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DSP for Smart Biometric Solutions

Ram Sathappan Digital Signal Processor Group

ABSTRACT

Biometrics is the science of measuring and statistically analyzing biological data. In information technology, biometrics refers to the use of a person's biological characteristics for personal identification and authentication. Fingerprint, iris-scan, retinal-scan, voiceprint, signature, handprint and facial features are some of the most common types of human biometrics.

Digital signal processors (DSPs), which are specially designed single-chip digital microcomputers that process electrical signals generated by electronic sensors (e.g., cameras, fingerprint sensors, microphones, etc.), will help to revolutionize this world of biometrics. The core of the biometric authentication process is made up of image processing and pattern matching or minutiae comparison algorithms. And the programmable DSP, with an architecture well-suited for implementing complex mathematical algorithms, can efficiently address all the processing needs of such a system.

The following information introduces the concept of a complete biometrics system solution based on Texas Instruments (TI) semiconductor components, development tools, and software solutions. Additionally, the various concepts that outline the inherent advantages of a DSP in a biometric system - better accuracy, faster recognition and lower cost, all leading to smarter biometrics - will also be covered.

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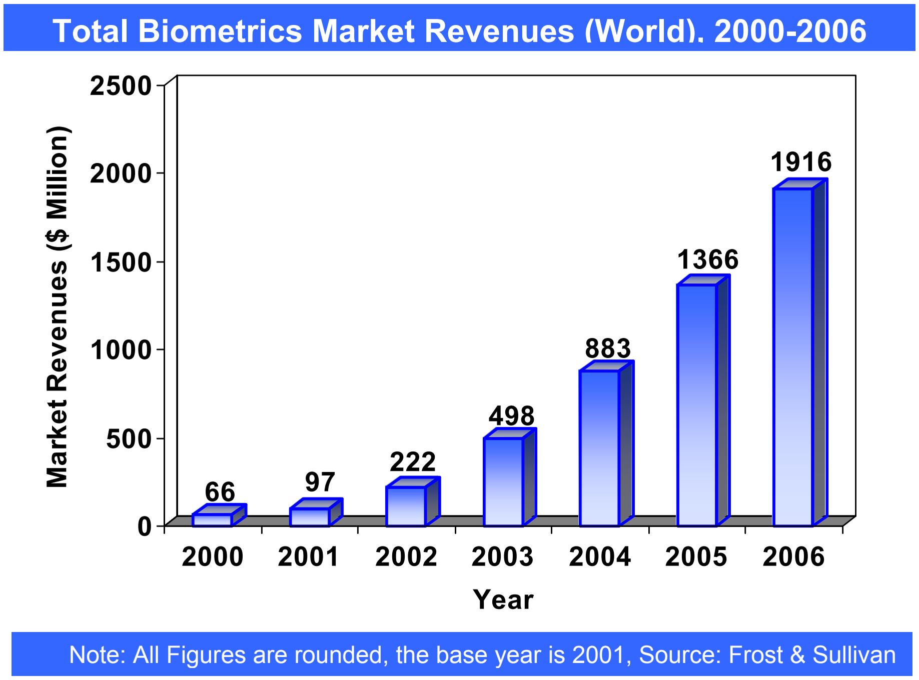
1 Introduction

Imagine how convenient it would be to activate the security alarm at your home with the touch of a finger, or to enter your home by just placing your hand on the door handle. How would you like to walk up to a nearby ATM which will scan your iris so you can withdraw money without ever inserting a card or entering a PIN. You will basically be able to gain access to everything you are authorized to, by presenting yourself as your identity.

This scenario might not be as far off as we might expect. In the near future, we may no longer use passwords and PIN numbers to authenticate ourselves. These methods have proven to be insecure and unsafe time and time again. Technology has introduced a much smarter solution to us: Biometrics.

Biometrics, the use of a person's unique biological characteristics (such as face, voice, or fingerprints) for personal identification, is a market ready to explode. Revenue projections for Biometrics in the year 2006 are expected to increase to $1.916 billion from $222 million in the year 2002 (Source: *Frost & Sullivan*).


Total Biometrics Market Revenues (World). 2000-2006

Note: All Figures are rounded, the base year is 2001, Source: Frost & Sullivan

Figure 1. Total Biometrics Market Revenues (World), 2000-2006

The advantages of biometrics are becoming more apparent with the increasing use of computers in our daily life. As cyber crime increases, the need for security against identity theft becomes more and more apparent. Add to this the ever-increasing threat to personal, corporate and government assets, the need for better forms of security is obvious.

Biometric authentication will help in enhancing the security infrastructure against some of these threats. After all, physical characteristics are not something that can be lost, forgotten or passed from one person to another. They are extremely hard to forge and a would-be criminal would think twice before committing a crime involving biometrics.

2 Biometrics System

The four basic elements of a typical biometric system are: sensing, processing, storage and interface to an existing infrastructure.

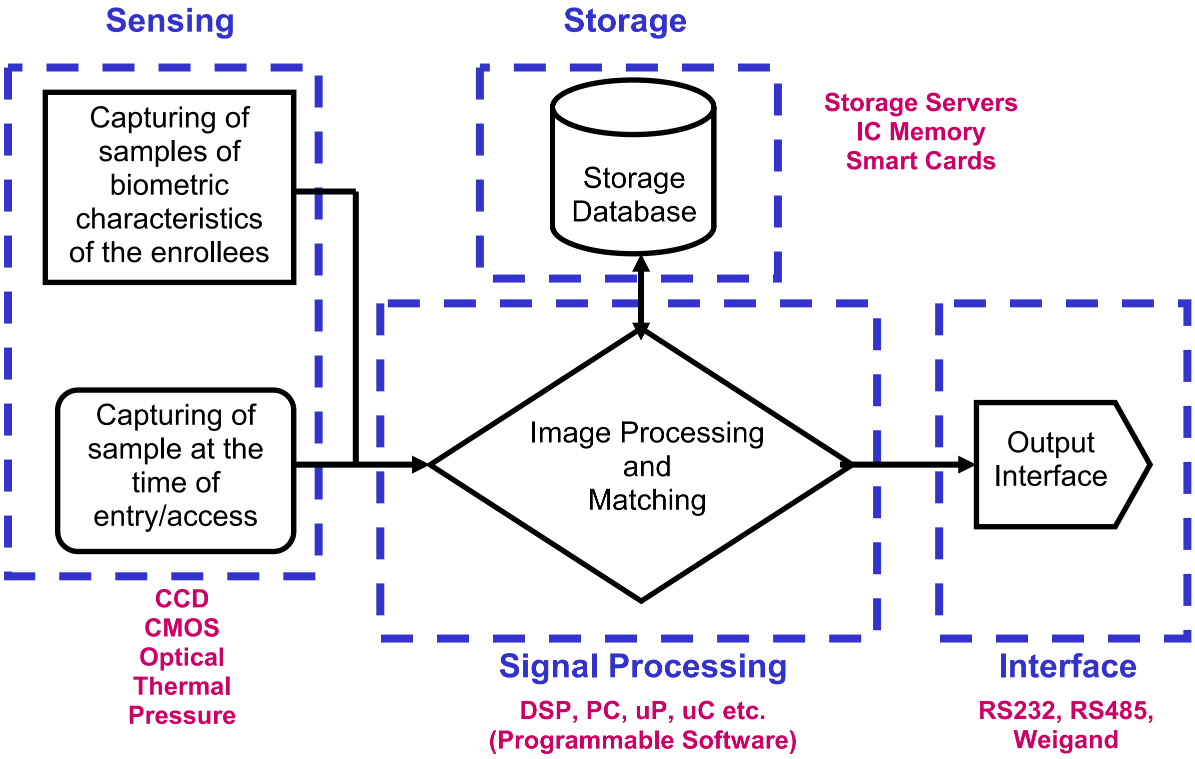


Figure 2. Biometrics System Elements

2.1 Sensing Element

The *sensing element,* or the input interface element, is the hardware core of a biometrics system and converts human biological data into digital form. This could be a complimentary metal oxide semiconductor (CMOS) imager or a charge coupled device (CCD) in the case of face recognition, handprint recognition or iris/retinal recognition systems; a CMOS or optical sensor in the case of fingerprint systems; or a microphone in the case of voice recognition systems. These sensors capture the biometric information and convert it into a digital form that can be processed by the next stage - the *processing element.*

TI manufactures and supports CCD that is suitable for both handprint and facial recognition biometrics systems. Products ranging from 336x244 pixels to 1036x1010 pixels resolution are available today. In addition to CCDs, TI Digital Imaging group supports CCD cameras ranging from ultraviolet (UV) to near-infrared (IR) sensitivity. For more information on TI's CCD Image sensor product line, please visit http://www.ti.com/sc/docs/msp/ccd.htm.

2.2 Processing Element

The *processing element* is generally a microprocessor, digital signal processor or computer that processes the data captured from the sensors. The processing of the biometric image generally involves image enhancement, normalization, template extraction, and matching/comparison of the biometric template during enrollment and authentication of the users.

A programmable processor like the DSP from TI can address all the processing needs of a biometric system while providing the most viable path to standards and feature upgrades. A DSP allows the product to be small and portable while maintaining power-efficient performance — all at a low overall system cost.

The DSP architecture is built to support complex mathematical algorithms that involve a significant amount of multiplication and addition. The DSP executes the multiply/add feature in a single cycle (compared to multiple cycles for RISC processors) with the help of the multiply/accumulate (MAC) hardware inside the arithmetic logic unit (ALU). In addition, the Harvard architecture of the DSP (multiple busses) allows instruction and operand fetches in the same cycle for increased speed of operation.

Developers of biometrics systems can take advantage of this architecture to enhance the resolution of the captured image with the use of two-dimensional fast fourier transforms (FFT) and finite IR filters. Because the accuracy of a system is as much dependent on the input image as it is on the processing algorithm, this helps in improving the overall accuracy and error rate of the biometrics system - a key performance metric.

With the high performance capabilities of the DSP, the total recognition time of the system can be reduced without an increase in power consumption generally associated with faster processors. This low-power consumption in TI DSPs is achieved with hardware enhancements and leading-edge process technology, providing customers with a powerful, yet low-overhead processor for multiple biometric applications. Both battery and AC-powered.

For more information on TI DSP product offering, please refer to Appendix A and visit http://dspvillage.ti.com/docs/dspvillagehome.jhtml.

2.3 Storage Element

The function of the *storage element* is to store the enrolled template that is recalled to perform a match at the time of authentication. For most identification solutions (1:N), the storage element would be random access memory (RAM) or flash EPROM or some other form of memory IC, and in some other cases it could be a data server. In the case of verification (1:1), a removable storage element like a contact or contactless smart card can be used.

TI DSPs have varying sizes of internal RAM to address the image processing and template extraction processes of the various biometric algorithms, along with read-only memory (ROM) for storing the constant parts of the programming code. Some DSPs also support on-chip flash memory for program-code storage. Additionally, the DSPs support SRAM, SDRAM, SBRAM, flash and other types of volatile and non-volatile memory components on the external memory interface bus. TI, however, does not manufacture any stand alone volatile or non-volatile memory or storage products.

2.4 Interface Element

Finally, there is the output *interface element*, which will communicate the decision of the biometric system to the interfaced asset to enable access to the user. This can be a simple serial communication protocol like RS232, or the higher bandwidth USB protocol. It could also be the TCP/IP protocol via a wired medium like 10/100 Ethernet or through a wireless medium using either the 802.11b protocol, ISM RF band, RFID, Bluetooth, or one of the many cellular protocols.

TI supplies products to support most of these interface elements. For more information on RS232, RS485, or USB-type wired Interface components, visit http://analog.ti.com/. For information on wireless communications solutions like RFID and 802.11b, please visit http://www.ti.com/sc/docs/apps/wireless/.

3 Complete System Solution

In addition to the analog products mentioned in the interface section, TI Analog solutions include data converters, amplifiers, and clock and timer components.

Add software solutions and development tools to the broad spectrum of DSP and analog components available from TI and you have a supplier with the most complete system solution offering (see Figure 3). A wide array of eXpressDSP™-compliant software and hardware development tools are available for all DSP platforms (described in Appendix B). These tools from TI and TI's third party network significantly slash development and integration time.

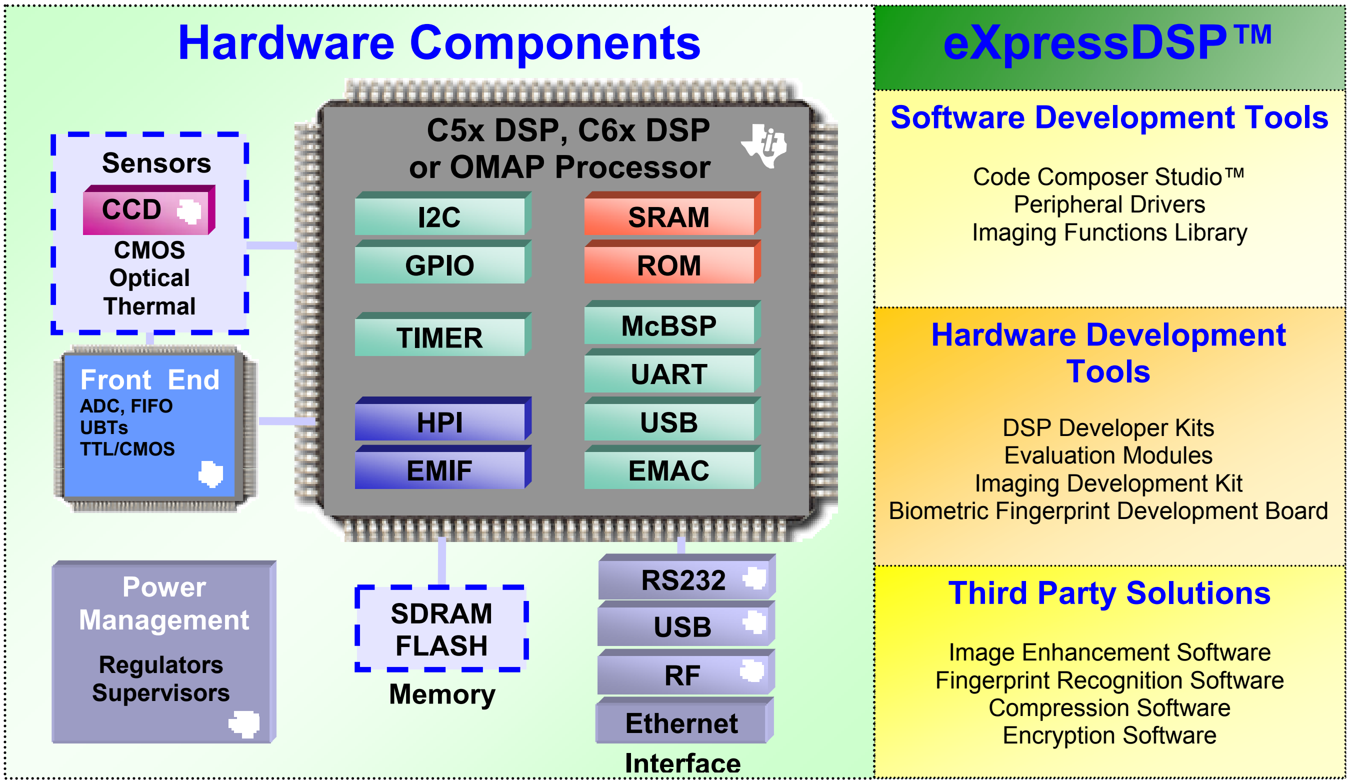


Figure 3. Complete Biometric System Solution

For biometrics, specific developments tools like fingerprint development kits, software drivers and multiple algorithms for fingerprint verification, speaker verification and signature verification are available today from third parties. For more information, see Appendix C or visit http://www.ti.com/3p.

4 DSP for Secure and Trusted Biometrics

Today's biometric systems are based mainly on interfacing the sensing element with a personal computer. The sensors are generally networked to a computer server to service unlimited users and multiple access points. The cost of using PCs is prohibitive and the communication link between the sensor and the PC/server could be a major cause for concern with regards to security and privacy. A biometrics solution based on DSPs can function both as a *secure standalone device* for recognition (1:1 or 1: few) and as a *trusted network device* for identification (1: many).

4.1 Secure Standalone Device

A *secure standalone device* is one where all the functions of authentication are carried out within the confines of the embedded processor and the result is communicated or displayed along with control signals to deny or grant access to the secured asset. The original enrolled template or pattern is either stored in the memory within the product or on a smart card which is carried on the user's person.

In a secure standalone device, the captured image is transferred to the embedded processor (DSP) which then converts/encodes the analog video stream into a digital image for camera-based biometrics like facial, and iris/retinal recognition. The encoding can then be done on the DSP using off-the-shelf encoding software available for the TI DSP (MPEG2, JPEG, etc).

With fingerprint recognition, no encoding is required as the output of the sensor module is a grayscale bitmap image. In the case of optical sensors, analog front-end components like amplifiers and analog-to-digital converters may be needed to generate the bitmap.

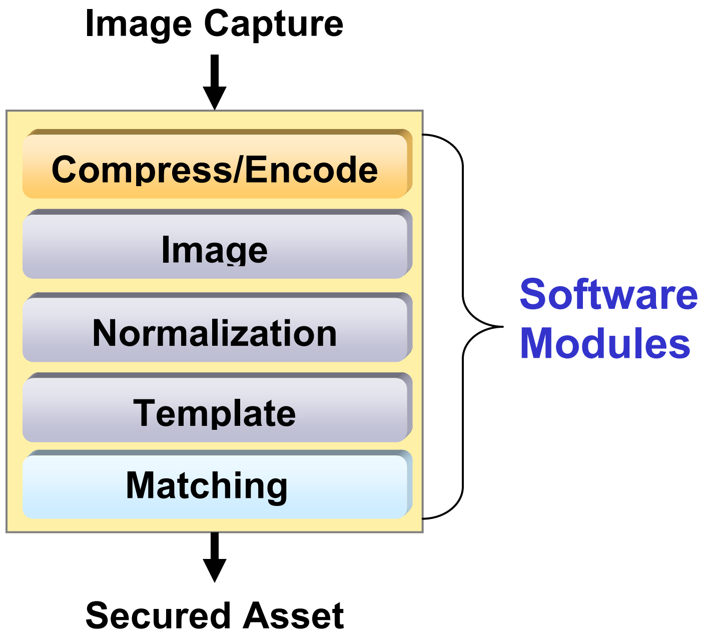


Figure 4. Use of DSP as a Secure Standalone Device

After the capture (and encoding), the image can then be enhanced with one or more functions like histogram equalization, filtering, edge correction, etc. The enhancement process results in a higher resolution image, which can then be normalized. Normalization is the process of creating standard input images with appropriate pixel information independent of the sensor used for image capture. This normalized image is then processed using the core algorithm to extract the template information. This template can then be stored in a memory module (external or internal) and recalled to perform the match against another live biometric data presented at the time of authentication (this live biometric data also goes through the same stages described above). The matching could be an image data comparison or a pattern matching function, which has additional information on the location of the reference, angle of rotation, scale, etc.

All of the functions mentioned above can be better implemented by using software on a programmable DSP while maintaining the flexibility of adjusting the parameters of the system as per the application requirements.

4.2 Trusted Network Device

A *trusted network device* is one in which the captured biometric can be extracted into a template (in the case of minutiae) or encoded and compressed (in the case of image patterns) and then encrypted before being transmitted to a computing server on which the matching against a database of templates/patterns is carried out as part of the identification process.

In the case of a networked identification system (like access to PCs in a LAN or WAN or POS terminals connected to a credit processing network), there are multiple access points and the user needs to be identified amongst a database of users as an authorized user. To secure such a network, the access point that is the source of the live biometric data being presented needs to be a trusted point of access.

First, encrypting the extracted template or the captured image and transmitting this encrypted data to the remote server using a public key infrastructure can help establish this trust. This can help ensure that the biometric data presented for a match is not a digital file of a bitmap image being fed into the system by hacking or breaking into the communication link between the access point and the database server.

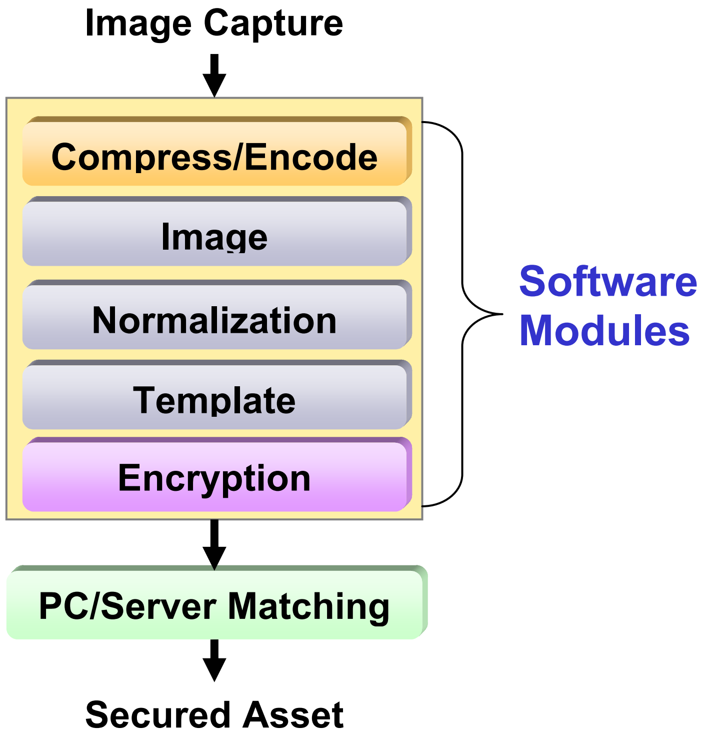


Figure 5. Use of DSP as a Trusted Network Device

With the use of an embedded DSP in the trusted network device, all the functions of a secure standalone device mentioned above can be implemented excluding the matching step and still have performance headroom to execute software encryption (e.g., 3DES, RSA1024, etc.) algorithms.

Basically, the same biometric system design based on a programmable DSP can be configured into two different products — one secure and the other trusted to address the requirements of a variety of different applications. Many of the functions mentioned here are available as third party software (For more information, visit http://www.ti.com/3p).

5 Biometric System Examples

The following sections provide examples of the TMS320C5509™ DSP-based biometric fingerprint solution and the TMS320DM642™ DMP-based biometric smart camera.

5.1 TMS320VC5509 DSP-Based Biometric Fingerprint Solution

An example fingerprint biometric system based on TI's TMS320C5509 DSP is shown in Figure 6.

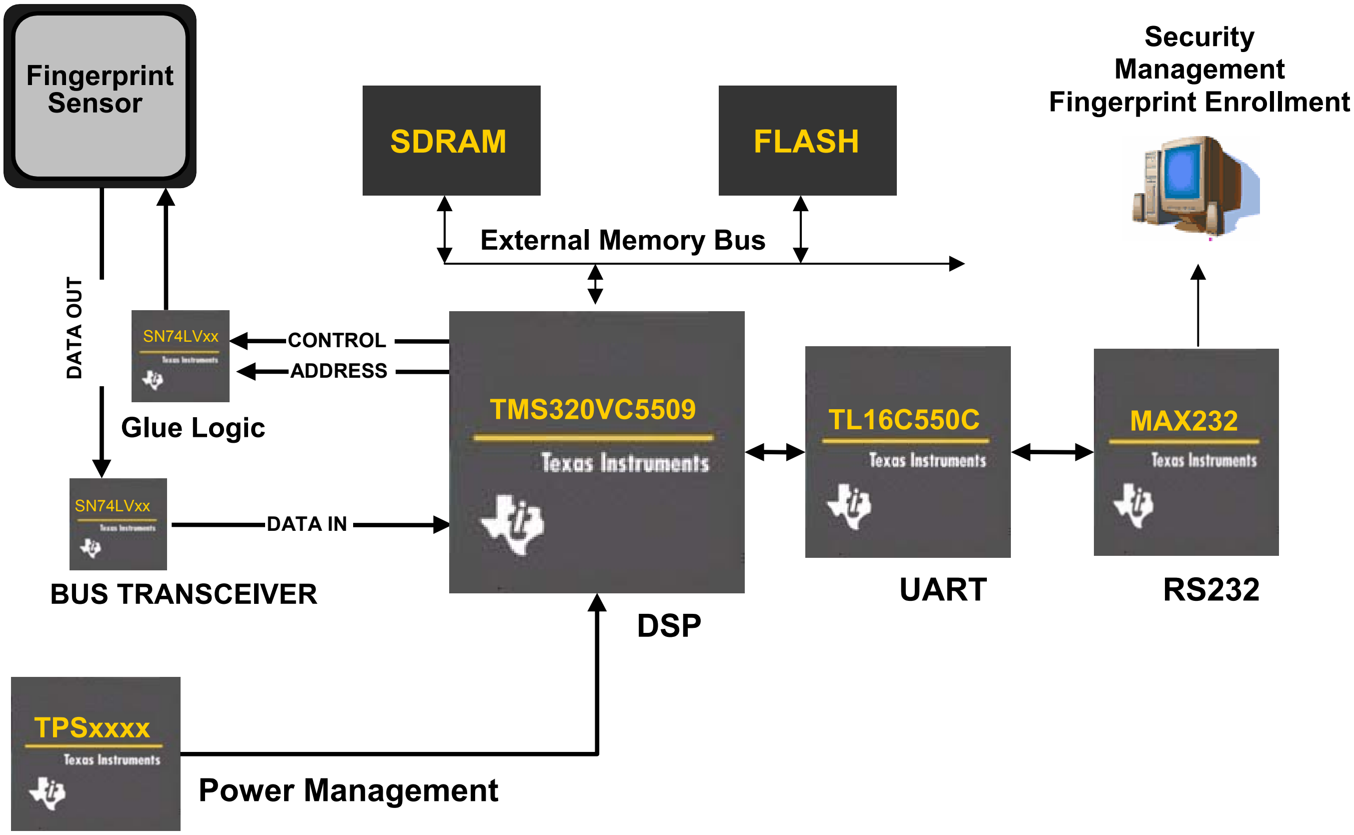


Figure 6. TMS320C5509 DSP-Based Fingerprint Biometric Solution

In addition to the DSP, the TPSXXX power management, TL16C550C UART, MAX232 serial driver (RS232), standard linear and logic components like universal bus transceivers and NAND gates are the other hardware components from TI used to build a standalone fingerprint system with serial interface. Additionally, third party software solutions for image enhancement and matching are available to complete the system solution.

If this design is used in a computer mouse or keyboard, the internal USB slave port can be used as the interface to the PC. If it is networked to a server managing multiple fingerprint access modules, the designer can make use of the RS485 component (SN65XXX and SN75XXX) or use a 10/100 Ethernet interface connected to the external memory bus on the DSP. If the application requires wireless connectivity then the system developer can opt to use an RFID component (low frequency, Tag-It™ high frequency and encrypted transponders and readers) for contactless smart card solutions.

5.2 TMS320DM642 DMP-Based Biometric Smart Camera

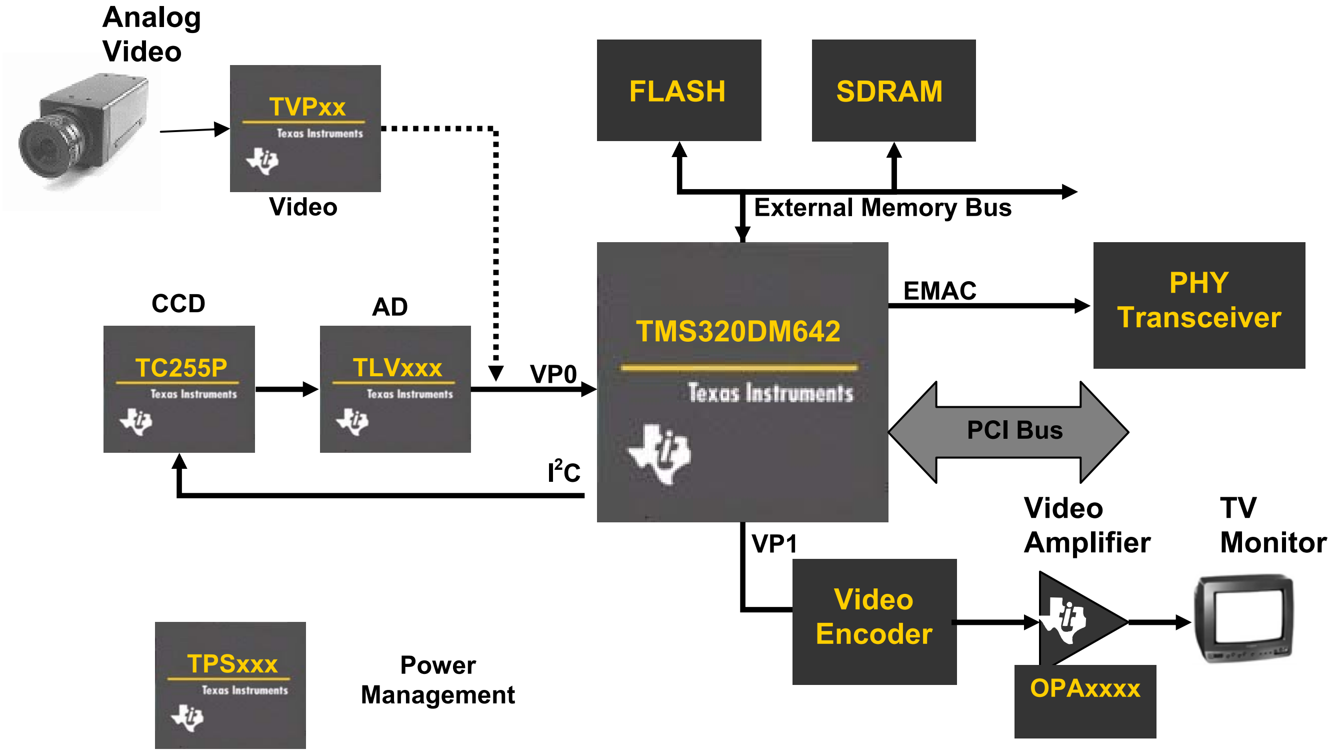


Figure 7. TMS320DM642 DMP-Based Biometric Smart Camera

Figure 7 illustrates a Biometric Smart Camera module that can be used as a digital surveillance camera or as part of a facial recognition system based on the TMS320DM642 digital media processor. The DM642 processor is made up of the C64x DSP core coupled with video ports, 10/100 EMAC controller and a 66 MHz PCI bus in addition to standard peripherals.

The facial image capture can be carried out either from a snapshot (CCD combined with data converter) or streaming video image (external camera source via TVPXXXX video decoders) as the video ports on the DM642 are configurable. One of the three video ports on the DM642 can be configured to output the image to a display/monitor.

In addition to the on-chip 10/100 Ethernet MAC controller and the 66 MHz PCI bus that provide flexibility in terms of interface options, TI supports independent or integrated FireWire™ IEEE1394 ICs (TSB43XXXX - integrated, TSB12XXXX - link layer and TSB14XXXX - physical layer).

6 Summary

Biometrics is a truly emerging market with great potential for success. Its roots may be in science fiction, but it is part of today's science and technology fact. In the near future, we will come to rely on biometric technology to protect our property, assets, and the people we love. We will see this technology become a secure and trusted form of authentication with uses varying from controlling access to personal information devices, to securing buildings and enabling eCommerce.

DSP plays an important role in the development and adoption of biometric systems. It helps improve the performance and accuracy of these systems with its high performance architecture. The differentiation will be in enabling multiple new applications with smart biometric solutions powered by a DSP. All of this can be achieved at a low overall system cost as a result of design reuse and faster time-to-market. This, in turn will help create a growth market for affordable intelligent security systems.

In conclusion, using DSP as the embedded processor of choice for enabling smart biometric systems can provide the following advantages:

- Fast, accurate, secure and trusted authentication
- Enable new applications with one scalable design
- Reduce overall cost of development

Appendix A TMS320 Digital Signal Processor Platform

The TMS320 DSP family from TI offers the widest selection of signal processors available anywhere, with a balance of general-purpose and application-specific processors to suit your needs. There are three distinct instruction set architectures that are completely code-compatible within the following platforms:

- High Performance: TMS320C6000 DSP platform
- Power Efficient: TMS320C5000 DSP platform
- Control Optimized: TMS320C2000 DSP platform

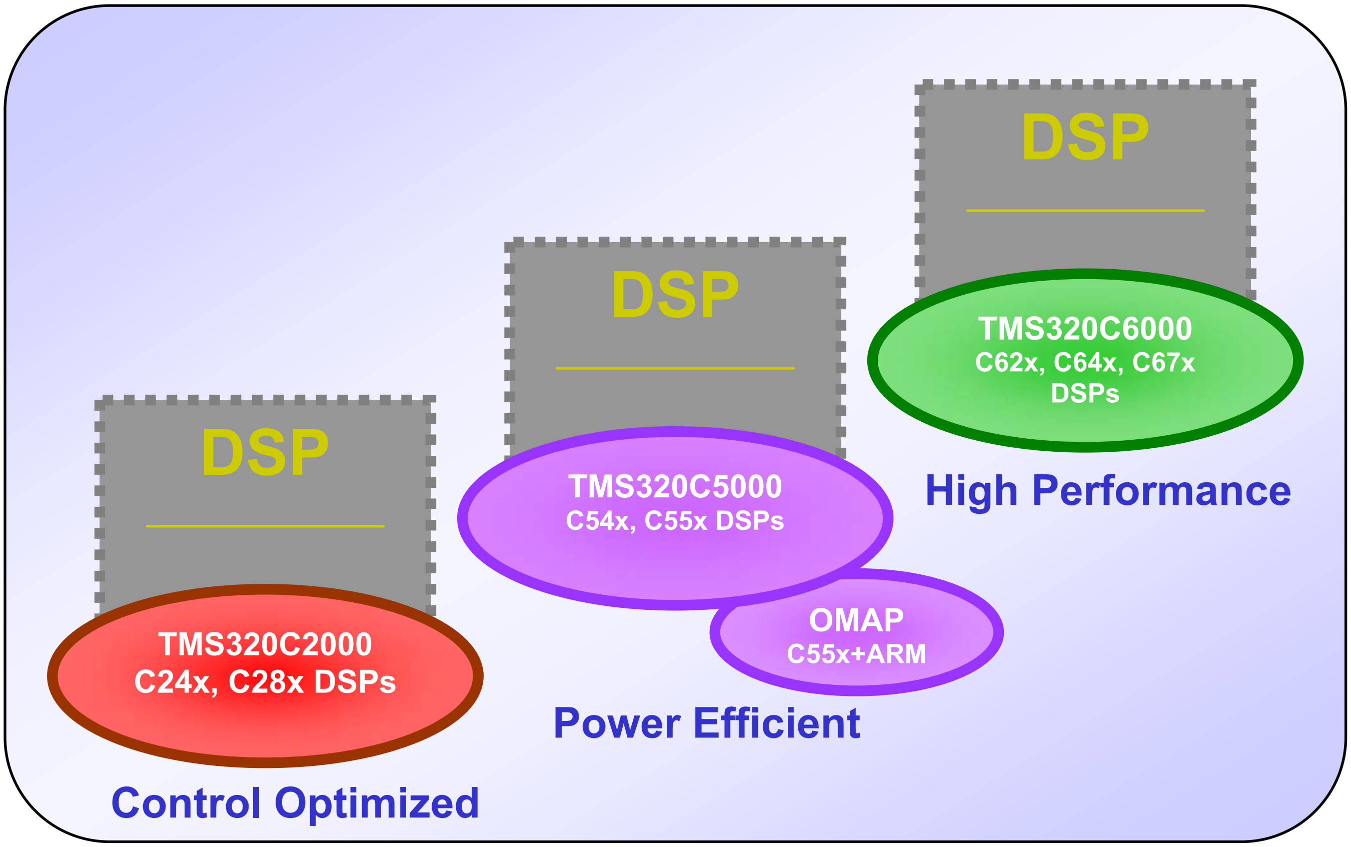


Figure 8. Texas Instruments TMS320 DSP Platforms

In addition to the three main DSP platforms, TI offers the OMAP™ processors, which are a combination of a C55x DSP with TI-enhanced ARM9 processor, for applications that require multiple user interfaces as well as signal processing capabilities in a single processor.

For additional information, visit http://dspvillage.ti.com/.

Appendix B eXpressDSP Development Tools

Code Composer Studio

Code Composer Studio™ software is a fully integrated development environment (IDE) supporting TI's industry leading TMS320C6000, TMS320C5000 and TMS320C2000 DSP platforms.

The main features and benefits of Code Composer Studio are:

- A development environment that tightly integrates all tools into a single easy-to-use application
- Real-time analysis tools for monitoring program interactions without halting the processor
- Leading C compiler in the industry
- A scalable real-time kernel (DSP/BIOS kernel)
- Visual linker for graphically arranging program code and data in memory
- Data visualization for viewing signals in multiple graphical formats
- Open plug-in architecture allows you to integrate specialized third-party tools
- Real-time JTAG scan-based emulation control across all TI DSPs with the XDS510™ emulator

Additional information is available at dspvillage.ti.com/studio.

DSK and EVM

DSP starter kits (DSK) and evaluation modules (EVM) are tools that allow developers to test their code in hardware before actually building prototype designs. DSKs are available for C5402, C5416, C5510 and C6711 DSP. EVMs are available for the C5509 DSP and OMAP.

Third-Party Network

More than 600 independent third parties provide a vital link between TI silicon and the final application by providing additional hardware, algorithms and libraries, software tools and consulting services. The software algorithms are eXpressDSP-compliant. This means they are tested to comply with the TMS320 DSP algorithm standards. This network is designed to reduce system integration time and lower support and development costs by eliminating recreation of standard functions and off-loading custom coding tasks. Additional information is available at www.ti.com/3p.

Biometrics system integrators, along with security and automation solution providers, will benefit from biometrics-specific development tools and support from TI and members of TI's third party network. These include fingerprint identification and recognition algorithms, image enhancement algorithms, fingerprint reference designs and developer's kits, encryption and compression algorithms, imaging developer's kits, and many more.

Third-Party Biometric Solutions

In addition to the BFP-100 from TI, there are multiple development tools and software available from TI partners and third party companies:

- AuthenTec - FingerLoc™ TMS320C5509 DSP Embedded Developers Kit
- Bioscrypt - MV1200™ Embedded Fingerprint module based on TMS320C6711 DSP
- Communication Intelligence Corporation (CIC) - Sign-on biometric signature device lock for OMAP™ processor
- Ethentica by Security First Corp – Image Enhancement Algorithm for Ethenticator™ Tactile Sense™ Sensor
- Fingerprint Cards AB - Distinct Area Detection (DAD) verification software for C5000 and C6000 DSPs
- Idencom - BioKey® 2002 Embedded Fingerprint module hardware and software
- IdentALink - Fingerprint image enhancement algorithm for C6000 DSP
- Lucent Technologies Inc - Speaker dependent Voice recognition engine for C5000 DSPs
- Neurodynamics - Verification software for C54x and C55x DSPs
- Neuvoice - Speaker dependent voice processing for C5000 DSPs

Software for facial recognition systems and additional tools are in different stages of development at the time of publishing this paper. For the latest information, please visit http://www.ti.com/biometrics.

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Mailing Address:

Texas Instruments
Post Office Box 655303
Dallas, Texas 75265