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Thermal Biometrics: A New Approach in Biometrics Detection

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Abstract

Authentication and verification in any system environment has become a very crucial part in today's age. There are many methods to verify personality or validate anyone. This field is started right from the use of some things and further advanced to use of biometric techniques that are based on structural and behavioral characteristics of humans. The use of such techniques is the most accepted method nowadays. However due to further advances these techniques are now being invaded by thefts or criminals.

Now these biometric techniques can be fully replaced by the new biometric techniques with the advancement of the thermal cameras. The thermal cameras based on IR imaging technique covers some most important drawbacks of conventional cameras. This camera can be used as a sensor for capturing the human vein patterns that are having higher temperature than body and which are variable from person to person.

Introduction

Biometrics is the science of identifying or verifying the identity of a person based on physiological or behavioral characteristics. Biometrics has received a lot of attention in the last few years both from the academic and business communities. Biometric has emerged as a preferred alternative to traditional forms of identification, like card IDs, which aren't embedded into one's physical characteristics. The key element of biometric technology is its ability to identify a human being and enforce security. The use of thermal imaging in biometric detection is a new emerging technique which provides lots of advantages over conventional methods using visible light. It is also known as infrared thermography (IRT).

Thermography is a non-invasive imaging technique that uses special infrared-sensitive cameras to digitally record images of the variations in surface temperature of the human body. A thermal infrared camera with reasonable sensitivity provides the ability to image superficial blood vessels on the human skin. Researchers have been using thermal imaging for good results considering it as an efficient approach when compared to the visual images.

Review of literature

The biometrics technology has a very huge past. The innovations in this technology have started in 19th century when people recognized importance of security and authentication. There were many technologies implemented so far in biometrics.

1. Conventional imaging

Zdeneˇk Rˇíha Václav Matyáš, has explained all the conventional existing biometric methods in "Biometric Authentication Systems" [2]. Some of them are discussed below:

1. Fingerprint identification:- Fingerprint readers are based on reflection changes at the spots where the finger papillary lines touch the reader's surface. The most common readers are based on capacitance, pressure, light reflection and the latest ultrasonic technique.

2. Iris detection:- The iris is the colored ring of textured tissue that surrounds the pupil of the eye. The iris scanner does not need any special lighting conditions or any special kind of light. If the background is too dark any traditional lighting can be used. Some iris scanners also include a source of light that is automatically turned on when necessary.

3. Retina scan:- Retina scan is based on the blood vessel pattern in the retina of the eye. Retina scan is personally invasive. A laser light must be directed through the cornea of the eye which is very intrusive.

4. Hand geometry:- Hand geometry systems produce estimates of certain measurements of

the hand such as the length and the width of fingers.

5. Facial recognition:- Any camera (with a sufficient resolution) can be used to obtain the image of the face. Any scanned picture can be used as well. Needs light supply for vision.
6. Speaker verification:- The principle of speaker verification is to analyze the voice of the user in order to store a voiceprint that is later used for identification/ verification.
7. DNA:- DNA sampling is rather intrusive at present and requires a form of tissue, blood or other bodily sample.

The common drawbacks of these systems are:

1. The systems explained above needed an ordinary light for capturing images. They are blank in dark conditions.
2. Some of the techniques are invasive to the humans. For ex. DNA or retina scan may have chances to harm human body. [2]
3. Systems can be cheated by using the visually exact images in case of 2D detectors. Such as the use of an exactly identical photograph instead of real face.
4. The biometrics appearing on the skin can be easily changed or altered.
5. The systems are less accurate. It needs very accurate samples for getting matched with the samples in the databases.

2. Thermal imaging

All materials, which are above 0 degrees Kelvin (-273 degrees C), emit infrared energy. The infrared ray is a form of electromagnetic radiation the same as radio waves, microwaves, ultraviolet rays, visible light, X-rays, and gamma rays [3].
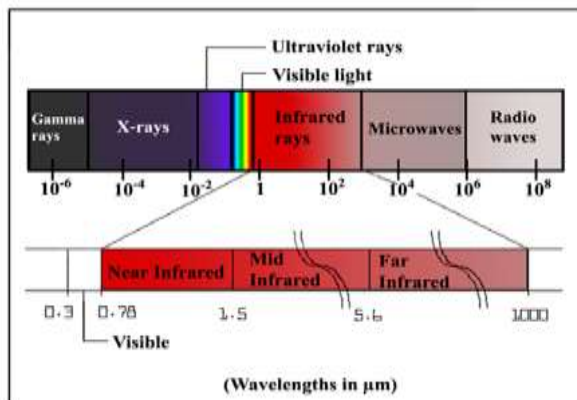

Fig.1 EM wave bands

The International Commission on Illumination (CIE) recommended the division of infrared radiation into three bands. These are as follows:

TABLE I Wave distribution in IR spectrum

Spectrum	Wavelength range	
Visible	0.4-0.7	µm (micrometer/micron)
Near infrared(NIR)	0.7-1.0	µm (micrometer/micron)
Shortwave infrared(SWIR)	1-3	µm (micrometer/micron)
Midwave infrared(MWIR)	3-5	µm (micrometer/micron)
Longwave infrared(LWIR)	8–14	µm (micrometer/micron)
Very Longwave infrared(VLWIR)	14-1,000	µm (micrometer/micron)

At wavelengths of 3 µm and longer imaged radiation from objects become significantly emissive due to temperature, and is hence generally termed as thermal infrared [4]. The infrared energy emitted from the measured object is converted into an electrical signal by the imaging sensor (microbolometer) [5] in the camera and displayed on a monitor as a color or monochrome thermal image.

Working procedure
1. Methodology
The method of using biometrics with thermal imaging involves following steps:

1. Image acquisition:- A continuous analog represention of an image can not be conviniently interpreted by a computer and an alternative representation, the digital image must be used. The objective of image acquisition system is to convert analog optical image to a digital image in a faithful manner. This is done by means of two steps namely:
   (1) Sampling
   (2) Quantization

The analog to digital converter or digitizer samples the video signal in some predefined fashion and quantizes the reflection function at those points into integer value called grey-scale level. Each integer grey-level value is known as a pixel and is a smallest discrete accessible subsection of a digital image. The number grey-levels in the (equally spaced) grey scale is called quantization. Most current acquisition equipment quantizes the video signal into 256 discrete grey-levels.

This is done by using a sensor to sample the analog optical image generating an analog video and then subsequently re-sampling the video signal, generating the digital signal.

2. Image enhancement:- Image enhancement can be defined as a way to improve the quality of image, so that the resultant image is better than the original one, the process of improving the quality of a digitally stored image by manipulating the image with MATLAB software. It is quite easy, for example, to make an image lighter or darker, or to increase or decrease contrast.

Image enhancement techniques to improve visual quality have been popularized with the proliferation of digital imagery and computers. Techniques range from noise filtering, edge enhancement, color balance and contrast enhancement, in both frequency and spatial domains.

     a. Spatial domain methods:- The value of a pixel with coordinates (x; y) in the enhanced image F is the result of performing some operation on the pixels in the neighborhood of (x; y) in the input image, F. Neighborhoods can be any shape, but usually they are rectangular.

     b. Frequency domain methods:- Image enhancement in the frequency domain is straight forward. We simply compute the Fourier transform of the image to be enhanced, multiply the result by a filter (rather than convolve in the spatial domain), and take the inverse transform to produce the enhanced image.

3. Normalization:- After removing the speckling and other high frequency noise, the vein pattern images are normalized to have pre-specified mean and variance values. The normalization process is to reduce the possible imperfections in the image due to the sensor noise and other effects [6]. Let $I(x, y)$ denote the intensity value at position (x, y) in a vein pattern image. The mean and variance of image are denoted as μ and $\sigma2$ respectively. For an image sized $N \times M$, they are computed using following equations:

$$\mu = \frac{1}{N * M} \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} I(x, y)$$

$$\sigma^2 = \frac{1}{N * M} \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} (I(x, y) - \mu^2)$$

Then the normalized image $I'(x, y)$ is given by the pixel-wise operations in following equation, where μd and $\sigma^2 d$ are the desired values for mean and variance respectively.

$$I'(x,y) = \begin{cases} \mu_d + \sqrt{\dfrac{\sigma_d^2 * (I(x,y) - \mu)^2}{\sigma^2}} & , I(x,y) > \mu \\ \mu_d - \sqrt{\dfrac{\sigma_d^2 * (I(x,y) - \mu)^2}{\sigma^2}} & , Otherwise \end{cases}$$

Normalization results in the better clarity and good background rejection

4. Feature extraction:- The features are extracted from the image after the normalization. The feature extraction depends upon type of the image whether it is of face or hand vein or the fingerprint. For ex. For face recognition the three distances are measured i.e. initially, the distance between the two eyes is measured. Secondly, the mid distance between the eyes is measured. Finally, the nose width is measured.

     For hand vein, the line segment Hausdorff distance is measured to match the samples and in ear recognition, the external structure and vein pattern are taken as measure while in fingerprint, the minutiae areas are used.

5. Sample matching:- The sample matching is done by matching the extracted features of the samples with the actual samples present in the databases. The procedure involves dividing the image in many parts and then matching the calculated features with the stored sample.

6. Result:- The result is totally dependent on the matching of the samples. The amount of samples to be matched for the accepting results is always dependent on the software or monitoring device and it depends on the level of security required.

2. Biometric methods

There are various biometric techniques using thermal imaging. Some of them are discussed below in details.

1. **Hand Vein Pattern Verification**:- Veins are hidden underneath the skin, and are generally invisible to the naked eye and other visual inspection systems. However, human superficial veins have higher temperature than the surrounding tissue [6]. Based on this fact, the vein pattern in the back of the hand can be captured using a

thermal camera. Vein patterns are much harder for intruders to copy as compared to other biometric features. All these special properties of hand vein patterns make it a potentially good biometrics to offer more secure and reliable features for personal verification. It is seen that in the thermal image veins appear to be brighter and are visually distinguishable. The technique of locating the ROI is similar to the one proposed by Lin and Fan, where the landmarks of the hand such as finger tips and valleys between the fingers are first located, then a fixed size rectangular region is defined as the ROI based on the location of these landmark points.

Fig.2 Thermal images of the back of the hand

The clearness of the vein pattern in the extracted ROI varies from image to image, therefore, the quality of these images need to be enhanced before further processing. A Median Filter used to remove the speckling noise in the images. The normalization process is to reduce the possible imperfections in the image due to the sensor noise and other effects. After noise reduction and normalization, the quality of the image improves. However, the vein pattern is still surrounded by many faint white regions. The locally adaptive thresholding algorithm is used to segment the vein patterns from the background [6].
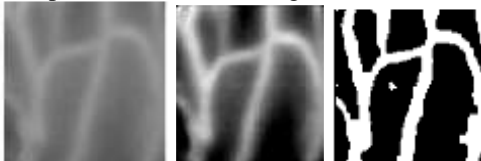
Region of interest   After normalization   After local threholding

Fig.3 Image processing techniques

As the size of veins grow as human beings grow, only the shape of the vein pattern is used as the sole feature to recognize each individual. A good representation of the pattern's shape is via extracting its skeleton. Figure shows the skeleton of the vein pattern after applying the thinning algorithm proposed by Zhang and Suen [6][7].

Fig.4 Skeleton of the vein pattern

Vein pattern matching is done by measuring the line segment Hausdorff distance between a pair of vein patterns. Hausdorff distance is a natural measure for comparing similarity of shapes. It is a distance measure between two point sets; Hausdorff distance uses the spatial information of an image, but lacks local structure representation such as orientation when it comes to comparing the shapes of curves. To overcome this weakness, the line segment Hausdorff distance (LHD) is calculated to match the shapes of vein patterns. Line segment Hausdorff distance was proposed by Gao and Leung for a face matching application [8]. It incorporates the structural information of line segment orientation and line-point association, and hence is effective to compare two shapes made up of a number of curve segments.

The vein patterns are divided into a number of curve segments. For each individual curve segment, a few points are sampled to represent the curve segment. Using these sample points as the end points, a set of line segments representing the shape of the vein pattern are obtained. By this means, the undirected LHD can then be calculated to measure the similarity of two vein patterns.

2. **Face recognition**:- In face recognition, the facial features or patterns for the authentication or recognition of an individual's identity is analyzed. Unlike visible spectrum imaging, IR imaging can be used to extract not only exterior but also useful subcutaneous anatomical information, such as the vascular network of a face or its blood perfusion patterns. Finally, thermal vision can be used to detect facial disguises as well. Thermal imaging has better accuracy as it uses facial temperature variations caused by vein structure on facial surface as the distinguishing trait. After the collection of thermal images from different subjects, image processing techniques can be applied to the images.
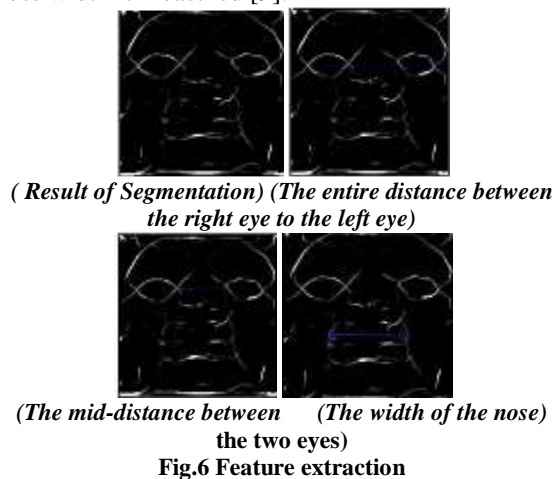
Finally the features are extracted from the thermal pattern created for each and every individual. These techniques are as discussed above. The facial temperature information from a thermal image is heterogeneous in nature; an appropriate segmentation

method successfully separates background temperatures from facial temperatures [9].

Thermal infrared images contain noise, which many times distort significant information and details that are important for the interpretation of the image. After the face was segmented from the rest of the thermal infrared image, unwanted noise is removed in order to enhance the image for further processing. The noise in the image should be removed and simultaneously the image information should be kept unaffected. This problem can be handled using a standard filter. Anisotropic diffusion or Adaboost filter is used to remove the noise from the image. Anisotropic diffusion is a technique used to reduce the image noise without removing significant parts of the image content like edges, lines or other details that are very important for the interpretation of the image. After the noise removal step in the process, morphological operations are performed on the image. Image morphology is a way of analyzing images based on shapes [9].

Input image   Segmented image
Fig.5 Acquired images
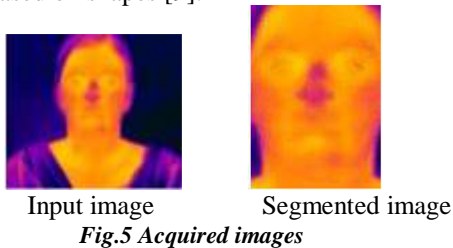
The features are extracted from the result of the segmentation method. The features extracted here are the distance measures. Three distances are measured using suitable MATLAB codes. Initially, the distance between the two eyes is measured. Secondly, the mid distance between the eyes is measured. Finally, the nose width is measured [9].

(Result of Segmentation) (The entire distance between the right eye to the left eye)

(The mid-distance between   *(The width of the nose)*
the two eyes)
Fig.6 Feature extraction

After storing these samples are matched with the existing samples of the same person and based on the matching the results are given. These results are used to authenticate the person undergoing detection.

TABLE II Different face recognition problems and use of thermal face images to solve them.

Different problems of face recognition	Problems that can be solved using thermal imaging
Illumination variation	Yes
Pose Variation	No
Variation in expression	Yes
Different scaling	Yes (except use of glasses)
Disguises	No
Aging problem	No
Variation in temperature	No

3. **Ear detection**:- In applications where remote recognition is necessary (such as in the military and law enforcement), face and ear biometrics are more convenient to be measured. The ear biometric especially has certain advantages: ears are relatively static in size and structure over each individual's life, and unlike human faces, they are unaffected by facial expressions. The typical 2-D ear biometric recognition system has three main stages.

   a. Ear Detection (segmentation) - The ear region is localized in a given 2D image. Further segmentation for edge localization is a second level of segmentation that is required by some ear-based feature extraction methods.

   b. Feature Extraction - Ear-based features are extracted using certain attributes such as Iannarelli's 12 geometrical measurements.

   c. Matching - Once the gallery ear features are properly extracted, they are matched against the probe features, to take a decision about the subject's identity.

Most of the current ear-based recognition approaches are mainly concerning the feature extraction stage in the visible band [10].

Fig.7 Anatomy of the ear

In addition, current methods require controlled imaging conditions, assuming that the image is a single head profile in front of a flat background, in order to achieve good recognition rates. Another issue is that in the current literature there is no well-established scheme for automatic 2-D ear detection: reported ear detection approaches depend on manual or semi-automatic methods. Methods that handle the problem of fully automated ear detection include

 a. Template matching [10], where the ear was modeled by its external curve; while Chen and Bhanu [11] fused skin-color from color images and edges from range images. In the range images, they observed that the edge magnitude is large around the ear helix and the antihelix parts. They clustered the resulted edge segments and deleted the short irrelevant edges.
 b. Morphological operators, where the images were filtered using top hat transformation, and the connected components were labeled after thresholding.
 c. Cascaded AdaBoost based of Haar features, a technique that is widely known in the face recognition society as Viola & Jones approach [12].
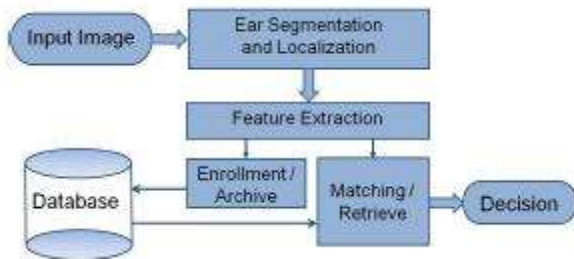

Fig.8 Ear recognition system

Although the thermal IR images are robust to lighting variations, their representation changes after applying different normalization techniques. The photometric normalization (PN) is used for normalizing because in PN proved to be useful for both MWIR eye detection and face recognition studies [13].

Advantages

The use of thermal imaging in biometrics have brought many advantages in ordinary biometric systems, some of them are:
1) Thermal images may deliver a larger discrepancy between the object of interest and the background. Hence, it is often combined with standard biometric methods to optimize the data segmentation.
2) The distribution (typically uneven) of our body temperature is relatively difficult to be copied and reconstructed on artificial objects imitating authentic biometric characteristics.
3) This allows to enhance the biometric modalities with aliveness testing, which matches the observed temperature distribution with common (or subject related) model of body thermal characteristics.
4) Thermal imaging do not required any light source for capturing the photograph; hence it can also be useful in total dark conditions.
5) The features extracted using ordinary cameras can be fooled because it uses the external features that can be altered easily on the other hand thermal characteristics are very difficult to alter as they are beneath the skin.

Disadvantages

Although the thermal cameras have great advantages over conventional cameras, they also have some noticeable disadvantages. These are as follows:
1. They cannot see through water, glass or any reflective surface as the IR image is reflected, much like an image in a mirror.
2. Water, in the form of rain, fog, mist, snow or steam may affect the ability to thermally image a scene.
3. Extreme temperatures consistent throughout the room may cause camera white out. This is where the image in the camera is white due to no gradient differences in the objects in the room.
4. Thermal imager's range of viewing, like all cameras imagers and our eyes is also limited about 200 feet only.

Future scope

The use of thermal imaging has brought new evolutions in this field such as the imaging in total darkness, the liveliness checking etc. Yet the use of thermal images in biometric technologies is not so common because of some problems like

1. The cost of thermal cameras is too high as compared to the conventional cameras working in the visible spectrum.
2. The IR radiations are scattered when fall on the glass etc.

Though there are some problems, the work is also being done in the area for enhancing the use of thermal images.

1. The work is going on to reduce the cost of thermal imaging cameras.
2. The more techniques are being studied for the higher resolution of the thermal cameras.
3. Scientists have implemented the use of plate of temperature sensors as an alternative to the thermal imaging by a camera.
4. The scientists are working on the use retinal veins that are present in the human eye, which are very difficult to be captured by the present thermal camera.

Conclusion

From the previous discussion it is clear that thermal images don't need any special techniques for processing other than common DIP tools.

Recent researches proved that thermal imaging have outperformed visible bands in the field of human biometrics in many challenges. The use of thermal imaging for biometrics is still not fully implemented because of two main factors:

1. The popularity of conventional biometric methods, their accuracy and cheapness.
2. The cost of equipment i.e. thermal camera is very high which not affordable to be installed in small scale applications.

But there still a lake for researches that introduce a fair comparison between the two bands that may introduce challenges of this new approach.

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