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3—25 A New Face-Recognition System with Robustness against Illumination Changes

Rui Ishiyama * Shizuo Sakamoto Johji Tajima
Computer & Communication Media Research, NEC Corp.

Abstract

Proposed here is a new face-recognition system based on 2D / 3D scheme. It acquires an ordinary 2D image as a query, which is then compared with each registered 3D shape and surface reflectance. The authors have developed two technologies: a novel range finder, and an image compensation technique to cope with changes in illumination.

The range finder employs a new design: sinusoidal grating projection combined with stereopsis. It offers accurate measurement (0.2mm, rms) of all pixels in a measuring time that is short enough (2 sec) to be appropriate for a number of human applications.

The 3D shape enables us to compensate for image changes due to changes in illumination. But it is difficult to parametrize illumination because the number of parameters which describe illumination is arbitrary due to the number of light sources. Here the authors reveal that the illumination subspace constructed by quite a few basis images cover almost all the illumination changes.

We conducted recognition experiments using images of 42 people in four poses and under four drastically differing sets of illumination conditions, for a total of 672 query images. Our method achieved a first-choice success ratio of 97 percent.

1 Introduction

Biometric person identification appears to hold great promise for use in a large number of applications, including security systems and man-machine interfaces. The face offers a particularly convenient source of biometric information because it is generally kept visible in daily life and it can be imaged with inexpensive, generally available cameras. Changes in pose and illumination, however, change appearance substantially, and if such changes outweigh individuality, recognition becomes difficult [1]. The three dimensional nature of the face makes this problem especially complex. If the 3D shape of a face were registered in a face recognition system, it shoul, however, be possible to estimate and compensate for image changes sufficiently to recognize individuals with significant accuracy.

We are developing a three dimensional face recognition system in which the input is a 2D image taken by an ordinary camera. The reference data, however, is based on a 3D shape and the associated surface reflectance data.

For the registration stage, we needed a device which would give us both 3D shape information and surface reflectance data. Since no existing products met our requirements, we had to develop it ourselves. This device, 'Fiore', measures range very accurately and provides the data necessary to calculate surface normals and texture for each pixel. This data is used to compensate for illumination effects. In order to make our system practical for use with human subjects, we have designed Fiore to measure this data in about 2 seconds.

In the recognition stage, the system compensates for the effects of changes in pose and illumination on the input image and creates a new image to compare with the original input. In this paper, we propose a method to compensate for the effects of changes in illumination without parametrizing the illumination conditions, because the number of parameters to describe the illumination is arbitrary. Our method constructs an illumination subspace based on the training images created from registered range and texture data. This illumination subspace can compensate for the illumination effect in the input image. We will demonstrate the effectiveness of this method by describing experimental results.

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*Address: 1–1, Miyazaki 4-Chome, Miyamae-ku, Kawasaki 216-8555 Japan.
E-mail: `r-ishiyama@bl.jp.nec.com`

2 A novel range finder with pattern projection and stereopsis

In developing our new range finder we used sinusoidal grating projection with a phase shift technique [2]. Although this method provides quick, dense and accurate 3D measurement, it also poses a fatal problem. In 2.1, we describe the past method, using sinusoidal grating projection with a phase shift technique, and its problems. In 2.2, we introduce our new method combined with stereopsis.

2.1 Sinusoidal grating projection with phase shift

As shown in Figure 1, the range finder is composed of a camera and a projector that casts sinusoidal fringe patterns onto an object (Figure 3). and a camera. The phase t of the fringe pattern is changed in steps and an image is captured for each step. The intensity of each pixel $I(u,v,t)$ varies as a sinusoid (Figure 2), and the system calculates its initial phase $\phi(u,v)$.

$$I(u,v,t) = I_{\text{bias}}(u,v) + A(u,v)\cos(\phi + t) \quad (1)$$

$$\phi(u,v) = \tan^{-1}\frac{-\int_0^{2\pi} I \sin t dt}{\int_0^{2\pi} I \cos t dt} \quad (2)$$

The initial phase $\phi(u,v)$ corresponds to the view angle from the projector, and depth can be determined by triangulation.

Here, howerver, a serious problem arises. Multiple sinusoidal patterns are projected to improve measurement accuracy, the calculated initial phase is wrapped in the interval (-pi,+pi), and some number of candidate values will appear possible for each depth to be estimated, with each candidate having a value equal to some multiple of 2pi. It is impossible to determine which is correct.

2.2 Determinig absolute phase by employing stereopsis

To solve this problem, we have developed a novel method that combines pattern projection with stereopsis by adding one or more cameras or projectors to the setup. Here we describe the method adding a camera. The phase is measured by two cameras. We call these main and sub. For each depth candidate $\{P_i\}$ for a pixel $Q(u,v)$ in the main camera, we calculate a pixel Q_i in the sub where the candidate point P_i would have to be if the candidate is correct.

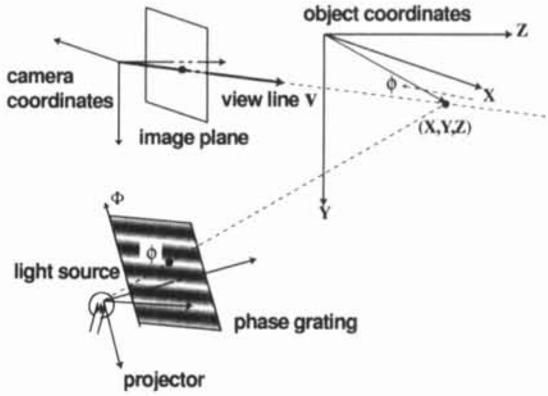

Figure 1: Phase shift method using sinusoidal grating.

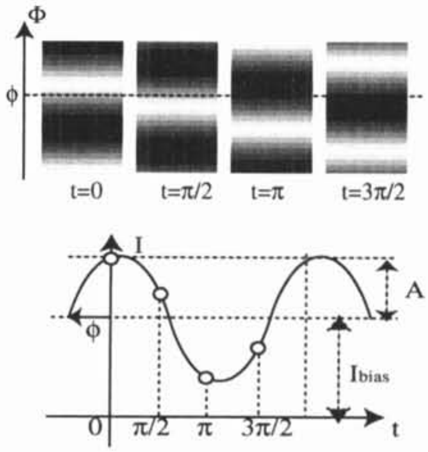

Figure 2: Phase shift and intensity change of the pixel in the image.

By comparing the measured phase ϕ of the main camera with that of the sub $\hat{\phi}_i$, we can reject unreal candidates. As shown in Figure 4, if P_2 is the correct depth, ϕ is equal to $\hat{\phi}_2$. When the one correct candidate has been determined, we can find the absolute phase corresponding to the absolute distance.

2.3 A range finder for human face measurement

We have applied our new method to the new range finder, Fiore (the commercial product name), for human face measurement (Figure 5). Fiore has two cameras upper left and right, and two projectors lower left and right. Each projector will be combined with both cameras to measure each own side of face. In our setup, the phase of a fringe pattern projected by one of the projectors

Figure 3: Sample target object (left) and projected fringe pattern (right).

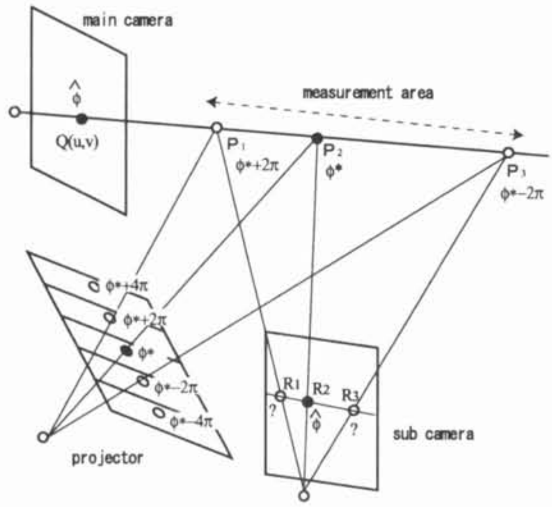

Figure 4: Our proposed method : ambiguity in measured phase is solved by using additional camera.

is shifted 3 times by $\frac{1}{4}\pi$. Images are captured before and after each of the shifts, for total of four times. This process is repeated for fringe patterns projected by the projector on the opposite side. The entire process takes slightly about 2 seconds in the current instruments, but, in theory, it could be cut down to $\frac{8}{30}$ second (as limited by video the frame rate). In our experiments, measurement error in depth is less than 0.16 mm, rms. Accuracy depends mainly on contrast in the projected fringe patterns (see Figure 6). As may be seen, even when maximum contrast is about 70, error is still only about 0.2mm. This result shows that Fiore can perform sufficiently accurate measurement even in dim rooms and does not require a special darkroom.

Figure 5: Our new range finder 'Fiore'.

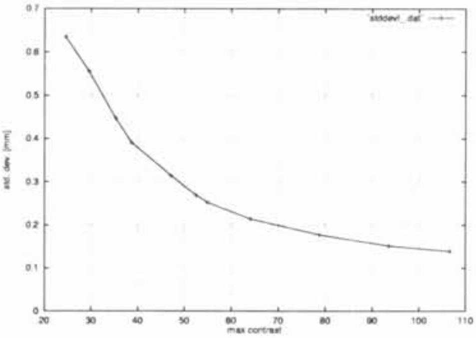

Figure 6: Measurement error in depth vs contrast of projected pattern.

3 A new method to compensate for changes in illumination

Let us now consider the effect on images of changes in illumination. If pose has been determined, images under any number of light sources can be described by the convex linear combination of images captured under a single light source, which form a convex cone [3] in the image space (Figure 8). If all the images under a single light source applied from an infinite number of directions could be memorized, a system could estimate and compensate for any illumination effect on the input image. But realistically, we have to

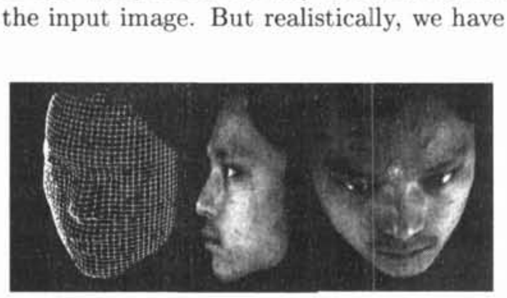

Figure 7: Sample of measured 3D data.

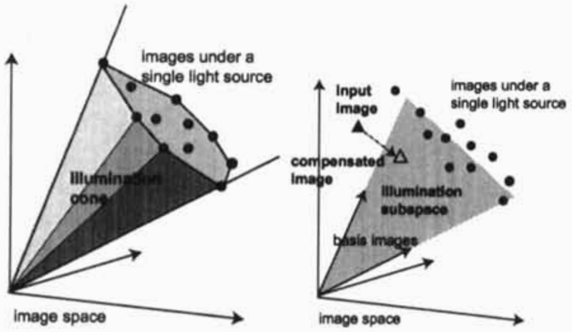

Figure 8: Illumination cone and subspace.

find a way to accomplish this on the basis of less information.

We do so through the use of computer graphics. We first generate an image on the basis of the range and textsure data measured in the registration stage. Then we create new images by simulating the application of a single light source from a variety of directions. By applying principle component analysis, we are able to calculate an appropriate number of basis images to store in the system. These basis images represent a reasonable estimate of the illumination cone that would have resulted from a far greater variety of changes in light source direction. We refer to this image subspace as the illumination subspace (see Figure 8).

In the recognition stage, an illumination-compensated image is created that has the same illumination condition as the input image (Figure 8). The compensated image is calculated as the nearest image to the input image in the illumination subspace of each individual, by a linear combination of the illumination basis images. The coefficients are calculated as correlations between the input image and the basis images. The similarities between the input image and the compensated images are the distances between the input image and the individuals' illumination subspaces. These distances are evaluated to identify the individual in the input image.

4 Experimental results

In an experiment to test the effectiveness of our proposed method, we measured the 3D shapes and textures of 42 individuals' face. We also took 16 images of each individual in 4 poses, under 4 different illumination conditions (see Figure 12). These images were used as queries for our recognition experiment.

Figure 9: Sample images for pose 1 created by changing illumination from registered 3D shape and reflectance data

Figure 10: Calculated basis images of illumination subspace of pose 1.

4.1 Evaluation of dimensionality of illumination cone

Our first task was to determine the number of dimensions needed to approximate the illumination cone. Instead of analyzing infinite number of images, we want to handle the set of sufficient number of sample images to approximate the whole set of images under various illuminations. In simulations, we subjected the 3D shape and texture data for each pose to light directed respectively in 5166(each 2 deg. in latitude and logitude on the equator),1294(4 deg.), 329(6), 216(8), 148(12) and 23(16) of separate directions distributed uniformly across the frontal hemisphere of the head (see Figure 9). In this experiment, calculated basis images and cumurative contribution ratio was almost unchanged even when more than 216 sample images were used(Figure 11). This reveals that 216 sample images are sufficiently approximates the whole set of the images under arbitrary illumination conditions.

We then applied principal component analysis to the 216 sample images and we found that the cumulative contribution ratio of the first 5 basis images produced in the analysis is more than 99% for all faces and poses. This implied that the illumination cone is sufficiently 'flat' to be approximated as a low dimensional linear subspace.

4.2 Recognition experiments

In our recognition experiments, we used the images of 42 people in four poses and four illumination conditions for a total of 672 query images.

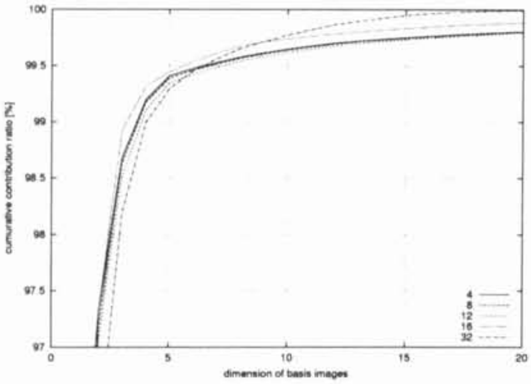

Figure 11: Dimension of basis images vs cumurative contribution ratio [%] (results of changing the number of sample images).

pose1	pose2	pose3	pose4	total
99.0	97.1	99.0	92.9	97.0

Table 1: Experimental results : first-choice success ratio [%] in each pose.

5 basis images were calculated and used to construct an illumination subspace for each individual. Figure 13 shows an input image, an compensated with data from the correct individual, and an image compensated with data from a different individual. As may be seen Table 1, for each pose, our method performed with high accuracy of recognition, achieving a first choice success ratio of 97%. The result of Pose 4 is worse than others, because the images have much specularity which is not included in our model.

5 Summary and future work

We have presented here a new face-recognition system that employs our newly developed range finder and a new method to compensate for variations in illumination conditions. To improve 3D measurement accuracy and speed, we developed a new measurement method that employs a combination of sinusoidal grating projection and stereopsis. Our experiments have shown that the illumination cone is sufficiently 'flat' to be approximated in the form of a low-dimensional linear subspace. In recognition experiments on images of 42 people in four poses and under four illumination conditions each, for a total of 672 query images, our method achieved a first choice success rate of 97%.

As a next step, we will develop a method to integrate pose estimation and illumination compensation. In this paper, it is assumed that pose is fixed or estimated separately from the illumination effects. But, in general, we have to estimate both acculately at the same time.

(a) pose 1 (b) pose 2 (c) pose 3 (d) pose 4

(e) illumination 1, pose 1 (f) illumination 2, pose 1 (g) illumination 3, pose 1 (h) illumination 4, pose 1

Figure 12: Poses and illumination conditions of query images taken to test recognition system.

(a) input image (b) compensation with correct individual's data (c) compensation with incorrect individual's data.

Figure 13: Results of illumination compensation experiments.

References

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