to simulate the circuit on PC. (2) Initial difficulty faced in getting software to carry out design of the circuit on a PC since the available proteus 8 professional has no Arduino except for its microcontroller. This was later done with Fritzing 0.9.2 software. However, the software has its own limitations in terms of available components too. It was expected that a custom design be made which involves many procedures in addition to other supporting software needed. (4) Also, getting the exact calculated values of some components was impossible. However, closely related standard values were used in their place. (5) The door operation at times becomes erratic. This was observed to result from a free-floating pin. That is a pin which has been declared in the sketch (program) but left unconnected. It may also result from connecting a jumper wire to the wrong port.

Conclusion

A low-cost automated sliding door system has been built. The performance of the door system after tests indicated it has met the design specifications and has also achieved the stated aim and objectives outlined. Although only a prototype, the door is efficient, compatible, portable. And given the available resources, the development of the system is quite economical. Modifications can easily be carried by reprogramming without any major change to the system hardware. Furthermore, an electronic speed controller with a keypad system would monitor speed and act as security, if included. Thus, the developed automatic door can be readily applied and maintained for home automation, schools, office and other business organisations.

References

Ahmed AU, Masum TM &Rahman MM 2014.Design of an automated secure garage system using license plate recognition technique.*Int. J. Intell. Sys.&Applic.*, 2(3): 22-28.

Arduino, Arduino Uno, Available athttps://www.arduino.cc/en/Main/ArduinoBoardUno, accessed April 8, 2016.

Arduino,An introduction, Available at https://www.arduino.cc/en/Guide/Introduction, accessed April 8, 2016.

Britannica Macropaedia 2010. *Automation.* USA: Encyclopedia Britannica Inc. Volume 14, 15th Edition, pp.546-548.

Dossis N 2013. *Basic Electronics for Tomorrow's Inventors.* New York: The McGraw Hill Inc, p.26.

Fraden J 2004. *Handbook of Modern Sensors Physics, Designs and Applications.* New York: Springer Verlag Inc., pp.239, 244.

Hayes TC&Horowitz P 2002.*Student Manual for the Art of Electronics.*Cambridge: Press Syndicate of Cambridge University., pp.71-72.

Jie-Ci Y, Chin-Lun L, Hshin-Teng S&Jiann-Jone C 2013. An Intelligent Automated Door Control System Based on a Smart Camera,Available at http://www.ncbi.nlm.nih.gov/pmc/articles/pmc/PMC3690038/ accessed March 26, 2016

Mohapatra A&Anand A 2014.Modelling and testing of automatic pneumatic sliding door.*Int. J. Scient.&Res. Public.*, 4(10): 3415.

Nishida D, Tsuzura K, Kudoh S, Takai K, Momodori T, Asada N, Mori T, Suehiro T&Tomizawa T 2014. Development of Intelligent Automatic Door System, Available at https://www.youtube.com/watch?v=WhrLetrTSYA, accessed February 15, 2016

Oladunmoye M, Oluwatomi AA & Obakin O 2014.Design and construction of an automatic sliding door using infrared sensor,computing, information system. *Devt. Information & Allied Res. J.*, 5(4): 29–32.

Wikipedia, the Free Encyclopedia, Door, Available at https://en.wikipedia.org/wiki/Door, accessed April 1, 2016.

Wikipedia, the free encyclopedia, Microcontroller, Available at https://en.wikipedia.org/wiki/Microcontroller, accessed April 7, 2016

Wikipedia, the Free Encyclopedia, Sliding door, Available at https://en.wikipedia.org/wiki/Sliding_door, accessed April 7, 2016.

Zungeru AM & Abraham-Attah PO, (n.d) 2013. Design and Construction of a Digital Automatic Sliding Door with a Room Light Control System, Available at http://arxiv.org/ftp/arxiv/papers/1303/1303.1728.pdf accessed January 15, 2016.

APPENDIX-I

ARDUINO SKETCH (PROGRAM)

```
//pins declaration and initialisation
intcalibrationTime=30;
int transbas1=11;
int transbas2=9;
int pir1=2;
int pir2=4;
intledGreen=7;
intledRed=8;
intinSensor=LOW;
intoutSensor=LOW;

//setting up pins functions
void setup() {
pinMode(transbas1, OUTPUT);
pinMode(transbas2, OUTPUT);
pinMode(pir1, INPUT);
pinMode(pir2, INPUT);

// display state on serial monitor
Serial.begin(9600);
Serial.print("calibrating sensors");
//calibrate for 30 secs
for (int i=0; i<calibrationTime; i++) {
Serial.print(".");
delay(1000);}
Serial.println("done");
Serial.println("SENSORS READY");
delay(50);}

//functions to repeat
void loop() {
inSensor=digitalRead(pir1);//check PIR for input
outSensor=digitalRead(pir2);
if (((inSensor==HIGH)&&(outSensor==LOW))||((inSensor==LOW)&&(outSensor==HIGH))){

//view motion state on serial monitor
Serial.println("Motion detected:Opening Door");
digitalWrite(ledGreen, HIGH); // turn on door display
digitalWrite(transbas1, HIGH); //turn on transistor1 if motion detected
delay(7000);
digitalWrite(ledGreen, LOW);// display turns off
digitalWrite(transbas1, LOW);
delay(5000);

digitalWrite(ledRed, HIGH);
digitalWrite(transbas2, HIGH);
Serial.println("Closing Door");//view door action on serial monitor
delay(7000);//
digitalWrite(ledRed, LOW);
digitalWrite(transbas2, LOW);
delay(5000);
}
else

if((inSensor==HIGH)&&(outSensor==HIGH)){
// view state on serial monitor
Serial.println("Wait! Motion detected on both Sides");
delay(250);
// ledpin state remains low in absence of motion
digitalWrite(transbas1, LOW);
delay(5000);
digitalWrite(transbas2, LOW);
delay(5000);
}
else
{
// view state on serial monitor
Serial.println("Motion ended or No Motion");
//keep track of motion state
delay(250); }}
```