Iris Recognition on Low Computational Power Mobile Devices

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1. Introduction

The growth in the use of smart mobile phones and PDAs, see Figure 1, for business transactions incorporating high performance cameras has created the possibility for developing camera and image processing applications for identity verification using handheld devices. The objective is to create a reliable, portable way of identifying and authenticating individuals. Another objective is to investigate the low power computing technology and establish a real-time biometrics software application. Improved, optimized and application specific image processing techniques are required to adapt to the currently available computing power on mobile phones.

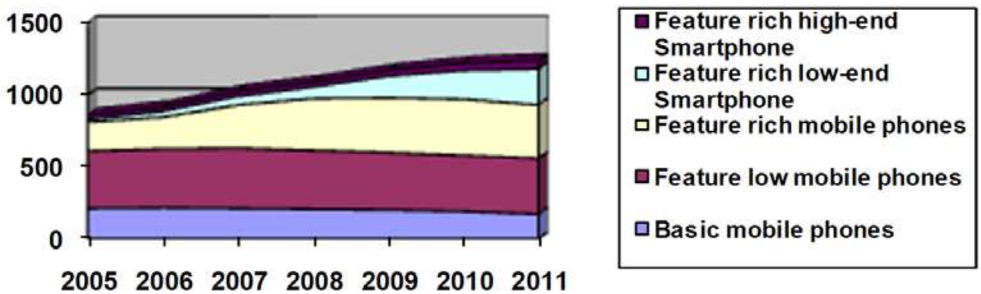


Fig. 1. Worldwide Mobile Phone Sales (in million), by technologies (Nokia Forum)

1.1 Biometrics technology and Iris recognition

Biometrics is the technique of using physiological or behavioural characteristics to identify or verify identities (Lu et al., 2007). The first evidence of using biometrics can be tracked back to Ancient Egypt, when a man called Khasehem used body measurements to distinguish people. His method prevented frauds when people were collecting food (Ashbourn, 2004). In 14th century China, children's palm prints were stamped on paper when they were born. These palm prints were stored and used by the Chinese Court for criminal identification purposes. In the 19th century a German, Franz Joseph Gall, founded the discipline of phrenology, whereby specific cranial shapes and features were thought to align with certain mental characteristics. A couple of years latter, an Italian physician Cesare Lombroso further developed the concept of phrenology with specific regard to criminal behaviour (Ashbourn, 2000). In 1897, Sir Richard Edward Henry of Scotland Yard developed a finger printing authentication system, later adopted by the British police (London Metropolitan Police, 2005).

Hundreds of years since the first traceable use of biometrics, the biometric technologies in use today include DNA profiling, fingerprinting, measurement of hand geometry, face recognition, iris recognition, voice verification and signature verification. These technologies are widely used in criminal investigations, applicant background checks, biometric visas and passports, border control, and preventing social services fraud.

Biometric technologies are popular because biometric characteristics are unique to the individual and cannot be shared, forgotten or stolen, as can keys, cards, passwords and usernames. Of course, a determined attacker will go to the great lengths to mimic the verification system by synthesizing a fake biometric input that is a close match to the authentic biometric signature (Vijaya Kumar et al., 2004). Applications demanding very high levels of security need a multilayered approach, in which passwords and multi-biometric technologies are employed.

Biometrics	Author	Error Handling	False Rate
Voice	Monrose	Discretization	20%
Signature	Monrose	Feature coding	28%
Fingerprint	Charles	Reed-Solomon code	30%
Face Recognition	Phillips	Discretization	43%
Iris Recognition	Daugman	Concentrated coding	0.47%

Table 1. Accuracy Comparison among Biometrics Technologies (Ma et al, 2004)

As shown in Table 1, of all the different biometrics technologies that are used for human authentication and are readily accessible for public users, iris recognition is the most accurate. This high reliability for personal identification is due to iris's randomly distributed features and its stability throughout life. According to Daugman (1993) the complex nature of the iris pattern has the highest variability in biometrics, 244 degrees-of-freedom.

The iris is an opaque sheet of tissue with a circular hole (the pupil) in it. It operates as an aperture stop in the optical pathway for the pupil. The iris lies just in front of the lens, a position that permits oblique rays to pass through the pupil to the peripheral retina, while limiting the size of the incident ray bundle (Clyde, 1999). The prenatal morphogenesis of the iris is completed during the eighth month of gestation. It consists of pectinate ligaments adhering into a tangled mesh causing striations, ciliary processes, crypts, rings, furrows, a corona, sometimes freckles, vasculature, and other features (Daugman, 1993). During the first year of a human life a layer of chromatophore cells often changes the colour of the iris, but the available clinical evidence indicates that the trabecular pattern itself is stable throughout the lifespan (Adler, F. H., 1965). At three years old, with the exception of people with eye diseases, for instance coloboma, ectopic pupils and subsidiary pupil, the iris is fully developed and is essentially stable over a person's life (Clyde, 1999).

Iris recognition is a mix of technologies from several fields, including computer vision, pattern recognition, statistical inference, and optics. The concept of automated iris recognition was first proposed by Flom and Safir in 1987 (Flom, L., and Safir, A., 1987). Perhaps the best-known and most thoroughly tested algorithm is that of Daugman. Currently, the most widely used systems for iris recognition are employing John Daugman's algorithm (Daugman, 1993). Since the development of Daugman's algorithm, Wildes *et al*. (1996-1997), Boles and Boashash (1998), Lim *et al*. (2001), Sanchez-Reillo *et al*. (2001), Tissue *et al*. (2002), and Ma *et al*. (2004) have made significant contributions to the study of iris recognition.

There are several advantages in using iris recognition compared with other biometric technologies. These include the constancy of features over time and the method of measurement without contact measurement tools. Moreover, because it is the internal part of an eye, iris features cannot be easily changed by surgery.

Iris recognition provides high accuracy identification compared to other biometric technologies, which is why it is an attractive technology. As most mobile devices have at least one embedded camera, iris recognition is examined as a means of personnel identification using mobile computing devices.

1.2 Iris recognition solutions that are used on handheld Iris recognition devices

IRIS ID (formly LG Electronics) and L-1 Identity are the two most well-known companies in the world for manufacturing iris identification machines. Both these iris recognition machines implement software solutions from a third party: Iridian Technology (http://l-1idsol.net). The Iridain Technology is committed to providing software solutions for iris identification based on the iris recognition algorithm developed by Daugman. Iridian and Secure Metrics (http://www.securimetrics.com) are a part of the L-1 Identity Group. A review is given below of these companies and their biometrics related products:

2. IRIS ID, formly LG Iris (http://www.irisid.com/)

LG Electronics Iris Technology Division (http://www.lgiris.com/index.php) of LG Electronics Incorporation was established in the United States in 2002, providing global management responsibility and overall direction of LG's iris recognition technology products. LG has released three main products up to now: 'LG IrisAccess 2200', 'LG IrisAccess 3000' and 'LG IrisAccess 4000'. The LG IrisAccess 2200 machine introduced in 1999 utilized conventional camera technology with advanced lens design and special optics to capture the intricate detail found in the iris. In 2001, LG IrisAccess 3000 was released, providing a platform incorporating more system security features, improved speed and enhanced user interfaces. LG IrisAccess 4000 is the third generation of iris recognition machine deployed. The latest generation offers more application versatility and integration flexibility. LG Electronics are using their product as a door entry system which can access significant computing power due to its static nature.

LG's Iris Technology Division later changed into IRIS ID Ltd. Their latest portable products released are iCAM TD100 (http://www.irisid.com/ps/products/icam_td100.htm) and iCam H100 (not released to the public until November 2010). Both are based on the Linux operating system and Daugman's algorithm 2Pi, multiband IR is used for illumination on both devices. Both machines require less than 2 seconds for complete two iris capture, and less than 8 seconds for a complete transaction, which includes face and iris (IRIS ID Systems Document #IRISIDTD100-0110).

3. L-1 Identity solutions (http://www.l1id.com)

L-1 Identity is a world-leading company providing multiple biometric identity solutions. They work closely with the US government for public safety enhancement. They have released two main products: *PIER™*, a portable Iris enrolment and recognition Device as well as *HIIDE™ Series* handheld interagency identity detection equipment.
Their iris recognition solution is a major achievement for the SecuriMetrics's devices. Their iris recognition algorithm is also based on Professor John Daugman's algorithm, the same as IRIS ID. According to a SecuriMetrics's report ('Offender Identification System-Fast and Accurate Offender Identification', SecuriMetrics Incorporated, CA 94553, USA), their iris recognition technology was chosen by the US Department of Defense and other government agencies because 'Iris recognition is the fastest, most accurate and scalable of all biometric technologies'.
Due to the similarity of their ambition to provide an iris recognition solution for portable devices, more information about the SecuriMetrics's products is give below:

- PIER™ 2.3: A hand-held device that allows an operator to identify individuals using the highly unique patterns and textures of the human iris. By linking to a computer, the device can match an unknown individual against a database of millions.
- HIIDE™ Series 5: This is the first handheld recognition device in the world that combines iris recognition, fingerprint recognition and face recognition solutions. This latest release uses an Inter ® Atom ™ Processor (1.6 GHz, 512KB cache, 533 MHz FSB) with 2GB DDR2 SDRAM. It supports 3G and 4G network.

4. Case study: A mobile biometrics system

4.1 System architecture

The main goal and the initial purpose of building this MBI system is to identify and/or verify individuals using a mobile phone. Hence, iris images are captured using a camera embedded in the mobile phone and are processed and identified locally. To deal with large-volumes of iris images that can be used by banks and mobile phone operators, an extended MBI system was developed. This extension allows the MBI system to run on benchmark workstations (server stations). Figure 2 demonstrates the components and functional design of the extended MBI system.
As seen from Figure 2, there are three kinds of medium used for storing template iris images. The first one is a SIM card. Using this medium, the mobile phone user's private iris codes are stored in a SIM card and the iris image identification can be carried out on the mobile phone. The benefit of this is that the iris information is retrievable locally and is reusable on different mobile phones. There is always a copy of the iris code stored in the SIM card and in the database of a mobile network operator. Users do not need to register their iris information again if they use another mobile phone with the old SIM card. The disadvantage of using a SIM card is the lack of privacy and security of personal information.
The second kind of medium is the local memory of a mobile phone. This is similar to using the SIM card but in practice uses a slightly shorter time when executing the MBI system. By using this medium, users do not need to worry about private iris information being shared or stolen by network operators, however, iris information can still be lost or stolen if the phone is lost or stolen. Both the first and second mediums suit users using mobile phones for personal iris image recognition, e.g. as a login authentication.

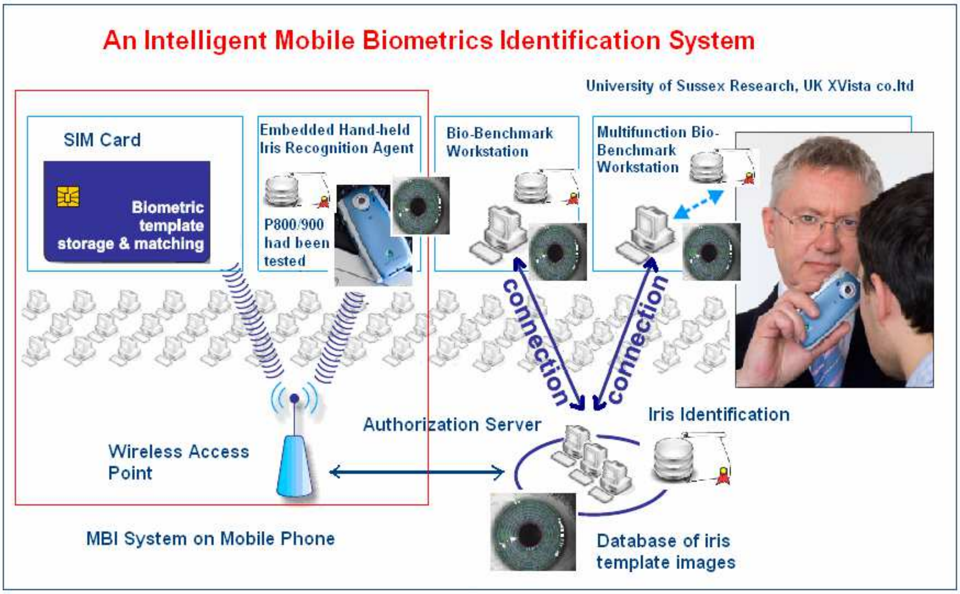


Fig. 2. Component and Functional Design of the MBI System

The third kind of medium is the database of a benchmark workstation. Comparatively, this method is specially designed to allow enterprise users access to a large-scale iris template database to authenticate iris images. However, this medium is currently not psychologically acceptable to some users.

As introduced in the abstract, the MBI system can collaborate seamlessly with other applications on mobile phones. In our work, we combined the MBI system with a mobile two-dimensional barcode reader as a biometrics mobile payment (BMP) system. The aim of the BMP system is to provide a secure means for authorizing users therefore preventing payment risks for both user (customer) and acquirer (financial institutions). The BMP system consists of two main parts: a two dimensional barcode reader and a MBI system.

Users firstly need to use the barcode reader to scan the barcodes of products or bills that they would like to purchase or pay. There are two means of getting information on products: locally from the database of the mobile phone or by logging into a server station. The local database in the mobile phone can provide personal preference information of the user, such as the list of favorite products and the account information of frequently scanned bills. This approach allows users to keep their iris information private. However it is not possible to save the entire history of what a user has been purchasing in a mobile phone database, due to the memory limitation on mobile phones. There is no such limitation when getting product information via the network; however, the network speed can be constrained, hence the purchase procedure may require more time.

Once the product information has been received, a user can decide whether or not to purchase the goods. If a user gives a confirmation for purchase, the MBI system will automatically start up and provide an authorization process to establish the user’s identity. There are two ways to get a user authorized. The first way is to recognize the user’s iris using the template images stored in a local database, for example on a mobile phone or PDA. By using this means, a user can send confirmation of a specific certificate of authorization that is generated on the mobile phone to a financial institution through the wireless network. Once a financial institution receives this certificate, they will decode the certificate and confirm the payment with both the merchant and the user; this confirms the user's identity and authorizes the payment. The second method is to send the iris code to the financial institution for transaction authorization; this method can help the financial institution reduce the risk of accepting fake certificates; however this method is currently not psychologically accepted by some users.

Once a payment confirmation is given to both a user (customer) and a merchant, the purchase by mobile phone is completed.

After explaining the working procedure and system design of the MBI and BMP system, the next section illustrates its agent oriented software architecture.

When designing the architecture of the MBI system, technologies such as distributed agent and multi-agent systems were employed. These technologies are the complementary approaches to the object paradigm and provide a means of designing and implementing complex distributed software (Garcia etc., 2004). Agent technologies (Chen etc., 2006) represent the most important new paradigm for software development (Luck, 2004), and have already been used in a diverse range of applications in manufacturing (Shen etc., 1998; Wada etc.,2002; Van Dyke Parunak etc., 2001), process control system, electronic commerce (Sandholm, 2002), network management, transportation systems (Chen, 2002), information management (Stathis etc.,2002), scientific computing (Boloni etc., 2000), health care (Huang etc., 1995) and entertainment (Noda and Stone 2003). The MBI system applies a combination of agent technologies, e.g. scientific computing, network management and information management.

By using these agent technologies, seven distributed agents are generated: image acquisition agent, data matrix decoding agent, iris image processing agent, iris image identification agent, wireless network agent, database management agent and communication agent. The organisational networks in the MBI system and the BMP system are shown in Figure 4 and Figure 5.

Image Acquiring Agent: This agent acquires images from live video inputs via cameras integrated into mobile phones to capture data matrix images or iris images.

Data Matrix Decoding Agent: With an image acquired using the image acquiring agent, the data matrix decoding agent will implement our algorithm to provide the decoded result of the data matrix.

Iris Image Processing Agent: With an eye image acquired using the image acquiring agent, the iris image processing agent can find the inner and outer boundaries and extract the iris information into an iris code.

Iris Image Identification Agent: The iris image identification agent compares an iris code generated by the iris image processing agent with template arrays stored in a local database using the Hamming Distance. If the similarity level between the user iris code and the best matched template code is higher than a threshold, the user iris code is considered to be correctly identified; otherwise a message 'no match' is displayed.

Database Management Agent: This agent is used to manage the local database of the MBI system. Its functionality includes register, update, check and remove user's personal iris code or other relevant information such as a person's name, address, banking details, etc.

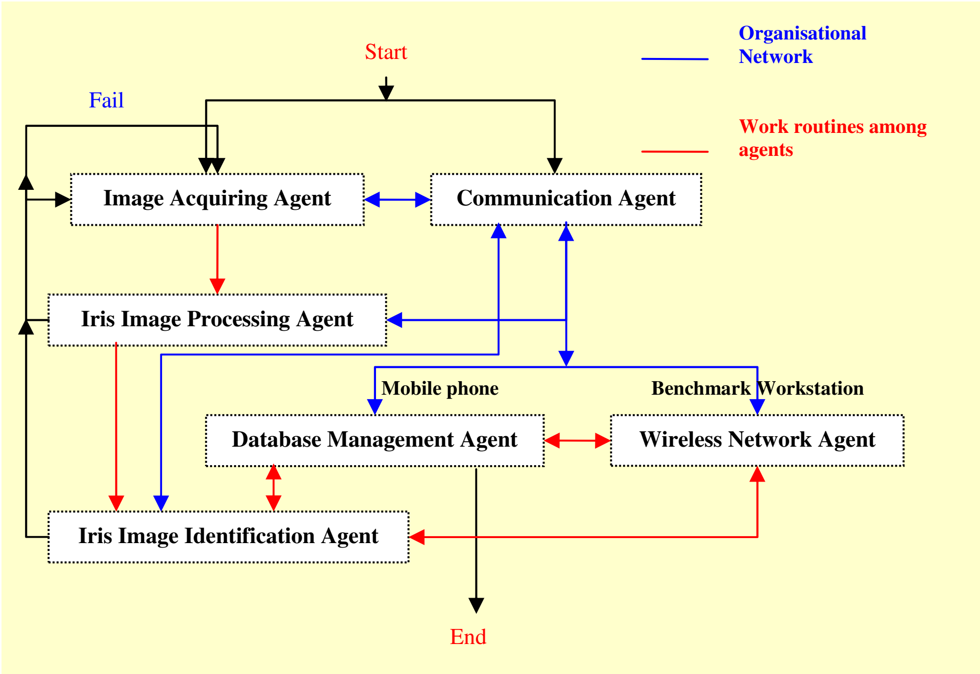


Fig. 4. Distributed Agents and Agents' Organisational Network in MBI System

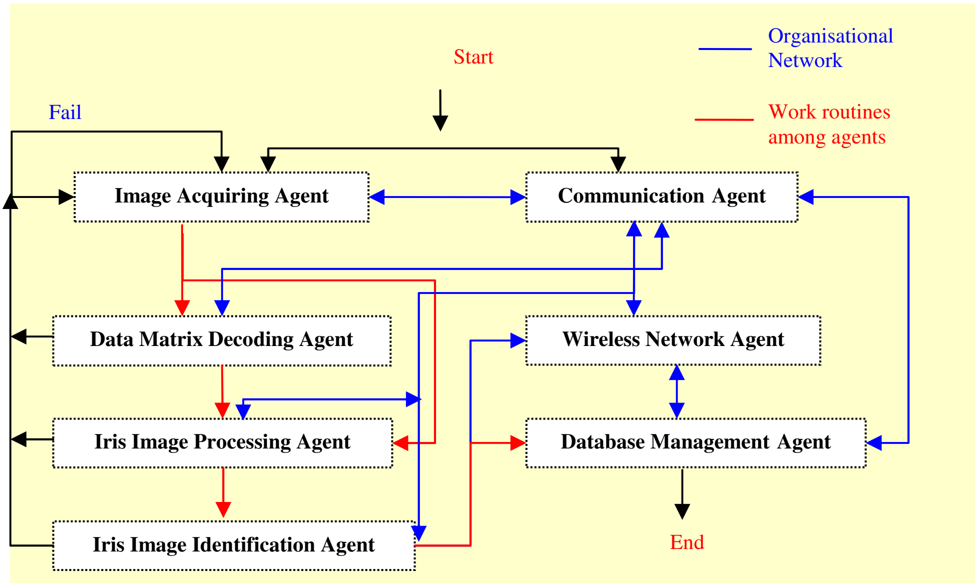


Fig. 5. Distributed Agents and Agents' Organisational Network in BMP System

Wireless Network Agent: This agent is used to transfer information between mobile phones and wireless network servers (also used for the benchmark workstation). Currently this agent can only enable the information transformation between mobile phones and network servers having fixed IP addresses due to security considerations. All internet information required by users needs to be downloaded by a server station and then filtered and redirected to the mobile users. This arrangement enhances the security of the MBI system.
Communication Agent: There is no core agent in the network. All communication such as requirements or negotiations should be sent via the communication agent. The communication agent creates links between the six other distributed agents and orchestrates all the actions required for both the data matrix decoding and iris image recognition.

4.2 Optics design

An assumption is made in developing the iris image processing that every eye image is taken from an environment with the same illumination and with the same distance between eye and camera. With this precondition, it is possible to set up parameters, such as boundary searching areas, and test the performance of the image processing algorithm. To achieve the same illumination, an 'eye cup' was produced with a luminous diode attached, as shown in the picture below:

Fig. 6. An 'Eye Cup' with a Luminous Diode links to the Sony Ericsson P800 Mobile Phone

This standardized illumination environment plays a crucial role in the design of the image processing algorithms. Several optical experiments were performed to test the 'eye cup' to ensure that the live video inputs taken with this 'eye cup' always focuses on the iris area.

4.3 Iris recognition algorithm

The procedure for iris image processing, designed to be run on mobile phones, follows the steps: loading an input image of eye, iris image localization and extraction of the iris characteristics into an iris code(patent no: GB0703399.6-PCT/GB2007/000591). This procedure is shown in Figure 7.
For the same illumination the same eye will give the same pupil response, hence, the relationship between the radius of the pupil and the radius of the outer iris boundary will not change, The variability due to the illumination response of the pupil is removed during iris localization, by using the 'eye cup'.

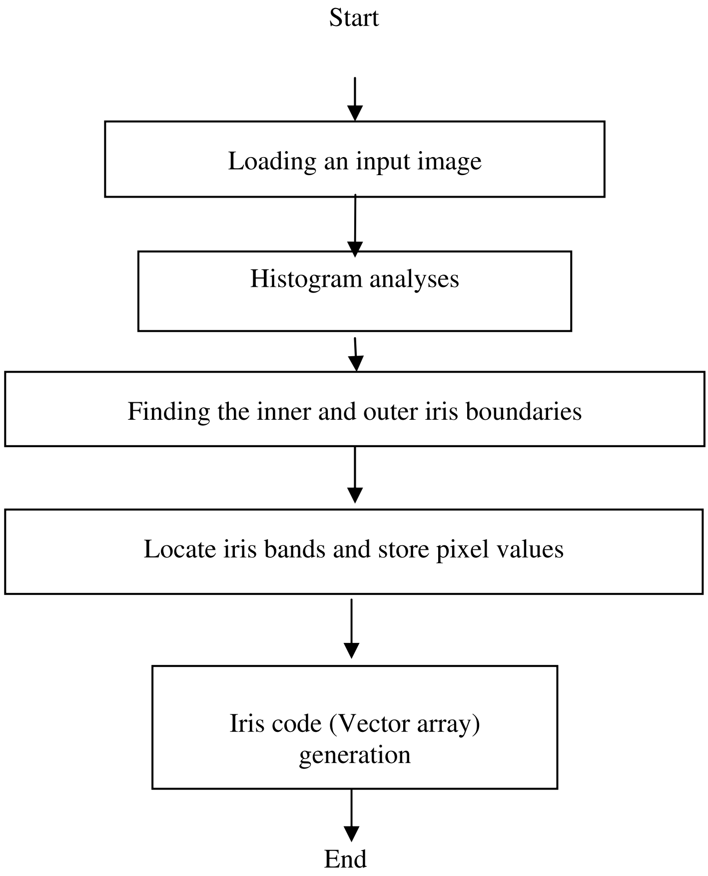


Fig. 7. The Procedures of Iris Image Processing

There are two sub-steps during the iris image localizations. Firstly, histogram analysis is applied for finding the average pixel values of the pupil area, iris area and sclera area from the input image, as well as the minimum pixel value and maximum pixel value of the iris area. Secondly, the inner and outer iris boundaries are found using the pixel-oriented method with the association of the different average pixel values and maximum/minimum values that are found from the histogram analysis. Figure 8 shows the calculated pupil boundary.

In these steps, failure is allowed in each step. Once a failure occurs, the iris image processing agent will communicate with the image acquiring agent via a communication agent to acquire a new image. There is a setting for the 'maximum number of images' in the MBI system, the communication agent monitors if the number of failures reaches this pre-set threshold. If this threshold is reached, a 'fail' notice for iris image decoding will appear on the main panel GUI of the MBI system. For more details of the iris recognition algorithms, please refer to (Lu, 2008).

Fig. 8. Pupil Centre and Pupil Boundary

The area between the inner and outer iris boundaries is the iris area. There are also two sub-steps in generating an iris code. First, a number of (in this algorithm the number is eight) iris bands will be located on the iris area. Second, a radial averaging filter is applied to transform the band-data into a one dimensional signal, as shown in Figure 9. For the cases of eight iris bands located on the iris area, eight one dimensional signals will be generated after filtering.

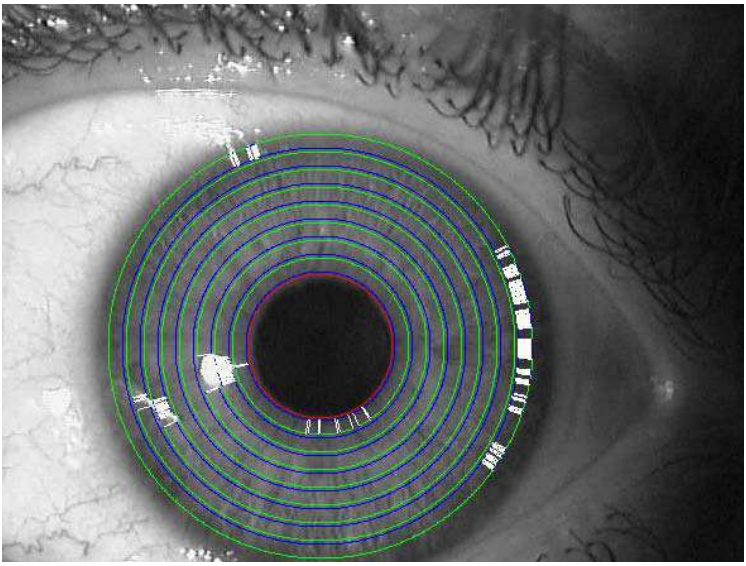


Fig. 9. An Example of the 8-Circle Iris Bands

5. Implementation

Based on the notion that many of the latest mobile phones are running on the Symbian operating system and using Java or the C++ programming language for programming developments, the biometric mobile payment system is developed for mobile phones running Symbian OS using *Java 2 Micro Edition* (J2ME) with *Mobile Information Device Profile* (MIDP). By using J2ME, the iris identification program is compatible with benchmark workstations with the benefits of the platform independency of Java codes.

All programming developments indicated in this paper have had been tested on a Sony Ericsson P800 mobile phone. It was the most advanced Symbian OS mobile phone at the time this project was started, supporting personal Java and MIDP 2.0 and equipped with a VGA sized camera. The Sony Ericsson P800 is embedded with an ARM 9 processor running at 156MHz. This processor power must be shared among common mobile phone functions.

In the following section, the design of the GUIs and their functions are described in detail. Moreover, how distributed agents are launched via the GUIs and how these agents communicate with each other is also outlined.

The different GUIs are described in a sequence following the working procedures of the BMP system. There are two main graphical user interfaces (GUIs) and six preference menu GUIs that were developed using Symbian UIQ. After starting the BMP system, the main panel of the mobile two-dimensional barcode reader is the first interface to be displayed, as shown in Figure 10 and Figure 11.

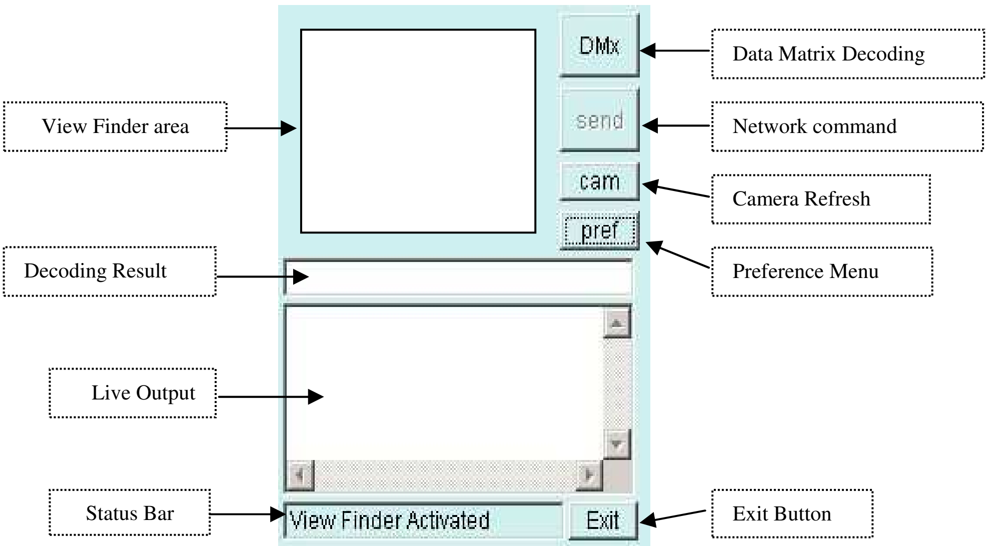


Fig. 10. Main panel of Mobile Two-Dimensional Barcode Reader

This main panel consists of three display windows and five command buttons. To use this barcode reader, users must position the mobile phone at a distance from the symbol so that the image formed on the mobile phone's *View finder area* is in focus and approximately centred and straight. The View finder area window is managed by the image acquiring agent and the barcode image processing agent for displaying a data matrix image taken by the camera on the mobile phone. After pressing the *DMx* button, the image acquiring agent will start the image acquisition and send an image to the data matrix decoding agent. The *view finder area* will be switched off during processing to optimize the available CPU power. When the code has been successfully decoded, information related to the barcode, such as price, amounts of product left, will be displayed in real-time in the *Live Output Window*. By using the *check* button (as shown in Figure 14(a)), users can access the local database to get information that relates to the barcode last scanned. The *send Button* is used to send the contents in the decoding result window to the server. This button is designed for the mobile commerce purposes and not to be used without a connection to a wireless network. According to the tests on the Sony Ericsson P800 mobile phone, an average decoding time, using a standard VGA size image, is 60ms to 100ms.

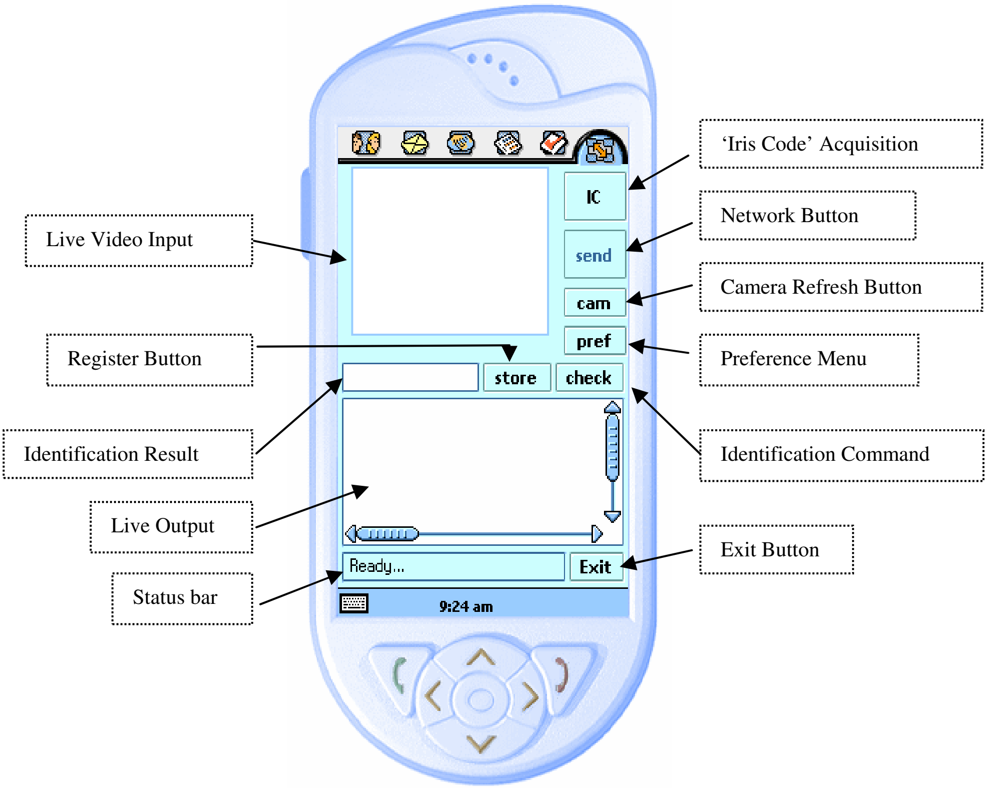
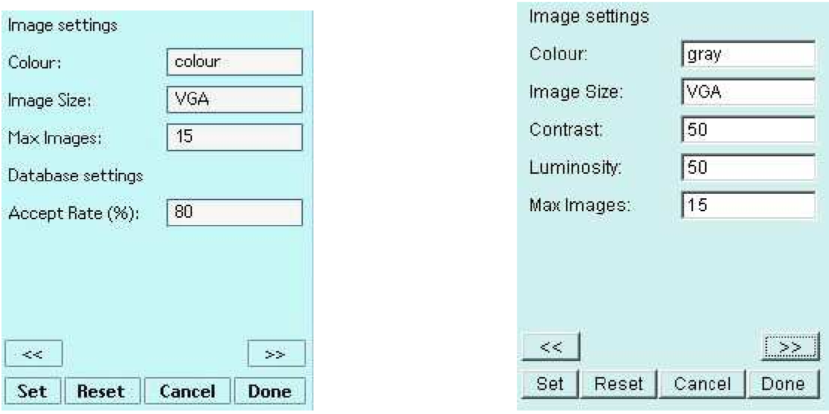


Fig. 11. Main Panel for the Mobile Biometrics Identification System

After users confirm purchase, a GUI for mobile biometrics identification will appear, as shown in Figure 10. There are four display windows and seven command buttons in this Panel. The *Live Video Input Window* is monitored by the communication agent and managed by the image acquiring agent and the iris image processing agent when displaying the live video input from the camera or displaying an iris image with its iris boundaries located (ie, when the iris image processing succeeds). The *Identification Result Window* is managed by the iris image identification agent and used to display an identification result in a single line. It is also used to name a new iris code with a registration procedure. The *Live Output Window* works as a real time messenger interface to display live messages received from each agent. The messages include the status of image processing progress (success or failure), the full list of iris comparison results and the iris code generation time, etc. The *IC Button*, short for 'Iris Code', is used to activate the image processing agent to achieve a valid iris code. After the IC button is pressed, the live video input window will be temporally closed to save computational power. It will be reopened after the iris image processing agent has produced an output, which is either a valid iris code or a notice of failure. When an iris code is successfully generated, the pupil boundary and the iris bands are shown on the iris image. Therefore users can manually decide whether the iris image processing agent produced a correct pupil boundary or not. If a user does not agree with the localization of a pupil boundary, s/he needs to press the '*cam button*' on the main panel and press the IC button again to restart the image processing procedures. Alternatively, if a user agrees with the localization, the iris code can be compared with iris templates in a database for iris identification (by pressing the '*Check button*') or be registered to a database as a template (by pressing the '*Store button*'). Different from the two dimensional barcode reader, the *Send button* in the MBI system is a network button used to activate the wireless network agent and send the iris code generated most recently to a server station for registration or removal purposes (the IP address and the Port number of the benchmark workstation are set in the *Network Preference Menu*). After pressing the *check button*, the last calculated iris code will be compared with the template codes stored in the database of a benchmark workstation or the mobile phone. This button is only activated after a 'success' notice is received from the image processing agent and the communication agent. The identification result will be displayed in the *Identification Result window*. The matching rate that is the total number of pixels matching the iris code's template pixels will be displayed on the Live Output window. The *store button* is used to store the iris code that successfully decoded most recently into a database, either located in the benchmark workstation or in the mobile phone. In order to register an iris code, a name must be typed in the identification result window. This name needs to be less than 20 characters and have a different name from other data that has been stored in the database. Any preceding or trailing spaces in this name will be removed automatically by the database management agent during registration. Associated with the panels of the two dimensional barcode reader and MBI system, there are in total six preference menus which can be set by users. These menus can be accessed by pressing the *pref button* on the main panel.

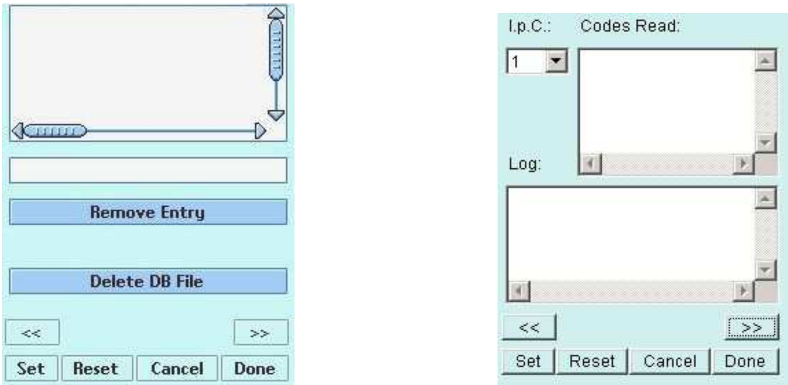
As shown in Figure 12(a), this menu provides the facilities for setting the image colour, image size and the maximum number of images that can be acquired during a biometrics identification process and the minimum matching rate (details are given in the latter part of this section). The image setting menu for barcode reading, as shown in Figure 12 (b) enables contrast and luminosity tuning which is required for barcode reading different coloured data matrix.

Figure 13 (a) illustrates the GUI for the database options. This GUI can help a user review or remove information, such as iris information and product information, on the local database on a mobile phone. Figure 13 (b) illustrates the GUI of the log monitor, as indicated by its name, this GUI is designed to help users monitor all the attempts and the history of attempts for accessing information from the BMP system on a mobile phone.



(a) (b)

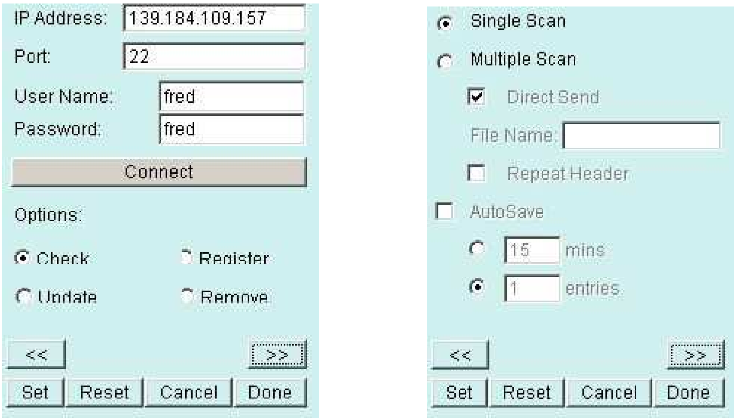
Fig. 12. Image Setting Menus of BMP System: (a) image setting and accept rate setting menu for biometrics identification; (b) image setting menu for barcode reading.



(a) (b)

Fig. 13. Graphical User Interfaces: (a) Database Options (b) Log Monitor

The GUIs shown in Figure 14 (a) and (b) illustrate the network menu and the tool options. These two GUIs help mobile phone users transmit product information and iris codes between server stations and mobile phones.



(a) (b)

Fig. 14. Graphical User Interfaces: (a) Network Menu; (b) Tool Options.

6. System performance test

In order to provide a statistical test result on the accuracy of the iris recognition algorithm that we developed to run on a mobile phone, 25,200 image-correlation tests (12,000 auto correlation tests on images of authentics and 13,200 correlation tests on images of imposters) were carried out using the iris images captured by the Chinese Academy of Science Institute of Automation (CASIA). The test results are used to compare with results from John Daugman, who developed an internationally used and tested iris recognition algorithm. In Daugman's (1993) theory, if authentics and impostors can be successfully separated using a Hamming distance (HD) threshold during statistical tests this recognition algorithm can recognize iris patterns reliably.

The HD between two Boolean codes is defined as the number of differences between those two codes when compared bit by bit, defined as follows:

$$HD = \frac{1}{n_{pixel}} \sum_{j=1}^{N} C_A(j) \oplus C_B(j) \qquad (1)$$

where C_A and C_B are the coefficients of two iris images and n_{pixel} is the size of the iris code. It is a Boolean Exclusive-OR (XOR) operation. Therefore the matching rate which is an XNOR operation can be written as:

$$\text{Matching Rate} = 1 - HD \qquad (2)$$

When two iris codes are matched, the greater the value of the HD, the bigger the difference is between the two. A result of 0 would represent a perfect match between these two iris codes. To reject all imposters, the decision threshold of Daugman's algorithm is 38%, which is equal to a 62% matching rate.

During the statistical independence tests of our algorithm, the mean value for authentic' HD results is 0.1743, the standard deviation is 0.0797, the minimum value is 0 and the maximum is 0.4200.When it comes to impostor's HD results, the mean value is 0.3748, the standard deviation is 0.0537, the minimum value is 0.2000 and the maximum value is 0.5400.

The distribution of impostor's and the distribution of authentics have an overlap area between 0.2000 (the minimum value of impostor's HD) to 0.4200 (the maximum value of authentic's HD). However, by setting a threshold of 0.2 on Hamming distance all impostors can be recognised and by setting a threshold of 0.42 on Hamming distance, all authentics can be recognised. The results indicate a success in separating authentics and impostors by setting a threshold between 0.2000 and 0.4200 (matching rate between 58% to 80%) for the iris recognition algorithm of the MBI system.

According to 25,200 test results, several conclusions can be given on the accuracy and stability of the MBI system for different security levels that applications require. First, the false negative rates are found to be between 0.13% to 4.3% with no change in sensitively resulting from changes of threshold. This result shows that the MBI system mostly does not reject authentic users hence providing good performance with a low inconvenience level for authentic users. Second, the false positive rates are found to be between 0% to 8%. According to table 2, from about 65% threshold, 0.13% false negative rate is achieved which leads to the rejection of almost all the impostors.

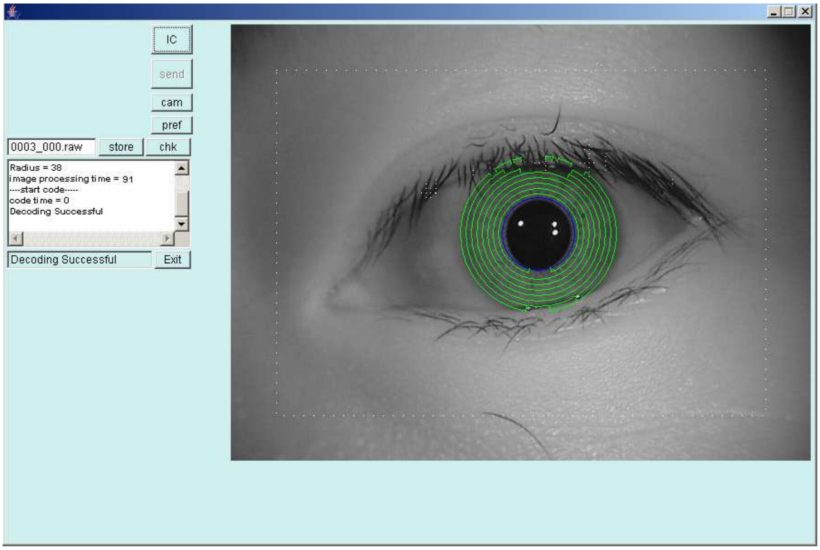
The false negative rate is also used in the paper of Wildes (1996), Lim ta al (2001), Tissue et al (2002), and Daugman (2007) for measuring the security of a recognition system. Among them, Daugman's algorithm provides 0 in 984 million FAR in cross comparison tests. Comparatively to Daugman's result, the MBI system has a 0.13% FAR rate when setting a threshold at 65%.

When it comes to true rates (true positive and true negative), the true negative rate increases greatly from a threshold of 50% depending on the threshold increment and reaches the value of 100% for the true negative rate for a threshold higher than 65%; The true positive rate decreases from a threshold of 60% depending upon the threshold increment. For both true rates, the closer to 100%, the better performance the system will provide.

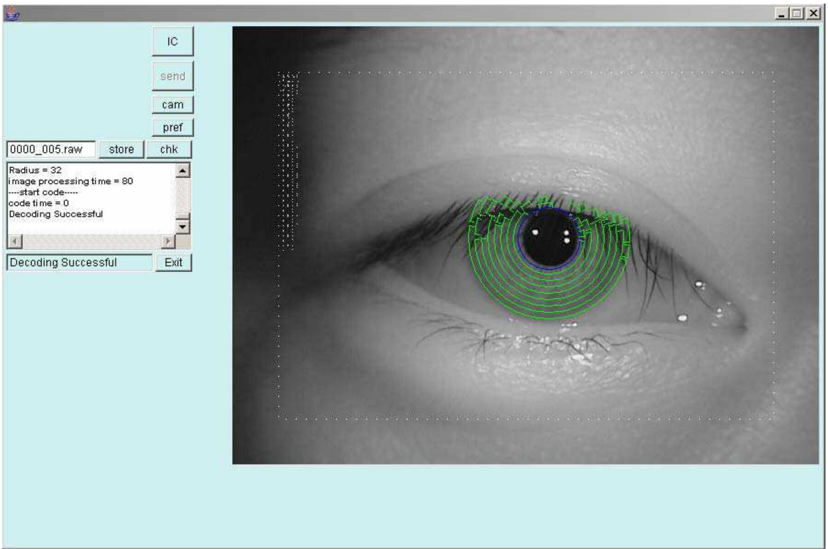
For demonstration and analysis purposes, three groups of false and true rates were generated when using three different threshold settings: 60%, 70% and 80% (these thresholds roughly indicate the min, medium and max value in the range of [58%, 80%]) are used. As shown in Table 2, these results can be used to analyse the security robustness of the MBI system.

Matching Rate	False Positive Rate	True Negative Rate	True Positive Rate	False Negative Rate
60%	8.3328882%	91.2605042%	97.12973594%	0.133539875%
70%	0.000000000%	100.000000000%	50.63145809%	2.29688585%
80%	0.000000000%	100.000000000%	7.347876005%	4.310667165

Table 2. True and False Rates in the Statistical Independence Test



(a)



(b)

Fig. 15. Performance of Iris Identifications on the MBI System: (a) and (b): identification results on the main panel GUIs of the MBI system.

By analysing the correlation test results, the authentic-group and the impostor-group can be successfully separated with a false acceptance rate of almost zero, by setting a decision threshold at 65% of matching pixels. Figure 15 provides two sample results from these tests to illustrate that the iris recognition algorithm itself produces reliable identification results.

As shown in Figure 15, the Live Output Window on the main panel GUI of the MBI system works as a real time messenger interface to display live messages to show the status of image processing progress (success or failure), the iris comparison results and the iris code generation time, etc; and the Identification Result Window is used to display the identification result. According to this feedback, the image processing time when implementing the iris image processing agent is 80 ms in (a) and the 91 ms for the image in (b). A note of '----start code---' is given when a successful result is achieved during iris image processing. Both 'code time' (iris code comparison time) shown in the Live Output Window are 0 ms. A message of 'Decoding Successful' is given when the image of an eye is identified. An identification result (the name of the template that the latest acquired image matched with) of '0000_005' is shown in the Identification Result Window in (a) and an identification result of '0003_000' is shown in (b). Moreover, these two typical examples demonstrate how the MBI system works based on different degrees of eye openness. As shown in Figure 15(a), one third of the iris image in (a) is covered by the eyelid and a small amount of noise comes from the eyelash. In Figure 15(b) a smaller amount of noise comes from the eyelid and the eyelash. All the noise in (a) and (b) has been removed when implementing the iris image processing agent (in other words, before implementing the iris image identification agent).

After demonstrating the performance of the BMP system (the two dimensional barcode reader and the MBI system), the execute time of BMP system is another issue that needs to be explored.

The procedure of barcode decoding and barcode information searching can be achieved within 100 ms if the product information has already been stored in the local database in the mobile phone. If product information is not stored in the mobile phone memory and an internet search is required, the execution time of the BMP system then depends on the data transmission speed between the server station and the mobile phone.

Once product information is received from server or found from the local database and the user decides to purchase, a 10ms pause will be given when switching user interfaces. This pause allows the communication agent to communicate with the image acquiring agent and iris image processing agent to activate the user identification process. After this pause, the biometric identification GUI, as shown in Figure 10, will appear on the screen. The 'Live Output Window' in this GUI will keep providing updated user information and information relating to a purchase, such as payment confirmation from a financial institution.

The execution time for local iris recognition is within 200 ms when compared to 100 iris code templates in the local database. If the user prefers to be authorized by a bank or other financial institution, code transformation times may vary but the iris code identification time will be less than 50ms, as shown in Table 3.

Based on the execution time of the mobile biometric identification and mobile two dimensional barcode reader, this BMP system can decode a barcode and produce the information related to this barcode and get a payment authorised within one second if there is no stand by time for data transfer via a network connection.

No. of Iris Templates	Database (ms=milliseconds)			
	Local		Server	
	IC generation	Identification	IC Generation	Identification
100	200 ms	-	<100 ms	50 ms
1000	500 ms	-	<100 ms	500 ms

Table 3. The Execution Time of the MBI System

7. Conclusions and future works

The growth in the creation and maintenance of secure identities for mobile devices has created challenges for individuals, society and businesses particularly in mobile added value services (mobile banking, mobile check-in, mobile ticket, et. al) and government security services. Although many obstacles remain, the growth in wireless technology, and the improvement of mobile devices will stimulate growth in the mobile biometrics market. The new product enhancements will result in an expansion of m-Identification and m-Commerce applications worldwide.

When it comes to enhancing the work being done in the MBI case study, there are two prospective areas that would benefit from further work.

The first aspect is the improvement of the performance of the MBI system. A test has been carried out on using three iris images at a time to produce lower false positive and false negative rates when applying the MBI system for iris recognition. According to the test, the false rates are about one tenth of those using one image with the same iris recognition algorithm that was implemented in the MBI system. However, using three images at a time for iris recognition requires higher computational power and a longer standby by time. The future work of this aspect addresses both the code modification of MBI system and the improvement of technologies applied on portable computing devices.

Secondly, an improvement can be made to the BMP system by employing a mobile shopping agent. In this blueprint, the shopping agent can be developed to enhance the intelligence of the BMP system to suit users' preferences. With such a shopping agent users scanning the barcodes of interesting products can be provided with multiple options on where best to buy or how to pay for the item.

The main difficulty of employing such a mobile shopping agent is not the algorithm development but the cooperation with the mobile network provider. In the design of a wireless network agent for security, mobile phone users need to connect to a network server with a fixed IP address. All the information required from the internet needs transformation and filtering through a network server. Therefore the functionality of the BMP system is unfortunately partly constrained by the security concerns. Many advanced mobile phones can explore the internet without using the BMP system, but the security level of the mobile phone is not yet ready for mobile shopping. There are some world leading anti-virus developers, such as McAfee who are currently committing on the software solutions for

anti-virus on mobile phones; however such software requires computation power and memory, which can make a mobile phone 'pause forever' when exploring the internet.
In a world challenged to find new ways to authenticate identity and privileges when processing people and information, all with increased levels of security, the future of iris recognition technology on portable computing devices looks bright.

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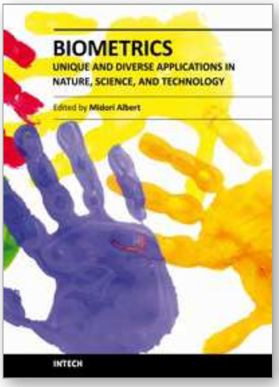

Biometrics - Unique and Diverse Applications in Nature, Science, and Technology

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Biometrics-Unique and Diverse Applications in Nature, Science, and Technology provides a unique sampling of the diverse ways in which biometrics is integrated into our lives and our technology. From time immemorial, we as humans have been intrigued by, perplexed by, and entertained by observing and analyzing ourselves and the natural world around us. Science and technology have evolved to a point where we can empirically record a measure of a biological or behavioral feature and use it for recognizing patterns, trends, and or discrete phenomena, such as individuals' and this is what biometrics is all about. Understanding some of the ways in which we use biometrics and for what specific purposes is what this book is all about.

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