A Cost-Effective Two-Way Household Wireless Door Intercom System

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Abstract —This study utilized a wireless transceiver module (NRF24L01) and ATmega328 to implement a cost-effective household door intercom. The intercom consist of two units; the outdoor and indoor. The outdoor unit was used by the guest to communicate with the household owner to notify them of their presence at the door while the indoor unit was used to respond to the call. The transceiver module transmits and receives audio signals between the two units, while ATmega328 handles the conversion of the signal from analog to digital during transmission and vice-versa at reception. The outcome of the test and analysis carried out on the developed prototype shows that it is user-friendly, consumes less power, and also proves that it is a cost-effective solution that can be affordable and made to be readily available to the consumer.

Index Terms—Transceiver module, wireless intercom, cost-effective, system usability test

I. INTRODUCTION

Due to the increased relevance of establishing communication with family, friends in distributed locations within a household building, residents utilize intercom systems in their daily activities which promotes convenience and establish safety [1]-[2]. The home intercom system has been in existence for over ten years, which has become part of the family lifestyle and its security. Intercom systems can be a simple two-unit system with only a call button, a microphone, and a loudspeaker combination in each unit. It can also be a complicated multichannel multi-station system with varieties of special features [3]. They are classified into two types; wired and wireless [4], [5]. The wired intercom, regarded as the traditional system, transmits signals via cables and analog buses [6]. The identified flaws of the traditional system are such that they are not mobile, extremely high costs are often incurred, retrofitting wires into buildings during installation and maintenance. Degradation in the quality of transmitted audio signals due to aging wires over a long period is also a major limitation [7]

However, the wireless intercom systems provide an improved performance solution that permits the transmission and reception via radio waves [8]-[9]. This has been achieved with advances in audio, video, and embedded system technology [10], [11]. Various designs and techniques have been explored by researchers, to develop communication systems that can meet the needs of households, residents, and offices. A two-line intercom using dedicated telephone cables was designed in [12]. A changeover circuit was integrated to allow the master unit to initiate a private conversation with several slave units. Also LM386, an audio amplifier was used to amplify the incoming audio signal before it is transmitted to its destination. Reference [13] designed a wired two-way intercom system. It consists of a tone generator, speakers audio input source, and amplifier. The system works in a full-duplex mode such that voice signals can be transmitted and received simultaneously between the two nodes using a wired connection.

An IOT-based automatic doorbell developed in [14] was specifically designed to aid the elderly in responding to visitors at the door and also identify unauthorized persons. It automatically alerts the house owner by triggering a bell situated indoor to ring once the presence of a visitor was sensed at the door. If access to the house is not granted to the visitor, after some specific period, a response will be sent by the house owner via an SMS which will be displayed on an LCD screen attached to the door. A Session Initiation Protocol (SIP) was employed in [15] to set up a free intercom system. A peer-to-peer communication was established via Wireless local area network using Asterisk-based server and wireless fidelity (WIFI) based clients. The setup allows users to transmit and receive information such as text, voice, and video between mobile phones, computers, and IP phones. Reference [16] implemented a half-duplex intercom system using an NRF24L01 wireless module. The results obtained showed that excellent signal quality was obtained within a distance coverage of 0-80 m.

The designs achieved in the previous studies are potential solutions to the identified problem, but additional considerations such as quality of the audio signal transmitted and received, power consumption requirement, and ease of installation and use were sidelined. Therefore, this study aims at developing a cost-effective two-way intercom system for households and evaluate its performance.

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II. METHODOLOGY

A. System Design

Fig. 1 shows the block diagram of the two-way intercom designed to work in a half-duplex mode. It uses a push-to-talk button to establish a connection and alternatively switches between the two units since only one link can be available at a time. At initialization, the outdoor unit is engaged by an incoming visitor using the push button by sending a verbal message through the microphone attached to the unit. The button has to be released instantly to await a response from the house owner through the same link. The audio signal is pre-amplified, converted to a digital signal, and transmitted via the antenna to the indoor unit. Furthermore, the transmitted signal is received and post amplified, to obtain an audible response through the loudspeaker. Afterward, the indoor can unit can also be engaged using the push button to respond to the message.

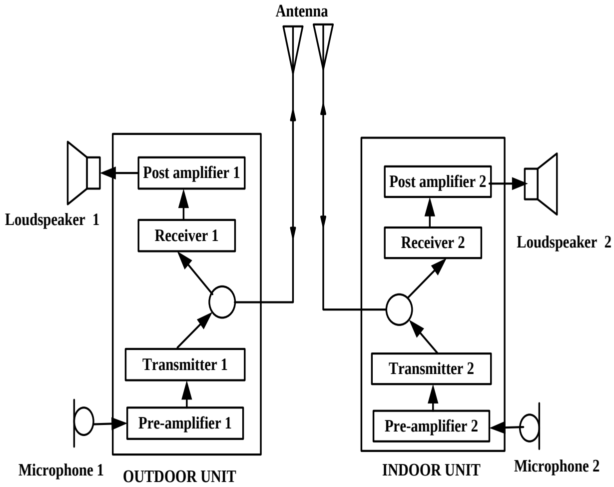


Fig. 1. Block diagram of a developed two-way household intercom.

B. Hardware Implementation

The system hardware is composed of the power supply, pre-amplification, transceiver, and controller section. The power supply units shown in Fig. 2 contain two regulators 7805 and LM317, connected to a direct current (DC) power source. The 7805 regulator supplies 5 volts to the controller unit while the second regulator LM317 produces a 3.3V output that powers the transceiver module. The capacitor C1 ensures the stability of voltage going into the regulator, while the potentiometer (RV1) was used to set the output voltage to 3.3V, required to power the transmitter. The pre-amplifier section shown in Fig. 3, was used to boost the weak audio signal from the microphone by providing a stable gain and prevent induced noise. BC547 NPN transistor employed for the design has a continuous collector current (Ic) of 100mA, emitter-base voltage (V_{BE}) of 6V, and base current (I_B) of 5mA maximum. In addition, BC457 has a gain value of 110 to 800 which determines the amplification capacity of the transistor.

Fig. 4 shows the pre-amplification designed with LM385; a low voltage audio operational amplifier. The coupling capacitor C4 and C1 connected at the input and output respectively is used to block direct current (DC) voltage noise and avert distortion of audio signals. While resistor, R1, and capacitor C2 are the filtering circuits, that prevent interference of high-frequency signals.

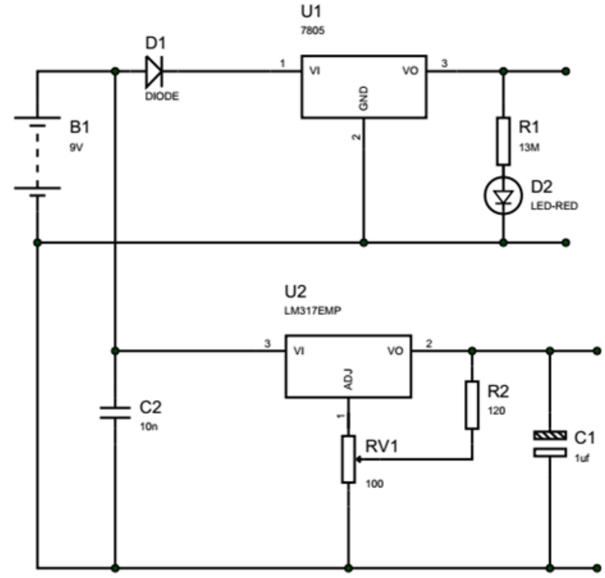


Fig. 2. Circuit diagram of the power supply section

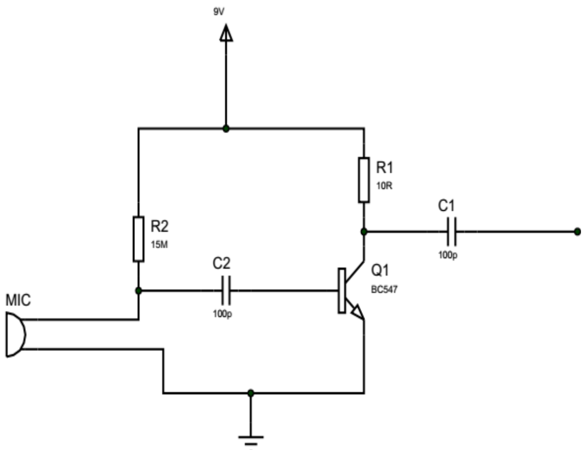


Fig. 3. Circuit diagram of the pre-amplification section

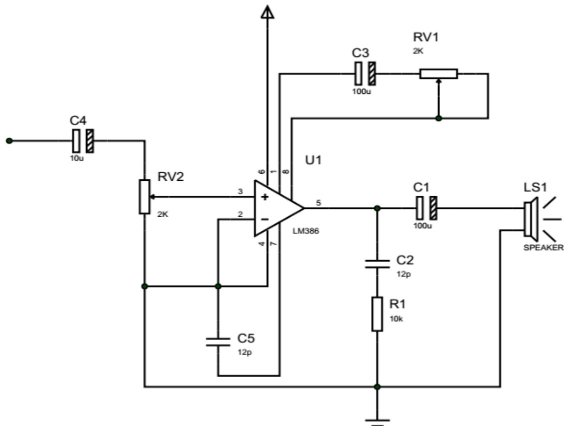


Fig. 4. Circuit diagram of the post-amplification section

The capacitor C3 connected between pin 1 and 8 was used to boost the gain to 200 (46 dB), while the potentiometer RV1 was used to control the volume, which invariably regulates the gain of the amplifier.

NRF24L01 was employed in the transceiver section, to handle the transmission and reception of signals. It is a single radio frequency RF chip that operates at a frequency of 2.4 GHz, with a data rate of up to 2mbps. It consumes ultralow power with an operating voltage of between 1.9v-36v, a minimum current of 26μA in standby, and 900nA power-down mode. NRF24L01 is based on the Gaussian frequency-shift keying modulation (GFSK) scheme. GFSK modulation is a variant of frequency shift keying modulation (FSK) shown in Fig. 5. It is composed of two blocks; the Gaussian filter and frequency modulator. The Gaussian filter is used to smooth incoming digital symbols before the frequency modulation procedure. In other words, Gaussian filtering helps to reduce the adjacent channel interference by eliminating high frequencies due to the switching, thus reduces the signal spectral bandwidth [17]. Its mathematical formulation is given in equation (1)-(5).

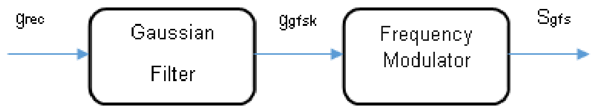


Fig. 5. A typical GFSK modulation scheme.

$$h_{gauss}(t) = K\sqrt{\frac{2\pi}{In2}}Be^{\frac{2(B\pi)^2}{In2}t^2} \tag{1}$$

$$g_{gfsk}(t) = g_{rec} * h_{gauss} \tag{2}$$

$$g_{gmsk}(t) = -\frac{k}{2\sqrt{In2}}\left(Erf\left(2B\pi t\frac{t-\frac{T_b}{2}}{\sqrt{In4}}\right) - Erf\left(2B\pi t\frac{t+\frac{T_b}{2}}{\sqrt{In4}}\right)\right) \tag{3}$$

$$Erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t2}dt \tag{4}$$

After the g_{gfsk} is applied to an FM modulator and the result is given as:

$$s_{gmk}(t) = 2\pi\frac{m}{T_b}\int_0^t \sum_{i=0}^{\infty} b_i g_{msk}(\tau - iT_b)d\tau \tag{5}$$

where m is the modulation index, Erf is the error function T_b is the symbol interval, g_{rec} is the pulse shape function, h_{gauss} is the impulse response function of the Gaussian, B is the bandwidth of the channel, and g_{gmsk} Gaussian-shaped bitstream

ATmega328, a high-performance microchip 8-bit AVR RISC-based microcontroller is the major component in the controller section. It combines 32KB ISP flash memory with read-while-write capabilities, 1024B EEPROM, 2KB, SRAM, 23 general-purpose I/O lines, 32 general-purpose working registers, three flexible timers/counters with compare modes, internal and external interrupts, serial programmable USART, a 6-channel 10-bit A/D converter. The device operates between 1.8-5.5V. The highlighted features make it robust in handling the conversion digital to an analog signal and vice versa. Also, the control section initializes the connection between the transmitter of the outdoor unit (Fig. 1) to the receivers of the indoor unit and vice versa.

Fig. 6 shows the flowchart depicting the sequence of instructions executed in the control unit. Once the system is initialized, the input and output port becomes active, keeping the intercom running. To transmit the audio signal from one unit to another, the push button attached to the unit is engaged. Instantly, its light-emitting diode (LED) glows red indicating that it is has been switched to a “transmitting mode”. Subsequently, the receiving unit acknowledges the signaling by prompting its LED to glow yellow, indicating its automatic switch to a “listening mode. Furthermore, to receive the transmitted audio signal, the unit’s button is pushed so that the signal is outputted through the loudspeaker.

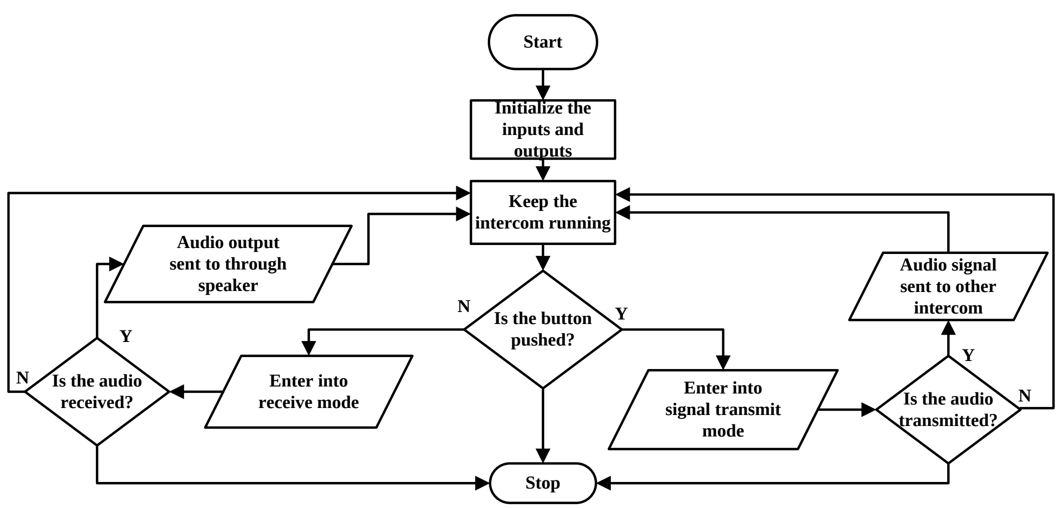


Fig. 6. Flowchart of the programmed control unit

After its implementation and testing on a breadboard, the pre-amplification, post-amplification, and power supply circuits were transferred to the Veroboard and soldered together using the point-point wiring method. Furthermore, those circuits were integrated with the Arduino board, battery, loudspeakers, and other components. Afterward, the completed design was packaged into a 6x6 *Polyvinyl chloride* (PVC) adaptable box as shown in Fig. 7. To make it handy portable and durable, the boards were fastened to the box with screws, while the battery and loudspeaker were secured with gum. The top cover was placed and screwed tightly together, Fig. 8 shows the prototype of the 2-way door intercom system.

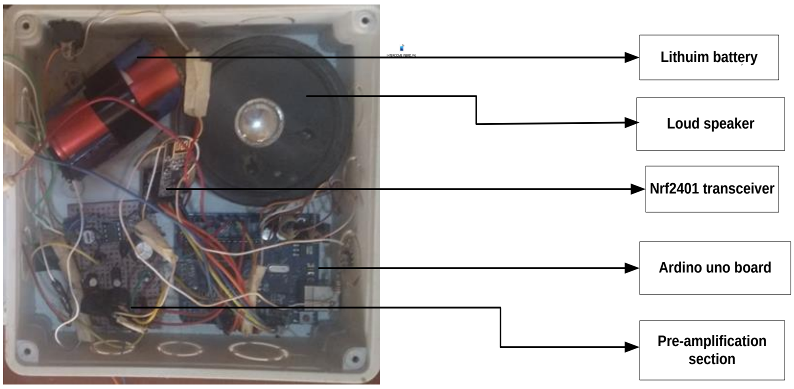


Fig. 7. The inner components and packaging of the developed circuit

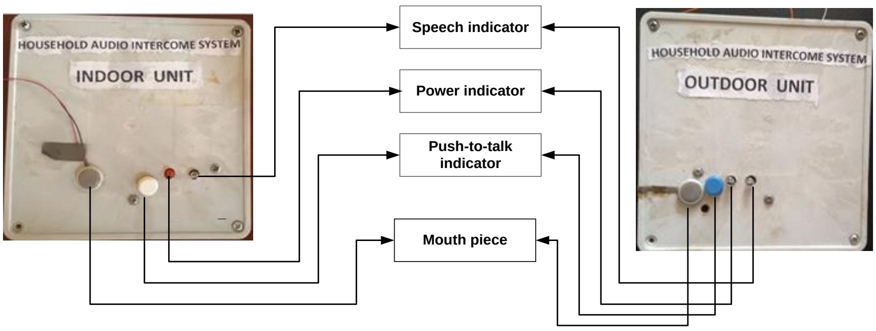
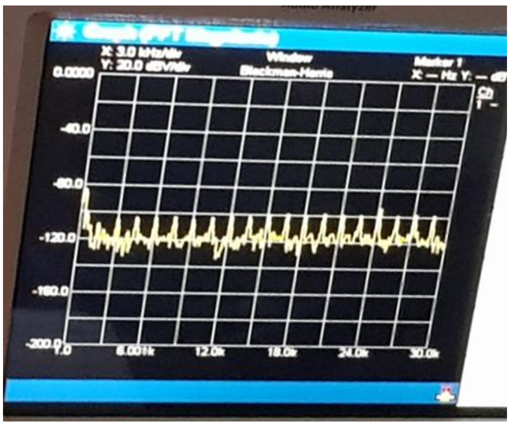


Fig. 8. Physical setup of the system intercom

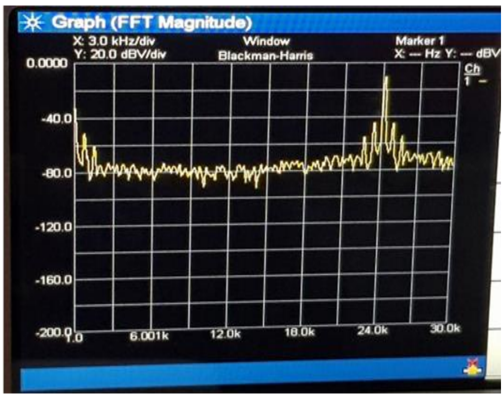
III. Results and Discussion

A. Audio Analysis Test

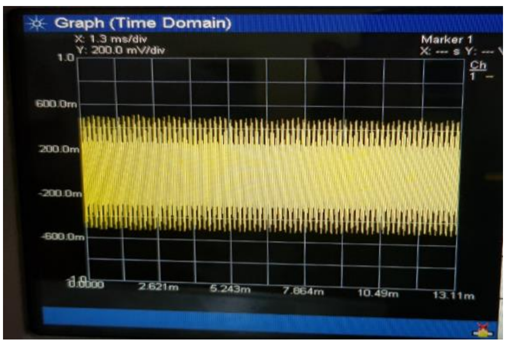
The output of the outdoor unit was connected to an oscilloscope, response of the system without a message signal transmitted in time and frequency domain is shown in Fig. 8(a) and (c). Furthermore audio signal was transmitted via the indoor unit, Fig. 8 (b) and (d) also shows the obtained results at the time the audio signal was transmitted in both domains.



(a)



(b)



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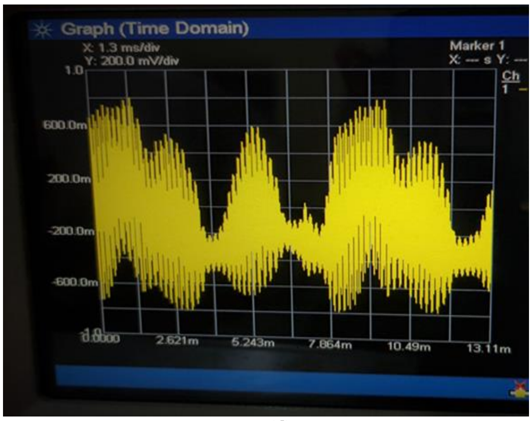

(d)

Fig. 8. (a)-(d) Oscilloscope plot of received signals in frequency and time domain

B. Battery Consumption Analysis

The estimation of the consumption rate was carried out to ascertain the number of days the system can remain functional before it finally runs out of power. The intercom system was attached to an apartment building, kept permanently switched on, and put into continuous usage by incoming visitors for five days. At the end of each day, a voltmeter was used to measure the voltage, at full charge the battery voltage was measured to give 7.2v. The chart in Fig. 9 shows the outcome of the analysis, a total of 25 visitors accessed the building, for the number of days under evaluation. It was observed that the power consumption on days 3 and 4 was higher because more visitors assessed the building than on other days. An estimate of the average consumption of 0.625 per day was obtained.

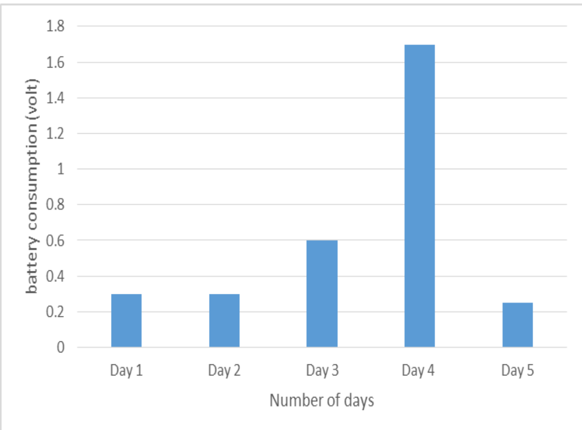

Fig. 9. Chart showing consumption analysis for the prototype for five days

C. System Usability Test

The system usability scale (SUS) is often carried out to ascertain the effectiveness, efficiency, and user satisfaction of the developed systems [18]. It involves the use of a questionnaire that provides a 10-item scale that gives a global view of the subjective assessments of usability. The questionnaire was distributed to 25 respondents. The result shows that the minimum and maximum scores are 92.50 and 51.50 respectively. An average SUS score of 74.6 with a standard deviation of 11.28 was obtained. Fig. 10 shows that 17 participants scored above 70 while 8 scored below. According to the SUS score interpretation guideline, products with scores less than 50 are judged to be unacceptable, products with scores between 50-70 are marginally acceptable and products with scores above 70 are passable [19]. The mean SUS score of 74.6 obtained indicates that the system's effectiveness, efficiency, and user satisfaction are adequate.

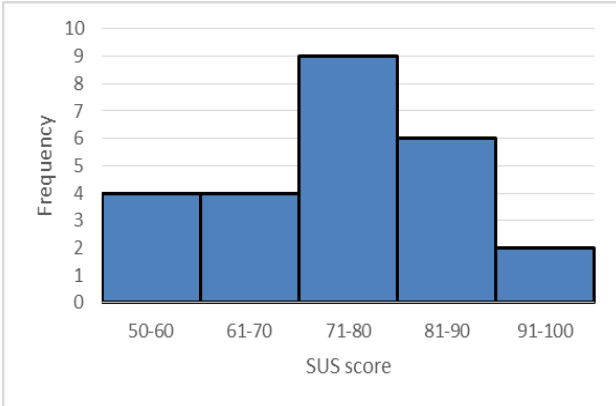

Fig. 10. Histogram showing the frequency distribution of computed SUS scores

D. Cost Analysis

The main purpose of cost estimate and analysis is to enable developers to ascertain the cost-effectiveness of the developed prototype by comparing it with different product alternatives. Table I shows the cost estimate for the design and development of the prototype.

TABLE I: COST OF THE ESTIMATE OF THE PROTOTYPE

S/N	Items	Amount
1.	Cost of component procurement	N 10,000
2.	Development cost (Hardware and software unit)	N 2, 500
3.	Profit margin @ 20%	N 2, 500
	Total cost	N 15,000($38.99)

TABLE II: COST COMPARISON OF THE DEVELOPED PROTOTYPE WITH ORDER PRODUCTS

S/N	Name of product	Mode	Range	Power Requirement	Cost	Shipping cost	Total cost
1	Hosmart wireless intercom	Full duplex	½ mile	5V/2000mA	$54.99	$ 42.36	$97.35
2	Wuloo wireless intercome doorbell	½ duplex		2A	$65.99	$38.05	$104.04
3	Vhppote one-one Doorphone intercom	½ duplex	½ mile	6V/200mA	$45.00	$ 36.32	$81.32
4	Sonew, Two way Doorphone intercom	½ duplex	Over 600 feet	6V/2A	$ 50.98	$38.10	$89.08
5	Local designed Intercom	½ duplex		7.2 /2A	$ 38.99	$ 2	$40.99

Furthermore, a market survey was conducted based on [20] to compare the locally designed prototype with the current market price of four similar products as shown in Table II.

From the table, it can be deduced that our local design is cheaper as compared with available products in the market, in terms of actual and shipping cost with slightly same specification except for product with serial number 1, that works on full-duplex.

IV. Conclusion

The study has presented a cost-effective intercom system that can transmit audio signals over a wireless channel. This will help household members to ascertain the identity of the guest via remote verbal communication before access is granted. The outcome of the performance test indicates that the transmission and reception of high-quality audio signals with minimum distortion were achieved.

In future works video capabilities will be integrated with the existing design, so that the house owner can visually identify and verbally ascertain the intent of the guest. Also, motion sensors will be incorporated to alert the house owner whenever anyone is close to the door. This will help to secure the house from stalkers and kidnappers. Furthermore, the use of advanced embedded systems which can integrate the aforementioned features is recommended, so that the computational task and signal processing can be properly managed, which should still retain its cost-effectiveness.

Conflict of Interest

The authors declare that the presented study was carried out with no conflict of interest.

Author Contributions

The first and second authors conceptualized, implemented, and evaluated the performance of the system. While, the third and fourth authors wrote the paper, analyzed, and presented the result.

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