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Fingerprint Scanner Recognition System using Arduino

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ABSTRACT

Biometric recognition has emerged as a reliable method for enhancing security in modern digital and physical systems. Authentication using fingerprints has emerged as a reliable method for enhancing security in modern digital and physical systems. The Arduino Uno microcontroller, Arduino IDE, and GT521-F32 fingerprint sensor module were used to create fingerprint recognition system presented in this paper. The design architecture, system workflow, and hardware as well as software integration were all reviewed in this paper. Additionally, reviewed were the system's accuracy, cost efficiency, and real-time performance. The review also discusses major challenges, such as insufficient storage capacity, sensitivity to the environment and security vulnerabilities. Additionally, the most recent developments in the field such as IoT-based authentication and intelligent biometric systems—are discussed to outline the advancements that will be made in the future. The results imply that fingerprint recognition with Arduino boards are a viable and economical alternative to bigger systems and can be enhanced in scalability and resilience. This project is aimed at offering an academic study as well as a procedural guide to the electrical characteristics, the specification of UART, the matching and enrolled individuals based algorithms on the module, and how to implement the module practically using Arduino.

Keywords: Fingerprint Recognition, Biometric Authentication, Arduino Uno, GT521-F32 Sensor, Embedded Systems and IoT-Based Authentication.

I. INTRODUCTION

The current digital age has seen a rise in the need to have efficient and sound mechanisms of authentication. Mainly because of the increased number of cyber threats and unauthorized access cases. Passwords, PINs, and smartcards are examples of traditional authentication mechanisms that are at risk for security breaches, such as theft, duplication, and brute force attack techniques [1]. As a result, biometric authentication alternatives have been identified that are safer and easier to use technologies. Every individual possesses since he/she has fingerprint recognition is a common technique that makes use of individual fingerprints which are long-term stable method of recognizing individuals. Because of this, it is an authentic manner to confirm identity. With microcontroller-based solutions, it is now possible to develop cost effective and efficient solutions. Connection to various sensors and modules interface, it can be used in fast research and prototyping. By combining the Arduino Uno with simple and efficient recognition systems can be created. With the goal to reduce the computational load on the microcontroller, the GT521-F32 module has an inbuilt digital signal processor that can carry out image extracting features and matching a standard template [2]. This enhances system efficiency as well as makes implementation faster. An in-depth examination of a recognizing fingerprints system through the Arduino Uno and GT521-F32.

II. LITERATURE REVIEW

Fingerprint recognition is very accurate, robust, and inexpensive to implement because it is characterized by high degree of accuracy, robustness and low cost of implementation. Contemporary studies have proposed the importance of sound fingerprint acquisition and matching process due to the importance of sound fingerprint acquisition and matching. Fingerprint optical sensors (as in GT521-F32 modules) are the norm because of their ability to identify quickly and their embedded capabilities [3].

The internal processing unit of the GT521-F32 fingerprint module has elicited the attention of having its own processing unit that internally performs the functions of fingerprint acquisition, feature extraction and template matching. This not only decreases the amount of computation needed by the Arduino microcontroller but also makes system design simpler. Studies into similar modules (e.g. GT521 series) observe that they can store fingerprint templates, and can communicate over UART protocols, which again makes them far simpler to implement with embedded systems [4].

The recent advancements in fingerprint recognition have been aimed at implementing better algorithms and to enhance the power and precision of it, machine learning. Deep learning techniques have been used to. The following conditions like moisture, dust and finger pressure can interfere with the quality of the. image and recognition in the fingerprint recognition systems. Hardware integration problems such as also. Also, hardware integration issues such as power consumption and communication problems can affect the working of the system particularly in the case of standardized systems based on Arduino [5]. Security issues are represented by attacks on and accessing stored templates through information. The literature inclines towards in the context of small-scale authentication. To make them

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more applicable in high security and large scale environments, however, they must be deployed with more security, scalability, and robustness.

Many research about fingerprint recognition system that use Arduino Uno and GT521-F32 modules for authentication already done, however there are lots of problem in research and in practical use, such as most system has the feature that simply manage register/check-in fingerprint and ignores about security, expansion and robustness of the system. A large problem of such system is lack of security.

Generally, no protection is applied on the fingerprint stored in the module, enabling anyone to clone the fingerprint or to gain an unauthorized access. Furthermore, a secure communication between the Arduino and the fingerprint module is not used generally and increases the possibility of information theft. Another aspect is the limited memory size available on the GT521-F32 module. Therefore, it cannot be applied in large premises such as a company or school. Lastly, research concerning robustness on such systems with dust or humidity conditions and also incorrect finger placement can also be increased to improve accuracy. Most systems do not have ways to deal with these issues well.

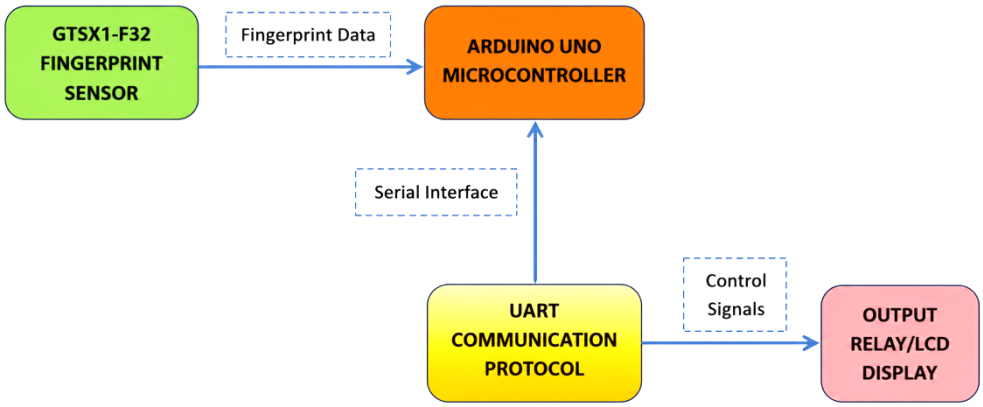

Fig. 1. Architecture of Fingerprint Recognition System Using GT521-F32 module

Lastly, many Arduino fingerprint systems do not fully use new technologies like IoT, cloud storage, and remote monitoring. This limits what they can do and how easily they can be accessed in real-time.

III. METHODOLOGY

The new fingerprint recognition system seeks to upgrade the already available biometric systems built on Arduino with the aim of improving them and introducing secure messaging methodologies as well as scalable technology architecture. It was built with an Arduino Uno, GT521-F32 fingerprint-reading module, and other parts that included an LCD display, a buzzer, and optional IoT connectivity to monitor remotely.

In order to enhance security, the system proposes simple encryption methods of storing and transmitting fingerprint data to the cloud. Even though, GT521-F32 stores templates within itself, the suggested system provides even greater protection of data by ensuring security in communication between Arduino and other external devices [6]. Moreover, access control can be added with the help of passwords to provide a second layer of authentication and achieve multi-factor authentication.

An enhanced enrolment and verification system is also embedded in the system. Several samples of the fingerprint are taken during enrollment, creating a more precise template, and enhancing the matching accuracy. In the verification, the system matches faster with command handling optimization thus minimizing the response time [7].

A. *System Architecture*

The GT521-F32 can only communicate with Arduino Uno by UART serial protocol, a proven and trusted communication standard that is natively supported by Arduino hardware. The serial connection needs 3 wires: transmit (TX), receive (RX) and ground (GND). The GT521-F32 can transmit on one line and receive on the other, allowing full-duplex two-way communication at a variety of adjustable baud rates [8]. Its default baud rate of 9600 bits per second offers good communication over standard cable and it has an option to have higher rates to 115200 bits per second to transfer data much faster in time-sensitive processes [9].

The code used to implement GT521-F32 communication on Arduino normally uses the hardware UART (Serial interface) or software-based serial libraries (Software Serial) on configurable digital pins [10]. Hardware UART implementation is better in performance and reliability, and consists of using the dedicated serial hardware of the ATmega328P, but software UART implementation can be more flexible in pin choice, at the expense of lower throughput and possible timing conflicts with other time sensitive activities. In the

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majority of production applications, hardware serial is used, allowing the communication with the fingerprint module to be reliable and high-speed, and software serial is used, allowing communication with external computers to be debugged.

B. Implementation Details

Hardware Overview:

Arduino Uno: Arduino Uno is a simple, low-cost board that uses the ATmega328P chip. It is popular for building projects because it is easy to use and flexible. This microcontroller comes with 14 digital and 6 analog pins and it could be used through a variety of means, i.e UART, SPI and I2C. Arduino Uno is being employed to control the two-way communication between the fingerprint sensor and other constituents within the fingerprint recognition system, sending out commands to the sensor, instructing it to execute certain commands (add fingerprint, verify fingerprint) and acquiring data in return to make decisions.

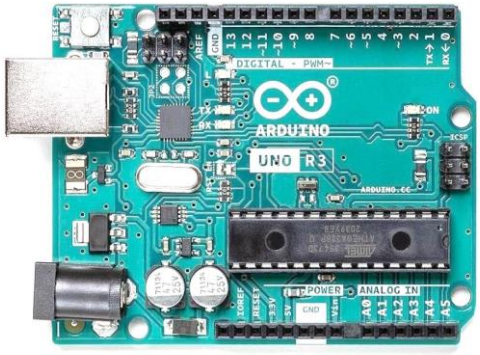

Fig.2. Arduino Uno

GT-521F32 module:

The GT521-F32 is a very small and compact but yet capable optical fingerprint sensor that is found in many kinds of embedded biometric projects. People like it because it's easy to fit into tight spaces, works fast, and doesn't take much effort to hook up. Inside, there's a digital signal processor that takes care of almost everything—snapping a fingerprint image, pulling out the key details, and matching it to saved templates. This means the main microcontroller barely has to do any of the heavy lifting. The GT-521F32 costs less but it can hold only 200 fingerprints. The module talks over UART, so you can connect it easily to popular boards like the Arduino Uno. You really just need four wires—TX, RX, power, and ground—and you're ready to go. Not much fuss on the hardware side.

Fig.3. GT-521F32 module

IV. EXPERIMENTAL SETUP AND RESULTS

A. Connecting w/ a 5V Arduino

Before using the Arduino's example code, make sure that the logic levels match. If you are using a 5V Arduino, you could use a dedicated logic level converter or resistors for voltage division. Here are the minimum parts you would need to get started:

1. Fingerprint Scanner (GT-521F32)
2. Qwiic Cable
3. Arduino Uno
4. Mini-Breadboard
5. Bi-Directional Logic Level Converter or 3x 10kOhm Resistors
6. M/M Jumper Wires

After wiring the circuit, it should look like this:

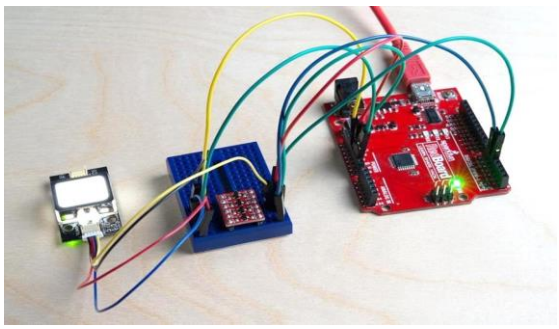

Fig.4. Hardware implementation of fingerprint recognition system using Arduino Uno and GT521-F32 module.

TABLE 1.
HARDWARE CONNECTION DETAILS BETWEEN FINGERPRINT SCANNER AND ARDUINO UNO

Voltage Divider	Fingerprint Scanner(Pin #)	Voltage Divider	5V Arduino w/ Atmega328P
	UART_TX (3.3V TTL) (Pin 1)		RX (pin 4)
GND < 10kOhm > 10kOhm	UART_RX (3.3V TTL) (Pin 2)	10kOhm	TX (pin 5)
GND	GND (Pin 3)	GND	GND
	Vin (3.3V~6V) (Pin 4)		5V

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Hand Drawn "FINGERPRINT" :

I was interested in seeing if the fingerprint scanner was able to identify any other items placed on the fingerprint scanner. I tested using a few drawings on a sticky note:

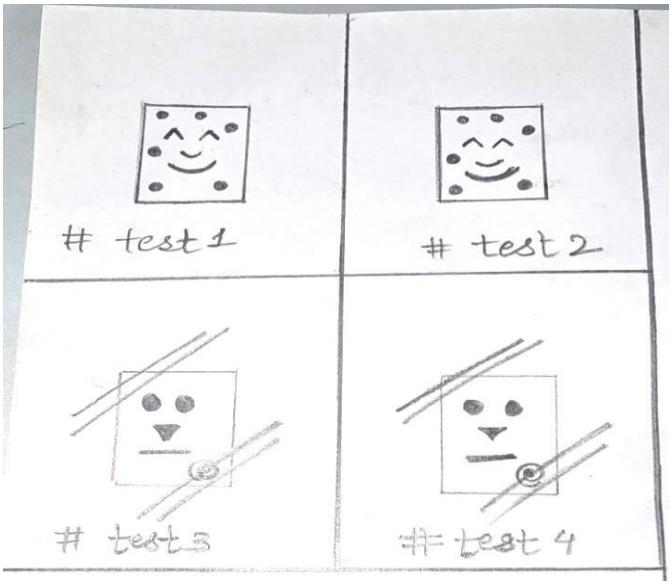

Fig.5. Experimental test cases showing fingerprint recognition outcomes under different conditions.

B. Performance Evaluation

The biometric fingerprint system employing the Arduino Uno and GT521-F32 functions excellently with respect to accuracy, speed, and reliability. Once your finger is properly placed on the sensor, it in most cases accurately identifies the match. The GT521-F32 not only extracts the features, it also performs the matching so you will be receiving accurate results. Even when your finger is dirty or you're not perfectly centered, accuracy still is a little lower-that's how this is.

The fact that it is also fast is a good advantage. Normally it authenticates you in less than a second. Which is fast enough for tasks like control over access or time registering. And this happens thanks to the UART interface between the Arduino and the fingerprint module.

V. DISCUSSION

The accuracy, response time and reliability of fingerprint recognition system with Arduino Uno and GT521-F32 module were tested. High accuracy was also obtained when the fingerprints were placed correctly with the system since the GT521-F32 module effectively processed the features extraction and matches [11].

The response time was seen to be approximately 12 seconds and this is sufficient to use the system in real-time like access control and attendance systems [12]. UART was used to provide stability in communication between the sensor and Arduino.

Nevertheless, the environmental influences on performance comprised dust and improper positioning of fingers, resulting in some cases of mismatches [13]. There is also a limited storage capacity of the system (about 200 templates) and no advanced security such as encryption. Generally, the system is cost-efficient, user-friendly, and can be efficient with small-scale applications, but with large-scale and high-security systems, it needs to be improved.

The current fingerprint recognition systems using the Arduino Uno and the GT521-F32 module offer a cheap and easy to use system in biometric authentication. These systems however have limitations when it comes to security, scalability and overall performance. In the current system, security is minimal with the storage of fingerprint templates being unencrypted and no protection is provided to the communication between the components. The proposed system enhances security by proposing simple encryption methods and the option of multi-factor authentication.

Existing systems have moderate to high performance in terms of accuracy and response time, with authentication times of 1-2 seconds. The suggested system supplements this, as it improves enrollment and matching procedures, which leads to quicker and more efficient authentication. The current system has a storage capacity of about 200 fingerprint templates, and the proposed system can expand the storage capacity to external memory or integrate with the IoT cloud making it applicable in larger applications.

VI. CONCLUSION

This summary has explored fingerprint scanner recognition systems based on Arduino microcontrollers combined with fingerprint modules, explored technical specifications, and methodologies of implementation, performance properties, and its application in various fields. The GT521-F32 will be a mature, proven platform that can provide advanced biometric authentication to a resource-limited embedded system, opening up fingerprint recognition technology to educational, business, and governmental use.

It boasts impressive specifications of 162-fingerprint capacity, matching speed of 0.8 seconds, 0.6 percent FAR, and 1.8 percent FRR, which makes it competitive with other sensors, and Arduino ecosystem compatible.

Although the fingerprint recognition system with Arduino Uno and the GT521-F32 module has proven to be effective, there exist a number of limitations. The storage capacity of the GT521-F32 module is one of the main limitations since it has a limited storage capacity, and only a few fingerprint templates can be stored. This renders the system inappropriate in large scale applications. Also the system is lacking on security features since the fingerprint data are not highly encrypted, and therefore can be spoofed and accessed unlawfully.

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Sensitivity to environmental factors, including dust, moisture, and the inability to put fingers at the right position can also be considered another limitation, as it can cause the system to be less recognizable and less reliable. Besides, the processing power of the Arduino Uno is quite limited and is also incapable of employing advanced algorithms such as machine learning-based recognition techniques. In addition, the system lacks a mechanism that enables remote access and remote data management capabilities, so it can only be used on the smallest possible scale in a distributed system.

It is possible to improve the system in future works with more security schemes like encryption and liveness detection in order to solve the spoofing attack. With limitations in storage capacity, it can be dealt with external storage, cloud storage based databases and to achieve better scalability. A connection to the system's IoT platforms would provide access to remote monitoring, real time data logging, and centralized system control.

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