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Development of a Hand-held Device for Women Assault Reporting

Bello K. Nuhu
Department of Computer Engineering
Federal University of Technology
Minna, PMB 65, Niger state Nigeria.
nuhubk@futminna.edu.ng

Paul O. Omagbemi
Department of Computer Engineering
Federal University of Technology
Minna, PMB 65, Niger state Nigeria.
paulwem3000@gmail.com

Eustace M. Dogo
Department of Computer Engineering
Federal University of Technology
Minna, PMB 65, Niger state Nigeria.
eustace.dogo@futminna.edu.ng

Rabiu O. Isah
Department of Computer Engineering
Federal University of Technology
Minna, PMB 65, Niger state Nigeria.
isah.rabiu@futminna.edu.ng

***Abstract*—The issue of insecurity is a major concern for women and society. The World Health Organisation's statistics show that about one in three women worldwide experience physical or sexual violence in their intimate or non-partner relationships. This is a disturbing figure. Various crimes against women such as physical violence, kidnapping, rape, sexual assault, and sexual harassment occur at different places at any given time of the day, especially in isolated places and mostly during late hours. These crimes contribute to the local and global crime indexes, as evidenced by the increasing criminality score. Governments have tried to address these security challenges by implementing stricter laws, but crime rates remain high. Unfortunately, related works exist but are limited as they lack critical features such as a secured and exclusive fingerprint verification for users, a subsystem to prevent a potentially detrimental false alarm from occurring, and an effective alerting mechanism to alert relatives. To overcome these shortcomings, this research proposes a hand-held device for women assault reporting that incorporates: a secured fingerprint verification subsystem, a vibration-based alert subsystem for prompting the user to prevent false alarms, an emergency text along with a phone call established to the predefined contacts as a more urgent alert mechanism, and a built-in microphone feature for environmental audio surveillance established via phone call connection. The system's response time was an average of 4 seconds, the False Acceptance Rate (FAR) was 6%, and the False Rejection Rate (FRR) was 5%. These promising results indicate that the system can effectively reduce crime against women, improve the sense of safety in women anywhere they go, and mitigate the overall crime rate.**

Keywords—Sexual Assault, Crime Against Women, Fingerprint Sensor, GPS, GSM.

I. INTRODUCTION

The augmentation roles that women play in society have increased at an accelerated pace, as women have engaged in diverse endeavours alongside men in the era of the twenty-first century [1]. They can form diverse collectives with a common goal; women frequently collaborate across ethnic, religious, political, and social boundaries to promote freedom [2]. Women compared to men, demonstrate an increased level of concern towards acts of aggression, thereby resulting in additional negative consequences such as suspicion towards unfamiliar individuals, evasive tendencies, and uneasiness [3]. The negative effects of violent behaviour, such as physical suffering, mental anguish, and other fatalities, make it clear why there is such a strong communal fear of aggression [3]. There are also major societal effects of these violent crimes, such as the costs of the criminal justice system, hospitalization, lost productivity, anti-violence campaigns and initiatives, and the indirect influence of poor results on the victims' and perpetrator's families and friends [3].

According to the estimations made by the (WHO) World Health Organisation, around 1 in 3 women worldwide have experienced physical or sexual intimate relationship violence or non-partner sexual violence at some point in their lives [4]. Most of this violence is committed by intimate partners. Furthermore, about 15 million young women between the ages of 15 and 19 have been raped [5]. "A violent act against the female gender disturbs the public health life of society and also, it violates the human rights of women", according to a WHO reporter [6]. Globally, low—and lower—middle—income nations and areas, are disproportionately affected by violence against women. The crime index for Nigeria in the year 2018 was 63.1, it has however increased to 65.5 as of the year 2023. This shows a 3.80% increase in the last five years. As of 2023, Nigeria ranks third in Africa and first in West Africa for the highest crime index [7]. The global score for criminality is 4.88 and that of Nigeria is 7.15; this makes Nigeria's criminality score 46.5% above the global score for criminality [8]. 37% of women between the ages of 15 and 49 who reside in nations deemed to be among the "least developed" under the Sustainable Development Goals have experienced physical or sexual intimate partner abuse at some point in their lives [9]. Violence against women must be eliminated to achieve worldwide gender equality and women's empowerment following Sustainable Development Goal (5) [10].

Unfortunately, sexual abuse is impeding women's freedom. Among other violent crimes against women today, sexual harassment is one of the most significant barriers to women's empowerment [1]. These violent crimes against women are often not far-fetched from civilization. Women have reported these crimes at workplaces, public places, their homes, public transits, pathways, and other places [11]. With the rise in these security issues and crime rates, the government has taken steps to prevent crime by enacting rules and regulations to ensure workplace and public safety [11]. The penalties for such crimes have been increased. Although new laws have been passed and existing laws have been amended, the crime rate remains high, as evidenced by statistics data [11]. Nevertheless, it is now possible to use modern technology to tackle societal problems wisely [12]. With the help of technological innovations, biometrics have been employed in many areas to ensure security via the authentication and verification of a person [13]. Technological innovation also brought about the advent of the Global Positioning System (GPS) [14] and, introduced the Global System for Mobile Communication (GSM) [15]. These technologies could be integrated, encompassing the use of a fingerprint sensor, a microphone, a vibration module, a GSM module for texting and calling the pre-installed emergency contact, and a GPS module for tracking the user's location.

A. *Contributions*

The contributions of the paper are in two broad categories:

1. Development of assault identification and alerting system devoid of false alarms
2. Development of a fast crime assault alerting system

B. *Organization of the Paper*

The paper is organised as follows: Section II presents the literature review, section III presents the proposed methodology, while results and their discussions are presented in Section IV, and conclusions are drawn in Section V.

II. LITERATURE REVIEW

Violence against women and girls causes physical, psychological, sexual, and economic suffering; denying women and girls the core ideals of equality, safety, dignity, and respect for one's self as well as the enjoyment of fundamental freedoms, stands out as one of the most egregious abuses of human rights [16].

This section presents recent advances in technology that aid alleviating of crime against women. [17] proposed "FEMME," a Women's Safety Device with GPS, GSM, audio recording, and a hidden camera detector. The device is activated by pressing the emergency button, which provides multiple functions: sending location to pre-installed contacts by one press of the button, recording and sending an alert message with two presses; and a long press, activating the hidden camera and sending a message. In seeking to cover more range for the device, [18] proposed a study that uses Radio Identification-Based Spectrum Sensing, GSM/CMA, and GPS. When the user presses the help button, similar to [17], the device sends the user's location URL to registered contacts through suitable frequencies, especially when out of transmission range.

Incorporating the device into a safety band, [19] proposed a device encapsulated into the Women Safety Band (WSB). it was based on Arduino mini, Bluetooth module, and a switch-over technology that goes along with the "ALERT" mobile app. When the user presses the button, the device switches its logic state and sends the user's location to the police and guardians for help. [2] proposed a study in view of making their system cost-effective and accommodating an additional self-defence feature. The system comprises of Arduino Nano controller, Bluetooth module, taser, and an Android application that works in hand with the system. The device has an emergency switch that when utilized by the user during threatening situations, enacts the taser to stun the perpetrator. The emergency switch button also activates the Bluetooth module to interface with the Android mobile application which sends messages and makes calls, using the GSM, to the pre-set contacts. Appending to the self-defence feature proposed by [2], [11] proposed a device that functions as a three-way safety module as it provides self-defence, evidence recording, and tracking information functionalities. The mechanism encompasses a Raspberry Pi, GSM module, GPS module, and mobile application. Upon activation, it delivers an electric shock to assailants, triggers an alarm, captures video footage, and transmits the user's location via SMS upon pressing the designated button or issuing the "Emergency" command via the app.

These stated technologies have limitations such as less automation since they require the pressing of a button or push of an emergency switch to carry out predefined functionalities; ambiguous operations, as they require a button or more for different modes of functionalities; lack of provision of exclusivity for the user, as the push of a button from any personnel could nullify the intended functionalities; smartphone-dependent, as the absence of a smartphone will make the essential functionalities futile. This study focuses on using a fingerprint module to make the device exclusive to the user and more automated in case the perpetrator attacks before the user can press a button, requiring less of the user's action to operate; using simpler operations to eliminate ambiguity; and making the device smartphone independent.

In a bid to extend the capabilities, [20] proposed a device that was activated with a press of a button, measuring alcohol concentration and distance to the attacker. Location, alcohol level, and distance are sent via GSM to the registered contacts. The device also includes a buzzer for alerting others at the push of a button. Similar to [20], [21] proposed Rakshak, an IoT wearable device that activates with a voice command, sending an SOS signal with the location to the registered contacts and authorities. The device records crime data using a camera, which is stored in the cloud for analysis. With the implementation of voice command activation similar to [21], [22] proposed a study to extend the functionality of the device and improve concealment. It includes two subsystems, BOHNNI (worn as jewellery) and BADHON (worn as a bracelet). Activated by voice commands or a manual switch, the device sends an alert message with the user's location to a pre-installed relative's number. It can also be used for self-defence by delivering an electric shock to immobilize attackers. In the quest for more automaticity, [23] proposed an IoT Based Wearable Women Safety Device with GPS, a buzzer, a push button, and a microcontroller. It includes pressure, temperature, and heart rate sensors to monitor the user's vital signs. If abnormal readings indicate danger, the device automatically alerts pre-installed contacts with the location. The user can also activate it manually with a button, triggering the buzzer as an alarm to scare away potential attackers.

These studies are however limited by: failing to address the potential case of false alarm occurrences, which can be life-threatening to loved ones with health challenges; failing to make their work stealthier by using a buzzer as an alarm, and the voice of the user for activation of the system, which can lead to aggravating the perpetrators to even potentially cause more harm than intended; failing to overcome the need for urgency by using only text, hence, not utilising enough options for alerting during emergencies; and, failing to address false positives when using automated sensors. There are major responses that humans choose in the face of danger: flight, fight, freeze. One of these responses is picked to ensure survival, depending on the person's experience in a similar occasion and the response that will guarantee more chances of survival [24]. About 12% to 50% of victims under perceived danger of assault or rape do not resist perpetrators [25]. In cases of sexual assault, rape or any perceived threat, some women might resist, run for help or freeze; unable to perform any action [24].

This paper factors in the possibility of a freeze response during emergencies or potential threats. When compared to the research in [2], [11], [17 – 23]; this study differs from the reviewed relevant studies. This study will: use a fingerprint sensor instead of a button, requiring less user interaction and benefiting victims in shock, improving automaticity and exclusivity; incorporate a vibration module prompting the user to input the required fingerprint, preventing false alarms that could distress relatives; incorporate both text and phone call alerts, improving urgency during emergencies; and lastly, implement an additional microphone feature enabling audio surveillance during calls.

III. PROPOSED METHODOLOGY

This section presents the development and working principles of the device. The hand-held system comprises different parts integrated: the Arduino Nano microcontroller, fingerprint module, A9G module (consisting of GSM and GPS module), microphone, vibration sensor module, Organic Light-emitting Diode (OLED) display, and power unit. This research aims to develop a hand-held device for women assault reporting which is designed to have the Arduino Nano microcontroller as the brain of the system, the fingerprint module as the authentication and verification subsystem, the GSM subsystem, the GPS subsystem, the vibration module as the alerting subsystem for prompting the user, and the OLED display as an output. The power unit powers the microcontroller which turns on the rest of the system as shown in Fig. 1.

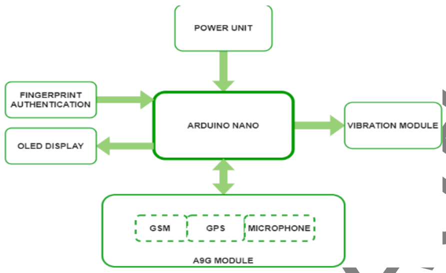

Fig. 1. System Block Diagram.

A. Development of the Fingerprint Authentification Subsystem

The fingerprint authentication subsystem involves both the enrolment and verification of the user. Fig. 2. shows the fingerprint authentication process.

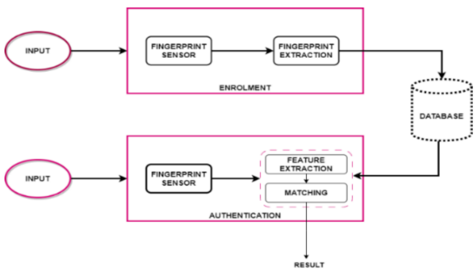

Fig. 2. Fingerprint Enrolment and Authentication Process

In this study, the Fingerprint R305 Sensor was used. It uses optical technology and can detect fingerprints with a high level of accuracy. Integrating fingerprint R305 with Arduino Nano provides security and exclusivity for the user. The Arduino Nano analyses the nonexistence of the authorized fingerprint during the designated time of 0 to 75 seconds, thereby inferring that the user is in a precarious situation. Subsequently, it proceeds to execute the intended operation.

B. Development of the Global Positioning and Global System for Mobile Communications Subsystem.

The A9G module, possessing the doubled-edged capabilities of both GPS and GSM, was incorporated into the system enabling reliable GPS tracking of its location. Without the registered fingerprint, the Arduino Nano microcontroller prompts the A9G module to send emergency text and call designated recipients, thereby facilitating prompt action and response. The text contains the location of the user retrieved via the GPS feature in the A9G module. The A9G module has a microphone embedded that can listen to the user's environment when a phone call is made between the device and the designated recipients.

C. Development of the Alert Subsystem

The alert subsystem is implemented by integrating the vibration module within the system. It is connected to the Arduino Nano, to facilitate vibration feedback. When the countdown for the timer of the device is at the 30th or 60th second, the system vibrates to remind the user to input the required fingerprint. By incorporating the vibration module, the system gains the ability to provide tactile feedback and stealthily improve user awareness, reminding the user to place fingerprint. This also aids in preventing false alarms from occurring.

D. Development of the Display Unit

The development of the Display Unit involves incorporating an OLED display to the Arduino Nano, to serve as the output. It is designed to showcase the countdown of the time interval. It also displays "MATCH" or "WRONG" depending on the required fingerprint. OLED displays are thin, lightweight, and flexible, making them suitable for portable devices.

E. Development of the Crime Identification Algorithm for the System

The algorithm comprises a set of structured procedures by which the system achieves the intended operation. Via the code, the fingerprint of the user is registered and stored in the fingerprint database. Stored fingerprints can also be overwritten or deleted. On activation, the system starts counting down from 0 to 75 seconds. At the 30th and 60th second, the system vibrates, respectively, to remind the user to input the required fingerprint. Approval or denial of a fingerprint is displayed on the OLED screen. In the absence of the required fingerprint within the time interval between 0 to 75 seconds, the GPS receiver, via the A9G module, picks the location of the user and feeds it to the Arduino Nano microcontroller. The microcontroller feeds the GSM, via the A9G module, the location of the user. The GSM module sends an SMS signifying that the user is in danger as the link of the location of the user and places a call to the pre-configured emergency contact. The microphone feature in the device aids the caller in hearing the surroundings of the system once the phone call communication on both ends has been established. The flowchart depicted in Fig. 3. provides a comprehensive depiction of the complete process of the algorithmic operation of the system.

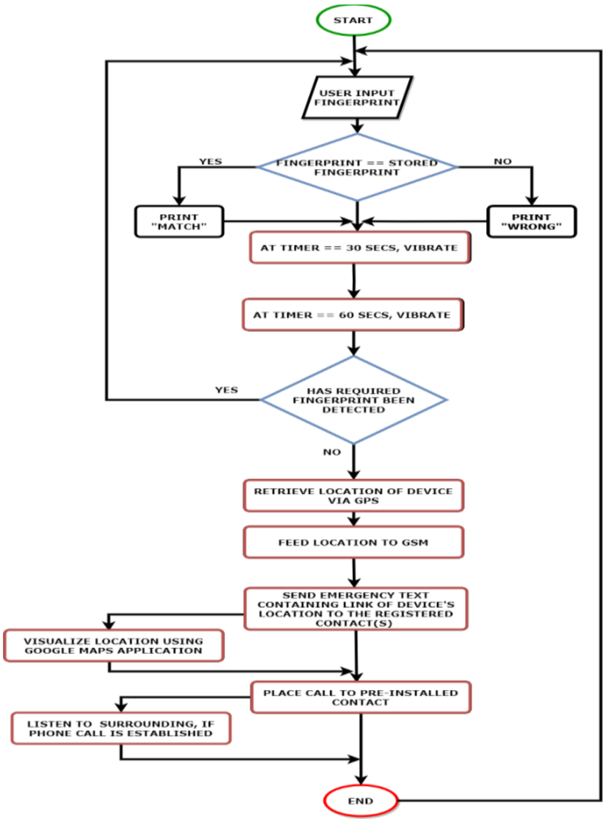

Fig. 3. Flowchart of System

F. *Visualization of Location*

The link to the location of the user can be accessed and visualized through the Google Maps application. The 3D model of the device is also shown in Fig. 4.

Fig. 4. 3D Model of the Device

IV. PERFORMANCE EVALUATION

The False Acceptance Rate (FAR), response time, and False Rejection Rate (FRR) were the evaluation criteria used to assess the proposed system's performance.

A. *False Acceptance Rate (FAR)*

FAR is the likelihood that the biometric sensor of the system will mistakenly claim that an input pattern and a non-matching pattern in the database have successfully matched. This occurs when an unauthorized user has been falsely approved. Equation (1) provides the formula for computing FAR. Equation (2) provides the formula for calculating the average FAR.

$$\text{FAR} = \frac{\text{Number of } \textit{False} \text{ Acceptance(s)}}{\text{The Number of trials made towards identification}} \quad (1)$$

$$\text{Average FAR} = \frac{\text{Total Number of } \textit{False} \text{ Acceptance(s)}}{\text{Total Number of trials made towards identification}} \quad (2)$$

B. *False Rejection Rate (FRR)*

FRR is a statistical indicator that describes the proportion of times the biometric authentication subsystem erroneously denies access to a legitimate user who should have been granted access to the system. FRR is the percentage of valid access attempts that the system mistakenly rejects. Equations (3) and (4) provides the formula for computing the FRR and the average FRR, respectively.

$$\text{FRR} = \frac{\text{Number of } \textit{False} \text{ Rejection(s)}}{\text{The Number of trials made towards identification}} \quad (3)$$

$$\text{Average FRR} = \frac{\text{Total Number of } \textit{False} \text{ Rejection(s)}}{\text{Total Number of trials made towards identification}} \quad (4)$$

Where the FRR is the ratio of the Number of False Rejections of the user per the number of endeavours made by the user towards identification.

C. *Response Time*

The response time of the system measures the time it takes for the system to respond to the non-detection of the registered fingerprint after the time interval. The system responds by sending a text message with the location of the user and placing a call to the predefined recipient when the required fingerprint is not detected. Response time for performance evaluation metrics is presented in (5). Furthermore, it can be utilised to solve for the average response time (6).

$$\text{Response Time} = T_{AR} - T_A \quad (5)$$

$$\text{Response Time} = \frac{\sum T_{AR} - T_A}{N} \quad (6)$$

Where:
T_{AR} = Time of Approval Receipt
T_A = Time of Approval
N = Number of samples used.

V. RESULTS AND DISCUSSION

Following system testing, the findings were extracted, collated, and analysed using graphs. FAR and FRR assessed the fingerprint authentication subsystem of the device, while response time assessed the duration for the system to respond when the registered fingerprint was not detected.

A. *Response Time Results*

The response time was used to assess the speed at which the system responded to sending an SMS and making a phone call when the required fingerprint was not detected within the 0 to 75-second (00:00 – 01:15) countdown. 20 samples in all were undergone through trial at various intervals. Table 1 demonstrates the test results that were achieved. The average response time of the system when tested was 4 seconds.

TABLE I. RESPONSE TIME OF THE DEVICE AFTER TIME INTERVAL COUNTDOWN

Trial(s)	*Time of Approval (T_A)*	*Time of Approval Receipt (T_{AR})*	*Response Time ($T_{AR} - T_A$)*
1	01:15	01:18	3
2	01:15	01:18	3
3	01:15	01:20	5

Trial(s)	*Time of Approval (T_A)*	*Time of Approval Receipt (T_{AR})*	*Response Time ($T_{AR} - T_A$)*
4	01:15	01:17	2
5	01:15	01:20	9
6	01:15	01:18	3
7	01:15	01:19	4
8	01:15	01:20	5
9	01:15	01:18	3
10	01:15	01:20	5
11	01:15	01:18	3
12	01:15	01:19	4
13	01:15	01:20	5
14	01:15	01:18	3
15	01:15	01:19	4
16	01:15	01:18	3
17	01:15	01:21	6
18	01:15	01:18	3
19	01:15	01:19	4
20	01:15	01:18	3

Response times for the 20 trials, as shown in Table I, revealed a slight difference in the results. The values *t* varied from 3 to 9 seconds. The delay was largely due to poor cellular service of the GSM network. The recorded average reaction time was 4 seconds. This, however, means that it took the system an average of 4 seconds to respond to perceived dangers each time the fingerprint sensor did not detect the registered fingerprint. Fig. 5. shows a graphical illustration of the response time of the system.

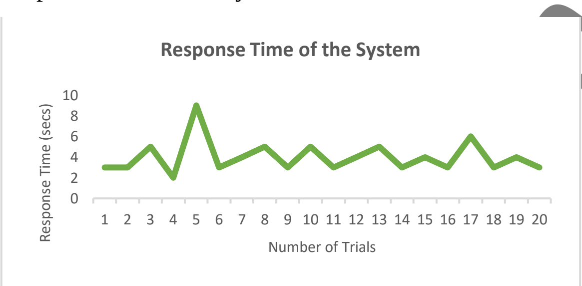

Fig. 5. Response Time of the System

B. *False Acceptance Rate Results*

The system recorded two valid users who registered two separate fingerprints of theirs into the database of the sensor, respectively, for the trials. 25 attempts with unregistered fingerprints were made on the device at four different intervals. For the first attempt, 2 out of 25 tested unregistered fingerprints were falsely approved. The second attempt yielded false approval of 1 out of 25 unregistered tested fingerprints. The third attempt resulted in false approval of 2 out of 25 unregistered tested fingerprints. For the final interval, 1 out of 25 unregistered tested fingerprints was falsely approved. The results are exhibited in Table II. Equations (1) and (2) were used to calculate the FAR and the average FAR of the system, respectively.

TABLE II. FAR OF THE DEVELOPED HAND-HELD SYSTEM

Matching Attempt(s)	*Accepted*	*Rejected*	*FAR*
25	2	23	8%
25	1	24	4%
25	2	23	8%
25	1	24	4%

The average False Acceptance Rate for the system was 6%. Fig. 6. depicts a pie chart that represents the FAR for the device.

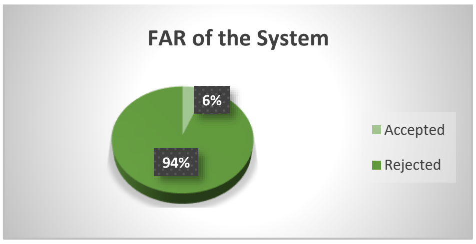

Fig. 6. Response Time of the System

C. *False Acceptance Rate Results*

To achieve this experiment, four distinct users had their fingerprints enrolled on the device. The number of times that legitimate users were denied access were recorded in Table III. This was largely a result of dust on the sensor, moisture, or poor fingerprint placement on the sensor.

TABLE III. FRR OF THE DEVELOPED HAND-HELD SYSTEM

User	*Number of Attempts*	*Number of times Accepted*	*Number of times Rejected*	*FRR (%)*
1	25	24	1	4
2	25	24	1	4
3	25	24	1	4
4	25	23	2	8

The graph (bar chart) outlines the number of acceptances, attempts, and rejections for each user of the system as shown in Fig. 7.

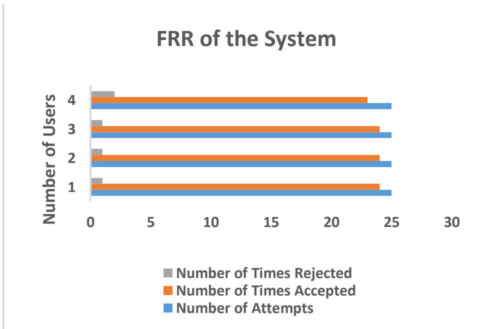

Fig. 7. Bar Chart showing FRR of the System for each User

The False Rejection Rate for the cumulative number of attempts made by individual users was comparatively low, as shown in Table III. The average FRR of the system was 5% and was calculated using equation 4 as earlier presented. It can be therefore inferred that the device exhibits a reasonable level of dependability for practical applications. The overall cost of the system was estimated to be **₦67,540.00.** Fig. 8. shows the developed system.

Fig. 8. The Developed System

VI. CONCLUSION

This study introduced a hand-held system for women assault reporting by integrating: a fingerprint authentication subsystem, providing exclusivity and autonomy; a GSM and GPS subsystem, for locating the user and alerting predefined contacts during emergencies via text and calls; an alerting subsystem to prompt user, alleviating potentially detrimental false alarm scenarios; an additional microphone feature for audio monitoring and surrounding surveillance during calls, improving crime scene identification. The Location of the user can be visualized using the Google Maps application. This device will significantly improve the sense of safety in women when in isolated or public places during late hours, or at any given time. It will also play a vital role in alleviating the rapid increase in crime against women in the society.

Further improvements in this study can include the integration of a capacitive fingerprint sensor for improved sensitivity; an enhanced vibration module to improve the tactile reflex of the user, and a miniature fingerprint sensor can for enhanced portability.

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