3D measurement of human faces for biometric application by digital fringe projection with digital light projection (DLP)

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Abstract: Facial recognition of people can be used for the identification of individuals, or can serve as verification e.g. for access controls. The process requires that the facial data is captured and then compared with stored reference data. In order to obtain better identification and verification performance and to avoid a number of security weaknesses, 3-dimensional facial recognition systems can be used, which outperform in both cases the 2-dimensional systems that are currently used. In this context, an optical 3D face scanning system with structured light projection based on DMD will be introduced, and the performance of the system will be analysed.

1 Introduction

1.1 Recognition of a person by their face

People are characterized by their individual biometric attributes, and facial recognition is the most natural means of biometric identification. The method of distinguishing one individual from another is an ability of virtually every human. Our brain uses a specific area for facial recognition called the Fusiform face area (FFA).[1] In the Regulation of the European Council of 2004 on the standardization of security features and biometrics in passports for EU citizens [4], the use of digital facial images and fingerprints in all future EU passports was established. Electronic facial images are already in all newly issued German passports since November 2005. The capturing of the image is proceeded in two steps. As shown in *Fig. 1.1*, there are guidelines on how

Fig1. 1: Sample for Biometric Picture
Source:www.Bundesdruckerei.de

to adjust the face by using the pupillary line and nose. Currently, a modification of the passport law is being prepared for the integration of fingerprint images [5]. These images do permit a limited representation of the three-dimensional structure and spatial recognition or computation of the examined images. However, a 2D image recognition system can not investigate information regarding shape or metrics of a body.

An additional and very important disadvantage of 2D recognition systems is their safety factor. 2D facial recognition systems can be cheated. Using a photograph, an image on the screen of a laptop, or even one on a mobile phone has been enough to register a pass from the systems. Finally, 2D recognition systems cannot be used in environments where additional human interaction is not available.

1.2 State of the art of 3D facial recognition systems

To improve the performance of facial recognition systems in the border control or identity management system is the present objective of academies and other research and development projects. The addition of a further dimension to gain 3D information of the human face could improve the whole process and take facial recognition systems into a new field of applications.

The acquisition of texture images as well as 3D data promises a significant improvement of recognition performance as well as increasing safety of the identity management system against false matching. The sensitivity of a three dimensional image can be sufficient to identify a human face even if the position of the head is different compared to the reference image by means of the capturing position and angle. The far greater advantage of 3D systems is that they are insensitive to the variability of object size with each measurement, which is a problem with 2D systems and is due to the difference in the distance between the imaging system and the human face during different measurements.

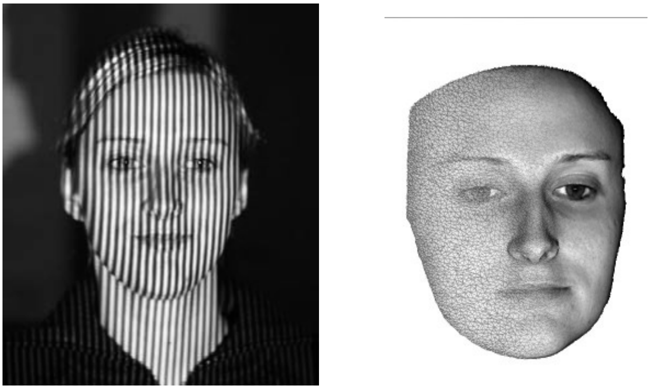

Fig. 1.2: Face with projected fringes and measurement including color texture

Three dimensional systems capture data with correct measurements of the face, and there is no centric shift. The three dimensional systems can not be fooled by a 2D replication of the face, like a photograph. In this case the system would recognize the lack of depth information and would not confirm the match.

From the working flow chart of the 3D facial scanning system (see *Fig 1.3*), it can be seen that after the establishment of the system, the calibration has to be carried out.

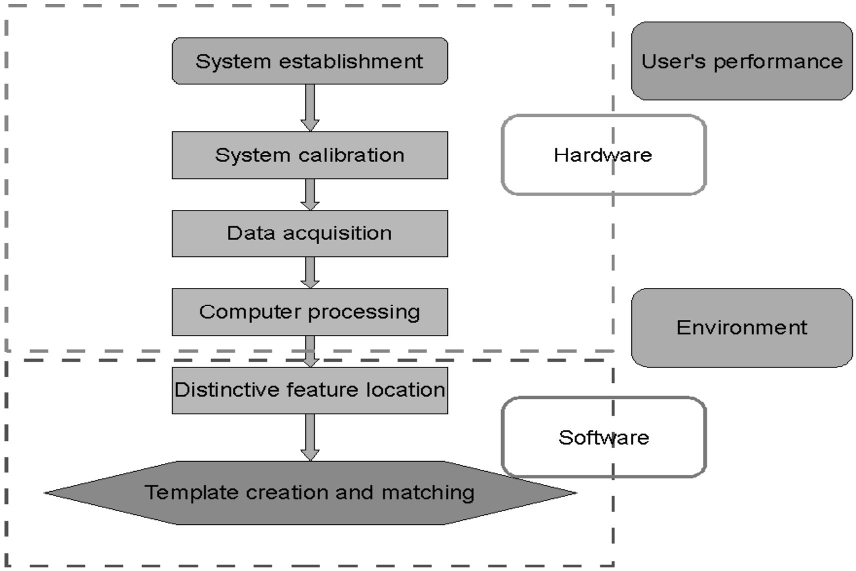

Fig. 1.3: Basic working flow of the 3D face scanning system

Many methods for the design of the 3D sensors used in data acquisition systems are well known, e.g. for stereo vision, time-of-flight (TOF), structured light, focusing methods, shading methods, etc.

Algorithms used to locate the distinctive features of the human face have been developed since late 1980's. However, throughout the spectrum of this research in facial recognition, only a very small portion has been directed toward the development of 3D methods.

Some 3D matching algorithms which are used to recognize and verify the human face that are well known are ICP (iterative closest points), the extension of the Eigenfaces approach and elastic graph matching. Both the Eigenfaces approach and elastic graph matching are extensions of 2D techniques.

The verification performance of current 3D face recognition has been reviewed widely. Furthermore, the results of this performance strongly depend on the operating conditions such as the environment (lighting and background) and the user's performance (distance from camera, orientation, expressions, etc.). [14]

1.3 Requirements of a 3D face scanner for recognition systems

A 3D shape scanning system can yield valuable information in regards to the identification of persons at border or entrance control without the need of further human observation. 3D acquisition technologies are already established not only throughout the world of industrial metrology for measuring rigid objects but also for application in life sciences to measure in vivo on human skin [12].

In order to apply these established technologies to the human identification and verification systems we have to take several requirements for these types of measurement instruments into account. Basic requirements in order to use 3D face scanning in an identification and verification system:

- Accuracy of measurement and capturing time

Accuracy and capturing time are two components which counteract each other. The measurement time depends upon the quantity of different light patterns projected on the object being imaged. When less light frames and different light patterns are used, the overall capturing time will be shorter. On the other hand, with an increase in the number of pattern sequences, the measurement noise is reduced and the robustness of the acquired data is increased.

- Short searching and verifying time

Speed is a requirement in the application of border control and identity management systems, as users will not appreciate long waiting times for the identification and verification to take place. Shorter searching and verifying time of the recognition system must be taken into account for improvement of the system.

- Stability

After the calibration of the whole system, the coordinate matrix and the parameters and coefficients of the algorithms in the system are calculated and saved. During long term operation of the system, some of the parameters of the hardware of the system may be shifted. (The angle between the projector and the image scan device can change due to elastic deformation of the inner construction, etc.) These changes will critically influence the verification results, so the stability of the system is very crucial for the human facial scanning system.

- No influence of different lightning conditions

The internal light source of the scanning system must be as strong as possible and independent from the uncontrolled surrounding light sources. Ultimately, the limiting factors regarding eye safety and safeness must be adhered to, so the internal light source is used according to the above mentioned regulations, and not at a potentially higher brightness. In addition, the light emission spectrum of the LED light source is similar to that of sun light, which means that direct sun light can influence the measurements.

- Minimal user cooperation

The acceptance of any technology depends very strongly on the amount of increased human cooperation needed from the user. The more requirements that a person must comply to in order to complete the process, the less the likelihood is of acceptance. One of the major ways to reduce the requirements on the user is to ensure that the system can provide an accurate measurement with only one trial. Every failed attempt by incorrect system operation will reduce the reliability and the acceptance of such a system.

- Less influence by user's performance

The basic principle of biometric face measurement is that every single face is unique. However, for biometric face measurement to be successful, the system needs to be capable of differentiating between concrete differences of facial features (feature shape, size, position and relative distance) and superficial changes made by the users (sunglasses, cosmetics, facial hair, jewelry, piercings, tattoos, etc.) This poses a challenge to the capturing technology, and to be successful, these factors should not impress the scanner and influence the measurement results.

1.4 State of the technology

In addition to the goal of improving the science and technology, there is also the requirement of many industrial applications to have accurate and rapid measurement of 3D shape information of objects. The contact-based 3D shape measurement system which consists of a Coordinate Measuring Machine (CMM), a coordinate measuring arm and a laser tracking system is no longer fulfilling the requirements from customers [2].

- The contact-based techniques require a lot of time to measure points on the parts' surfaces through the use of mechanical probes.
- In cases that the object surface which needs to be measured is soft, fragile or easy to be scratched, the contact-based technique will not work.
- The contact-based measurement techniques are indirect measuring techniques. (The 3-D point coordinates obtained in measurement are not of points on the object's surface but positions of a characteristic point on the measuring device.)

In order to solve the problems associated with the contact-based measurement techniques, many non-contact measurement methods have been developed, such as photogrammetry, laser scanning and structured light, etc. All of these techniques use digital imaging and triangulation methods to resolve the shapes of objects. Compared to contact-based measurement techniques, non-contact methods are much faster. They are able to measure thousands or even millions of points on the objects' surfaces in a few seconds. There is no need to touch the surface during the measurement and offsetting of point coordinates is not required. Furthermore, non-contact techniques can also provide good measurement accuracy and precision. These kinds of techniques can be used in face scanning systems as well.

The laser scanning technique measures the shape of object by scanning a laser beam or projecting a laser sheet on the surface of the object and observing the laser spots in different positions and angles by using a camera. Laser scanning systems offer good accuracy and high data rates (thousands of points per sec.). But it is a line-scan device, and an additional device is required to reposition the laser so that it can measure the whole area of an object (CMM, etc.)

The photogrammetry is a kind of technique which measures the 3D shape of the object by combining two or more perspectives to a 3D view of the object. Special marks have to be applied as retro-reflective targets on the surface of the object which needs to be measured. However, by using the technique of applying special marks on the measuring object, the number of points obtained in one measurement cannot be very high. So the data rate of photogrammetry is quite low.

The structured light method comes closer to fulfilling the requirements listed in Section 1,3, and compared to other non-contact 3D measurement techniques, like photogrammetry and laser scanning, the structured light method allows for higher data rates and lower costs. A typical 3D shape measurement technique based on structured light consists of one projection unit and one or more camera units. During the measurement, the structured light pattern is projected on the object, images under the projection are captured by the camera and the 3D shape is resolved by using the triangulation method. The fringe light pattern is commonly used for shape measurement; it is often called a Shape Measurement based on Fringe Patten (SMFP). Nowadays, digital projectors offer increased performance over traditional projection techniques (glass grating and laser interferometry) in terms of shape measurement. The shape measurement with digital projectors is often referred to as Shape Measurement based on Digital Fringe Projection (SMDFP).

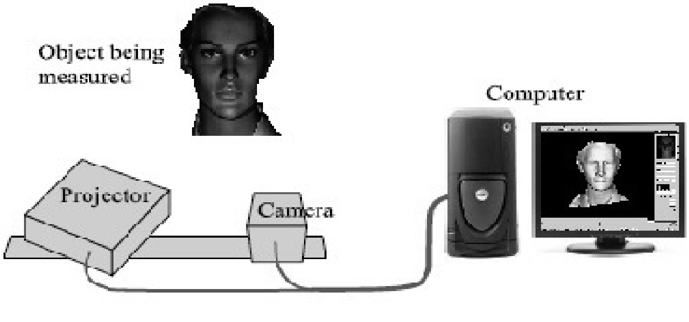

Fig. 1.4: The typical face scanning system with SMDFP technique

Fig. 1.4 shows a typical SMDFP system. It consists of one computer fringe projector and one camera. The projector and camera are placed away from each other with a defined angle between their optical axes. Both the projector and the camera are controlled by the computer system. The object to be measured is placed in the measuring field where it will be covered by the fringe light pattern. After the image acquisition by the camera, the digital data will be resolved and processed by the computer system and the 3D shape information will be showed on the monitor.

1.5 Digital projection based on DMD

The accuracy and repeatability are crucial to the success of the 3D shape measurement, and a number of different technologies for fringe projection and data acquisition have been developed in order to obtain an accurate 3D point cloud of a measured object. There are different methods and devices for the generation of the digital fringe pattern, such as: DLP, LCD, fixed gratings, frequency modulated gratings and others. Recently, computer projection based on Digital Micro-mirror Devices^{TM} (DMD^{TM}) has gained more and more weight in SMDFP systems compared to other fringe projection techniques.

The digital fringe projection used for the face scanning device uses a DMD, which were developed and introduced by Texas Instruments Inc., U.S.A in the early 1990's.[2] Using the DMD solution, Texas Instruments has opened up a completely new concept of digital light projection. The DMD matrix used for measuring devices is based on a micro-mechanical silicon chip with 800 x 600 or 1024 x 768 single mirrors Each mirror has an area of 13 sq µm and the distance between each mirror is 1 micron. The average diameter of a human hair thus corresponds to an area of about four micro-mirrors. An REM image of micro-mirrors is shown in *Fig. 1.5 and Fig. 1.6* below:

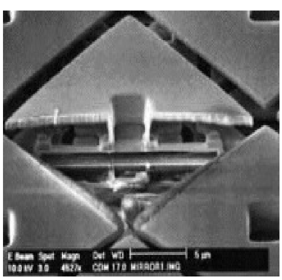

Fig 1.5: Single mirror

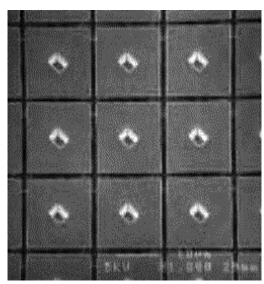

Fig 1.6: part of a DMD

Each individual micro-mirror can be controlled to move with great precision at very fast speed. The light pattern generated by a DMD projector can reproduce a high resolution gray-scale bitmap. The value of each pixel can be set individually to at least 256 different levels. Due to the large number of pixels and precise controllability, it is possible to generate a fringe light pattern with different fringe widths, fringe orientations and phase-shift values.

2 GFM face scanner

The prototype of the GFM face scanner is equipped with a DLP based projection unit and one camera. The light source of the projector is a LED light source. Paying careful attention to eye safety, the exposure limit values are 28 sec of exposure at a distance of 10cm. The nominal measurement distance for the GFM scanner is 72.5 cm which allows an exposure time of more than 230sec. The color texture is captured by using the color projection option of the DLP projector. The three RGB color sequences are projected and superimposed onto the measured 3D profile of an overlay and represent the complete color information of the recorded face.

The prototype for the GFM face scanner is shown in *Fig 2.1* and the measurement principle is based on the above mentioned structured light method using DLP technology from Texas Instruments. The device consists of a DLP projection unit with SVGA resolution and a fast grey scale camera with high resolution for capturing the 3D data of the human face.

The camera for the face scanner provides a resolution of XVGA pixels with a frame rate of 60 Hz. The time for the data acquisition by the CCD camera is separated into the procedure of measuring the 3D shape and capturing the colour texture.

The field of view of the face scanning device is 400 x 300 sq mm and the resolution of about 30 µm can be achieved.

Fig 2.1: CAD model of the prototype design model

3 Performance analyses

In order to apply this face scanning system into the human face identification and verification system and fulfill the requirements for better adaptability in different border control and identity management applications, the special interface and software module with specific calibrating algorithm, image processing algorithm and matching program have been developed (*see Fig. 3.1*). The attractive performance of GFM face scanner will be showed in this chapter.

Fig 3.1: New GFM Software for recognition

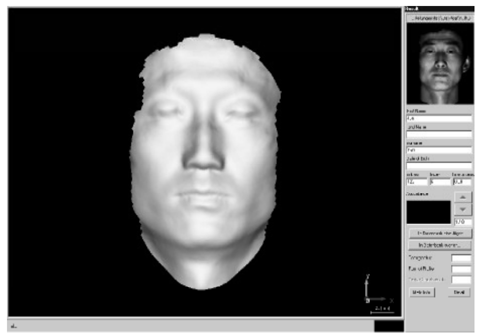

Fig 3.2: The data key in the data base (2,75KB)

- **Accurate calibration**

An accurate calibration is the most essential step in achieving better human face recognition results. In order to make an accurate calibration, one precise and standard calibration board with grids is utilized in the calibration process of the face scanning system. From the calibration, different coordinate systems of the camera, projector and the object can be calculated and transformed accurately, and the system parameters needed for calculating and processing will have good incipient values. After calibration of the face scanning system, typical values of the topographic deviation are less than 0, 04 mm.

- **Fast data acquisition**

To obtain the 3D shape of a human face, a number of shifted fringe patterns will be projected and recorded. The complete 3D measuring process is finished in less than 200ms. For the registration of the colour texture only the three RGB-colour pictures are digitally projected and recorded. This will take an additional 50ms. This data acquisition time ensures that error will not be introduced due to movement of the object. Furthermore, longer waiting time is not necessary.

- **Facial feature location and small template creation**

After the image processing in the computer with the special algorithm, the distinctive human face features can be determined, and a very small template (less than 3KB) with almost all the needed facial feature information can be generated in the database. (See *Fig. 3.2*) Due to the very small template in the database, the searching and verifying time can be very short in the human face identification and verification process. For example, in a database that contains data from N=120 different human faces, the 1:N identifying and searching time can be shorter than 1,25 s. And the 1:1 verification time can even shorter than 0, 2 s.

- **Less influences by user's performance**

In order to obtain the verification performance which fulfills requirements from customers, GFMesstechnik developed a software module with specific algorithms for coordinate transformation and for image matching. The software was created to compare images with different performances and cosmetic treatments from the user (e.g. with glasses, different orientation, different distance from camera, with hat, with different hair style, etc.).

Fig. 3.3: Picture with glasses before matching

Fig. 3.4: Picture with glasses after matching

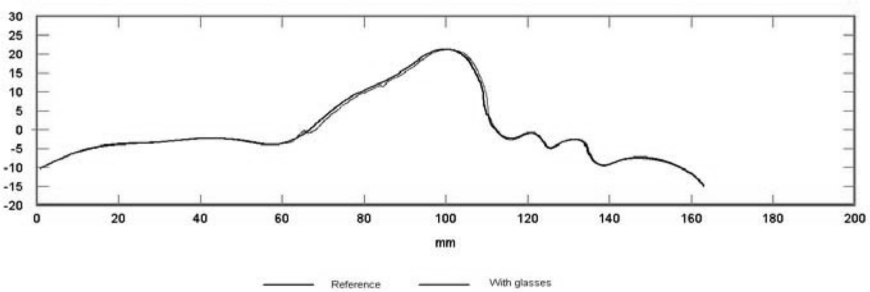

Fig. 3.5: Cross section according to the cross line in Fig. 3.4

From these four pictures below which are taken from a volunteer with minimal cooperation, the verification performance of the software module can be seen. The leftmost picture in *Fig. 3.3-3.4* shows the reference and the second picture shows the volunteer using her glasses. Furthermore the orientation is not similar to the reference. A 2-dimensional comparison seems to be very difficult or impossible. The 3-dimensional matching function was able to match the pictures without problems, accurately and very fast. A cross sectional line was fitted into the pictures after matching and the cross section is shown in *Fig. 3.5.*

The example given by *Fig. 3.6* shows another significant case of poor performance by the user. Here, the user is wearing sunglasses, wearing a hat, and is poorly oriented towards the system, and these conditions are all absent from the reference. However, a significant match is still recognized by the GFM face scanning system.

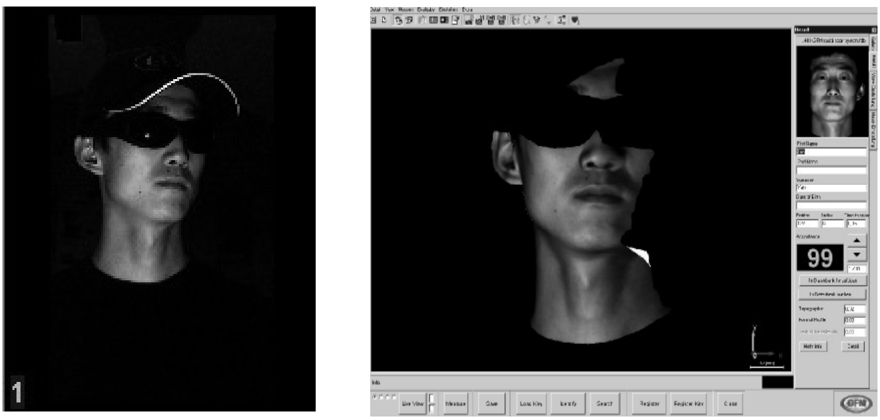

Fig 3.6: The verification result of the user with sunglasses, hat and different orientation

- **High stability**

As mentioned the requirements of face scanning system in the identity management system in the chapter 1.3, the stability of the face scanning system is quite crucial. The perfect ATV (ability to verify) must be achieved by the face scanning system in long term conditions.

Long-term, stable performance is the most important issue of the face scanning system in the identity management system. Good identification and verification performance has to be assured during the stable period of the face scanning system after the system calibration.

According to the stability analysis of the face scanning system through a long-term experiment, the face scanning system developed by GFMesstechnik is able to work stably for at least three months without re-calibration. The performance can be seen in the graph in *Fig. 3.7*, which shows that over a three month period without re-calibration, the deviation in results of scanning from day to day was rarely enough to bring recognition below 100 percent.

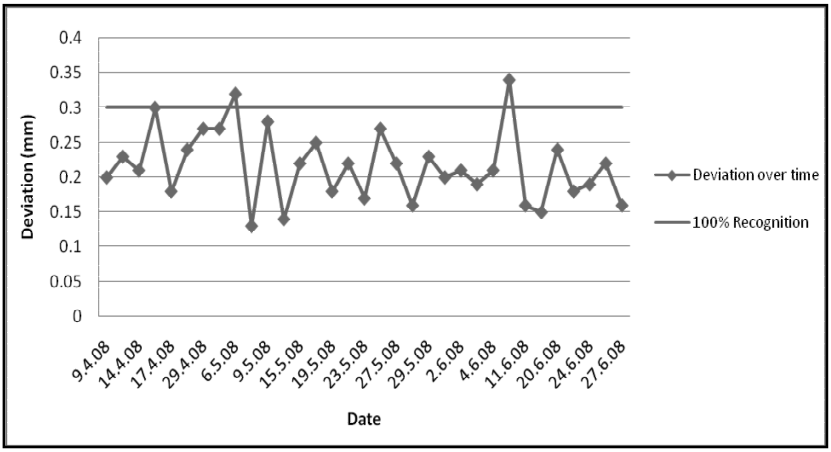

Fig. 3.7: Measurement deviation of the same person in three month
(Calibration date: 08.04.2008)

4. Conclusion

An optical 3D measurement procedure with a prototype for a biometric face scanning device on the basis of the digital fringe projection method with DLP technology from Texas Instruments is presented. The device in the current configuration is able to scan human faces in a short time and the measurement results are stable against different positions, different background lighting and long-term working conditions. The color texture will be captured by taking three more images of the RGB-color projection. It is not necessary to use an additional camera for the color texture. The use of the Texas Instruments micro mirror device ensures spatially as well as chronologically highly resolved measurements of the face within a precision range of a few micrometers.

The software used could recognize a person with different performances in factors like distance, orientation and with suitable modifications of the face like different hair style or wearing glasses. Much shorter identification and verification time is also achieved by the software module with specific processing and matching algorithms. Further steps of improvement should be the implementation of light sources in the near infrared light spectrum. This will reduce the influence of other light sources – especially sun light. A further optimization aim is to reduce the capturing time and enable the GFMesstechnik face scanner to measure in real time.

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