

## Chapter 2

# Multispectral Biometrics Systems

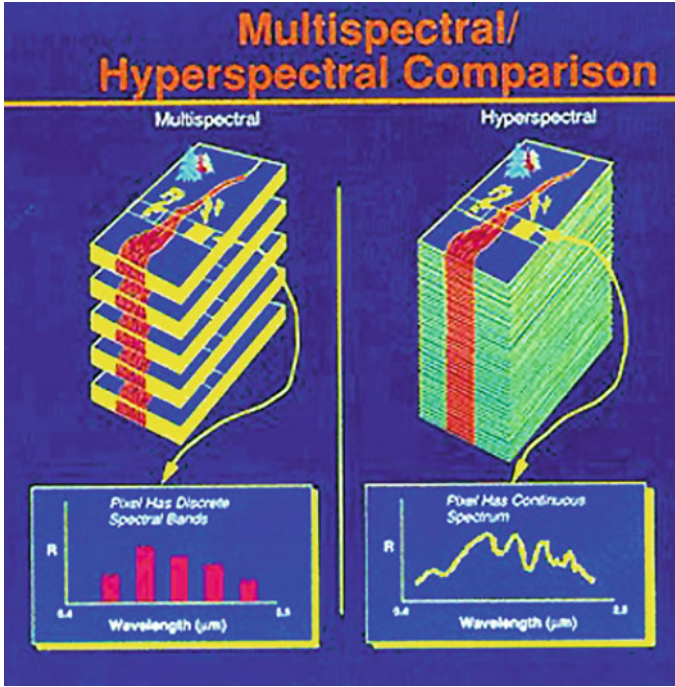
**Abstract** Until now, many multispectral biometrics technologies and systems have been proposed. Different multispectral biometrics systems have their own characteristics. This chapter gives an overall review of multispectral imaging (MSI) techniques and their applications in biometrics.

**Keywords** Multispectral biometrics • Face • Fingerprint • Palmprint • Iris • Dorsal hand

### 2.1 Introduction

Multispectral biometrics is based on data consisting of four to ten separate images of the same biometrics trait and representing sensors' responses in different wavelengths of the electromagnetic spectrum. In contrast to conventional images, which generally represent an integrated response of a single sensor over a wide range of bands in the same spectral zone, multispectral data usually refer to multiple separate sensor(s) responses in relatively narrow spectral bands. The word multispectral was first used in space-based imaging to denote data acquired in the visible and infrared spectra. In biometrics, the word multispectral has been used to describe responses in multiple narrow bands either all in the visible, or all in the infrared, or a mixture of both. Even though the words hyperspectral and multispectral have often been used interchangeably, hyperspectral imaging usually refers to cases where the number of bands is higher than 10 and when these bands encompass more than one region of the electromagnetic spectrum, such as the visible and the infrared. Figure 2.1 shows difference between hyperspectral and multispectral.

There are mainly two kinds of methods, touch-based and touchless, to acquire multispectral biometrics data. The former method utilizes light with different wavelengths to illuminate the object and capture multiple images by a camera.

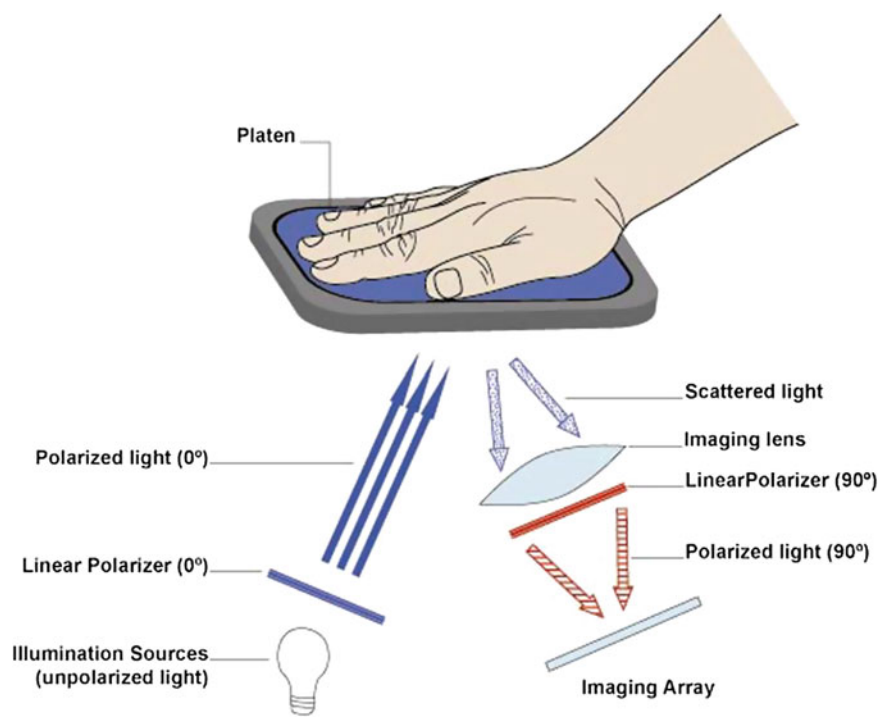


**Fig. 2.1** Hyperspectral and multispectral differences (Hyperspectral imaging 2014)

It requires the subject to touch a glass or prism and is suitable to collect palmprint and fingerprint data. Figure 2.2 shows an example of multispectral hand imaging system. The latter method usually utilizes a full spectral light, such as halogen lamp, to illuminate the object. A liquid crystal tunable filter (LCTF) (shown in Fig. 2.3) or a filter wheel (shown in Fig. 2.4) with multiple filters is mounted in front of the camera. This technique is suitable to collect iris, face, palmprint, and dorsal hand data. Figure 2.5 shows an example of multispectral/hyperspectral face imaging system.

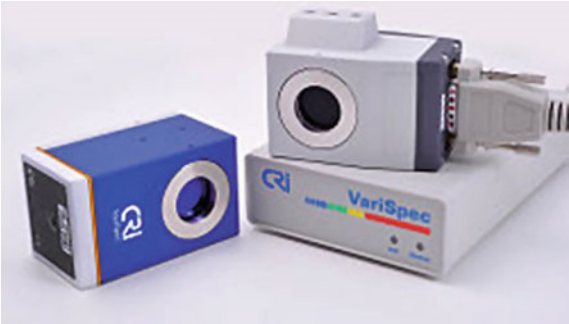
## 2.2 Different Biometrics Technologies

At present, there are many different multispectral biometrics technologies and systems. Each existing system has its own strengths and limitations. The following shows different multispectral biometrics applications.



**Fig. 2.2** Major optical components and layout of the multispectral whole-hand imaging system (Rowe et al. 2007)

**Fig. 2.3** Liquid crystal tunable filter (2014)



**2.2.1 Multispectral Iris**

Traditionally, only a narrow band of the near-infrared (NIR) spectrum (750–850 nm) was utilized for iris recognition systems since this will alleviate any physical discomfort from illumination, reduce specular reflections, and increase the amount of iris texture information captured for some of the iris colors. Commercial



Fig. 2.4 Filter wheel (2014)

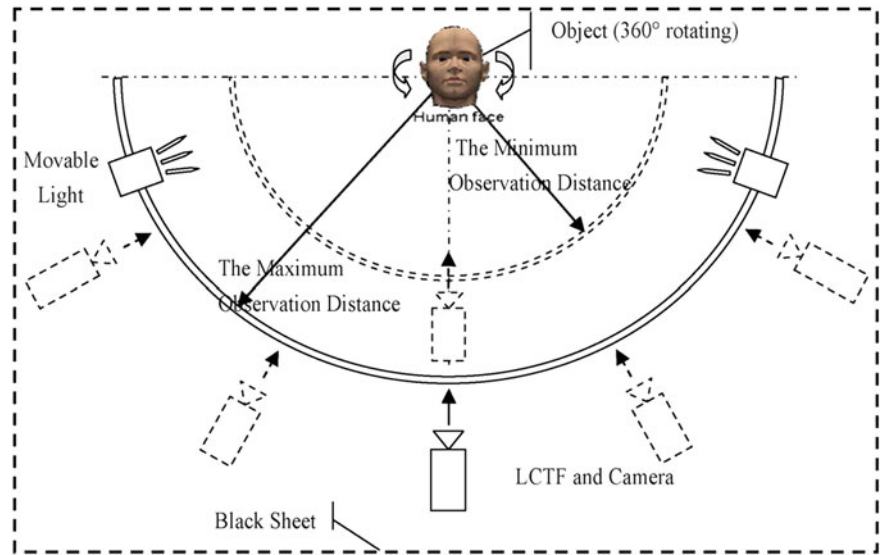


Fig. 2.5 Multispectral/hyperspectral face imaging system (Di et al. 2010)

iris recognition systems predominately operate in the NIR range of the electromagnetic spectrum. The spectrums indicate that current systems are using wavelengths that peak around 850 nm (Panasonic and Oki), with a narrow band pass. However, some systems traverse into the range of 750 nm (LG) and use multiple wavelength illumination to image the iris. The infrared light is invisible to the human eye, and the intricate textural pattern represented in different colored irides is

revealed under an NIR range of illumination. The texture of the iris in IR illumination has been traditionally used as a biometrics indicator (Boyce 2006).

However, the textural content of the iris has complex components, including numerous structures and various pigments, both fibrous and cellular, which are contained on the anterior surface, including ligaments, crypts, furrows, collarettes, moles, and freckles. The NIR wavelengths can penetrate melanin, showing a texture which cannot be easily observed in the visible spectrum, but the cost is substantially high. Most of the texture presented in the NIR spectrum is only generated by the iris structures, not by the pigments. The effect of melanin, the major color-inducing compound, is negligible on the NIR wavelengths in iris recognition. But, melanin is always imaged in certain wavelength for extraction and classification, such as in tongue image processing (Liu et al. 2007).

The above study has inspired us to consider that the iris textures generated outside the NIR spectrum may have more information over those that are only generated in the NIR spectrum, because melanin can be present in the shorter wavelengths and becomes another major source of iris texture.

Previous research has shown that matching performance is not invariant to iris color and can be improved by imaging outside the NIR spectrum and that the physiological properties of the iris (e.g., the amount and distribution of melanin) impact the transmission, absorbance, and reflectance of different portions of the electromagnetic spectrum and the ability to image well-defined iris textures (Wilkerson et al. 1996). Performing multispectral fusion at the score level is proven feasible (Ross et al. 2006a, b), and the multispectral information is used to determine the authenticity of the imaged iris (Park and Kang 2007).

When we are ready to accept a fact that multispectral iris fusion can improve matching performance, which has been proven by several previous experiments, two questions need to be answered as the cornerstones that support the above conclusion. Question 1: How do the colors of the irides influence the matching performance of multispectral iris recognition? Question 2: How does the iris texture generated from the structures and pigments change with the illumination of different spectral wavelengths?

Some researchers have tried to answer Question 1 and achieved some initial results. Burge and Monaco (2009) demonstrated that iris texture increases with the frequency of illumination for lighter-colored sections of the iris and decreases for darker sections. This means that the effects of an illumination wavelength on various colored sections of the iris are not the same; sometimes the texture increases, and sometimes it decreases, depending on the color of the iris. Hence, the feasibility of multispectral iris recognition cannot be explored from only the perspective of an electromagnetic spectrum, and the colors of the irides should be studied as a very important factor, combined with illumination wavelengths.

Although these previous studies did not really answer Question 1, at least they clarified a basic principle: The accuracy of conclusions is based on the basis that the iris images used in a multispectral study should belong to a certain color classification. This is because the same research methods may produce an entirely different conclusion on the iris images of different colors.

In terms of Question 2, there is no related in-depth research and no published results. From the previous studies, we are only able to observe the phenomenon in which iris images captured across multispectral wavelengths show differences in the amount and distribution of texture and should be used for feature fusion in order to increase the diversity of iris textures, but we do not know the specific mechanisms of the iris texture that change with multispectral wavelengths. Studying the above mechanism has great significance, especially in the choice of which band of the electromagnetic spectrum can be used for iris fusion.

### ***2.2.2 Multispectral Fingerprint***

The multispectral imaging (MSI) technology has been widely used in the fingerprint. Testing performed to date has shown strong advantages of the MSI technology over conventional imaging methods under a variety of circumstances.

The source of the MSI fingerprint advantage is threefold. First, there are multiple anatomical features below the surface of the skin that have the same pattern as the surface fingerprint and can be imaged by MSI. This means that additional sub-surface sources of signal are present for an MSI sensor to gather and compensate for poor quality or missing surface features. Second, the MSI sensor was designed to be able to collect usable biometrics data under a broad range of conditions including skin dryness, topical contaminants, poor contact between the finger and sensor, water on the finger platen, and bright ambient lighting. This sensor characteristic enhances the reliability of the MSI sensor and reduces the time and effort required by the authorized user to successfully conduct a biometrics transaction. Third, because the MSI sensor does not just measure the fingerprint but instead measures the physiological matrix in which the fingerprint exists, the resulting data provide clear indications of whether the fingerprint is taken from a living finger or some other material (Rowe et al. 2008).

For example, in the case of maritime environment, a fingerprint reader equipped with high-end MSI technology is used, which adds more to the image quality and the robustness of the data acquisition process (Fakourfar and Belongie 2009). In the case of spoof detection, the MSI fingerprint is configured to image both surface and subsurface characteristics of the finger under a variety of optical conditions. The combination of surface and subsurface imaging ensures the liveness of an object.

Nowadays, most of the MSI fingerprint image is compatible with images collected using other imaging technologies. Thus, the MSI sensor is usually incorporated into systems with other sensors, which is called multispectral multibiometrics sensing system. Commonly, the system consists of an MSI and a conventional optical sensor based on total internal reflectance (TIR). The two sensors are combined in a way that both sensors could collect data on a finger placed on the platen in approximately one second (Rowe et al. 2005). Some systems are constructed and used to collect data in a multiday, multiperson study. The sensor is based on multispectral technology that is able to provide hand shape, fingerprints, and palmpoint

modalities of a user's hand by a single user interaction with the sensor. Thus, it will reduce the overall size and complexity of the multibiometric system when compared to other systems that use multiple sensors, one per trait. One minor disadvantage is an increase in computational requirements due to multispectral processing of data (Rowe et al. 2007).

Along with those advantages, the MSI fingerprint has some shortcomings, such as noise and compatibility. Some have proposed a method using the texture of fingerprint images to reduce multispectral noise, which has been proved to be efficient (Khalil et al. 2009). Besides, a lot of methods have been proposed and achieved great progress, both in device and in algorithm. Still, there is a lot of work need to be done.

### 2.2.3 *Multispectral Face*

MSI is widely used technique for face recognition. Some studies regard multispectral face images as a kind of multimodal biometrics, thus different feature or decision level fusion schemes are explored. Zheng and Elmagbraby (2011) explore and compare four face recognition methods and their performance with multispectral face images and further investigate the performance improvement using multimodal score fusion. Nicolo and Natalia (2011) introduce a robust method to match visible face images against images from short-wave infrared (SWIR) spectrum. Later, Boothapati and Natalia (2013) propose a methodology for cross-matching color face images and SWIR face images reliably and accurately. Zheng et al. (2012) and Zheng (2011) propose a wavelet-based face recognition method under the framework of Gabor wavelet transform (GWT) and Hamming distance (HD), which results in two algorithms, face pattern word (FPW) and face pattern byte (FPB). Bourlai and Bojan (2012) study the problems of intra-spectral and cross-spectral face recognition in homogeneous and heterogeneous environments and investigate the advantages and limitations of matching between different spectral bands. They also utilize both commercial and academic face matchers and performed a set of experiments indicating that the cross-photometric score-level fusion rule can improve SWIR cross-spectral matching performance. Bendada and Moulay (2010) introduce the use of local binary patterns (LBP) like texture descriptors, including LBP, local ternary patterns (LTP), and a simple differential LTP descriptor (DLT), for efficient multispectral face recognition, which is less sensitive to noise, illumination change, and facial expressions. Similarly, Akhloufi and Abdelhakim (2010) introduce a new locally adaptive texture feature descriptor called local adaptive ternary pattern (LATP) for efficient multispectral face recognition. Singh et al. (2008a, b) develop a novel formulation of multiclass support vector machine called multiclass mv-granular soft support vector machine, which uses soft labels to address the issues due to noisy and incorrectly labeled data and granular computing to make it adaptable to data distributions both globally and locally. In a multispectral face recognition application, the proposed multiclass



classifier is used for dynamic selection of four options: visible spectrum face recognition, short-wave infrared face recognition, multispectral face image fusion, and multispectral match score fusion.

Some works focus on image/feature-level fusion of multispectral images. Buddharaju and Pavlidis (2007) have outlined a novel multispectral approach to the problem of face recognition by the fusion of thermal infrared and visual band images. In Yi (2006), by choosing appropriate weights of wavelet transformation coefficients, a novel pixel-level wavelet-based data fusion method is proposed. In Chang et al. (2006), a novel physics-based fusion of multispectral images within the visual spectra is proposed for the purpose of improving face recognition under constant or varying illumination. Spectral images are fused according to the physics properties of the imaging system, including illumination, spectral response of the camera, and spectral reflectance of skin. In Chang et al. (2010), several novel image fusion approaches for spectral face images, including physics-based weighted fusion, illumination adjustment, and rank-based decision-level fusion, are proposed for improving face recognition performance compared to conventional images. A new MSI system is briefly presented which can acquire continuous spectral face images. Singh et al. (2008a, b) present a two-level hierarchical fusion of face images captured under visible and infrared light spectrum to improve the performance of face recognition. At image-level fusion, two face images from different spectrums are fused using DWT-based fusion algorithm. At feature-level fusion, the amplitude and phase features are extracted from the fused image using 2-D Log-Gabor wavelet.

A few of works try to identify the optimal feature band for multispectral face recognition. In Koschan et al. (2011), the fundamentals of MSI and its applications to face recognition are introduced. Then, a complexity-guided distance-based spectral band selection algorithm, which uses a model selection criterion for an automatic selection, is developed to choose the optimal band images under given illumination conditions.

#### **2.2.4 Multispectral Palmprint**

Multispectral analysis has been used in palm-related authentication (Hao et al. 2007, 2008; Rowe et al. 2007; Likforman-Sulem et al. 2007; Wang et al. 2008a, b). Rowe et al. (2007) proposed a multispectral whole-hand biometrics system. The object of this system was to collect palmprint information with clear fingerprint features, and the imaging resolution was set to 500 dpi. Likforman-Sulem et al. (2007) used multispectral images in a multimodal authentication system. Their system used an optical desktop scanner and a thermal camera which make the system very costly. The imaging resolution is also very high (600 dpi, the FBI fingerprint standard). Wang et al. (2008a, b) proposed a palmprint and palm vein fusion system, which could acquire two kinds of images simultaneously. The system uses one color camera and one near-infrared camera. Hao et al. (2007, 2008)



developed a contact-free multispectral palm sensor. Overall, multispectral palmprint scanning is a relatively new topic.

The information presented by multiple biometrics measures can be consolidated at four levels: image level, feature level, matching score level, and decision level (Ross et al. 2006a, b). Wang et al. (2008a, b) fused palmprint and palm vein images by using a novel edge-preserving and contrast-enhancing wavelet fusion method for the use of personal recognition system. Hao et al. (2007) evaluated several well-known image-level fusion schemes for multispectral palm images. Hao et al. (2008) extended their work to a larger database and proposed a new feature-level registration method for image fusion. The results by various image fusion methods were also improved. Although image and feature-level fusion can integrate the information provided by each spectral band, the required registration procedure is often too time-consuming (Wang et al. 2008a, b). As to matching score fusion and decision-level fusion, it has been found (Ross et al. 2006a, b) that the former works better than the later because match scores contain more information about the input pattern and it is easy to access and combine the scores generated by different matchers. For these reasons, information fusion at score level is the most commonly used approach in multimodal biometrics systems and multispectral palmprint systems (Rowe et al. 2007; Likforman-Sulem et al. 2007).

### 2.2.5 *Multispectral Dorsal Hand*

Since dorsal hand took a role as a biometrics feature in 1990s, the vein underneath the skin has always expressed its good property of permanence and particularity. In traditional research, vein is taken as a web-like structure and most of studies use structure-based feature extraction. However, relevant work shows that even very limited number of minutia missing would cause great performance degradation because the total number of minutiae is usually very small and it is uncomparable to that of other biometrical features (Wang et al. 2008a, b). To pursue higher and more stable results, reserving sufficient original information of vein shape seems to be increasingly important. The original information can be further transferred to various kinds of descriptors by coding or space transformation.

Shape-based feature extraction puts forward higher requirement for original image. Specifically, the vein edge should be clear to avoid the occurrences of broken and blurred vein; the non-vein region should not be extracted as foreground object in case of unwanted interference. Capturing high-quality image has been one of the main guarantees for correct implementation of recognition. In the view of skin optics, light with a different wavelength has a different ability to penetrate skin surface (Aravind and Gladimir 2004). The reason is that various biological tissues in different skin layers vary on their absorptivity and reflectivity. These metrics do not maintain the same values when the wavelength of incident light changes.

Short-wave near-infrared light (700–1100 nm) is widely used in dorsal hand vein capture system, on the ground that deoxyhemoglobin in vein has remarkably higher

absorptivity than other tissues in this spectral region. Nevertheless, chromophore, melanin, carotene, and even adipose may bring about negative impact when the light spectrum is closer to red light or long-wave NIR. For example, melanin can severely impede the light flow with shorter wavelength and cause decrease of image contrast. To our knowledge, multispectral dorsal hand study is not well studied. For example, although 850 nm is the most widely used wavelength according to subjective assessment on image quality (Chen et al. 2007), light source optimization has not ever been studied systematically.

## 2.3 Security Applications

Biometrics applications span a wide range of vertical markets, including security, financial/banking, access control, healthcare, and government applications. Biometrics can be used in both customer- and employee-oriented applications such as ATMs, airports, and time attendance management with the goals of improving the workflows and eliminating fraud.

It is expected that the use of multispectral identification systems to supplement or even replace existing services and methods in some applications with high security requirement, such as border control, citizen ID program, banking, and military.

### **Border Control**

Passengers going aboard or entering a country must present passports and other border-crossing documents to the border guard. It will spend time for the border guard to verify these documents. In order to let border control becoming faster, convenient, and safer, now there are more and more countries start using biometrics passport, such as USA, Canada, Australia, Japan, and Hong Kong. With the development of multispectral biometrics technologies and system, we believe they will play an important role in border control for their high accuracy.

### **Citizen ID Program**

It is a trend for governments to use biometrics technology on the issuance of citizen identity cards. In Hong Kong, a project called Smart Identity Card System (SMARTICS) uses the fingerprint as the authentication identifier. Efficient government services using SMARTICS will provide increased security and faster processing times on different operations such as driver license or border crossing. We think that multispectral biometrics technologies are effective to be used on similar applications.

### **Banking**

The internal operation of banking such as daily authentication process can be replaced by using biometrics technology. Some banks have implemented an authorization mechanism for a different hierarchy of staff by swiping their badge for audit trail purpose. But a supervisor's badge may be stolen, loaned to other

members of staff or even lost. Biometrics system eliminates these kinds of problems by placing an identification device on each supervisor's desk. When a junior member of staff has a request, it is transmitted to the supervisors' computer for biometrics approval and automatically recorded.

### **Military**

Department of Defense of USA distributed more than 11 million Common Access Cards (CAC) as its primary form of identification and enhanced protection to the military network. Although the CAC has proved to be a valuable tool, there are still security gap concerns if cards are lost or stolen and corresponding personal identification numbers are cracked. To fill that void, the Air Force is using biometrics as a way to provide positive identification and authentication (Biometric Technology Working for Military Network 2008). Biometrics is also being used in support of the war on terrorism. Combined with other security measures, biometrics has fast become the preferred solution to military-controlled access and can keep track of who has entered to particular areas because biometrics cannot be shared or borrowed.

## **2.4 Summary**

In this chapter, the MSI technologies have been discussed. Different feature extraction technologies and systems for multispectral biometrics are also discussed. Thus, we have some preliminary understanding of the multispectral biometrics recognition technologies. In the following chapters, the multispectral iris system, multispectral palmprint system, and multispectral dorsal hand system will be presented separately.

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