DSP based Embedded Fingerprint Recognition System

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***Abstract*—Along with the rapid development of biometric recognition techniques, the fingerprint recognition became a significant subject. Fingerprint recognition is a method to identify a person, based on the physiological characteristics of the finger. Many of today's recognition systems are realized on the PC-based platform, which has high power consumption and cannot be used with ease. But, the recently developed market for civil applications has more demand for system's portability and power consumption. So, the trend of miniaturizing and embedding the system for automatic fingerprint identification became more distinct. In this paper, a convenient, fast, and inexpensive low power Digital Signal Processor (DSP) based embedded fingerprint recognition system is introduced. Reliable extraction of features from input fingerprint image is the most challenging problem faced in the area of fingerprint recognition. However the performance of the Minutiae extraction algorithm relies heavily on the quality of the input fingerprint image. In order to ensure to extract the true minutiae points it is essential to incorporate a good enhancement algorithm. The earlier fingerprint image enhancement methods are FFT based and has a drawback of poor image quality which results in unreliable minutiae extraction and thereby reduces the accuracy of recognition result. In this paper, at the algorithm level a new approach for fingerprint image enhancement based on the Gabor filter is introduced. Comparatively this algorithm produced the good results in the view of image quality and accuracy.**

Keywords- Biometric; Fingerprint; Recognition; DSP processor; Gabor filter; Image enhancement;

I. INTRODUCTION

The Biometrics are automated methods of recognizing an individual based on their physiological (e.g., fingerprints, face, retina, iris) or behavioral characteristics (e.g., gait, signature). Each biometric has its strengths and weaknesses and the choice typically depends on the application. There are a number of desirable properties for any chosen biometric characteristic. These include Universality, Uniqueness, Permanence, Measurability, Performance and Acceptability. For any particular application, no single biometric characteristic is expected to effectively meet all these properties. Various biometric technologies are fingerprint, face, iris, hand geometry, voice and signature recognition. Among all those, fingerprint technology is the oldest biometric technology, but still it is most widely used because it provides good levels of accuracy and simplicity. This technology is highly reliable for the recognition purpose because of their uniqueness and consistency over the time. Also, the fingerprint is fast biometric technique for more reliable and secure system.

A fingerprint, as the name suggests is the print or the impression made by our finger because of the patterns formed on the skin of our palms and fingers since birth. With time, these marks get prominent but the pattern and the structures present in those fine lines do not undergo any change. Because of their permanence and unique nature, they have been used in criminal and forensic cases for a long time [1].

Every fingerprint consists of ridges and furrows. Literature survey [1] [2] confirms that fingerprints are not distinguished by ridges and furrows but by Minutia. Minutia refers to some abnormality in a ridge. There can be various such Minutia but the two most important and useful minutia types are Termination and Bifurcation. A ridge Termination is defined as a point on the ridge where a ridge ends abruptly or suddenly. On the other hand Bifurcation is defined as point on the ridge where a ridge is divided into two separate ridges. These minutiae points are treated as the features of fingerprint image.

II. HARDWARE DESIGN OF EMBEDDED FINGERPRINT RECOGNITION SYSTEM

The literature survey [5] has confirmed that a number of hardware platforms exist to implement the real time signal processing solutions. Each platform has its strengths and weaknesses. A number of design criteria determine the best hardware platform for signal processing applications. The criteria include performance, ease of development, power consumption, feature flexibility, economy, etc. These parameters help to make the right choice. The hardware platforms available for implementing the real time signal processing applications; are Application-Specific Integrated Circuit (ASIC), DSP (Digital Signal Processor), FPGA (Field Programmable Gate Array), MCU (Micro Controller Unit) and RISC (Reduced Instruction Set Computer).

Among the above mentioned hardware platforms, FPGAs and DSPs offer unique and different options for signal processing. The DSPs will continue to be used for many of today's challenging signal processing applications. The reasons for this are stated below.

The DSPs are especially designed for signal processing applications. They provide good flexibility in real time environment. But FPGAs are not as much flexible as DSPs in real time aspect. So finally, DSP selected for the implementation of the embedded recognition system.

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A. System architecture

The DSP is the nucleus of this embedded recognition system. The system can run independently without Personal Computer (PC). At the same time, combined the external circuit, the system can achieve fingerprint collection, processing, identification, output and display. The embedded fingerprint recognition system architecture is shown in Fig. 1. The system architecture includes ADSP - BF532, fingerprint sensor, SDRAM, 2x16 LCD, MAX232, and clock generation circuit. The purpose of each hardware module is clearly explained below.

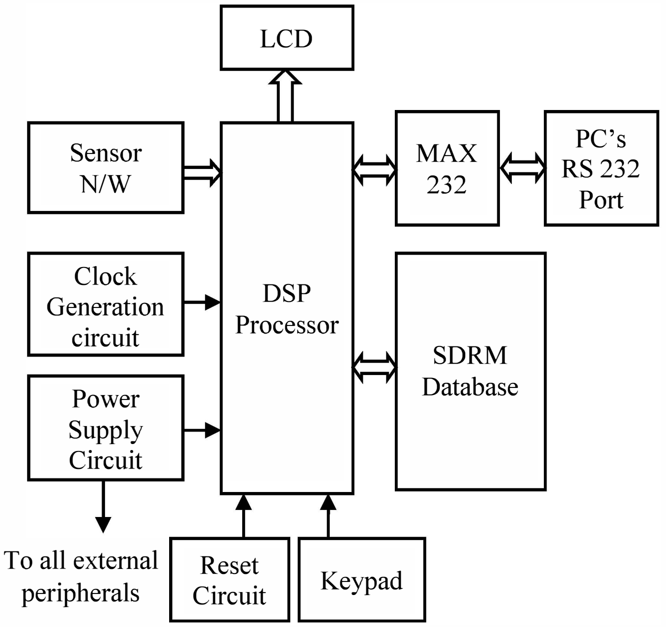

Fig. 1. Embedded fingerprint recognition system architecture

ADSP - BF532 is the core of the embedded recognition system. BF532 produced by Analog Devices (AD) is a high performance and low power DSP. DSP-BF532 has plentiful on-chip peripheral interfaces included External Memory Interface (EMIF), a UART port, an SPI port, two serial ports (SPORTs), four general-purpose timers (three with PWM capability), a real-time clock, a watchdog timer, and a parallel peripheral interface (PPI).

The fingerprint sensor first illuminates the print with a laser or LED light and then captures the image. Resolution, dynamic range and pixel density are factors that contribute to the image quality and influence the accuracy of the sensor. Here Tooan OP-100N optical sensor is used for the implementation of recognition system because it provides high resolution.

The embedded fingerprint recognition system application software is developed on the PC using Visual DSP++ project management tool. After development, this program needs to be dumped into DSP processor to achieve recognition task. So a communication path is required between PC and DSP. Generally the voltage levels supported by DSP are incompatible with PC's RS232 voltage levels. So a voltage convertor is required for communication between PC and DSP. Here MAX232 is used as the voltage level convertor.

This embedded recognition system requires 3 different voltages. These voltages are 5V, 12Vand 3.3V. The 3.3V is generated with the help of LM117 variable voltage regulator and is used to power up the BF532. The LCD, MAX232, keypad operates from a single 5-V power supply, and this supply is acquired by using a bridge rectifier and 7805 voltage regulator. The fingerprint sensor requires 12V power supply for its satisfactory operation and it is obtained with the aid of bridge rectifier and 7812 voltage regulator.

The Reset circuit resets the DSP device by assigning the internal registers and memory with default values.

This embedded recognition system is a user friendly design because it is designed to operate in 4 flexible user modes. The user can easily select any specific mode with the assist of portable common cathode configuration keyboard attached to the DSP.

A 2x16 LCD is connected to DSP device to display the result of various modes. The LCD can add a lot to our application in terms of providing useful interface to the user. The DSP is interfaced to LCD with the aid of port F.

B. ADSP BF532 Hardware Interfacing circuits

The BF532 DSP alone does not perform the recognition task, so to perform the recognition task, several peripherals are necessary to interface to the DSP.

i. SDRAM interfacing with DSP

The BF532 processor supports a 4G byte address space using 32-bit addresses. All resources, including internal memory, external memory, and I/O control registers, occupy separate sections of this common 4G address space. The BF532 processor supports up to 148K bytes of on-chip memory. An SDRAM of 128 MB is connected as external memory to the BF532 DSP. The SDRAM interfacing with DSP is shown in Fig. 2.

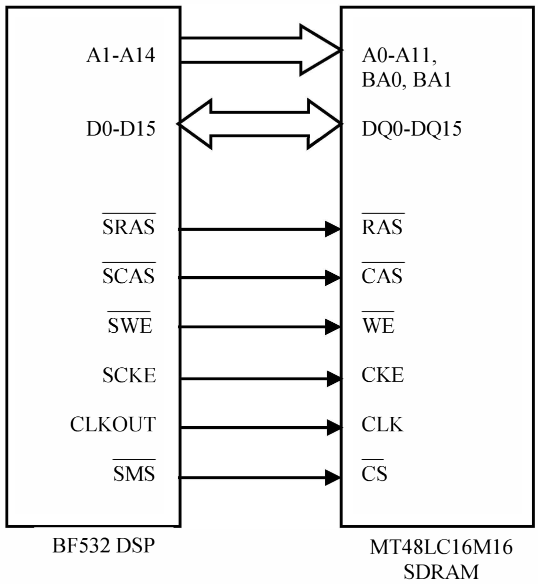

Fig. 2. SDRAM interfacing with DSP

This embedded recognition system application software is stored in on-chip memory of ADSP-BF532. The 128 MB SDRAM (external memory) is used to store fingerprints collected by the sensor, temporary data from image processing and recognition process.

ii. PC and Sensor Interfacing with BF532 DSP

The communication between DSP and PC is established with the assist of DSP's UART port and MAX232 where as DSP's serial port SPORT2 is used to communicate between fingerprint sensor and DSP. The DSP's RX & TX pins constitute a UART port.

Since the PC's RS232 is not compatible with today's DSPs, we need a voltage convertor to convert the RS232's signals to TTL voltage levels that will acceptable to the BF532's TX and RX pins. The MAX232 has 2 drivers and 2 receivers. While program is dumping into DSP, the signals TXD pin of RS232 cable is given as input to second receiver R2IN PIN of MAX232, the second receiver output R2OUT is connected to the RX pin of DSP. Similarly on transmitting the data from DSP to PC, second driver of MAX232 is used. The Sensor and PC interfacing with DSP is shown in Fig. 3.

The BF532 DSP supports two serial ports SPORT1 and SPORT2. The serial port pin TFS1 (I/O pin) is connected with the fingerprint sensor output. The DSP device collects the digital data from the sensor through TFS1 pin and performs the necessary operation specified by the user via keyboard.

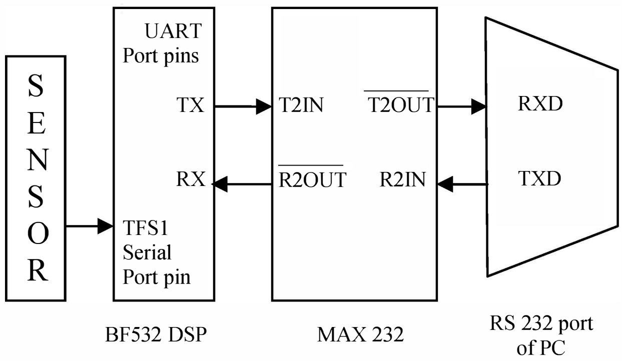

Fig. 3. Sensor and PC interfacing with DSP

iii. LCD and Keyboard Interfacing with BF532 DSP.

The Keyboard and LCD interfacing with DSP is shown in Fig. 4. The LCD used in the system is 16X2 LCD and keyboard is connected in common cathode configuration.

This embedded recognition system is designed to work in 4 different modes. User can select the specific mode with the help of keyboard. A common cathode configuration keyboard with 6 keys is connected to the port F of BF532 DSP. The keys include New User Enrollment to register a new user, Match for fingerprint matching; Delete to delete a particular print, Delete All to delete all the prints in database (SDRAM), Increment to increment the SDRAM pointer, Decrement to decrement the SDRAM pointer. Finally, the results of these modes can be viewed with the support of the 16 LCD. A 1Kohm resistor is connected to pin 3 of LCD to maintain fixed contrast.

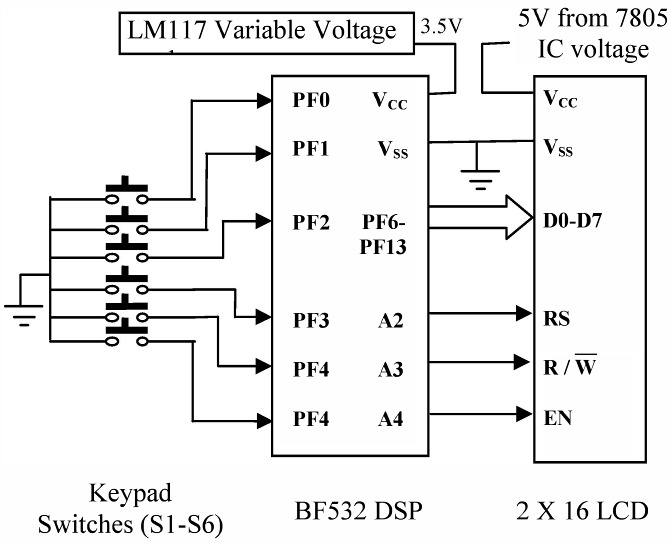

Fig. 4. Keyboard and LCD interfacing with DSP

III. SOFTWARE DEVELOPMENT OF EMBEDDED FINGERPRINT RECOGNITION SYSTEM

The embedded fingerprint recognition system application software is developed on the Visual DSP++ project management tool using C language. This C code is translated into assembly level language with aid of Visual DSP++ project management compiler. Finally the assembly level program is dumped into BF532 DSP. System application software mainly includes whole system initialization program, program of fingerprint feature extraction and matching, and computer communication program. This embedded recognition system application software mainly performs following tasks:

1. Initialize the ports of BF532 DSP.
2. Initialize the program memory and program memory pointer; pointer value indicates memory location where the processor starts program execution.
3. Initialize the stack memory and stack memory pointer.
4. Initialize the external SDRAM where the database is maintained and also initialize the I/O peripherals.
5. After the initialization process, the processor switch to user mode i.e, the processor checks the status of keyboard.
6. The processor changes its program sequence to one of the six subroutines. The six subroutines are new user enrollment, matching, delete, all delete increment and decrement. Each key in the keyboard is associated with one subroutine.
7. After the execution of a particular subroutine specified by the user through keyboard, processor switches to normal program flow.
8. Now the processor sends the data to LCD that displays the result corresponding to mode selected by the user. Suppose if the use select the matching mode, then LCD displays either *matching success* or *matching fail.*

This embedded recognition system is a *user friendly* design because it is designed to operate in 4 flexible user modes. The can easily select any specific mode with the assist of portable keyboard. Each user defined mode can be clearly explained below.

A. New User Enrollment Mode

The new user can be registered into embedded recognition system by means of *New Enrollment* key on the keyboard. During the enrollment mode, a fingerprint sensor scans the person's fingerprint to create a digital representation. The pre-processing algorithm and feature extraction algorithm processes the digital representation to generate a more compact and expressive representation called a template. The template for each user is stored in a recognition system database (SDRAM) for the purpose of future comparison. The *New User Enrollment mode* is supported by the enrollment algorithm comprises of pre-processing algorithm feature extraction algorithm [6] [7] [8]. After extracting the minutia points, form the template corresponding to new input user and then stored in a specific memory location. The desired memory location can be selected with the help of increment and decrement keys on the keyboard. Enrollment algorithm steps are briefly furnished below. Enrollment algorithm flow is shown in Fig. 5.

i. Noise Removal and Image Segmentation

The image acquired from the fingerprint sensor is temporarily stored in the SDRAM. The noises introduced into the image during fingerprint acquisition process, so the image is first subjected to noise removal process. After removing the noise, image is segmented. In a fingerprint image there are foreground regions and the background regions. The Segmentation process separates the foreground regions in the image from the background regions. The background regions where the noises introduced into the image during fingerprint enrolment process. When minutiae extraction algorithms are applied to the background regions of an image, it results in the extraction of noisy and false minutiae. Thus, segmentation is employed to discard these background regions, which facilitates the reliable extraction of minutiae [3].

ii. Local Normalization

Normalization is performed on the segmented fingerprint image to standardize the grey-level intensity values in an image by adjusting the range of grey-level values so that it lies within a desired range of values.

iii. Block Orientation Estimation

The block direction estimation defines the local orientation of the ridges contained in the fingerprint. The least mean square estimation algorithm is used to calculate the block direction

iv. Image Enhancement using Gabor filter

The Gabor filter is applied to the fingerprint image by spatially convolving the image with the filter. The convolution of a pixel (i, j) in the image requires the corresponding orientation value $O(i,j)$ and ridge frequency value $F(i,j)$ of that pixel. Hence, the application of the Gabor filter G to normalized image provides the enhanced image.

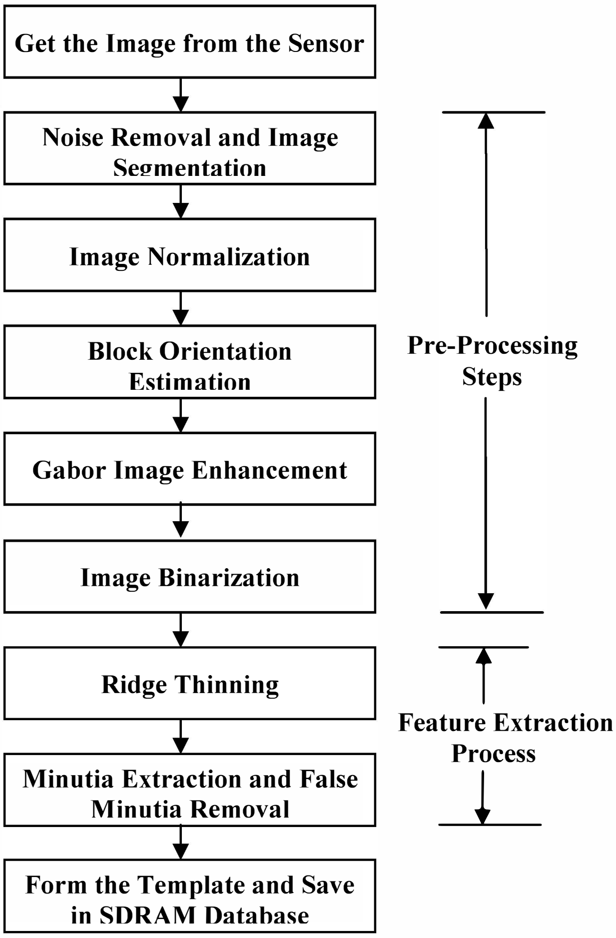

Fig. 5. Enrollment algorithm flow

v. Image Binarization

The original image is an 8-bit grayscale image. The binarization process converts a grey-scale image into binary image by assigning pixel values '1' for furrows and '0' for ridges.

vi. Minutia Extraction and False Minutia Removal

After the ridge thinning process, the next step is to extract the minutiae from the thinned fingerprint image. The concept of Crossing Number (CN) is most extensively used method for extracting the minutiae from fingerprint image. Along with genuine minutia points some false minutia points are also present in the fingerprint image. So identify where these points are located and remove those points.

After extracting the minutia points, form the template corresponding to new input user fingerprint and then stored in a specific memory location of SDRAM.

B. Matching Mode

The matching mode is responsible for identifying individuals at the point of access. Matching Process is shown in Fig. 6.

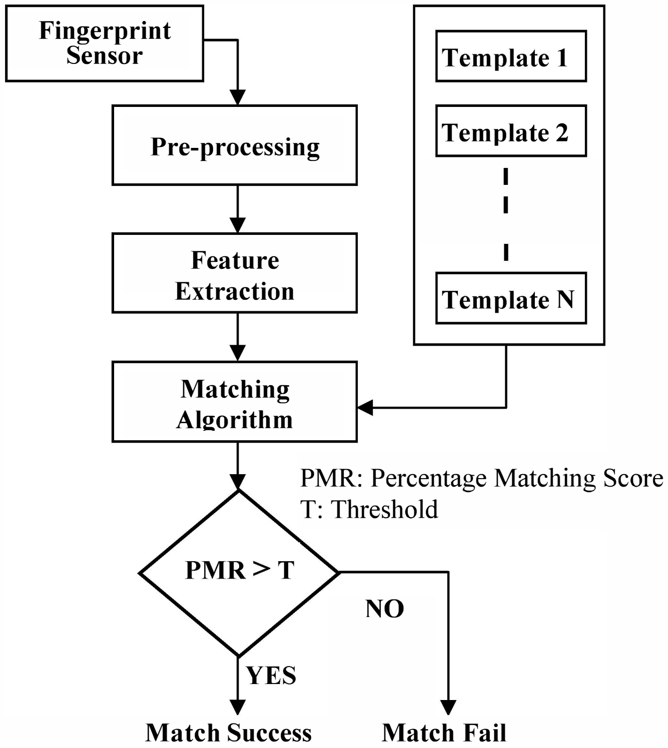

Fig. 6. Matching process

During the operation phase, the fingerprint sensor captures the fingerprint of individual to be identified and converts it to a digital format, which is further processed by the pre-processing algorithm and feature extraction algorithm to produce the same representation. The resulting representation is fed to the minutia matching algorithm which compares it against the template(s) stored in the SDRAM database to found the identity. The matching algorithm calculates the Percentage Matching Score (PMR). If the matching score satisfies the specific condition then match is declared as successful match otherwise it is considered as the Failure match [9].

C. Delete and Delete All Modes

The Increment and Decrement Keys on the keyboard are utilized for incrementing and decrementing the SDRAM memory pointer. Deletion mode allows user to delete a preferred fingerprint in the SDRAM by making use of increment, decrement and Delete keys. Suppose for example, if a user wants to delete any particular fingerprint from the SDRAM database, first he/she has to select the memory location from which the print is to be deleted by using increment/decrement keys and then press the Delete key.

The Delete All mode permits user to delete all the prints in the database.

IV. RESULTS

The main objective of this work is to enroll fingerprints of different persons and add them to the database which would be referred at the time of verification. The hardware kit of the embedded recognition system is shown in Fig. 7.

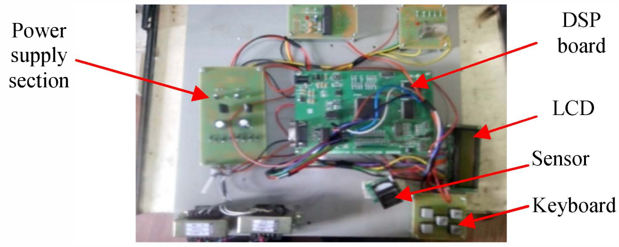

Fig. 7. Hardware kit of the embedded recognition system

For the trial run of the system, fingerprints of persons were captured and then added them to database using the hardware kit in the laboratory. The templates stored were named from Person_1 to Person_50. This registration can be done with the help of new user registration mode. The system is tested with 50 registered users; in all cases it provides satisfactory result. Fig. 8 shows the System result when a registered user accesses the system.

Fig. 8. Display of registered user accesses

The system is also tested with 50 Unregister users; in all cases it provides satisfactory result. Fig. 9 shows the System result when an unregistered user accesses the system.

Fig. 9. Display of unregistered user accesses

The performance of the minutiae extraction algorithm relies heavily on the quality of the input fingerprint image. If the image quality is good, then the extraction algorithm extracts only a few number of false minutia points along with true minutia points. In case of poor image quality, the extraction algorithm extracts a more number of false minutia points together with required true minutia points. So in order to ensure to extract the true minutiae points (reliable extraction) it is essential to incorporate a good enhancement algorithm. The earlier fingerprint image enhancement methods has a drawback of poor image quality which results in unreliable minutiae extraction (extraction of both true and false minutia points) and thereby reduces the accuracy of recognition result. Hence a hybrid technique-Gabor filter based enhancement was devised to improve the performance of enhancement techniques of fingerprint. The Table I shows the comparison of different enhancement techniques

TABLE I
COMPARISON OF VARIOUS ENHANCEMENT TECHNIQUES

	Existing Methods		Proposed method
Enhancement Method	Without Enhancement	FFT Method[11]	Gabor Filter Method
Ridge Endings	214	186	63
Ridge Bifurcations	98	72	17

The accuracy of the system depends on the quality of the fingerprint. Here accuracy is measured by means of False Rejection Rate (FRR) and False Acceptance Rate (FAR).

Sometimes the fingerprint recognition system may incorrectly *reject an access attempt by an authorized user* or *accept an access attempt of an unauthorized user*. To measure these types of incidents FRR and FAR is basically used. A system's FRR basically states the ratio between the number of false rejections and the number of identification attempts whereas FAR is the ratio between the number of false acceptances and the number of identification attempts.

During result testing, this embedded recognition system gives only two incidents of false rejections for 50 authorized identification attempts. Hence FRR of the embedded recognition system is 0.04 %.Upon observation; the system also gives one true result for 50 unauthorized user attempts. Thus the system maintains FAR of 0.02%.

Comparing with the existing enhancement algorithms, the proposed algorithm using Gabor filter in spatial domain, not only improves the quality of image but also effectively increases the accuracy by decreasing the error rates FRR & FAR.

Basically the PC based Recognition System (existing system) uses general purpose processor. This embedded recognition system employs Application Specific Integrated Circuit (ASIC) DSP device and it consumes a very little amount of power compared to general purpose processor.

V. CONCLUSION

This paper presents an embedded fingerprint identification system. It used DSP, Fingerprint Sensor, and SDRAM & LCD. This implementation was an effort to understand how Fingerprint Recognition is used as a form of biometric to recognize identities of human beings. This system can collect real-time fingerprint image signals, process fingerprint image quickly, extract fingerprint features, and then match the input fingerprint with one existing in a database to perform fingerprint recognition. Finally, the LCD displays the results of recognition process. In addition, the system has features of small size, low power and using conveniently. A program is coded in MATLAB and C to implement algorithms for enhancement, minutiae extraction and matching processing.

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