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Design, Implementation and Evaluation of a Smart Home Surveillance and Security System

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ABSTRACT—*This work presents a new innovation in home security where overall safety of lives and property is improved. Unlike the existing security systems, such as the CCTV which provides only surveillance, this work did a bit more by applying some basic image processing algorithms to detect pixel changes and movements on the cameras' view. The processing, using relatively low resolution cameras, would help monitor the direction where movement is spotted and try to predict intrusion and other anomalies and trigger some actions on the arduino controlled hardware based on the outcome of a prediction. This system on full implementation in the general security setting would serve as a chief deterrent to burglary and intrusion and aid largely the investigation process.*

KEYWORDS*—SMS (Short Message Service),CCTV(closed-circuit television), GSM(Global System for Mobile Communication), Microcontroller, Camera.*

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I. INTRODUCTION

Security is a basic and major concern in our day-to-day lives and home security systems are a key player in the safety of homes and environments. There are many forms of security which range from human resources to machines and a combination of both, all with the aim of keeping our environment and homes safe and peaceful. A long time before now, the CCTV surveillance systems and alarm systems have worked independently on their own and haven't been able to provide optimum and efficient security independently. A lot of other approaches have been exploited in the past to help curb this menace. This work is geared at exploiting an intelligent system to help deter and follow up to resolve attempts. Every individual wants to have a complete ownership and control of their homes. This has put up a high demand for effective, efficient and dynamic security and surveillance systems in our homes to begin with as a place that provides rest and safety. Companies and offices that generate huge income can afford to use others forms of security, that are both expensive and complex. It is true these systems and forms are effective in the corporate scenario, but individuals, especially average residences would find it difficult to deploy and maintain such. In developing countries in sub Saharan Africa, especially Nigeria according to World Population Review (2019), communication from crime scene to law enforcers is usually limited and this does not help in dissuading crime, rather it encourages crime and aids the culprits to get away from the law (Kasumu, 2017). Burglary basically means getting unauthorized access to a part of building or other premises; including use of forceful methods; with the intention of stealing (breaking and entering), theft from a house; apartment or other place of residence; factory; shop or office; from a military base; or by using false keys should all be added up as burglary. This work is going to employ intelligent systems that are not the regular to help discourage, alert and keep record of evidence of burglary attacks or attempted attacks on homes. This is going to play out with different security levels as will be stipulated by the owner of the house, so as to avoid false alarm triggers or reduce efficacy of the system. With the implementation of this work, homes will get safer and the law enforcement agencies will have it a lot easier to manage and curb crimes of burglary attacks and break-in into residential buildings. The work will be limited to residential buildings, but little features can be added to customize it for all kinds of buildings.

As earlier mentioned in the text that security is a basic and major concern in our day-to-day lives and home security systems are major players in the safety of homes and environments. Nigeria being a focal case study, suffers a lot of burglary attacks on daily basis and these attacks either go unreported or sorting for security agency rapid response isn't possible due to backward technology or after help finally arrives no proper identifiable evidence to track down the perpetrators of such acts (Kasumu, 2017). And this has been a major challenge for many years from research.

II. PROPOSED SOLUTION SYSTEM

After looking at the statistics from research a decision to tackle the burglary side of it brought the "SMART HOME SURVEILLANCE AND SECURITY SYSTEM (SHSSS)".

A system that will keep watch 24/7 and help deter burglars and armed robbers from getting access into protected areas and getting away with it. The work makes use of a set of cameras, installed at strategic points in a home, to spot any movement and then tries to analyze and interpret the meaning of these movements and then communicates with a set of hardware, controlled by a microcontroller, to perform certain actions. These actions range from sounding alarms to sending SMS notifications to the owner of the home or the police in the case of intrusion. Also a main camera, of high resolution, is included to capture high-resolution footages and is only triggered when an anomaly or other suspicious cases are sensed.

III. REVIEW OF RELATED WORKS

Olafusi(2009) in his thesis, individual home control security system,used control systems and information technology to control equipments (homeappliances), his system was such that electrical appliances could be remotely andautomatically controlled or accessed, the system gave a feedback on the present state ofthe home appliance and an automatic detection to fault, e.g. (if thermostat in the waterheater goes bad).

The system uses PIC18F4455 microcontroller, a mobile phone RS232 standard for communication between themicrocontroller and the mobile phone.

When the mobile phone receives the required signal it
communicates with the RS232 ad HIN232 to the PIC18F4455, the PIC18F4488 controlsthe relay state via a driver and this in turn determines the state of the connectedappliance, whether switched on or off.

Omorogiuwa and Elechi(2012) in their thesis GSM intelligent home security system, they focused on the use and integration of power electronics, operational amplifier, telecommunication, and software engineering. They used PIR sensors to detect intruders (in the form of variation in temperature, gas leakage and pressure) the relevant sensing devices respond and the microcontroller sends encoded alarm signal to the wireless sensor networks established in the home. The moment the alert signal is received, it sends a short message to the users (owners of the building) through the GSM network immediately.

Budijono et al (2014) in their work; 'Design and implementation of modular home security system with short messaging system', designed a smart security system that makes use of the GSM(Global System for Mobile) mobile device to send fast information via SMS (Short Messaging System) to the owner of the house. The mobile device could also deactivate the system via SMS. Hardware of this system has been designed using microcontroller AT Mega 328, PIR (Passive Infrared) motion sensor as the primary sensor for motion detection, camera for capturing images, GSM module for sending and receiving SMS and buzzer for alarm. For software this system uses Arduino IDE for Arduino and Putty for testing connection programming in GSM module. This Home Security System can monitor home area that surrounding by PIR sensor and sending SMS, save images capture by camera, and make people panic by turn on the buzzer when trespassing surrounding area that detected by PIR sensor.

Sathishkumar and Rajini (2015) in their work; 'Smart Surveillance System Using PIR Sensor Network and GSM', designed a security system that is based on the embedded system along with GSM and sensor networks. The human movement is detected using the PIR sensors. In this time, the system triggers an alarm detecting the presence of person in a specific interval of time and simultaneously sends the how many persons are intruder via message to the SMS through GSM Modem. When the security system is activated, the CCTV camera is activated. This highly reactive approach has low computational requirement. Therefore it is well suited for home surveillance system. This surveillance security system implemented using PIC micro controller, camera, gsm and sensors.

In the work, Remote Controlled Cellular Phone home/office security system (RCCP), put together and overseen by *Oppong* (2011), The PIR sensors send signals to microcontrollers and this sends signal to the computer via serial connection. This software processes these info and the two cameras connected are activated to start

recording events taking place in the environment. A text containing a link is sent to the user of the system with mobile equipment via GSM network. The user connects to the link to watch a live video feed of the occurrence.

Hsieh and Cao (2004), in their work, Home Security System, A digital home security system with voice feature which can monitor room temperature, smoke, motion, windows and door. All signals from the sensors and the keypad go into the security system; the system processes the info and sends signals to the LED, Alarm circuit and voice circuit. The most difficult part of their work was timing.

IV. WORK COMPONENTS/TOOLS

A. HARDWARE TOOLS

THE MICROCONTROLLER (ARDUINO)

The Arduino UNO is a microcontroller board in accordance with the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a power jack, an ICSP header, USB connector and a reset button. It has all needed support for the microcontroller; you just connect to a computer via a USB cable or power it with a AC-to-DC adapter or DC battery to get started. Diagram is seen in Figure 1 (Trossen Robotics Interboti, 2019)

SPECIFICATION OF THE MICROCONTROLLER (ARDUINO)

Microcontroller: ATmega328P
Operating Voltage: **5V**
Input Voltage (recommended) **7-12V**
Input Voltage (limits) 6-20V
Digital I/O Pins: 14 (of which 6 serve PWM output)
Analog Input Pins:6
DC Current per I/O Pin: 20 mA
DC Current for 3.3V Pin:50 mA
Flash Memory: 32KB with reserved 0.5 KB that the boot-loader uses
SRAM: 2 KB (ATmega328P)
EEPROM: 1 KB (ATmega328P)
Clock Speed 16 MHz
Weight 25g

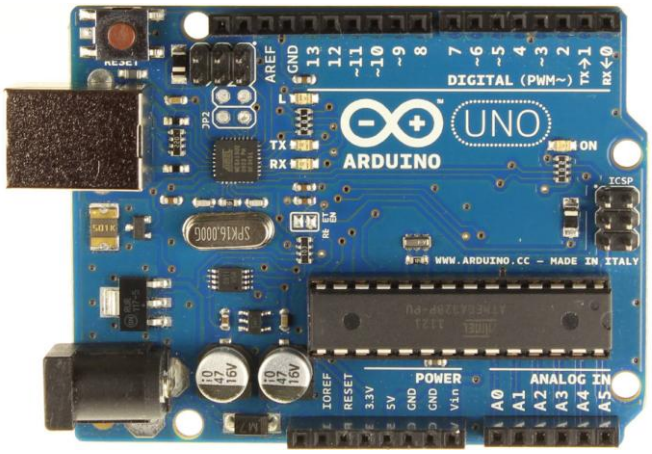

Figure 1: Arduino Uno Micro-controller

JUMPER WIRES

Jumper wires are one of the most important gear components for the tinkerer. Often underestimated, but one of the first things to miss. If you are starting to assemble your tinker gear and wondering if this is really needed, doubt not, this is at some point or another always used. Wire or pieces or wire are basic, even for the non-often tinkerers. Jumper wires are not just for prototyping but also a good resource for repurposing.

Due to their minimal cost and great usability these are usually seen on most gears. Breadboard is one important step for electronic tinkering and electronic circuit development. Jumper wires go together with breadboards and Arduino. We use these wires for everything! They function well with breadboards, Arduino, and any 0.1" pitch board. When working with Arduino at some point, jumper wires are sure to be very useful.

They are very useful for quick prototyping, and always an amazing resource for wiring, testing and analysis.

Diagram is seen in Figure 2 (Trossen Robotics Interboti,2019).

Figure 2: Jumper Wires

THE PIEZO BUZZER

The buzzer speaker produces sound for feedback. Rated Voltage: A piezo buzzer is driven by square waves (V p-p). Operating Voltage: For normal operating. Current Requirement: The current is stably consumed under the regular operation. Nevertheless, it usually takes three times of current at the point it starts working. Sound Output: This is usually measured by a decibel meter. Rated Frequency: A buzzer can make sound on any frequencies, but advisable that the highest and the most stable SPL are gotten from the rated frequency. Operating Temp: Keep working well between -30ºC and +70ºC. (APC International Ltd, 2019)

SERVO

This library permits an Arduino board to control servo motors. Servos contain embedded gears and a shaft that can be precisely controlled. Standard servos permit the shaft to be positioned at different angles, usually between 0 and 180 degrees. Continuously rotating servos allow the shaft rotation to be set to different speeds. On boards apart from Mega, use of the library disables the analogWrite () (PWM) function on pins 9 and 10, whether or not a Servo is on those pins. On the Mega board, about 12 servos can be used concurrently without interfering with PWM function; use of motors numbering between 12 to 23 will disable PWM on pins 11 and 12. Diagram is seen in Figure 3 (Robotzone LLC, 2019)

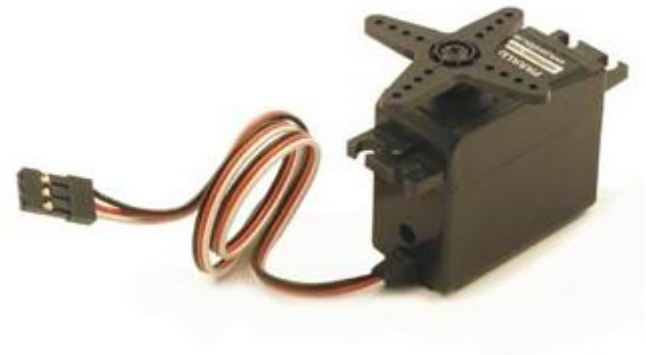

Figure 3: Servo

LED (LIGHT EMITTING DIODE)

An LED stands for light-emitting diode – it's basically a small light that you'll be able to turn on and off with your button. Diagram is seen in Figure 4 (LEDs Magazine, 2004)

Figure 4: Light Emitting Diodes

Webcam – USB

This is a simple USB Webcam that can be plugged into your computer and start capturing video right away. The resolution is 1024x768 which is adequate for motion-tracking or object-detection, but not expected to be used it for movie-making or photography.

LIQUID CRYSTAL DISPLAY

The Liquid Crystal Display library permits control of LCD displays that are compatible with the Hitachi HD44780 driver. There are many of them and they are easily identified by the 16-pin interface. The LCD display Module is built in an LSI controller, the controller has two 8-bit registers, an instruction register (IR) and a data register (DR). The IR contains instruction codes and address information for display data RAM (DDRAM) and character generator (CGRAM). The data register stores data on temporary basis to be written or read from DDRAM or CGRAM. When address information is written into the instruction register, the data is then saved into the DR from DDRAM or CGRAM.(Electronics Foru, 2019)

Figure 5: Liquid Crystal Display

PUSH BUTTON

The Push Button is simply a connection component that links two points in a circuit when you press it.

Figure 6:Push buttons

GSM MODULE (FOR SMS)
This device is a circuit (chip) used to transmit information between devices on a GPSR or GSM network.

B. SOFTWARE TOOLS
PROCESSING

Processing is an open-source programming language, development environment and online community with hundreds of libraries that extend its core software. Since the year 2001, Processing has supported software literacy awareness within the visual arts and visual literacy in the technological sphere. It was initially created to be used as a software sketchpad and to tutor computer programming fundamentals within a visual context, but moving forward in time Processing evolved into a development tool for technology professionals. As of today, processing is now used for learning, prototyping and production. (Fry and Reas, 2019)

V. DESIGN METHODOLOGY

With the aim of the work being the design of a surveillance and security system that will keep watch over the house at all hours, the SHSS system employed various hardware and software tools to be able to achieve this feat. Outlined below is the design approach.

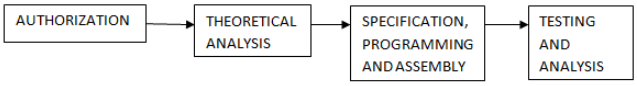

Figure 7: Stages of the Design Methodology

Figure 8: Steps of the Authorization Stage

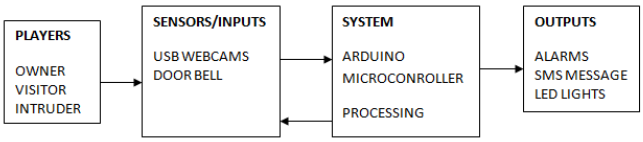

Figure 9: Block diagram of relationships between system components/human players

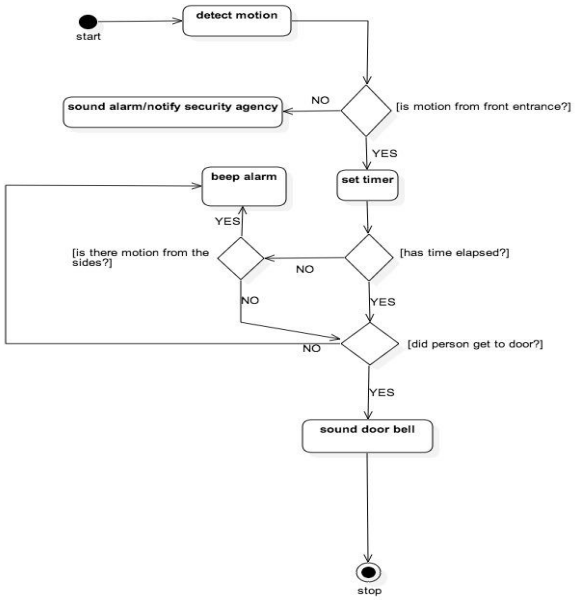

Figure 10: Flow Chart Diagram of the System Actions/Feedbacks in Home Mode

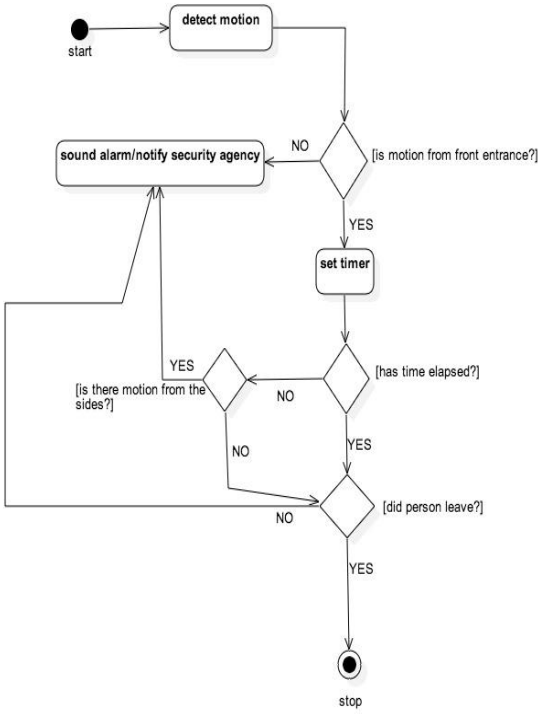

Figure 11: Flow Chart Diagram of the System Actions/Feedbacks in Away Mode

Specifications, Programming and Assembly

This section of the report tells first about the underlying calculations of the design and the specifications of the hardware tools. The tools were acquired at this stage of the work after the calculations and specifications. After this stage came the software and simulation tools and the programming. The final stage for this section of the work was the assembly of the prototype.

SENSOR CAMERAS MATHEMATICAL MODEL

$\mathbf{P_{i,j} < K}$ **(Eq. 1)**

$\mathbf{P_{i,j} > K}$ **(Eq. 2)**

The first equation (Eq. 1) works for the black pixel while the second equation (Eq. 2) is the working model for the white pixels. Considering equations 1 and2 the sensitivity threshold figure was raised to **100** to ensure the only motion picked was that of a human, large enough to fill the pixel canvas of **threshold100**.

ARDUINO AND PERIPHERALS

Peripherals connected in parallel, and to common ground of the arduino, to ensure the 5V supplied across the Arduino UNO still remains same across the peripherals (buzzer, LCD Display).

$V_s = V_1$, $V_s = V_2$ and $V_s = V_3$.

PROGRAMMING AND FUNCTIONALITY

The software tools described above are the controlling programs that take care of the functionality of the system. While the Processing controls the camera sensors, the arduino controls the other hardware tools in the system. The arduino was written in the arduino language which comprises of C and C++ languages. The processing tool language made use of Java programming language.

VI. TESTING AND RESULTS

To test the Home Surveillance and Security System to satisfaction, an empty room was used to simulate without interruption of a real life occurrence of how the system will operate and react to given scenarios. With the aid of various test objects the different scenarios that can occur within the home security system were demonstrated and the response that the system gives to those different scenarios documented as shown in chapter 4 of this work. The evaluation was carried out by observing the way the system reacts to the various channels of entry demonstrated by a person and if the response given is the correct response according to the original design.

TEST AND ANALYSIS MATERIALS/TOOLS

- Dummy Bird (Teddy)
- Dummy Cat (Teddy)
- Dummy Dog (Teddy)
- Real Man
- Stop Clock
- MATLAB Software
- Snipping Tool Software

TESTING FUNCTIONALITY OF CAMERA SENSORS POWERED BY PROCESSING ENVIRONMENT

With the help of open-source processing software a program was developed capable of distinguishing when motion has occurred and when motion has not occurred. This was done using an effective and accurate algorithm of image processing capable of detecting human motion by affecting the threshold level that allows the stationed cameras to detect black pixels only when an object of a reasonable size moves passed it, the smaller the object the move difficult it is for the cameras in sight to detect anything.

With the aid of webcam(s) installed and connected to a computer, the webcam(s) lens were displayed on a window frame in a monochrome mode (black and white) where motion is represented as black pixels changes displayed on the computer's window frame illustrating that no motion close to the size of a human has moved in the sight of the installed cameras.

When the processing analyzes the signal from the low resolution sensor cameras, if the pixel changes are large enough to depict a human, the processing triggers the Arduino microcontroller which swings into action to see if the motion is authorized or not and takes appropriate action.

System total response time formula

T(xt) = **W(t)** + **R(xt)** (Eq. 3)

(Total Response Time = Waiting Time + System Reaction Time)

Table 1: Cases, Players' action and System feedbacks gotten during the system testing

Mode of operation	Action carried out	Feedback
Home 1	Enters through front door and presses doorbell	Home owner is informed through a doorbell sound
Home 2	Jumps through the fence	Sounds alarm
Home 3	Enters through front door and does not press doorbell after a reasonable time period (30 Seconds)	Sound alarm
Away 1	Enters through front door and does not press doorbell after a reasonable time period (30 Seconds)	Sounds alarm, SMS message is sent to home owner and police
Away 2	Enters through front door and presses doorbell and exceeds the given time (45 Seconds)	Sound alarm, SMS message is sent to home owner and police.
Away 3	Jumps through the fence for the side and back of the home.	Sounds alarm and sends SMS message to home owner and police.
Away 4	Enters through the front door and decides not to press the doorbell or/and leave after a given period of time.	Sound alarm, Send SMS message to home owner and police.

Table 2: Pixel Thresholds versus Motion Detection versus Sensitivity Levels derived from the processing software platform during the programme testing

Pixel Threshold	0	5	10	20	25	30	50	80	100
Motion Detection	NO	YES	YES	YES	YES	YES	YES	YES	YES
Sensitivity Level	0.0	0.9	0.8	0.7	0.65	0.6	0.45	0.35	0.1

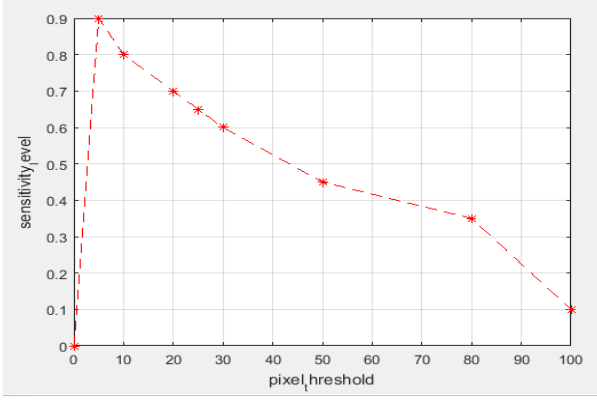

Figure 12: Plot of the Pixel Threshold versus the Sensitivity level as shown in table 2

Table 3: Cases and System response times derived from equation 4.1 and the test stop clock

CASES	TOTAL RESPONSE TIME (Txt)
HOME 1	1000mS
HOME 2	2000mS
HOME 3	32000mS
AWAY 1	32000mS
AWAY 2	47000mS
AWAY 3	2000mS
AWAY 4	15000mS

Table 4: Comparative Analysis of PRI Sensors versus LR Camera Sensors

TEST ITEM USED	PIR SENSOR RESPONSE	LOW RESOLUTION CAMERA RESPONSE (HSSS)
Dummy Bird	YES	NO
Dummy Cat	YES	NO
Dummy Dog	YES	NO
Real Man	YES	YES

VII. DISCUSSION

As seen in Table 1, 7 cases were considered, 3 out of which the owner ishome and the remaining 4 cases were tested with the owner away. The table showed the input action into the system by the player involved either visitor or presumed burglar, and the corresponding response (feedback) outputted by the system as it is designed to give. The reactions were different depending on the input and the predesigned instructed output of the system. The sensors capture the signals, process them and give a feedback to the Arduino which functions according to the signal received and delivers a system output accordingly. Moving to the next table which is 3, the cases and their corresponding total system response times, Txt were displayed. The total time included both the time the system gave the player to react fully in some cases and the time the system took to process the signals and give an output. This table depicted a very efficient system speed that will enable swift response to each case as needed. Considering the third result table, Table 2 has displayed on it the pixel thresholds, motion detections, and sensitivity levels. This table helps us to relate the motion detections to the pixel thresholds and also relates the sensitivity levels to the various pixel thresholds. Therefore considering the information delivered by this table, the most appropriate and efficient pixel threshold that provides the best sensitivity level for our camera sensors in pixel threshold 100. This is therefore the ideal pixel threshold adopted in the Home Surveillance and Security System and also declared best for further related works. The same information in Table 2 has been graphically illustrated in Figure 14 for further clarity and understanding.

COMPARATIVE ANALYSIS

Finally on the tabulated results is the Table 4. The table displays a comparative analysis between the Passive Infra Red (PIR) Motion Sensors utilized in the work "GSM Intelligent Home Security System" (Omorogiuwa and Elechi, 2012) and also in the work "Home Security Systems" (Ajah and Aina, 2015) as against the Low Resolution Camera sensors which was utilized in this work "Home Surveillance and Security System".

The information from the comparative analysis shows the feedbacks from both systems using the various test materials. The tabulated results in table 4 showed that the motion sensors from the older systems picked and responded to all motions no matter the size of the motion causing subject or object. This has a very huge disadvantage especially when used in larger systems with more complex functionalities because false alarms will be triggered on a regular basis as there is little or no control over the motion detection. This is the huge and major advantage of the camera sensors over the PIR motion sensors which is the fact that the camera sensors can be trained to pick only specific motions by the monochrome pixel manipulation while the PIR picks any and every possible motion within its range.

VIII. CONCLUSION AND LIMITATIONS

A. Conclusion

This work, home surveillance and security system has been fully developed to meet the functional requirements outlined. It has been tested and is working fine. During testing, users were made to undergo the various scenarios and check to see if the system could detect motion, analyze it, and then carry out the necessary action. This system, if fully implemented in the general security setting, would serve as a chief deterrent to burglary and intrusion. In addition, it would provide surveillance images on the occurrence of an anomaly (like intrusion and others), and this would help law enforcement agencies to better tackle and clamp down on crime drastically.

B. Limitation of Work

Developing this work presented a few problems mostly in the areas of acquiring and configuring the necessary hardware components. Challenges were also faced in the learning and application of the image-processing program using Java programming language. Linking the arduino and the processing also posed challenges. The next major limitation was in the acquisition of authorization to visit the sites for survey and linking the private security firm and this lowered the number of visited sites.

X. RECOMMENDATIONS AND FUTURE WORKS

A. RECOMMENDATIONS

In order to ensure the full benefits and security provided by this work, we stress that the following recommendations be adhered to:

- Training of users should be carried out to ensure that they understand properly how the system works and how to operate it.
- A backup power source should be made available in order to ensure that the system is not bought to a total halt in the event of power outage in places without regular power supply.

B. FUTUREWORK

Because of certain constrains some admirable features could not be implemented at this time. These features would increase the viability of this system and also increase its scope and as such would be good addition in the advancement of this system in the future. Some of these features are:

- Enhancement of the image-processing algorithm in order to be smarter, detect different shapes and movements, and provide more accurate and useful data.
- Provision of a backup system where data collected would be stored in a database on a centralized remote server. This database could be queried and analyzed in order to provide better statistics and help law enforcement agencies function better.
- Develop better algorithms to study the behavioral pattern of intruders and train the system to be smarter and more efficient.

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