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DEVELOPMENT OF A WEB-BASED WIRELESS-ENABLED EMERGENCY EXIT DOOR CONTROL SYSTEM

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Abstract

Emergencies occur when least expected, posing threats to life and property. One of the basic challenges with conventional and technologically based emergency exits is door control, which is usually unsatisfactory considering the response time. Hence, a better method for controlling emergency exit doors for the evacuation of people during emergencies is needed. This paper presents the development of an emergency exit control system using a web application and a microcontroller with various inputs like a smoke detector, a push button, and a radio frequency wireless system. When the input device is activated, the microcontroller receives the signal, processes it, generates the necessary alarms, and transmits the processed signal to the web-based application system. The web-based application interfaces with the microcontroller via the GPR/GSM module. The designed web-based application provides a user-friendly interface to the administrator and operators, allowing them to view real-time scenarios around the emergency exit door and activate the door locking mechanisms. The system was tested in a real-life scenario, and the response time was measured. The results show that the developed system could successfully detect input signals to the web application, providing a robust and easy way of evacuating people.

1. INTRODUCTION

In today's world, emergencies frequently occur. These events often pose a threat to the lives of people, prompting the seeking of escape routes from such dangerous areas [1]. Emergencies can take many forms, including fire outbreaks, equipment failure, warfare, terrorist attacks, biological hazards, chemical discharges, flooding, and

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earthquakes. Emergencies are characterized by suddenness, uncertainty, and serious harmfulness and have continued to constitute a major challenge to the sustainable development of human society [2]. Preparations for emergencies are often overlooked while disasters like fire outbreaks and equipment failures can occur at homes, workplaces, or anywhere at any time. Thus, proper handling of such events, when they occur, is crucial to the prevention of breakdown of law and order, loss of lives, and associated attendant spillover effects. Electrical supply power surges and petroleum pipeline vandalism may lead to fire incidences, which may cause significant loss, especially in areas with slower emergency response times [3]. The Triangle Shirtwaist factory fire in 1911, where 146 factory workers were burned to death when locked in their workrooms [4]; the Cocoanut Grove fire in 1942, where 492 people died because of fire incidence [5]; and the Victoria Hall Theater disaster in Sunderland, England, where over 180 children died because of a door bolted at the stairwell bottom, were all typical instances of outbreak of fire incidences that ended up in huge fatalities. Other instances include the 2004 Repblica Cromaón nightclub fire, in which 194 people were killed due to locked doors [6], and the case of a trapped sleeping woman in a building that was burned to death by an inferno that gutted the building with no escape route after she woke up [3].

These incidents and similar ones led to the enactment of laws and regulations by governments of different countries requiring large buildings to have outward exits and sufficient emergency exits. In addition, to ensure that people understand how to behave in the event of an emergency, periodic evacuation drills are recommended to be scheduled to help people know how to use emergency exit doors in an emergency [1] because emergency exits are meant to complement normal passages in the event of an emergency situation. These emergency routes must be free of obstacles that can impede the free flow of movements to guarantee safe exit. Depending on the environment and application, emergency exit routes may involve passageways, ramps, stairs, stairwells, and a series of doors. Emergency exits are the safest route for people to take in an emergency to avoid stampedes and crowd egress.

One unique feature of emergency exits is that they are not always left open unless an emergency occurs. Traditional methods for the management of emergency exits include the use of keys, bolts/bars, knob twists, and a host of others that are purely mechanical in nature. Usually, these exits are left unused for long periods of time. As a result, cases of misplaced keys may arise or damaged keys may occur while opening the door when the situation demands their usage. The location or place where the keys are kept may be forgotten, or the person in charge of the key may not be available in an emergency. The bolt and nut may be corroded and the opening may not be easily accessible during an emergency event, which may lead to a stampede. Evacuation via an emergency exit may be difficult, resulting in loss of life and *property damage.*

Electronic methods and biometric technologies have been equally used in the management of access control systems, including emergency exits. Several implementations and developments exist in the literature on door/access control systems for different applications. Some of such developments include the use of face recognition technology [7]-[11], voice recognition [12]-[13], fingerprint recognition [14]-[16], code-based [17]-[20], internet of things (IoTs) based [21]-[28], artificial intelligence-based method [29], wireless connection-based [30]-[31], combination of smart card and fingerprint technology [32], combined smart card and pin code [33], and Raspberry Pi technology-based [34].

However, electronic and biometric techniques are more suitable for normal situations than when an emergency occurs because verification of enrolled users is often required. In addition, another major issue with biometric methods is that they are prone to various failures that may arise from accidents and permanent injuries. For instance, if facial recognition is used to access a door, the person whose face is registered may be sweating in an event of emergency, which may make face recognition scanning impossible. For a system that is built around the

use of a one-time password for door access control, in an event of emergency, there may be network coverage failure, which makes the use of the unique one-time password practically impossible. To avoid such a situation, there is a need to develop a reliable system in which emergency exit doors could be controlled remotely without the use of keys or human biometrics, allowing people to be evacuated on time without loss of life or property. This need constitutes the driver of this work, which is concerned with the development of a web-based wireless-enabled emergency exit control system for a faster response and management of evacuation of people in an emergency caused by a fire outbreak.

2. METHOD

2.1 System Overview

The proposed web-based wireless-enabled emergency exit door control is built around both hardware and software subsystems. The software subsystem takes the form of a web application for remote control of the door operation through a console (computer system, tablet, smartphone) that houses the application and is internet enabled. The hardware subsystem, which comprises a few units, is depicted in the block diagram shown in Figure 1.

It is obvious from Figure 1 that the hardware subsystem has the following subunits:

i. Input unit: This provides an input signal to the microcontroller through which it takes decisions with respect to the operation of the emergency exit door. The proposed door control system is designed such that the input signal to the microcontroller can come from three sources: a signal from the smoke detector (which senses presence/absence of smoke in the area as an indicator of fire outbreak), a command from the web application through the console, and a signal from a hard-wired push button in the event an internet connection is not available.

ii. Control unit: The heart of the control unit is the PIC18F4620 microcontroller, which processes and coordinates activities surrounding the operation of the proposed door control system. In essence, it performs the logical opening and closing of the emergency exit door. Physically, an actuator is used to effect the physical opening or closing of the exit depending on the logic signal it receives from the PIC18F4620 microcontroller.

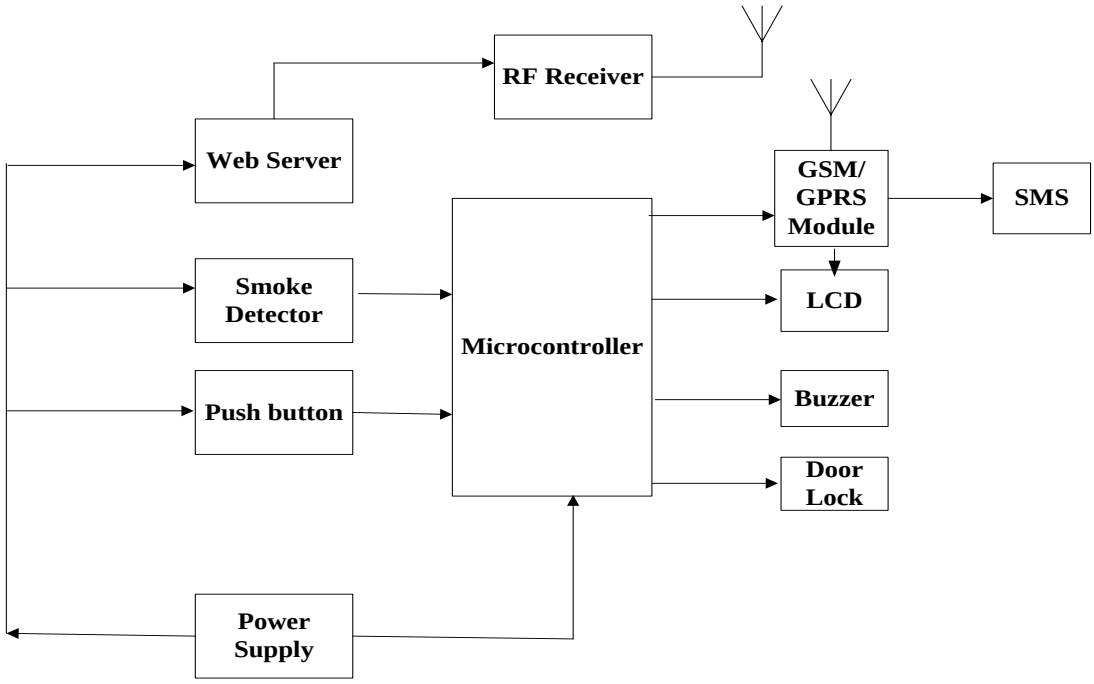


Figure 1: Block diagram of the hardware subsystem

iii. Alert and reporting unit: this comprises three entities: visual display, buzzer, and short messaging. A liquid crystal display unit is used to visually display the status of the emergency exit door in real time. A buzzer is used to create awareness through audible sound in the event of an emergency situation, while the short message service reports real-time activities around the emergency exit door and its operation.

iv. Communication unit: The smooth operation of the proposed emergency exit door controller is hinged on the availability of a robust communication link between the console that houses the web application and the door controller. The wireless communication link for device operation is facilitated by using a wireless receiver module and a GSM/GPRS module. The former handshakes with the console and the PIC18F4620 microcontroller to establish the communication needed for command issuance via the web application, while the GSM/GPRS module establishes a communication link between the PIC18F4620 microcontroller and the short message service unit for real-time status reporting.

v. Power supply unit: this unit is concerned with providing the needed voltage to power different components/units that make up the entire emergency exit door control system.

Having highlighted the units that make up the hardware subsystem, a few design considerations that inform the choice of components are presented in what follows, beginning with the power supply unit.

2.2 Design Considerations for the Hardware Subsystem

2.2.1 Smoke detector

A 12 V dc smoke detector is employed in this work. It receives a 12 V supply directly from the battery and is connected to the PIC18F4620 microcontroller through pin 15 for the exchange of logic signals. To avoid false triggering of the smoke detector, it is connected to the ground through a 10 k resistor. The choice of resistor is informed by the information made available in the smoke detector manufacturer's datasheet.

2.2.2 Push button

The primary method for operating the developed emergency exit door control system is remote control enabled by a wireless link. However, provision is made for a 12 V DC hardwired push button to forestall the lack of internet connectivity. The push button is connected to pin 25 of the PIC18F4620 microcontroller for the logic signal input.

2.2.3 Microcontroller unit (MCU)

A 40-pin PIC18F4620 is used. Based on the available information in the datasheet, the PIC18F4620 is connected to the positive power terminal at pin 1 via a 10 kΩ, while pins 13 and 14 are used for clocking, two capacitor 33 μF each and connected in parallel are used for smoothening the clock signal. A 10-MHz crystal oscillator is used to supply the required clock signal. The firmware of PIC18F4620 is written using C programing language to facilitate communication with other connected units.

2.2.4 Actuation unit door lock

The actuation unit is made of a magnetic door lock that operates on a 0.3 A, 12 V DC supply. These requirements cannot be interfaced directly with the microcontroller pin, which is at 5 V DC. Hence, a driver circuit. The driver circuit for the modular door lock is built around a 12 V relay and an NPN transistor configured as a current amplifier. The driver circuit is shown in Fig. 2.

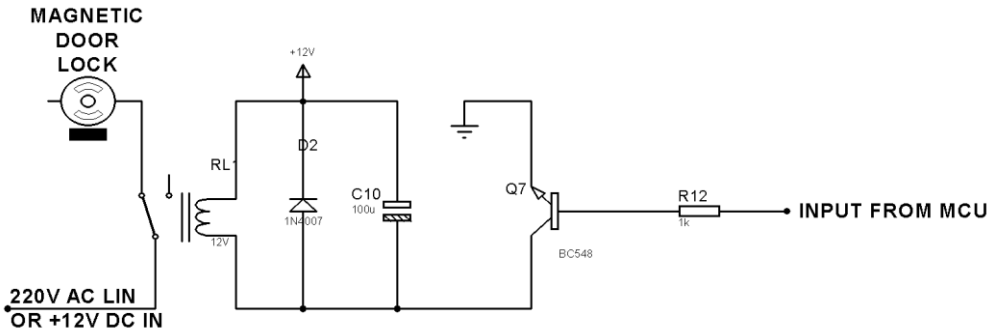


Figure 2: Driver circuit for the door lock

2.2.5 Power supply

The entire web-based wireless-enabled emergency exit control system is powered by a direct current (dc) source, which is a 12 V, 7-AH battery. Provision is made for its charging from the main supply. In addition, provisions are made for conversion from the supplied 12 V to lower voltage levels as required by different units of the system. A 12 V dc to 5 V dc converter is used to obtain the 5 V dc required by the PIC18F4620 microcontroller, while a series resistor arrangement is used to reduce the 5 V dc to 4.4 V dc required by the GSM/GPRS module. Figure 3 shows the power supply sub-circuit with values of relevant components.

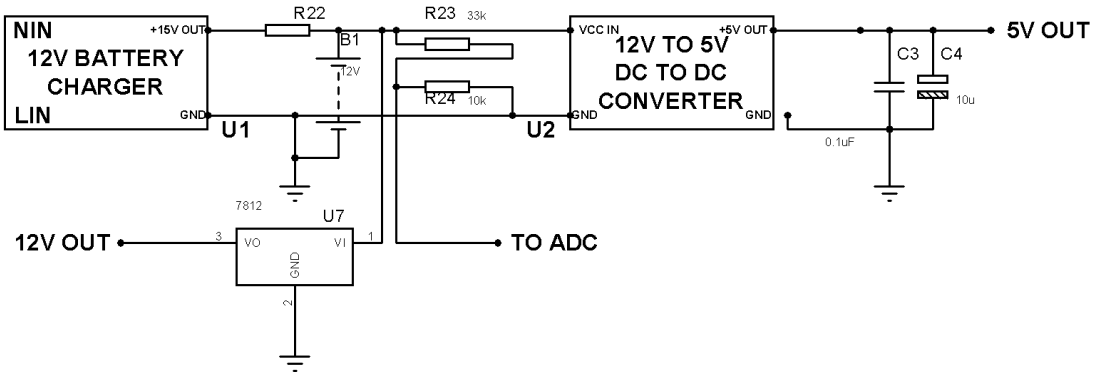


Figure 3: Power supply unit sub-circuit

Note that R_{22} which is a 1 Ω,1 W resistor, is used to interface the battery with the battery charger, while a series combination of R_{23} and R_{24} with values of 33 and 10 kΩ respectively is used in between the 12 V battery terminals and the 12 V-to-5 V dc-to-dc converter. A pair of capacitors C_2 and C_4 with respective values of 0.1 µF and 10 µF are used as smoothen capacitors at the output of the 12 V-to-5 V DC-to-DC converters.

2.2.6. Alert and reporting unit

Provisions are made for alerting people on the premises of an emergency. Both audio and visual displays are used in the alert mechanism. For audio, a 5 V dc buzzer is used, while a 16 by 2 liquid crystal display is used for visual display. There is no need for a driver circuit as both interfaces directly with the microcontroller from which they obtain control signals.

Reporting of the situation around the emergency door operation via short messages is realized through the use of a GSM/GPRS module that facilitates the transmission of text messages to some pre-determined mobile numbers.

2.2.7 Wireless communication infrastructure

The wireless link is established using a GSM/GPRS module that has a subscribed line in place and a 433 MHz radio frequency receiver module. The GSM/GPRS module facilitates real-time situation reporting via short messages, while the 433 MHz radio frequency receiver module ensures communication between the web application and the PIC18F4620 microcontroller.

2.3 Software subsystem

The software subsystem of the proposed web-based wireless-enabled emergency exit control centers on web application development and deployment. In the development, MySQL was used for database creation with SQL as the required query language and PHP scripts used on the server side, while HTML, CSS, and JavaScript were employed on the client side. At the most basic level, whenever a browser or MCU needs a file hosted on a web server, the browser requests the file via HTTP. When the request reaches the correct (hardware) web server, the (software) HTTP server accepts the request, finds the requested document, and sends it back to the browser or MCU, also through HTTP. If the server cannot find the requested document, it returns a 404 response instead. In an emergency situation, the MCU will send data to the web through the GSM/GPRS module, and the format of the data is as follows:

REGSTARTS07044519251 08031170172 07052208095 07067936448 REGENDS

The admin, upon seeing the message displayed on the Web page on the console, presses the "OPEN" button link on the displayed web page. With this action from the admin console, a message is sent back to the MCU as an instruction to activate the door and to the first responder to assist those in the emergency environment. The developed Web application is structured such that it can be deployed on a PC, tablets, smartphones, or other devices that are internet-ready and wirelessly enabled.

The developed Web application interface has, among others, the following links:

i. Login page: where an enrolled or registered user/operator enters details to gain access. Registered users/operators are stored in the database created using MySQL. The application is hosted at doitniger.com.ng/emergency.
ii. Control link: the first of the ten links accessible after successful login by a user/operator. Through this link, a user/operator can remotely control the operation of the exit door.
iii. Reporting link: for reporting the status or activities around the emergency exit door in real time.
iv. Devices: Display real-time status of devices through which the emergency exit door can be activated
v. Key link: this link displays how the emergency door is triggered and opened from available alternatives.
vi. Web: the link that gives a summary of web activities with respect to emergency exit door operations.
vii. Monitoring link: displays the real-time status of user(s) with their details.
viii. Admin/operator link: display details of enrolled admin/operators in the database. It allows the editing of registered users of the application.
ix. Setting: this link allows the addition and editing of connected emergency doors for remote control in the application.
x. Change password: this allows a user to change his/her login password.
xi. Sign out: this link enables the user to log out from the Web application and by extension interact with the emergency exit door.

2.4 Prototype of the developed system

A prototype door, with a dimension of doors is 1940 mm × 700 mm × 57 mm, was designed using an aluminum frame with polyvinyl chloride. The system client side of the web application was designed using Microsoft visual C#, HTML, and CSS, while JavaScript plugins along with the dot.netframe47.2 compiler was used for the user interface design. The Web application was hosted http://doitniger.com.ng/emergencyexit for accessibility and operation. MySQL bench was used as a querying language on the client side and for the management of the database of the system. The administrator (admin) and operators were registered the system database as authorized users.

3. RESULTS AND DISCUSSION

3.1 Performance evaluation tests

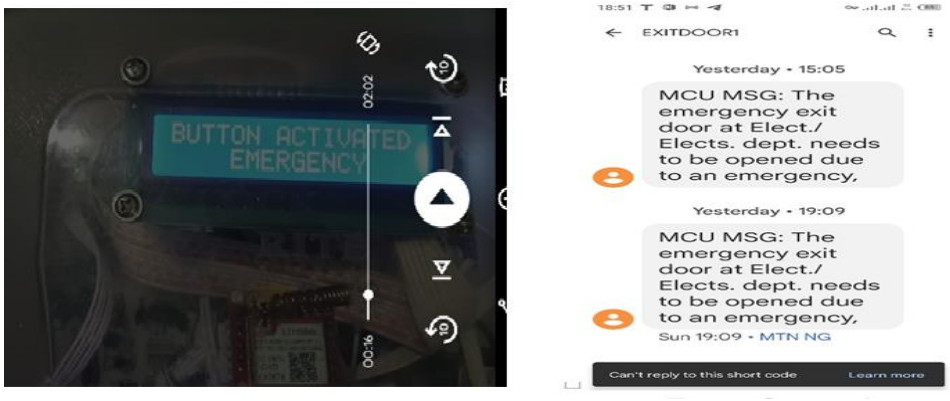
The following tests were carried out on the prototype of the proposed emergency exit door control system:

i. input device activation
ii. Web interface evaluation
iii. overall system evaluation
iv. user acceptability test

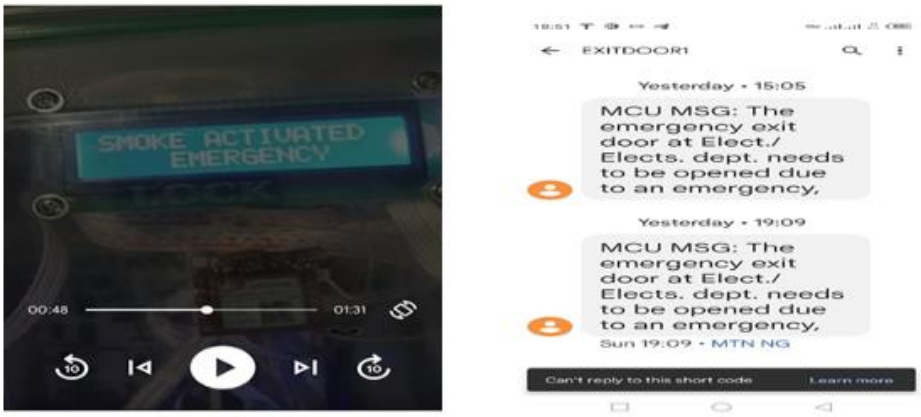
The obtained results from each of the test results are described in what follows.

i. Input device activation

This test was conducted on the prototype of the developed system to determine if it responds to various inputs (like smoke detector, push button, and radio frequency wireless system) for activation and to display the real-time status of the emergency exit door. Figures 4(a) and 4(b) show the situation when the emergency exit door opening was initiated by a push button and smoke detector signal, respectively, while Table 1 summarizes the obtained results when the developed system was triggered by various alternatives provided in the system development.



(a)



(*b*)

Figure 4: Displayed controller status and SMS alert sent to operators when the emergency exit door is activated by a signal from (a) hard-wired push button (b) smoke detector

Table 1: Overview of all devices

Date	Time	Activation input					
		Wired push Button	Wireless button	Smoke Detector	Web application	MCU	Door status
11-12-2022	15:22:03	No	No	No	Yes	No	Opened
11-12-2022	12:12:36	No	No	Yes	-	-	Closed
08-12-2022	12:13:06	-	-	-	No	Yes	Opened
08-12-2022	12:16:39	No	No	No	-	-	Closed
08-12-2022	15:22:03	-	-	-	No	Yes	Opened

ii. Web interface

The developed Web application interface was tested with different links/buttons used to determine that each of them works to specifications. They were found to be satisfactory. As an illustration of the obtained results, Figure 5 depicts a snapshot of real-time records of the scenario around the emergency exit door as being monitored by the admin/operator. The page shows notification from the controller, door action, time, and date. It is clear from the illustration that the Web application works according to specification.

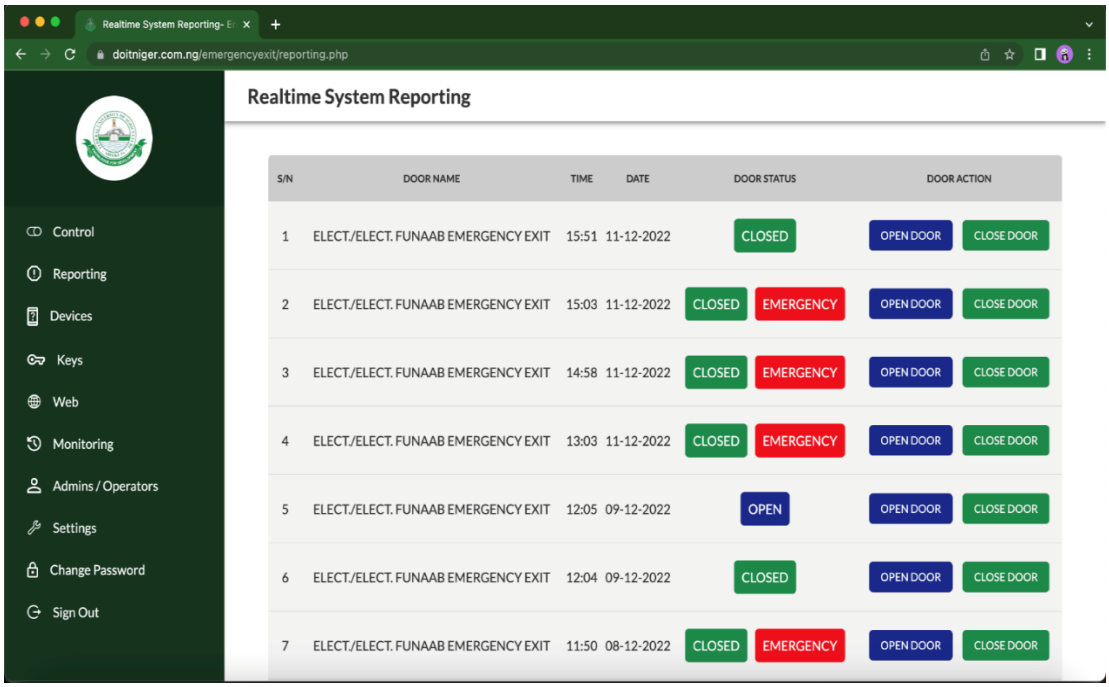


Figure 5: Real-time system reporting using the Web interface

The developed prototype of the emergency exit door controller was evaluated in a real-life scenario using each of the three alternatives provided for the door to open. It was found that the developed system responded appropriately to control signals from each of the smoke detectors provided (when smoke is introduced as an indication of fire outbreak), the hard-wired push button was pressed, and a command to open was issued at the Web interface. The time taken by the MCU to process signals from each of the input sources (hard-wired push button, wireless button and smoke detector) for, the emergency exit door to open was, noted. On average the response time for input signals from all sources was less than 90 s.

Table 2 shows the response time of the MCU to process signals from different sources to activate the emergency exit door to open in an emergency as performed by three different operators for five different instances. The time elapse between the issuing of the Web command and emergency exit door activation was found to be less than

15 s. In other words, it takes an average of less than 15 s to activate the door to open when the OPEN button is clicked on the Web application. Results of random experimentation at five different instances are shown in Table 3.

Table 2: Response time of the MCU to process input signals and trigger the door to open

	Hard wired push button	**Wireless button**	**Smoke detector**
	1:31.26	1:17.35	01:31.10
Time	1:22.08	1:10.29	01:24.67
Taken (s)	1:21.11	1:12.31	01:22.24
	1:21.31	1:11.89	01:25.45
	1:23.38	1:24.38	01:23.44

Table 3: Time elapse between the issuing of Web command and activation of emergency exit door

Web activation	**Time (s)**
1	13.28
2	13.87
3	14.29
4	14.58
5	14.03

In the event of an emergency, the MCU on receipt of the input signal communicates with the Web application to activate the emergency door. If the response from the Web application is delayed for more than 80 seconds on average, the microcontroller is configured to override the Web application command and to trigger the door to open after 80 seconds had elapsed in an emergency. This is specifically the case when there is a network connectivity issue or the microcontroller is not receiving a signal from the Web application for the door operation within the stipulated duration of time. Table 4 illustrates typical results of situations in which the MCU has to override the Web application response for emergency exit door opening.

Table 4: Typical results of overriding the Web application response by the MCU for emergency exit door opening

Time taken by the MCU to override the Web application response to trigger door opening (s)	
Hard-wired push button input	**Wireless push button input**
1:28.62	1:20.67
1:21.79	1:22.46
1:21.93	1:22.20
1:23.03	1:22.90
1:22.96	1:23.02

iii. Web interface users' acceptability test

This test was conducted to obtain feedback from various users (administrators and operators) of the developed Web application for remote operation of the emergency exit door controller with respect to usage, response time, and suitability of various sections of the Web application. Figure 6 shows the responses of 30 users who were involved in the evaluation of the developed Web interface. It can be inferred from Figure 6 that most of the users are satisfied with the developed Web application interface for remote interaction with the developed emergency exit door controller.

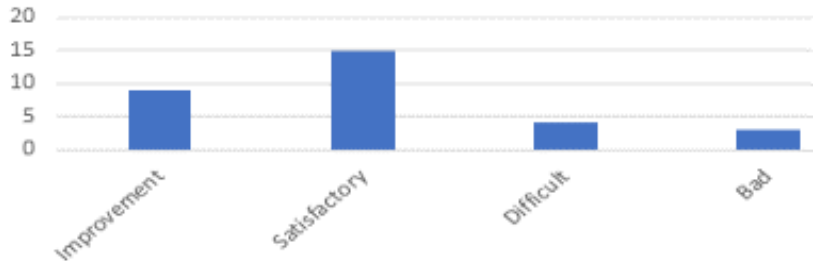


Figure 6: Performance evaluation of the interface

3.2 Comparison of the developed system with previous proposals

Results of comparison of the developed door control system in this work with similar proposals in the literature are presented in Table 5, where six features that are germane to the operation of the door controller are used as indices.

Table 5: Comparison of the developed emergency exit control system with previous similar works

Researches	Ease of user configuration	Wireless link	Real-time reporting	Web application	Multiple activation	Multiple door control
[9]	√	√	√	x	x	x
[15]	√	√	x	x	x	x
[19]	√	√	√	x	x	x
[20]	√	x	x	x	x	x
[21]	√	√	√	x	x	x
[23]	√	√	√	x	√	x
[24]	√	√	√	x	x	√
[29]	√	√	√	x	x	x
[30]	√	√	√	x	x	x
[31]	√	√	√	x	x	x
This work	√	√	√	√	√	√

It is obvious from Table 5 that the door control system proposed in this study is more robust than similar proposals in the literature. In addition, our proposed system is capable of being deployed for the management of multiple doors from a central location, unlike most previous proposals.

4. CONCLUSION

A web-based wireless-enabled emergency exit door control system that provides an efficient means of ensuring the safety of lives and properties in an emergency is presented in this paper. Based on evaluation tests conducted on the prototype, the performance of the developed door controller was found satisfactory for the intended operation of the emergency exit door when inputs were supplied from any of the alternatives provided (smoke detector, hard-wire push button and command from Web interface). The developed web-based wireless-enabled emergency exit door controller can facilitate smooth operation for the evacuation of people in emergency situations where it is deployed.

Ethical Consideration: This work has no conflict whatsoever with any known ethical standards that require the seeking of permission and approval.

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