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3D fingerprint imaging system based on full-field fringe projection profilometry

Shujun Huang, Zonghua Zhang*, Yan Zhao, Jie Dai, Chao Chen, Yongjia Xu, E. Zhang, Lili Xie

School of Mechanical Engineering, Hebei University of Technology, Tianjin 300136, China

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ABSTRACT

As an unique, unchangeable and easily acquired biometrics, fingerprint has been widely studied in academics and applied in many fields over the years. The traditional fingerprint recognition methods are based on the obtained 2D feature of fingerprint. However, fingerprint is a 3D biological characteristic. The mapping from 3D to 2D loses 1D information and causes nonlinear distortion of the captured fingerprint. Therefore, it is becoming more and more important to obtain 3D fingerprint information for recognition. In this paper, a novel 3D fingerprint imaging system is presented based on fringe projection technique to obtain 3D features and the corresponding color texture information. A series of color sinusoidal fringe patterns with optimum three-fringe numbers are projected onto a finger surface. From another viewpoint, the fringe patterns are deformed by the finger surface and captured by a CCD camera. 3D shape data of the finger can be obtained from the captured fringe pattern images. This paper studies the prototype of the 3D fingerprint imaging system, including principle of 3D fingerprint acquisition, hardware design of the 3D imaging system, 3D calibration of the system, and software development. Some experiments are carried out by acquiring several 3D fingerprint data. The experimental results demonstrate the feasibility of the proposed 3D fingerprint imaging system.

1. Introduction

Biometrics means recognizing (verifying or identifying) a person by using the inherent physiological or behavioral characteristics of human body [1,2]. Physiological characteristics refer to data directly measured from the human body parts and some representative physiological features include fingerprints, hand shape, palmprint, face, iris, retina, and so on; while behavior characteristic is a measure of personal habitual action indirect from human body characteristics, such as voice, keystroke habits and signature. Human recognition based on biometrics is widely applied in many fields like government, army, bank, social welfare safeguard, e-commerce, security defense, and to name a few.

Fingerprint, as one of the most important biometrics, has been widely studied and applied to personal recognition in both forensics and civilian. It is a unique and unchangeable physiological characteristic of human being during the whole life. The traditional 2D fingerprint has been captured by using an ink-based offline method or an imaging device, for example a CCD camera, to get an image for recognition. These methods need the subject to press (roll) his/her fingers against a surface to obtain 2D fingerprint image, so that the captured 2D fingerprint images are often distorted in a nonlinear way. Such nonlinear distortion increases the intra-class variations among the fingerprint images of the same finger and introduces matching errors. The existing 2D methods are also greatly affected by the brightness and contrast of environmental light, the dirty things on finger surface, so the matching results are inaccurate.

Due to 3D to 2D mapping, the captured fingerprint features by using 2D methods have unavoidable distortion and illumination shading [3,4]. Therefore, identification and verification are based on the captured inaccurate 2D fingerprint biometrics. Jain [1] pointed out that "Efforts are afoot to design better biometric sensors/readers, to improve algorithms to extract features from raw biometric data and to match two biometric samples quickly and accurately". In fact, fingerprint is a 3D biometric feature and has many advantages in comparison to 2D biometrics. Firstly, due to non-contact operation, there is no elastic deformation of the obtained features; secondly, 3D fingerprint can obtain the characteristic distribution patterns of fingerprint without distortion; thirdly, they give local space coordinate geometry and azimuth of fingerprint in details; finally, they are insensitive to brightness, contrast of environmental light, and dirty things on finger surface.

With the development of CCD cameras and DLP (Digital Light Processing) projectors, 3D biometrics have been widely studied in recent years. 3D face recognition [5] is in a period of rapid expansion and 3D ear recognition [6,7] is in the very early stage. A few researchers have attempted 3D fingerprint as biometrics.

* Corresponding author. Tel.: +86 22 265 824 03; fax: +86 22 602 041 89.
E-mail addresses: zhzhangtju@hotmail.com, zhzhang@hebut.edu.cn (Z. Zhang).

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Parziale et al. [8] reported one surround imager by using multi-camera system to acquire different finger views, so that 3D representation of fingerprint is obtained by using shape-from-silhouette method. Recently, a new type of touchless 3D fingerprint identification access control system is developed by TBS in Switzerland (www.tbs-biometrics.com). It greatly improved the accuracy of access control and attendance system. Wang et al. [9] employed a noncontact 3D method based on phase measuring profilometry (PMP) to acquire 3D ridge-depth information of human finger. Gabai et al. [10] introduced a dual-channel interferometric imaging system to obtain phase imaging of fingerprints. Due to the speckles in interferometry, the obtained phase and then shape information are inaccurate.

This paper presents a new imaging system to get 3D fingerprint data based on the sinusoidal fringe projection technique [11–14]. The system includes a color CCD camera, a small DLP projector and a laptop computer. The straight sinusoidal fringe patterns are generated by software in the computer and projected onto the finger surface by the DLP projector. From another viewpoint, the fringe patterns appear deformed with regard to the finger surface shape. The modulated fringe patterns are recorded by the CCD camera and saved into the computer for post-processing. Combining four-step phase-shifting algorithm [15] and optimum three-fringe number selection [16–17] can independently calculate absolute phase at each pixel position. An automatic 3D calibration method builds up the relationship between absolute phase map and 3D shape, so that 3D fingerprint data can be obtained.

The following section introduces the principle of 3D fingerprint imaging system based on absolute phase measurement. Some experiments on capturing 3D fingerprint are demonstrated in Section 3. Section 4 gives the conclusions and future directions.

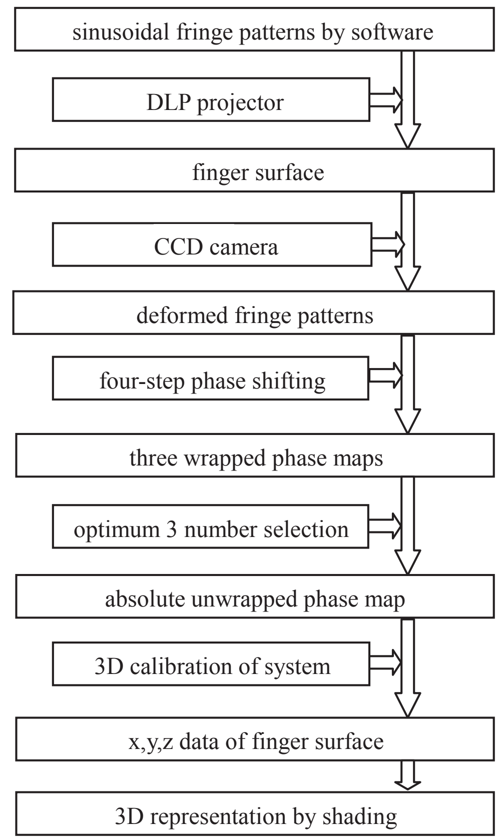

Fig. 1. Flowchart of 3D fingerprint data acquisition and processing.

2. Principle of 3D fingerprint system

Phase calculation-based full-field sinusoidal fringe projection technique is used to obtain 3D shape of fingerprint. Three wrapped maps are calculated by using four-step phase-shifting algorithm and optimum three-fringe number selection method is applied to independently calculate the absolute phase information pixel by pixel. After 3D calibrating the system, the absolute phase at each pixel position can be converted into x, y, and z coordinates. Fig. 1 shows the flowchart of 3D fingerprint data acquisition and processing.

2.1. Components of the 3D imaging system

The proposed 3D fingerprint imaging system is based on the full-field sinusoidal fringe projection technique, as demonstrated in Fig. 2. It consists of a DLP projector, a color CCD camera and a laptop computer. The DLP projector and the CCD camera satisfy a conventional triangulation arrangement. Sinusoidal fringe patterns are generated by software in the computer and projected onto a measured finger surface by the DLP projector. From another different viewpoint, the fringe patterns are deformed with respect to the finger surface and ridges. The CCD camera captures the deformed fringe patterns and saves them into the computer for post-processing.

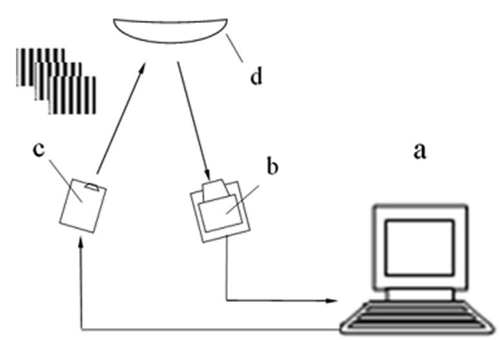

Fig. 2. System schematic diagram. (1) Computer, (2) CCD Camera, (3) DLP projector, and (4) finger surface.

2.2. Four-step phase-shifting algorithm

Multiple-step phase-shifting algorithms have been widely used to calculate phase information because of their high accuracy. Among them, four-step phase-shifting algorithm is one of the most used phase calculation method in fringe pattern processing and has gained many achievements in research and industrial fields [15]. There are $\pi/2$ shift in between for the four fringe patterns. In order to make this paper self-contained, the mathematical model and distribution characteristics of fringe patterns are briefly described.

The intensity distribution of a captured fringe pattern can be expressed by the following mathematical expression:

$$I(m,n) = I_d(m,n) + I_m(m,n)\cos\,\varphi(m,n) + I_n(m,n) \quad (1)$$

where m, n are the index of a pixel in the captured image along vertical and horizontal direction, respectively; $I(m,n)$ is the measured intensity at (m,n) pixel position; $I_d(m,n)$ and $I_m(m,n)$ are the intensity of background and the fringe modulation, respectively; $\varphi(m,n)$ is the phase corresponding to the measured object shape; $I_n(m,n)$ is he additive random noise during capturing process.

Four-step phase-shifting algorithm means four fringe patterns have $\pi/2$ phase shift in between are successively projected into the

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