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Face recognition in the SWIR band when using single sensor multi-wavelength imaging systems☆

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ABSTRACT

In this paper, we study the problem of Face Recognition (FR) when using Single Sensor Multi-Wavelength (SSMW) imaging systems that operate in the Short-Wave Infrared (SWIR) band. The contributions of our work are four fold: First, a SWIR database is collected when using our developed SSMW system under the following scenarios, i.e. Multi-Wavelength (MW) multi-pose images were captured when the camera was focused at either 1150, 1350 or 1550 nm. Second, an automated quality-based score level fusion scheme is proposed for the classification of input MW images. Third, a weighted quality-based score level fusion scheme is proposed for the automated classification of full frontal (FF) vs. nonfrontal (NFF) face images. Fourth, a set of experiments is performed indicating that our proposed algorithms, for the classification of (i) multiwavelength images and (ii) FF vs. NFF face images, are beneficial when designing different steps of multi-spectral face recognition (FR) systems, including face detection, eye detection and face recognition. We also determined that when our SWIR-based system is focused at 1350 nm, the identification performance increases compared to focusing the camera at any of the other SWIR wavelengths available. This outcome is particularly important for unconstrained FR scenarios, where imaging at 1550 nm, at long distances and when operating at night time environments, is preferable over different SWIR wavelengths.

1. Introduction

In a biometric-based recognition system, there are different modalities that can be used (fingerprints, face, iris, retina, voice etc.). Among those modalities, face is considered one of the top choices because, face recognition is one of the most common human experiences: it is easy to capture at a distance and in a non-cooperative manner and, finally, face recognition (FR) technology is fairly accurate. Depending on the application, face can be used either independently or in combination with other modalities in order to increase the performance of human recognition systems.

There are a number of practical issues that still need to be solved with FR systems. When designing such systems, one has to deal with a variety of problems that arise from each module of the overall architecture, i.e. data collection, transmission, data storage, signal processing and decision making. The data collection module has its own challenges. For example, FR systems perform well with frontal faces captured under controlled conditions (indoors, short standoff distance, controlled illumination). The problem becomes more complicated when face images are captured under variable illumination conditions, expressions and poses.

Another problem is when the collection of face images is performed using sensors that operate at different spectral bands (visible or infrared). The main question here is "depending on the application and the conditions (controlled or uncontrolled) under which we operate, which band should be selected (either independently or in combination with others) so that we can achieve high face/eye detection and face recognition accuracy?". Since we are dealing with different camera systems, covering different bands (multi-spectral imaging) and different wavelengths within each band (hyperspectral imaging), lets move on to discuss about the IR spectrum and the focus of our work.

The infrared (IR) spectrum is comprised of the active IR band (near-IR or SWIR), and the thermal (passive) IR band. The passive IR band is further divided into the mid-wave (MWIR) and long-wave IR (LWIR) bands. The MWIR range is 3 μm to 5 μm, whereas the LWIR range is 7 μm to 14 μm. Both MWIR and LWIR cameras can sense temperature variations across human faces at a distance and produce thermograms in the form of 2D images. In this paper, our work is focused in the SWIR band. It is a part of the reflected IR (active) band (in our experiments, it ranges from 0.9 μm to 1.7 μm). SWIR has a longer wavelength range than Near Infrared (NIR) and is more tolerant to low levels of obscurants like fog and smoke. Differences in appearance between images sensed in the visible and the active IR band are due to the properties of

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the object being imaged. The reflected spectral signatures in the SWIR band require an external light source. However, some of the benefits of SWIR-based imaging systems are that they can take advantage of sunlight, moonlight, or starlight [1]. Another benefit is that when images in the SWIR spectrum are fused with visible images, FR performance can increase [2].

There are three main disadvantages of using the SWIR band in comparison to the LWIR band. First, thermal imagery can be acquired without any external illumination in day or night environments, while regions in the active IR band might require an external light source. Second, vein patterns or other anatomical features not observable in the SWIR band, can be observable in the LWIR. Finally, background clutter in thermal images is not always visible. For example, the texture of a wall will not usually be visible if it is uniform and has the same surface temperature signature. Thus, under certain conditions, we can say that when operating in the thermal band, the tasks of face detection, localization, and segmentation (fundamental processes of a typical face recognition system) are comparatively easier and more reliable than when operating in the active IR and visible bands.

1.1. SSMW face recognition systems in the SWIR band

Conventional imaging systems use a specific sensor (e.g. an SWIR camera) that can be operated without an external hardware, and utilize their complete spectral range to capture images. The information is collected over the wide spectrum and the integration process is responsible for getting less qualitative information than multi-spectral systems. Moreover, it is difficult to separate the information related to the light distribution (amount of light absorbed and reflected back from an image) when operating at an arbitrary band. *Multi-Imaging Systems* (MIS) are either *Multi-Sensor* (MS), *Single-Sensor Multi-Wavelength* (SSMW), or a combination of the two, i.e., *Multi-Sensor Multi-Wavelength* (MSMW). MIS are composed of multiple sensors that operate in different bands. For example, we can use band-specific cameras to acquire images in the visible, NIR and SWIR bands. On the other hand, SSMW imaging systems utilize a single imaging sensor in combination with external hardware. Such systems, before applying the aforementioned processing steps, are capable of acquiring images at specific wavelengths within the same band, e.g. a camera system like that can have a set of wavelength-selective band pass filters placed in front of a camera.

The key drawback of current SWIR-based face image acquisition systems is that they lack the capability of real-time simultaneous acquisition of multiple, wavelength-specific face images. In our work, we have developed a SSMW face image acquisition system, where faces are acquired at a selected set of wavelengths. The proposed system supports the acquisition and usage of unique facial information per individual that can enhance the performance of our proposed FR system. However, when using a SSMW system, such as the one proposed for the purpose of this work, there are challenges that the system designer has to mitigate.

During data collection, in order to acquire good quality face images, different design steps need to be considered, including the selection of the appropriate hardware components and image acquisition parameters that the practitioner can select via the graphical user interface that handles image acquisition. Design steps include (i) the selection of light source (e.g. tungsten, fluorescent etc.), (ii) the selection of the wavelength to focus the camera during data collection, (iii) the setting up of the optical sensor response, (iv) the camera and filter wheel synchronization, and (v) the set up of the filter wheel speed. In our previous work [3], an empirical optimization of the experimental set up was performed to acquire good quality face images. In this work, we are focusing on developing the necessary algorithms to further pre-process the acquired good quality face images. This design step is very important because it can further contribute to the performance of our proposed SSMW FR system. What follows is a description of the three specific challenges that this paper is addressing.

- *Challenge 1, classification of multi-wavelength face images to individual IR wavelengths*: The purpose of our proposed classification approach is that, in practice, during or after data collection, an operator needs to deal with the processing of many face datasets (as we will show, the data were captured at five different wavelengths within the SWIR band). This can be a large pool of images that need to be categorized to the right wavelength. When this effort is performed manually, it can be very time consuming and can result in many errors, especially when dealing with large datasets [4]. Thus, classification needs to be performed automatically, using either supervised or un-supervised methods [5]. In this work, we propose an *automated quality-based score level fusion scheme for the classification of multi-wavelength face images*. Classification is performed using a combination of parametric and non-parametric statistical-based methods, namely an estimation-based Bayesian Classifier [6] and a multi-wavelength face image *k*-NN classifier [7]. The big challenge we originally had to deal with was the extraction and, then, selection of features. The way we mitigated this challenge will be discussed in detail in the Methodology section.
- *Challenge 2, classification of frontal vs. non-frontal face images*: FR systems perform well when dealing with full-frontal face images. In this work, our collected SSMW dataset consists also of face images captured at variable face poses. In order to keep only full-frontal, good quality, face images to be used for FR studies, *we developed an automated method that classifies frontal* vs. *non-frontal face images based on a set of image quality scores*. These scores were generated by estimating different image quality factors (such as blurriness).
- *Challenge 3, wavelength-based selection of frontal face images for improved FR performance*: Our SSMW FR system was used to first focus the camera at various wavelengths, and then, capture multiple face samples at various wavelengths and at various poses and light sources. Thus, it is pertinent to investigate under which conditions good quality, full frontal, face images can be selected out of the raw dataset for further processing (face matching). The goal is to have a *fully automated system* where *accurate localization of faces and eyes* as well as *high recognition performance* can be achieved. The system should be able to perform well when using the normalized face images generated from the selected full frontal, good quality dataset constructed after we successfully mitigated the previous two challenges.

1.2. Goals and contributions

In this paper, our main contributions are the following: (i) A SSMW system is designed and developed that operates within the SWIR band. By using our system, a database was collected under the following scenarios, i.e. Multi-Wavelength (MW) images were captured (by placing a tunable filter wheel in the optical path) when the camera was focused at either 1150, 1350 or 1550 nm. We also developed, a hybrid image quality assessment method (reference and no-reference-based) to compute different image quality scores from our collected face images. (ii) An automated image quality-based score level fusion scheme was also designed and developed. The purpose of this scheme was the automated classification of multi-wavelength face images to individual wavelengths. Note that the images were acquired when the camera was focused at three different SWIR wavelengths, namely the 1150, 1350 and 1550 nm. (iii) An image quality, weighted-based, score level fusion scheme, was designed and developed for the automated classification of full frontal vs. non-frontal SWIR face images. (iv) A set of experiments were conducted indicating that our proposed classification algorithms developed are beneficial when designing different steps of a multi-spectral face recognition (FR) system, including face detection, eye detection and face recognition. In the latter set of experiments, we also determined *the most beneficial wavelength to focus the camera* in order to acquire good quality SWIR face images and achieve increased