A Wireless Voting System Using Wi-Fi-Based Microcontrollers and Face Verification

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***Abstract*—Voting systems nowadays are highly interesting due to their importance in expressing opinions. The proposed work aims to design a cost-effective and reliable Electronic Voting System (EVS) that can tackle the issues faced by manual election. The system uses small and low-cost microcontrollers with Wi-Fi network connectivity to avoid the issues of installing wire connections. Eligible voters are authenticated by recognizing their faces using deep neural networks (VGG-16 model). The Wi-Fi connections between the server and the clients are carried out through the Internet Protocol suite (TCP/IP) transmission method to ensure data arrival without loss. The client's side comprises four small and cheap microcontrollers known as ESP8266-01, whereas the server side contains one NodeMCU ESP8266-12E microcontroller connected to a program computer. The voting results are displayed using the Visual Basic programming language. The system is specifically designed to facilitate voting on a particular opinion by providing two options: (Yes) and (No). Besides, it can be utilized for electing a committee manager or group leader and can be expanded to accommodate more options. The VGG model's robustness is demonstrated through experiments, achieving 99.12% accuracy on Faces96 images and 98.61% on our database. Moreover, the practical implementation of the election process demonstrates that the system is highly reliable, secure and cost-effective.**

***Index Terms*—face verification, electronic voting, wireless communication, TCP/IP, ESP8266 microcontrollers, VGG-16, deep learning**

I. Introduction

The majority of contemporary civilizations care a lot about democracy. The election of representatives is one of a democracy's most significant activities. Fair elections and accurate computation of the results are necessary for the representatives to represent the people and carry out their duties effectively [1].

Based on the past, it can be deduced that hand-rising polling systems had security issues because elections were not anonymous, and it took longer to collect votes. On the other hand, a paper-based polling system has expedited the voting process and increased safety. There is no valid reason to continue using a paper polling system; however, numerous security considerations support adopting a new electronic polling system to adapt polling methods to the digital age [2, 3]. A major challenge that needs to be tackled is the manual voting system, which is prone to several issues. The most significant problem is the possibility of fraud, either by the voting committee itself or by voters who attempt to manipulate the results by casting multiple votes for a particular candidate. The repetition of votes is another concern that needs to be addressed. This fraud can be eliminated by giving each voter a programmed voting tool that is not falsifiable or repetitive, and no one can vote without it. Additional to the time it provides to perform the voting, a huge number of voting can be done simultaneously without crowding [4].

The use of computers or computerized equipment in an election is called Electronic Voting (E-Voting), which aims to increase participation, reduce election administration expenses, and improve the accuracy of results. Furthermore, E-voting systems have a lower probability of errors due to the absence of human interference in the voting process. Using digital processing platforms ensures automatic completion of the process, reducing costs and increasing speed [5]. The wireless E-voting process offers many essential advantages, including reducing the hardware connections implemented by wires, which are sometimes difficult to install due to the long distance or the structure of the buildings [6]. Different techniques can be accomplished to identify people using biometrics or security keys, such as fingerprint [7], face recognition [8, 9], iris recognition [10], and Radio Frequency Identification (RFID) [11, 12].

Although many researchers have addressed the problem of electronic voting, our study focused on the practical design of electronic circuits. Several recent approaches have been mentioned, whereas the duplicated methods are excluded. In [13], an EVS was proposed using a microcontroller, InfraRed sensors, voting switches, and Liquid Crystal Display (LCD). The PIC16F877A microcontroller was used as a processing unit to collect data and analyze the results. Six voting switches were used for the election candidate, and one was employed to reject the process. The researchers in [14] used a microcontroller, RFID tags, and a Global System for Mobile Communication (GSM) technique to construct an EVS. Once the voter's ID is verified, the

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AT89C51 microcontroller sends a unique GSM password to the user's mobile device. The election process is then conducted through a mobile device. An EVS was introduced in [15] using an AVR ATMEGA8 microcontroller and push buttons to select one of the existing candidates. The authors added a solar power source to maintain the desired power for the system. In [16], a secured EVS was proposed using an encryption technique such that the data sent to the server should be encrypted with a homomorphic algorithm. Twenty voters were subjected to select four candidates using their computers, where their choices were encrypted through the transmission and decrypted at the server node to display the result. An EVS-based Visual Basic (VB) language was introduced in [17], where the voters could choose their candidates from the voting window on the computer display. The system could check the authenticity of the voters according to their information and the unique pin code presented for each voter. The authors in [18] used a private key to encrypt the votes before sending them to the server, where they should be decrypted to show the results. Some security procedures were applied to preserve the election process and prevent violence. In [19], an Arduino mega board was used as a microcontroller in the EVS design. The researchers utilized the fingerprint and RFID to identify the recorded voters, where they should press any of the three push buttons to select the desired candidate. A raspberry pi with a night-vision camera was employed in [20] to implement an EVS, where the security investigations were represented by the Iris, Fingerprint and RFID identifications. The users could cast their votes through a graphical user interface (GUI) window on the computer display, designed using MySQL. In [21], the researchers used Arduino UNO as a microcontroller, a keypad to enter the voter's ID and push buttons for selecting a candidate. They suggested connecting with the central unit via the internet using an ESP8266 Wi-Fi board.

This work proposes a wireless EVS using GSM technology and face verification. Face recognition is a biometric technology that verifies identity without physical contact. It is faster and more accurate than other biometric technologies, like fingerprints, that sometimes fail to identify individuals with diabetes or fingerprint problems. Furthermore, other identification technologies, such as RFIDs, passwords, and ID cards, can be vulnerable to impersonation. Therefore, face recognition is preferred to verify voters. The system uses affordable and compact microcontrollers, known as ESP-8266, first introduced in 2014. These boards have sufficient power to carry out Wi-Fi tasks efficiently. The proposed EVS has mainly three parts: clients, wireless connection and server. The clients are the voters' nodes, sending the data to the server through a private network using the transmission control protocol/internet protocol (TCP/IP). The server is the processing unit that receives the client's votes, processes them with a certain algorithm, and displays the results. Voters are identified through their faces, and some actions are considered for the integrity and fairness of the election process.

II. Background and Theory

The section explains the components used in designing the EVS and the related techniques.

A. *VGG Deep Learning Model*

This approach uses the VGG-16 network for face recognition due to its strong expandability and image data transfer. The Visual Geometry Group (VGG) developed a powerful convolutional neural network at Oxford University in 2014. VGG-16 implements deep convolutional neural networks with 16 layers, including 13 convolutions. The 16 layers are equipped with both Max Pool and Softmax layers and other trainable parameter layers. The VGG model's ruling structure comprises five convolutional layers, each followed by a max pool layer, as demonstrated in Fig. 1 [22].

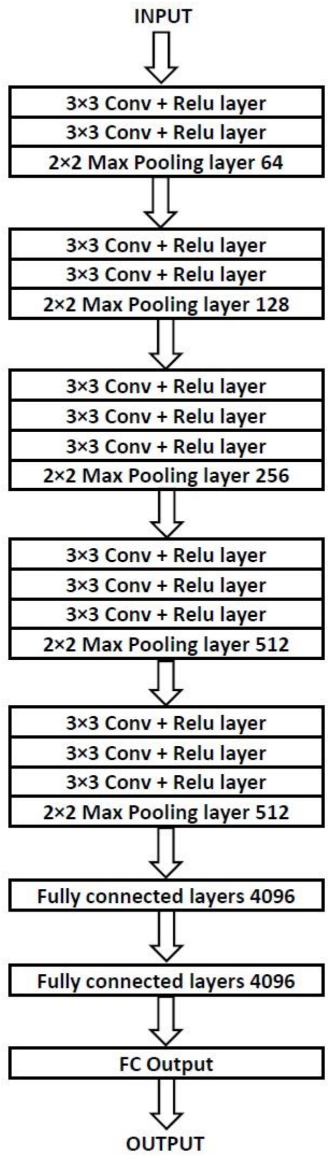


Fig. 1. Structure of VGG-16 layers [22].

The VGG-16 architecture starts with 64 channels and increases them to 512 by doubling them after every max pooling layer. The architecture comprises five blocks, each ending with a max pooling layer. The first two blocks contain a couple of convolutional layers, and the other three consecutive blocks, each comprising three convolutional layers. Finally, the architecture ends with three dense layers. It is essential to note that the last three convolutional layers exhibit varying depths across different architectures. It is worth emphasizing that the size is consistently halved after every max pooling, which is currently under scrutiny and is considered critical. CNN neurons commonly use the most widely used activation function called rectified linear unit (ReLU) [22].

B. Transmission Protocols

The User Datagram Protocol (UDP) operates in one direction, where the client sends data to the server without checking the arrival status, which may result in losing some data frames. However, UDP has a faster transmission speed than TCP/IP, a connection-oriented protocol requiring handshaking to establish end-to-end communications. Additionally, retransmission, message acknowledgement, and timeout are all managed [23]. Therefore, the best way to serve the sending data is to use the TCP/IP despite its long transmission time [24].

C. Microcontroller NodeMCU (ESP8266-12E)

The ESP8266-12E (ESP-12) board is a microcontroller planned by Espressif Frameworks. The least demanding depiction of a microcontroller is to think about a miniature PC: it incorporates a processor, I/O peripherals, and memory to associate buttons, sensors, displays, and so on. It is a Wi-Fi module that makes an absolute necessity for expanding the capabilities of the basic microcontrollers. With a USB connector, a range of pin-outs, and a mini USB cable included for added convenience, this module is the ultimate solution for the difficulties of wire installation [25].

D. Microcontroller ESP8266 (ESP-01)

The ESP8266-01 (ESP-01) is a highly popular microcontroller for its Wi-Fi capabilities. It includes types of equipment such as antenna switches, a built-in low noise amplifier, a power amplifier, an RF balun, power management modules, and filters. Besides, it features a compact 32-bit core processor with a 16-bit short mode, 80 MHz and 160 MHz clock speeds, and an embedded Wi-Fi antenna. The module is compatible with the TCP/IP protocol and follows the standard IEEE 802.11 setup [26].

III. Methodology

The proposed wireless EVS can be used to decide on a suggested opinion using a (Yes) or (No) selection by pushing either the green or red push button. Besides, it can be used for choosing a group's leader, where the server provides two names, and the group's members may vote for one of them. It comprises four main stages; face verification, clients, wireless connections, and a server, as illustrated in Fig. 2. It is implemented using a prototype model, which comprises a hardware circuit programmed according to a specific manner of election.

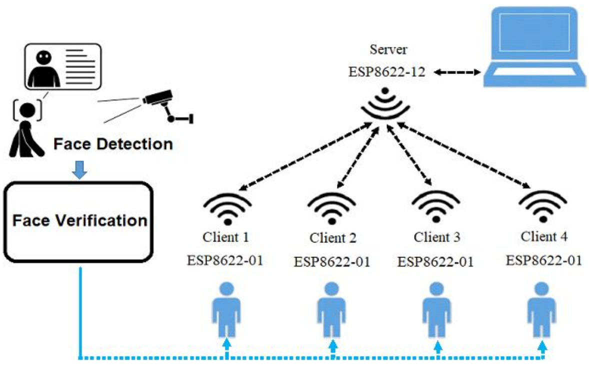


Fig. 2. Proposed EVS structure.

To prevent voter fraud, verifying the identity of eligible voters is crucial. This verification process involves analyzing the images captured by cameras to detect faces using the well-known Viola-Jones method [27]. Once detected, the face image is extracted and resized to 224×224 pixels to meet the required image size of the VGG-16 network. After verifying the voters, they can use the clients based on their designated role in the election.

The clients are four voting nodes containing an ESP-01 Wi-Fi board and two push buttons to select between two choices. The Wi-Fi network with the TCP/IP transmission mode is used for easy implementation and to prevent the sending data from being lost. Fig. 3 illustrates the procedure of the election process on the client's side.

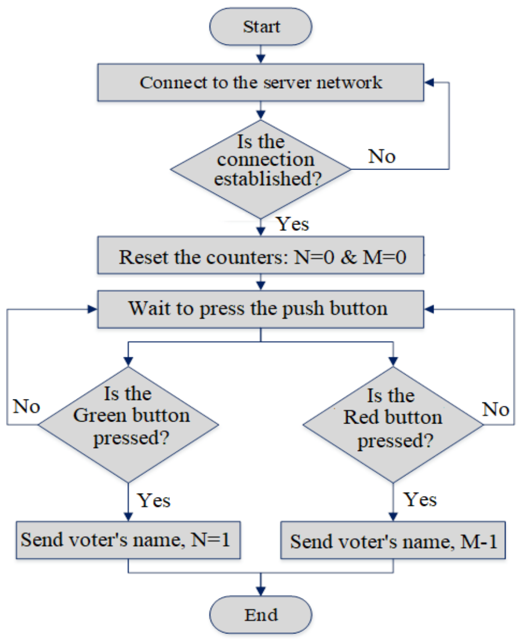


Fig. 3. Procedure of the voting process on the client's side.

When the ESP-01 board powers on, it searches for a Wi-Fi network to connect with the server (ESP-12). Each user can then select a candidate by pressing the corresponding push button.

The server is the system's processing unit implemented by the programmable microcontroller (ESP-12), which is linked to a computer via a USB port to display the voting information. The ESP-12 microcontroller works as a router to connect with the clients and receive the voters' options. The collected data undergoes processing through a specific algorithm, and the computer screen displays the resulting outcomes. Fig. 4 clearly illustrates the voting process on the server's side.

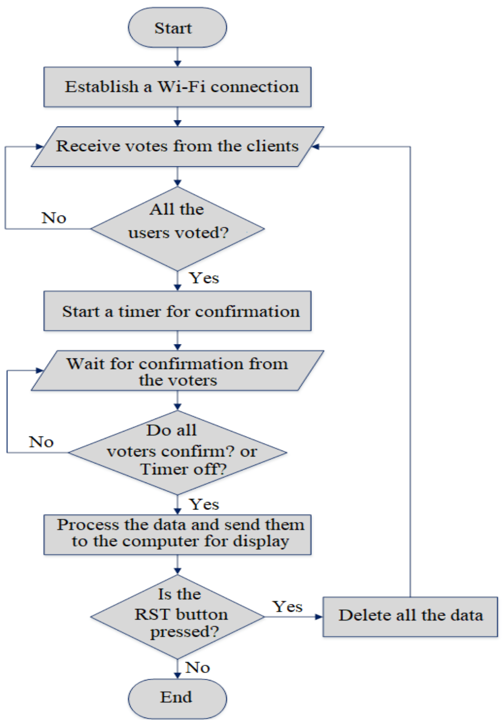


Fig. 4. Procedure of the voting process on the server's side.

When the TCP/IP connection is established, the server waits to receive data from the clients' nodes. During the election process, voters cannot change their selections until all clients have sent their votes. Afterwards, the ESP-12 circuit initiates a timer for about 20 seconds to allow voters to revise their selections or confirm their choices. Once the timer runs out or all voters have confirmed their selections, the server will stop receiving clients' data and begin processing the votes. The computer screen displays the results in detail according to the available choices.

A. *Software Programming*

To implement the proposed wireless EVS, four ESP-01 boards serve as voters' nodes in conjunction with one ESP-12 board, a computer, and various electronic components and cables. The ESP-01 and ESP-12 boards are programmed to follow the election process procedure. Furthermore, the VB programming language sets up the server and displays the results.

The ESP-01 board of each node is programmed using the Arduino Integrated Development Environment (IDE) software by connecting the ESP-01 board to Arduino UNO, which in turn is connected to the computer using a USB port cable. Fig. 5 illustrates the connection between the ESP-01 board and Arduino UNO. The P2 push button must be pressed, and the (Reset) pin of Arduino UNO is connected to GND while uploading the code to the ESP-01 board.

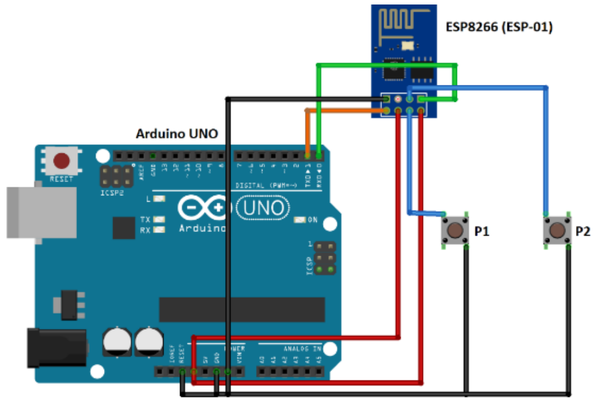


Fig. 5. Connecting Arduino UNO to the ESP-01 board for programming.

The VB programming language exhibits a graphical window allowing the users to provide the required settings and select the existing choices, such as displaying the results and resetting the operation. Therefore, the VB is utilized in the proposed work due to the window's nature, making it easier for users to deal with and navigate the options. The system's efficiency is enhanced by displaying options simply and in English, which saves time. On the other hand, the system's security is unaffected since the operation is done without human interference, and only the professional manager can set settings or select choices. Fig. 6 shows the connection settings between the ESP-12 board and the computer.

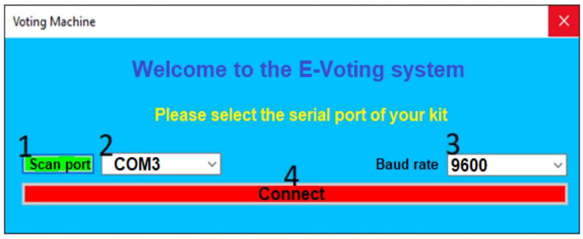


Fig. 6. GUI of the connection settings.

The settings window of the connection between the computer and the ESP-12 board (Fig. 6) comprises the following choices:

1) *Scan Port command*: this command response is used to scan available serial ports connected to the computer and list them in the second choice. If no serial port is connected, the program will display a message about this event.
2) *Serial ports combo box*: it lists the available serial ports named COMn (Communication Port), where n is the port number. It lets the user select any serial port; otherwise, the program will select the first one by default.
3) *Baud rate combo box*: it already displays the most commonly used baud rates, such as 1200, 2400, 4800, and 9600 bps, as well as four additional customizable options labelled 19200, 38400, 57600, and 115200. The user can select the appropriate baud rate or the baud rate (9600) bps is used by default.
4) *Connect/disconnect command*: initially, this command is highlighted and labeled "Connect" after

selecting the operating serial port. When the "Connect" command is pressed, it will be changed to "Disconnect", which disables the serial port combo box and connects the selected serial port to ESP-12 board to receive voting data. If the "Disconnect" command is pressed, it will remove the connection with the selected serial port, letting the user change the serial port with another one.

After completing the connection settings, the window is changed to the 2nd form as shown in Fig. 7.

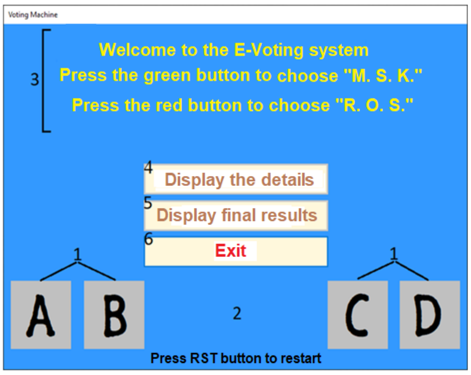


Fig. 7. GUI of Voting instructions and results.

TABLE I: COLORS OF VOTING STATES

Label's color	State
Gray	Waiting for voting
Green	Voting is done
Pink	The vote is confirmed
Black	The vote is saved

When pressing the RST button of the ESP-12 board, the GUI is displayed, which includes the following sections:

1) *Voter labels*: Table I displays the different colors assigned to each voting node.
2) *Timer label*: it is initially hidden, but when all voters send their votes, it appears for 20 seconds to allow the voters to change their votes or confirm them.
3) *Explanatory labels*: they aim to clarify every stage of the voting process. They instruct voters on what actions to take and provide a visual representation of the outcome of those actions.
4) *Voters show command*: it is initially disabled and will be enabled after the votes are saved. The existence of this command is to display the selection of each voter.
5) *Results show command*: it is enabled concurrently with the previous command. The functionality of this command is to show the number of votes for each candidate.
6) *Exit command*: this command is used to end the whole program.

B. Hardware Implementation

The clients section of the proposed EVS comprises four voter's nodes, such that the ESP-01 board is installed on each node circuit, as illustrated in Fig. 8.

The descriptions of the components used in the voting node circuit are illustrated in Table II.

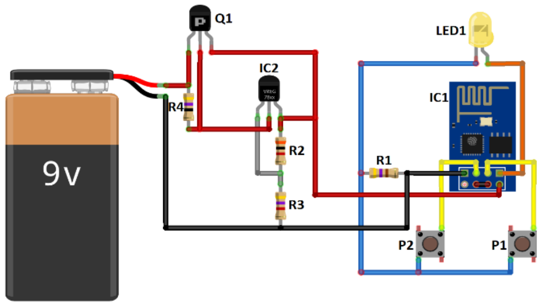


Fig. 8. Voting node circuit diagram.

TABLE II: DESCRIPTIONS OF THE COMPONENTS USED IN THE VOTING NODE CIRCUIT

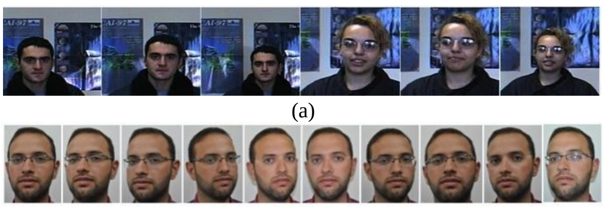
Component	Description
IC1	ESP8266 (ESP-01)
IC2	LM317L
Q1	BC557 PNP Transistor
LED1	Yellow color
P1&P2	Double pin push button
R1	470 Ω
R2	3 kΩ
R3	4.7 kΩ
R4	47 Ω

When the ESP-01 circuit is turned on, it automatically searches for the server connection. During the search process, the yellow LED blinks to indicate that the ESP-01 is now searching for a network. Once the connection is established, the yellow LED stops blinking, and the voting operation is initiated.

After connecting the ESP-12 board to the computer's USB port, the voting manager presses the "Scan Port" command to search for the COM port. The connection is not established if an error message appears; otherwise, the COM ports will appear in the combo box. When the COM port is selected, the "Connect" command is highlighted, waiting to be pressed to connect with the voters' nodes. The "Connect" command is changed to "Disconnect" when the connection is accomplished. Meanwhile, the voting operation is ready to start, and each voter can send their vote to the server after reading the rule of voting and understanding what to do.

IV. RESULTS AND DISCUSSION

Before implementing the proposed EVS, the face verification part is simulated using the Fases96 database [28] and the ESV database specially created for the proposed work. A sample of the two databases utilized in this study is presented in Fig. 9.



(a)

(b)

Fig. 9. Sample of Face images (a) Faces96 database and (b) ESV database.

The Faces96 database comprises 3040 color face images belonging to 152 individuals, each with 20 different images of size 196×196 pixels. The ESV database includes 24 persons, each with 10 color images of size 192×192 pixels.

The simulation step uses the MATLAB program (R2021b) installed on the Windows 10 operating system. Each database is split into 70% training and 30% testing images, where the VGG-16 network is used to train the randomly selected images. Because the VGG-16 network accepts color images with a specified size, all the images are resized to 224×224 pixels before entering the network and remain in color form. The VGG-16 model's efficiency in recognizing faces was evaluated using the most popular metrics: accuracy, precision, recall, and F1-score, as in (1), (2), (3) and (4), respectively [29].

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \quad (1)$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP+FP}} \quad (2)$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP+FN}} \quad (3)$$

$$F1-\text{score} = 2 \times \frac{\text{Precision}\times\text{Recall}}{\text{Precision+Recall}} \quad (4)$$

where TP, TN, FP, and FN are true positive, true negative, false positive, and false negative, respectively.

The simulation results of the face recognition using images from the Faces96 and ESV databases are tabulated in Table III.

TABLE III: SIMULATION RESULTS OF THE FACE RECOGNITION

Database	Faces96	ESV
Accuracy	99.12%	98.61%
Precision	99.45%	98.61%
Recall	99.67%	100%
$F1-$score	99.56%	99.30%

It is evident from Table III that the VGG-16 model performs exceptionally well with the Faces96 and ESV databases. With the Faces96 database, the model attains approximately 99.12% accuracy, while other metrics are slightly higher. The ESV database results in a Recall percentage of 100% due to zero FN, while the accuracy rate is about 98.61%. Therefore, the VGG-16 model can be employed in real-time face verification.

The election operation is started with the voter's face verification. A camera is installed in front of the individuals to capture facial images. The Viola-Jones method is employed for face detection, so each image of the detected face is resized to 224×224 pixels and fed into the VGG-16 network for classification. The real-time face verification achieves an accuracy rate of 100%, where no error is found.

The proposed EVS is designed to select one of two candidates by pressing the corresponding button at the ESP-01 circuit. When the voter chooses someone, the voter's label is highlighted with green color, indicating that he has voted, as shown in Fig. 10.

As shown in Fig. 10, three voters have cast their votes at that time, while the fourth user still needs to vote. As a result, the labels of the three voters are changed to green, and the other is still gray, indicating waiting for voting.

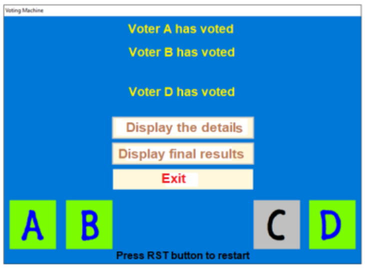


Fig. 10. First round voting.

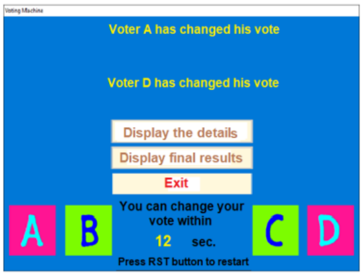


Fig. 11. Changing the votes during the allowed period.

Each voter cannot change the selection until all the voters finish their selections. When any voter wants to change the selection, the program gives a chance by starting a timer for about 20 s. In addition, the program indicates each voter's label after changing the selection or confirming the previous one, as shown in Fig. 11.

According to Fig. 11, two voters changed their selections after the timer was started for 20 s, changing their labels to pink. The two other labels are still with the green color because the corresponding voters still need to change or confirm their selections, where the remaining time is 12 s. Once the timer has run out, no more votes can be cast, and the voting operation is finished. If all voters send their votes for the second time before the timer runs out, it will disappear and be set to zero, indicating the end of the voting operation.

The election operation is conducted to select a committee leader, where "M. S. K." and "R. O. S." are suggested for this task. When the voting operation is completed, the VB GUI window enables the two choices, "Display the details" and "Display final results". The first command shows each voter's selection, as shown in Fig. 12, whereas the second command shows the votes for each candidate and the winner, as shown in Fig. 13. The results, displayed in Fig. 13, show that "M. S. K." received three votes and "R. O. S." got one vote.

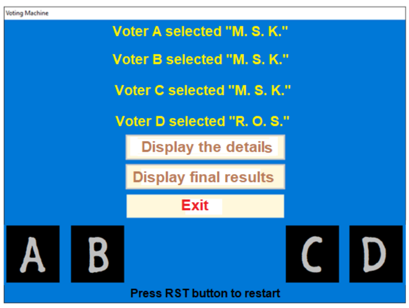


Fig. 12. Displaying voters' selections.

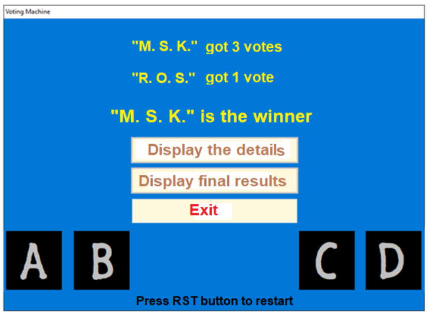


Fig. 13. Displaying the result.

The procedure is repeated for each group of four voters to cast their votes. Once all groups have cast their votes, the overall results are calculated by summing up the individual results from each group.

The system's accuracy relies on how well the clients and server microcontrollers are programmed. Any errors or inefficiencies in the programming can affect the accuracy. The "Display final results" option protects voters' privacy, while the "Display the details" option shows individuals' selections under voter agreement. The system ensures high security using face recognition technology to identify voters. Besides, Data transmission occurs through a dedicated Wi-Fi connection, unused for long distances or internet communication. The system is designed to facilitate an election process within a company or department, making it a suitable choice for such scenarios. Additionally, the electoral process must adhere to legal and ethical standards, which experience monitors can investigate.

V. Conclusion

The proposed wireless EVS is a low-cost scheme that can be used to choose a committee manager or vote about a decision. In this system, the voters are identified according to their faces, so it is impossible to cheat by replacing or repeating votes, where only the users can send their votes, and no others can participate in the voting operation. In identifying and categorizing images from the Faces96 and EVS databases, the most effective convolutional neural network used is the VGG-16 network. During the training stage, 70% of the images are utilized, while the rest are kept for classification. The classification rate of this simulation step is 99.12% and 98.61% for the Faces96 and EVS databases, respectively. The real-time face verification achieves 100% accuracy, indicating that the VGG-16 network is a more convenient deep learning structure. The proposed EVS comprises four voting nodes containing an ESP-01 Wi-Fi board and two push buttons to select between two choices. The ESP-12 Wi-Fi microcontroller receives the votes and sends the results to the PC screen via VB programming language. In addition to its simplicity, low cost, and reliability, the proposed EVS utilizes a TCP/IP wireless connection to save time, reduce costs, and ensure vote data integrity.

In the future, the EVS could be improved to engage more voters by incorporating a mobile application that enables individuals to vote from anywhere in the world. To guarantee the security of the election process, a sophisticated encryption method will be implemented to prevent hackers from interfering during transmission.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors conducted and analyzed the research; the first author wrote and revised the paper; all authors approved the final version.

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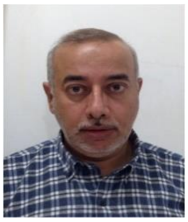

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