Stand-off Biometric Identification using Fourier Transform Profilometry for 2D+3D Face Imaging

Brian Redman, John Novotny, Taylor Grow, Van Rudd, Nathan Woody, Michael Hinckley, Paul McCumber, Nathan Rogers, Michael Hoening, Kelli Kubala, Scott Shald, Radek Uberna, and Tiffanie D'Alberto

Lockheed Martin Coherent Technologies
135 S. Taylor Ave., Louisville, CO 80027
ph. 303-729-5463, fax: 303-379-3146
brian.c.redman@lmco.com

Thomas Höft

Tufts University
Department of Mathematics
Bromfield-Pearson Hall
503 Boston Avenue
Medford, MA 02155

Russell Sibell

SIBELLOPTICS
815 Beauprez Avenue
Lafayette, CO 80026

Frederick W. Wheeler

GE Global Research
1 Research Circle
Niskayuna, NY 12309

Abstract: We developed and tested a Fourier Transform Profilometry, 2D+3D face imager operating with subjects moving at ≤1.5 m/s at ≤25-m range with <1.4-mm resolution and range precision at 1-Hz capture rate using low cost components.

OCIS codes: (150.6910) Three-dimensional sensing; (110.6880) Three-dimensional image acquisition; (120.2650) Fringe

1. Introduction

The ability to capture biometric data from minimally cooperative subjects with a minimally invasive system at significant stand-off distances is desired for security and defense applications. Lockheed Martin Coherent Technologies has developed a Fourier Transform Profilometry (FTP) based 2D+3D face imager operating with minimally- to non-cooperative subjects moving at ≤1.5 m/s at ≤25-m range with <1.4-mm lateral resolution (at maximum range) and <1-mm range precision at 1-Hz capture rate using technologies that are potentially low cost in production. Studies have shown that 2D+3D multi-modal face recognition performs better than either 2D or 3D face recognition alone [1,2]. We, therefore, designed our system to capture 2D grayscale and 3D face imagery simultaneously with one camera so that the 2D and 3D data are inherently pixel registered. To operate with minimally- to non-cooperative subjects, our system includes person/head/face acquisition/tracking with automatic focusing. The transmitter is Class 1M eye-safe as measured in accordance with the ANSI Z136.1 (2007) standard.

2. Fourier Transform Profilometry (FTP) Technique

The method of 3D shape measurement called Fourier transform profilometry (FTP) was invented by M. Takeda, et. al., in 1982-1983 [3,4]. FTP is based on projecting an intensity fringe pattern onto an object and imaging the object and fringe pattern with a camera offset laterally from the fringe projector. The FTP processing consists of computing the two-dimensional fast Fourier transform (2DFFT) of the fringe image data, extracting the complex data in the spatial frequency domain near the fringe carrier spatial frequency (bandpass filtering), inverse Fourier transforming the extracted data to form a complex spatial image, extracting the "wrapped" phase image from the complex image, "unwrapping" the "wrapped phase," and scaling the "unwrapped" phase image to spatial dimensions.

The FTP concept is shown in figure 1. The transmitter projects an image of a transmission grating onto a subject as a periodic fringe pattern. A digital camera, separated from the transmitter, captures the fringe image of the subject. The FTP method measures the phase of the fringe pattern, within a 2π-radian phase ambiguity interval, at the intersection of the pixel's line-of-sight with the surface of the target. The measured phase at the surface for each pixel is converted to a distance. Since the phase is periodic, so is this distance measurement, and the resulting range image must be unwrapped to produce a continuous range 3D image. The 2D grayscale intensity image without fringes is derived from the same fringe image by notch filtering out the peaks in the 2DFFT at the spatial frequency of the fringe pattern and its harmonics, and then computing the magnitude of the inverse 2DFFT.

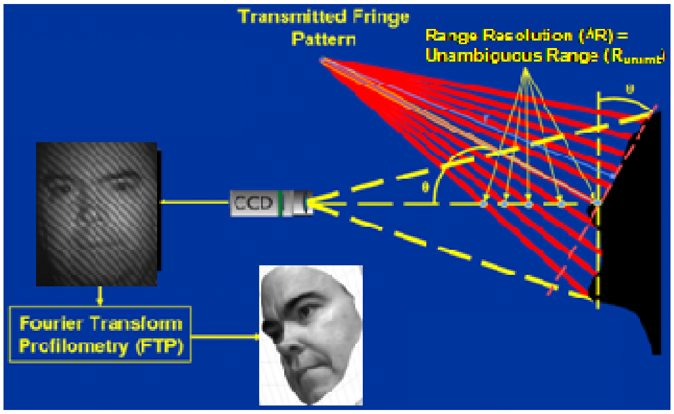

Figure 1. Fourier transform profilometry (FTP) Concept.

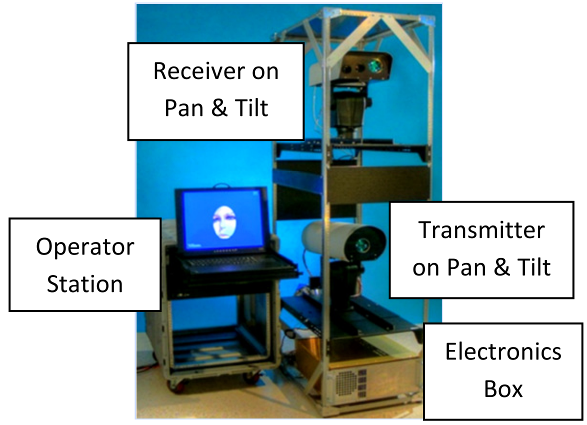

Figure 2. FTP Engineering Development Unit

3. 2D+3D Face Imager Engineering Development Unit (EDU) Description and Test Results

The EDU uses a near-infrared (NIR) diode laser illuminator in order to produce sufficiently short pulses with sufficient peak power to reduce image smearing to sub-millimeter levels for brisk walking speed motion (≤1.5 m/s). By operating in the NIR in the response band of silicon (Si) detectors, inexpensive Si CCD/CMOS focal plane array (FPA) based digital video cameras can be used.

Figure 2 shows a photograph of the EDU. A wide field-of-view (WFOV) camera (not shown in figure 2) is placed on top of the EDU rack to capture video images for person tracking by software developed by GE Global Research. The approximate head position from the GE tracker is handed over to the head/face tracking software which points the intermediate FOV (IFOV) cameras at the person to acquire and track the head/face accurately enough to keep the narrow beam transmitter and narrow FOV receiver pointed at the subject's face. An eye-safe laser rangefinder on the transmitter pan and tilt platform is simultaneously pointed at the tracked subject to provide range data for the transmitter and receiver autofocus systems. A half-height rack contains the operator control station which provides control of the EDU, collection of the data from the EDU, and the processing and display of the captured 2D+3D face data. A separate computer or server (not shown in figure 2), is connected via ethernet to the operator station, which transmits the captured data to this computer/server for face recognition ID matching with the data from subjects enrolled in the gallery database. In our current setup, the 2D and 3D face recognition ID matching is performed using the FaceVACS-SDK commercial software from Cognitec Systems Corporation.

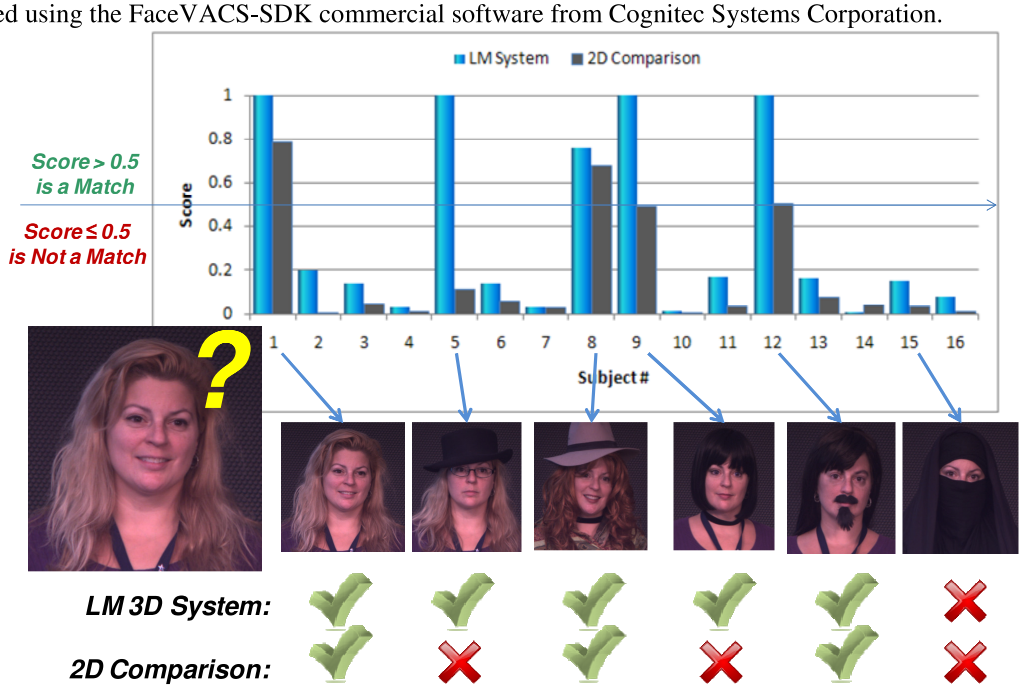

Figure 3. FTP Engineering Development Unit Identification Test Results

We used the EDU to collect data on people at brisk walking speed (~1.5 m/s) at standoff distances from 10 m to 30 m. Most of the data were collected at 10-m standoff distance due to the available space limitations for collecting data on a group of 40 volunteers, but we also took data on a few individuals at standoff distances up to 30 m. This latter data showed that the EDU was limited to standoff distances up to and including 25 m as configured for these tests. Figure 3 shows the results for matching one of the subjects' gallery image against her undisguised and disguised probe images, and against ten other undisguised subjects' probe images both for 2D passive image only matching and for our 2D+3D image matching. The results for the 2D+3D face imager EDU show good robustness against disguises and against false cross matching for this limited data set, except for the case of the subject wearing a burqa for which the occlusion of the face was too great for good matching. The 2D passive image only matching had trouble with two other disguises in addition to the burqa.

Calibration target measurements at 21-m range demonstrated 1.2-mm lateral resolution (9.1% from the pixel limit) and 0.6-mm range precision (standard deviation) at this range. The pixel-limited lateral resolution at 25-m range is 1.3 mm. Limited, initial testing with varying head pose angles showed an 18.2% extension of the off-axis azimuthal pose angle out to which 2D ID matching against a frontal pose gallery image worked by using the 3D data from the EDU for pose estimation and rotation, compared to using 2D only data.

Figure 4 shows the normalized histograms of matching scores for the entire set of 40 subjects (no disguises) for the cases of brisk walking speed with frontal facing pose and with right facing pose (~25^o-30^o from frontal), comparing our system's performance when both the gallery and probe 2D+3D images are collected by the EDU versus when the probe is collected by the EDU, but the gallery image is only a 2D photograph. The percentage of scores above 0.5 (i.e., matching scores) are annotated in each graph. The EDU does quite well in these cases even when the gallery is only a 2D photo, except for the off-axis pose case, which has historically been a problem for 2D face recognition. The use of 2D+3D data in both the probe and the gallery significantly improves performance.

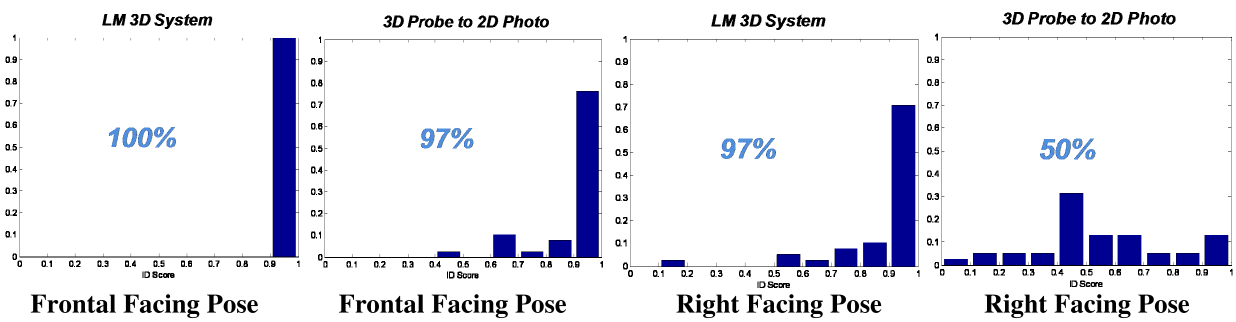

Figure 4. Normalized histograms of matching scores for 40 subjects at 10-m range, brisk walking speed, & 2 poses.

The test results show that the EDU has met the goals of 2D+3D face capture at >20-m standoff distance, <1.4-mm lateral resolution (at maximum range), <1-mm range precision, and real-time capture at 1-Hz update rates for brisk walking speed (up to ~1.5 m/s), minimally cooperative subjects. The EDU uses technologies and techniques that are potentially low cost in production. The EDU is now ready for off-site data collections and demonstrations.

4. References

[1] K.I.Chang, K.W. Bowyer, and P.J. Flynn, "An evaluation of multimodal 2D+3D face biometrics," Pattern Analysis and Machine Intelligence, IEEE Transactions on, Volume 27, Issue 4, pp. 619-624 (April 2005).

[2] K.W. Bowyer, K.I. Chang, P.J. Flynn, and Xin Chen, "Face Recognition Using 2-D, 3-D, and Infrared: Is Multimodal Better Than Multisample?" Proceedings of the IEEE, Volume 94, Issue 11, pp. 2000-2012 (Nov. 2006).

[3] M. Takeda, H. Ina, and S. Kobayashi, "Fourier-transform method for fringe-pattern analysis for computer-based topography and interferometry," JOSA, 72, pp. 156-160 (1982).

[4] Mitsuo Takeda and Kazuhiro Mutoh, "Fourier transform profilometry for the automatic measurement of 3-D object shapes," Applied Optics, Vol. 22, No. 24, pp. 3977-3982 (15 December 1983).