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Crypto Talk Voice Shield: Secure Speech Communication System Using Arduino

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Abstract

In the rapidly evolving landscape of communication security, this study presents a system designed around Arduino Uno technology, specifically engineered for the secure encoding, transmission, and decoding of speech data. By integrating advanced encryption algorithms, the system ensures that speech data is transmitted in segmented bit chunks, each enveloped in multiple layers of security to prevent unauthorized access or interception. This multi-tiered encryption approach establishes a highly secure communication channel, making it nearly impossible for malicious entities to compromise the integrity of the transmitted data. Furthermore, the system's architecture is optimized for real-time applications, ensuring both efficiency and reliability. This solution not only enhances confidentiality but also reinforces the overall security framework necessary for sensitive communication. In conclusion, the proposed system stands as a powerful integration of cryptographic security and embedded technology, making it highly suitable for applications where data protection and privacy are of paramount importance in today's increasingly digital and interconnected world.

Keywords: Arduino uno, decoding, encoding, audio transmission, waveform audio format, pulse code modulation

INTRODUCTION

We are in the era, where data security is predominant, the need for a robust encryption and transmission systems has become more critical than ever. The Arduino based secure speech encoding, speech decoding, and decoding project emerges as an important solution aimed at building defenses around the confidentiality of transmitted data. By integrating encryption algorithms into the transmission process, this project attempts to ensure that speech data remains shielded from unauthorized tampering. At its core, the project addresses the dual challenge of confidentially and integrity in data transmission. Using flexibility and versatility of Arduino technology, it offers a framework for securing speech data during the wireless transmission, sculpting it to unreadable to any unauthorized entities attempting to intercept the communication between the two Arduinos. In essence, the project offers a solution tailored to meet the tight demands of applications requiring heightened levels of data confidentiality and protection. It focuses on using how to use the minimal computation resources offered by Arduino Uno for safe signal processing.

LITERATURE REVIEW

Borse *et al.* proposed an algorithm that enhances speech which mainly focuses on improving the quality of speech signals by reducing or removing background noise focusing on the speech [1]. This process involves processing noisy speech signals to enhance human perception. This algorithm can be used in the proposed project to improve speech quality for the transmission.

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Weng *et al*. proposed a deep learning-based approach for speech transmission [2]. They used in their research deep neural networks to enhance various aspects of the process, including speech recognition, denoising, and compression. By integrating deep learning at each stage, their proposed method adapts to different channel conditions and noise environments which improves the robustness and reliability. This approach can be implemented efficiently using modern hardware accelerators, offering potential for real-time processing and low-latency communication.

Gao *et al*. research focused on improving speech communication in challenging environments like underwater acoustic channels [3]. They explored in the research about advanced signal processing algorithms, adaptive modulation and coding schemes, error control coding techniques, and acoustic channel modeling to enhance communication reliability. Their findings provide valuable insights for designing communication systems in similar challenging scenarios, such as underwater exploration or marine research projects, enabling more robust and reliable communication.

Debnath *et al*. explained that the lossless compression technique described in the paper utilizes discrete 2-D wavelet transformation followed by quantization and Huffman encoding to compress audio signals without losing any information [4]. The approach aims to reduce the size of the audio data while maintaining fidelity, making it suitable for applications where preserving the original signal is crucial.

The model approached by Abu *et al*. tells about lossless audio compression by using discrete wavelet transform, discrete cosine transform as well as Huffman based LZW encoding [5]. This study focuses on addressing the challenges of reduced size of digital audio files without considering the quality of the audio. This is achieved through a multi-stage compression algorithms that uses different signal processing techniques. First, about the DWT which is applied to the audio signal to analyze and decompose it into frequency sub-bands. This decomposition enables efficient representation of both low frequency as well as high frequency components of audio signals. Next, the DCT is being used to further transform the audio data, facilitating the extraction of spectral information and reducing redundancy. Finally, the compressed audio data is encoded using Huffman based LZW encoding mechanism. This step creates a dictionary of variable-length codewords to represent repeating patterns in the audio data.

The authors Al-Nuaimi *et al.* proposed a novel approach to enhance MP3 encoding using a Predictive Complex Valued Neural Network (PCVNN) [6]. This study addresses the challenge of improving the efficiency and the quality of PCVNN; this is a type of neural network that is capable of modeling data which contains complex values and predicts the future values based on the previous data. The PCVNN is trained using a dataset of audio samples which helps it to learn complex patterns within the audio data.

The model proposed by the authors Huang *et al.* uses advanced lossless audio compression techniques for AAX [7]. The study aims to improve the efficiency and effectiveness of lossless compression algorithms for the data which is the form of audio. The paper explores various methods and algorithms tailored to the specific requirements and constraints of AAC standard. These includes predictive coding techniques, entropy coding methods and many more. Experimental results and performance to demonstrate the efficiency of the model. The model includes metrics such a compression ratio, signal-to-noise ratio (SNR), and subjective audio quality assessments.

The model proposed by the authors Jaldén *et al*. explores about the use of Arduino Due which is a microcontroller based on Atmel SAM3X8E ARM Cortex-M3 CPU, as a base platform for training the digital signal processing concepts [8]. This model highlights affordability, accessibility, and ease of use of the base platform that is Arduino Due, making it an option for educational purposes. The authors tell about the various concepts of DSP and algorithm that can be implemented in the base platform, like for example filtering, Fourier analysis, modulation techniques, and digital audio processing.

The paper published by Patil and Sundari presents a method for embedding secret messages within audio signals which discuses techniques for concealing information within audio data while preserving the quality [9]. The authors explore different approaches to audio steganography. This is a field that is concerned with hiding messages within digital audio. This involves methods like least significant bit (LSB) manipulation, spread spectrum techniques, and frequency domain manipulation. The paper also focuses on the challenges of maintaining robustness against signal processing operations and attacks, minimizing perceptual distortion, and ensuring secure communication of hidden messages.

The model proposed by Meenakshi *et al*. introduced an Arduino based fingerprint recognition technology with Arduino which is a micro controller to create a secure authentication system [10]. The study discusses about the design and implementation of the system using hardware components like fingerprint sensors, Arduino boards, and additional peripherals. They have also detailed the software aspects which includes algorithms for fingerprint feature extraction and matching.

Al-Heeti *et al*. explain the properties of speech, including how sound waves are generated and classified as voiced or unvoiced [11]. They introduce Pulse Code Modulation (PCM) as a common technique for converting analog speech signals into digital data. PCM involves sampling, quantizing, and encoding speech waveforms, facilitating their storage, transmission, and processing in digital systems. The researchers also discuss practical considerations and challenges associated with PCM implementation, providing insights into optimizing performance for efficient and reliable speech communication. Linear Predictive coder, Regular Pulse-Excited (RPE) and Code-Excited Linear Predictive (CELP) voice encoders are compared with DRT and MOS.

Wen *et al*. propose a new method in their study [12]. A discontinuous transmission method employing linear predictive vocoder is used to optimize bandwidth. They do it by detecting voice and silent frames with transition frames introduced. Silent frames use lower bit rates encoded as silence descriptors. Adaptive transmission of silent frames ensures adaptability and auditory comfort.

Gopinath *et al*. explain the concept of audio steganography, as described in the paper, involves embedding secret messages within audio signals, leveraging the redundancy present in audio data [13]. While voice encoding and decoding using Arduino may not directly involve steganography, knowledge of these techniques can inform considerations for optimizing voice data transmission, ensuring security, and enhancing authenticity. They explain how they have used a data logger on an Arduino UNO and show the advantages it has to offer; this implementation can be used in the future and can help monitor the proposed project.

Deekshit *et al*. developed a wireless network to remove noise from their given sensor data [14]. The authors provide a hardware design (using Arduino UNO); this implementation can be helpful for the proposed project.

Dandamudi *et al*. implement a signal channel for wheelchair users using an Arduino board, Dandamudi *et al*. show how the signal is input from the microcontroller, which can be useful for the proposed project [15].

Sreelesh *et al.* talk about the outlines of the telecommunications security in the mobile cloud computing and how it has been implemented [16]. It talks about safe control while accessing it with protection of important data and cloud infrastructure. It includes encryption techniques like ABE and HIBE which ensures privacy and permission control of data. Techniques like AES and ECC mitigate security risks in cloud.

Praveen *et al.* talk about the scope of digital image processing and its exponential growth with applications in defense, healthcare, space exploration, etc. [17]. This makes the safe processing and transmitting of digital images an important feature. Encryption assumes a great importance when pictures are being sent to protect them from being accessed illegally in absolution. Changes in DES algorithm through pipelining and core key schedule skewing is used for higher encryption rate and high throughput. This, therefore, makes a better provision for secure image data through the Block cipher technique. The hardware implementation alters a selected device as it evaluates the device's performance depending on the FPGA devices.

Ayyanki and Khanna propose a novel multi WSN validation mechanism using decentralized blockchain technology for Web of Things [18]. A hybrid blockchain model, which incorporates both public and local chain hubs is introduced for mutual authentication. This ensures robust security and advanced performance for routine verifications and cluster head validation.

METHODOLOGY

The process begins with a speech recording audio file that includes additional noise. Simulink, the graphical language for visual programming, is chosen as the main tool for preprocessing, and denoising. The "From multimedia" block from the DSP System Toolbox is used for loading the audio file. The sample rate and other essential values are constant in order to remain consistent. To mimic a noisy environment, a sample of Gaussian noise is stacked up on the audio signal. Next a lowpass filter is put in place to reduce this noise which will result in smooth denoising of the audio data. The audio is downloaded in the standard Waveform Audio Format (. wav) file. Moreover, the "Audio Device Writer" block also plays the denoised audio for checking the quality. The denoised audio requires a format with a smaller footprint for efficient processing in Arduino. Audacity, a digital audio editor, is employed to convert the .wav file into a 9-bit Pulse Code Modulation (PCM) format. This results in a compact Audio Interchange File Format (.aiff). The processed .aiff file is exported to an SD card which is connected to Arduino Uno. We create an Arduino sketch to read in the data from the SD card using the SD card module library. Data is sent through a serial communication from the computer to the Arduino device. The library helps to achieve a smooth data transfer. For data security during the transmission, symmetric XOR encryption is applied to avoid data violation. By encrypting, the data is rendered unintelligible without the corresponding decryption key. The encrypted information is then conveyed to another Arduino board through the Universal Asynchronous Receiver/Transmitter (UART) ports. While the receiving Arduino runs a separate sketch intended to de-crypt the message using the same XOR key. Thus, the reverse of this procedure restores the original audio data to be used again in the Arduino. The flow of the project is given in block diagram in Figure 1.

Algorithms

Low Pass filter algorithm with simple moving average is used for this demonstration. A low pass filter allows low frequency signals to pass through while attenuating the higher frequency signals. This is helpful in reducing the noise in our audio. The simple moving average smooths a signal by averaging a fixed number of previous samples which is called the window size. The window size is set according to our needs and is set to '4' in our example as shown in Figures 1 and 2.

Hardware and Technologies Used

Arduino Uno

Arduino Uno serves as the central control unit responsible for processing, encoding, encrypting and transmitting the speech data securely. It is used on both the sending and receiving sides to encrypt and decrypt the audio data respectively. It receives input data from the sd card through sd card module using .sd header file.

SD Card Module

SD card is used to increase the Arduino's storage capacity for storing additional data which is necessary for encoding. This expanded storage is very important for projects that usually involves in handling huge data size, which Arduino cannot accommodate on the onboard memory. In order to interface the SD card with an Arduino, a SD module is needed. The module connects to Arduino via SPI (Serial Peripheral Interface) pins which enables Arduino to read from and write to the SD card.

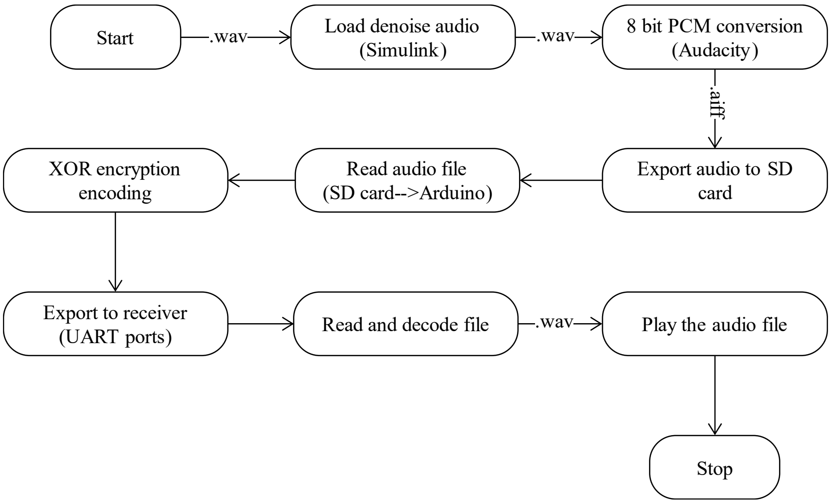

Figure 1. Block diagram.

Algorithm 1 Low pass Filter(data,window_size)

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if window_size $< = 0$ **then**
  $Error : Windowsizemustbepositive.$
  if length of data $<$ window_size **then**
    $Error : Datalengthmustbegreaterthanorequaltowind$
    $sma \leftarrow []$
    $sum\_window \leftarrow sum(data[0 : window\_size])$
    $sma \leftarrow sma + (sum\_window/window\_size)$
    for i in range (window_size, length of data) **do**
      $sum\_window \leftarrow sum\_window + (data[i] - data[i -$
$window\_size])$
      $sma \leftarrow sma + (sum\_window/window\_size)$
      $return$ sma

Algorithm 2 XOR Encryption (data, key)

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procedure XOR ENCRYPT
  $encrypteddata \leftarrow empty_byte_array$
  $keylength \leftarrow lengthofkey$
  for each byte in data **do**
    $encryptedbyte \leftarrow byteXORkey[i\%keylength]$
    $appendencryptedbytetoencrypteddata$
    $return$ encrypted data

Algorithm 3 XOR Decryption (encrypted data, key)

$return\ xorEncrypt(encrypteddata, key)$

Figure 2. Algorithms used in the paper.

Simulink

Simulink is an environment used to design system with multidomain models. It is designed for modeling, simulating, and analyzation of multidomain dynamic systems. It provides a block diagram interface for creating complex system models. It is used to simulate IoT scenarios, signal processing and other domain too.

Audacity

Audacity is an open-source audio editing and recording app. This application allows users to normalize, trim and apply numerous post-processing tasks, at the same time making sure high quality results. Also, Audacity can handle many tracks at one go based of the SD card's capacity to handle. This feature is very useful for complex audio projects which requires huge storage. Audacity directly applies all the changes made to the waveform. Audacity has the ability to primarily support WAV, AIFF, and MP3 file extensions which are supported by a library known as libsnd file. Audacity can be used for converting files from one extension to another one. Audacity is compatible with a huge range of audio plugins, this includes LV_2, Nyquist, V_{amp} and many more. This enables users to use most available audio effects. Audacity also includes a console Nyquist which allows users to script their plugins based on individual preferences by using Nyquist programming language. The application also supports external Python scripting which enhances the functionality and flexibility of the application. It is used to convert our wav file's encoding from 16-bit integer to 8-bit PCM as Arduino Uno can support a smaller bits of data. This compatibility with Arduino is very useful as it can handle smaller bit data efficiently.

Connections

The GND pin of Arduino is connected to the GND pin of the SD Card Module. The Arduino 5 V pin is connected to SD Card Module's VCC pin. Arduino Digital Pin 10 is connected to SD Card Module CS. Arduino Digital Pin 11 is connected to MOSI pin of SD Card Module. Arduino digital pin 12 is connected to MISO pin of SD Card module. Arduino Digital Pin 13 is connected to SD Card Module SCK pin. And for the communication between the two devices, Arduino board A's TX and RX pins are connected to Arduino board B's RX and TX pins respectively. By connecting TX of Arduino A to RX of Arduino B, data sent from Arduino A will be received by Arduino B. Likewise, connecting TX of Arduino B to RX of Arduino A allows data sent from Arduino B to be received by Arduino A; and the two Arduinos are connected to a same ground.

RESULTS AND DISCUSSION

The study has demonstrated the secure encryption and transmission of audio data. From the research it has been inferred that using Arduino Uno for complex signal processing and encryption tasks has several limitations primarily due to its hardware constraints. Arduino Uno functions at a clock speed of 16 MHz and has a SRAM of 2 kb which limits its processing speed. Complex encryption algorithms and advancing audio processing like Fast Fourier Transform will take a long time to execute, which impacts its real-time performance. The limited memory restricts the complexity of the code which forces us to use simpler processing and encryption algorithms which affect the integrity and safety of the system. Filtering out background noise requires complex algorithms which are not run optimally in Arduino UNO, impacting noise reduction effectiveness, which forces us to use external software like Simulink (2023b) and Audacity to preprocess the audio. Simulink (2023b) provides packages and libraries dedicated to Digital Signal Processing which we have used in this research for noise reduction of the audio. Through research and trial, the HC-05 Bluetooth module which is generally used in Arduino UNO applications was tried for data transmission. The HC-05 module uses Serial Peripheral Interface for communication which has a slower data transfer rate compared to the size of audio files.

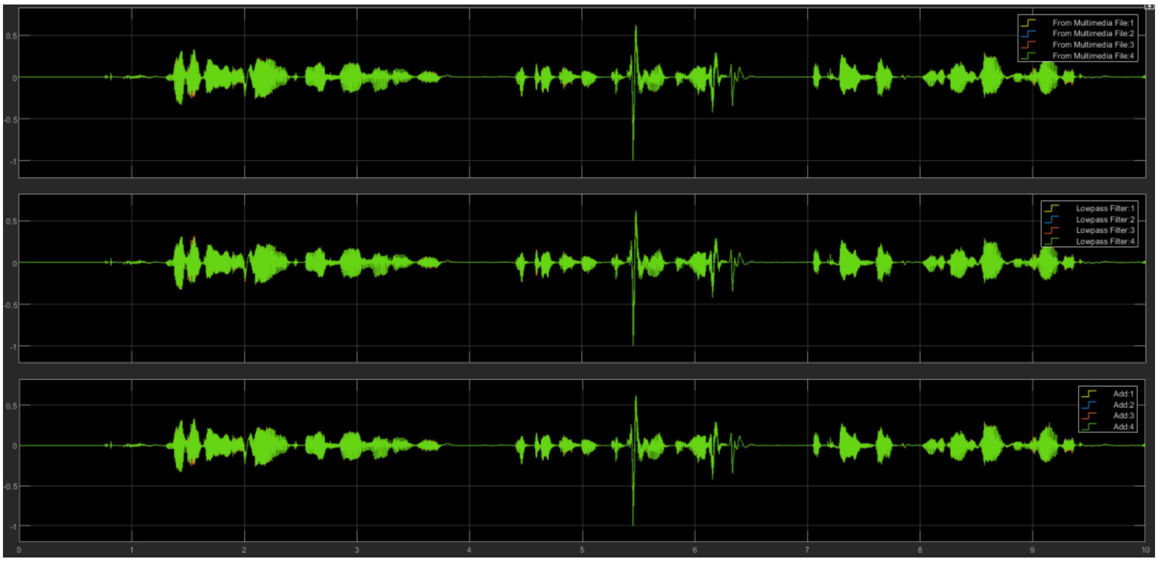

Figure 3. Output waveform: denoised audio signal using Simulink.

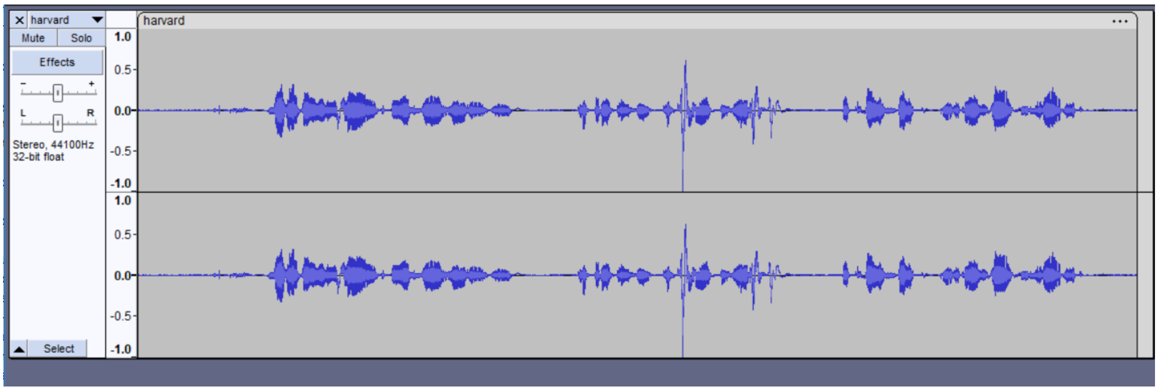

Figure 4. Audacity output waveform: 9-bit PCM form of the audio.

It uses Serial Port Profile Peripheral which is designed for text-based data exchange and not large files like audio. Arduino UNO does not allow transfer of files using Zigbee, and such technologies. Therefore, we opted to use an external SD card to transfer the preprocessed audio file from our system to the Arduino UNO. The disadvantage of this method is that it requires human intervention and cannot be used in real-time communication. Development of custom hardware modules at low cost that can handle computationally expensive tasks and easy usage of higher-level languages like Python for the programming of Arduino UNO is a future scope. Lightweight but strong, encryption algorithms, transmission methods and audio processing methods can be developed and integrated with the custom hardware module to provide an easy solution for secure communication as shown in Figures 3 and 4.

CONCLUSION

The CryptoTalk VoiceShield system effectively showcases a secure and efficient approach to speech communication using Arduino Uno. By incorporating encryption, encoding, and transmission methods, it ensures the confidentiality and reliability of voice data. External tools like Simulink and Audacity enhance preprocessing, helping to overcome Arduino Uno's hardware limitations. While the system establishes a strong foundation for secure voice transmission, challenges such as processing speed and real-time communication remain. Future improvements can focus on developing specialized hardware and refining encryption techniques to enhance real-time performance. As concerns over data security continue to grow, this project underscores the potential of embedded systems in protecting sensitive audio communications across various fields, including defense and secure private networks.

REFERENCES

1. Borse BH, Mahajan R. Implementation of Speech Enhancement Algorithm and its Wireless Transmission. In 2022 IEEE International Conference on Industry 4.0 Technology (I4Tech). 2022 Sep 23; 1–6.
2. Weng Z, Qin Z. Semantic communication systems for speech transmission. IEEE J Sel Areas Commun. 2021 Jun 10; 39(8): 2434–44.
3. Gao D, Zhao X. A speech coding error control transmission scheme based on UEP for bandwidth-limited channels. In 2013 IEEE International Conference on Computational and Information Sciences. 2013 Jun 21; 318–321.,
4. Debnath A, Mondal UK, Roy BB, Panja N. Achieving lossless audio encoder through integrated approaches of wavelet transform, quantization and Huffman encoding (LAEIWQH). In 2020 IEEE International Conference on Computer Science, Engineering and Applications (ICCSEA). 2020 Mar 13; 1–5.
5. Abu SK, Jorquia JR, Mendoza JM, Tolentino CT, Lucas CR. Lossless Audio Compression using DWT, DCT and Huffman-based LZW Encoding. In 2023 IEEE 22nd International Symposium on Communications and Information Technologies (ISCIT). 2023 Oct 16; 357–362.
6. Al-Nuaimi AY, Amin MF, Murase K. Enhancing MP3 encoding by utilizing a predictive complex-valued neural network. In The 2012 IEEE International Joint Conference on Neural Networks (IJCNN). 2012 Jun 10; 1–6.

7. Huang H, Shu H, Yu R. Lossless audio compression in the new IEEE Standard for Advanced Audio Coding. 2014 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Florence, Italy. 2014; 6934–6938. doi: 10.1109/ICASSP.2014.6854944.
8. Jaldén J, Moreno XC, Skog I. Using the Arduino Due for teaching digital signal processing. In 2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). 2018 Apr 15; 6468–6472.
9. Patil AS, Sundari G. An embedding of secret message in audio signal. In 2018 IEEE 3rd International Conference for Convergence in Technology (I2CT). 2018 Apr 6; 1–3.
10. Meenakshi N, Monish M, Dikshit KJ, Bharath S. Arduino based smart fingerprint authentication system. In 2019 IEEE 1st International conference on innovations in information and communication technology (ICIICT). 2019 Apr 25; 1–7.
11. Al-Heeti MM, Hammad JA, Mustafa AS. Voice encoding for wireless communication based on LPC, RPE, and CELP. In 2022 IEEE International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA). 2022 Jun 9; 1–4.
12. Wen X, Zhu J, Chen H, Wang N, Feng Z. An Improved MELP-based Voice System Transmission Algorithm. In 2023 IEEE International Conference on the Cognitive Computing and Complex Data (ICCD). 2023 Oct 21; 123–126.
13. Gopinath A, Arun C, Hanumanthaiah A, Murugan R. An analogy of the datalogger implementation in arduino UNO and PSoC5LP. In 2020 IEEE 3rd International Conference on Smart Systems and Inventive Technology (ICSSIT). 2020 Aug 20; 328–332.
14. Deekshit VN, Ramesh MV, Indukala PK, Nair GJ. Smart geophone sensor network for effective detection of landslide induced geophone signals. In 2016 IEEE International Conference on Communication and Signal Processing (ICCSP). 2016 Apr 6; 1565–1569.
15. Dandamudi AG, Rao DN, Aravilli VP, Sunitha R. Single channel electromyography controlled wheelchair implemented in virtual instrumentation. In 2019 IEEE 3rd International Conference on Computing Methodologies and Communication (ICCMC). 2019 Mar 27; 1040–1045.
16. Sreelesh NK, Santhosh KB. An advanced hierarchical attribute based encryption access control in mobile cloud computing. Int J Eng Technol. 2018; 7(3.10): 18–22.
17. Praveen K, Poornachandran P, Ajai AR. Implementation of DES using pipelining concept with skew core key scheduling in secure transmission of images. In Proceedings of the 2nd international conference on computational science, engineering and information technology. 2012 Oct 26; 637–641.
18. Ayyanki GL, Khanna M. Empowering Secure and Authenticated Multi-WSN Communication Through a Hybrid Blockchain Framework. In International Conference on Advances in Data-driven Computing and Intelligent Systems. Singapore: Springer Nature Singapore; 2023 Sep 21; 421–433.

