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Compact Camera for Real-Time 3D Measurement

Development of MEMS Scanner with High Speed Phase Shift

Toshitaka Wakayama, **Toru Yoshizawa**, Saitama Medical University

Abstract:

To improve difficulties inherent to the conventional three-dimensional profiling system based on pattern projection method, we have proposed incorporating a recent digital device such as a MEMS scanner into projection optics. We have used the MEMS scanner which is not a digital mirror device (DMD) but a single MEMS mirror. Due to this revision, first of all, such a small size system like a palm-top camera was attainable, and low cost measurement system was potentially realized. In the projection system, a laser diode and the single MEMS mirror are employed. We can control the scanner to produce the projection pattern with an appropriate periodical structure and a sinusoidal intensity distribution. Due to this flexible pattern projection, phase-shifting technique becomes applicable for industrial inspections and measurements in the automobile industry and others. The camera is as small as a photographic digital camera in size. We finally aim at developing a high speed 3D measurement. In this paper, the measurement speed is 0.6 seconds for acquiring 3D profile.

Introduction

Three-dimensional measurement has been attracted interests in the fields of the industry, the medical care and the amusement [1]. In these fields, there are strong requests to achieve a high-speed measurement. In recent years, a pico-projector with a DMD has been brought a revolution in 3D measurement [2] and a lot of paper has been published to realize a high speed measurement [3]. However, conventional three-dimensional measurement system is very large, very heavy and very expensive. From this background, a compact 3D camera for a high speed measurement has been strongly requested. Until now, we have developed compact cameras for the 3D measurement based on a single MEMS mirror [4-5]. Moreover, we have proposed a principle of a real-time 3D measurement with three color laser diodes and camera with three CCDs. We theoretically realized a real-time 3D measurement [5]. However, we are now continuing to develop a real-time 3D measurement, since there is a problem that the response speed of the green laser is very slow. In this paper, we aim at developing a compact 3D camera for high speed 3D measurement using a laser diode.

Principle

A MEMS scanner [4,5]

Figure 1 shows the optical setup of the pattern projection method. We employed a laser diode with monochromatic light source. The laser beam is expanded by a cylindrical lens or a line generator lens which deforms from a point beam to a fan beam. The fan beam illuminates two-dimensional plane by the scanning of MEMS mirror. The projection pattern is formed into the sinalsoidal pattern by controlling the voltage of the laser diode shown in Fig.1. That is to say, we can control the projection pattern with appropriate periodical structures and with the sinusoidal intensity distribution transformed from a time domain to a spatial domain. The phase shift of the projected pattern can be achieved by shifting the initial phase of the sinusoidal voltage to the laser diode. The single MEMS mirror is resonated at 500 Hz in this paper. That is to say, the scanner can project the pattern onto the sample and shift the phase of the projection pattern up to 2 milliseconds. The scanner can project onto the large area without a distortion since the scanner doesn't use the projection lens.

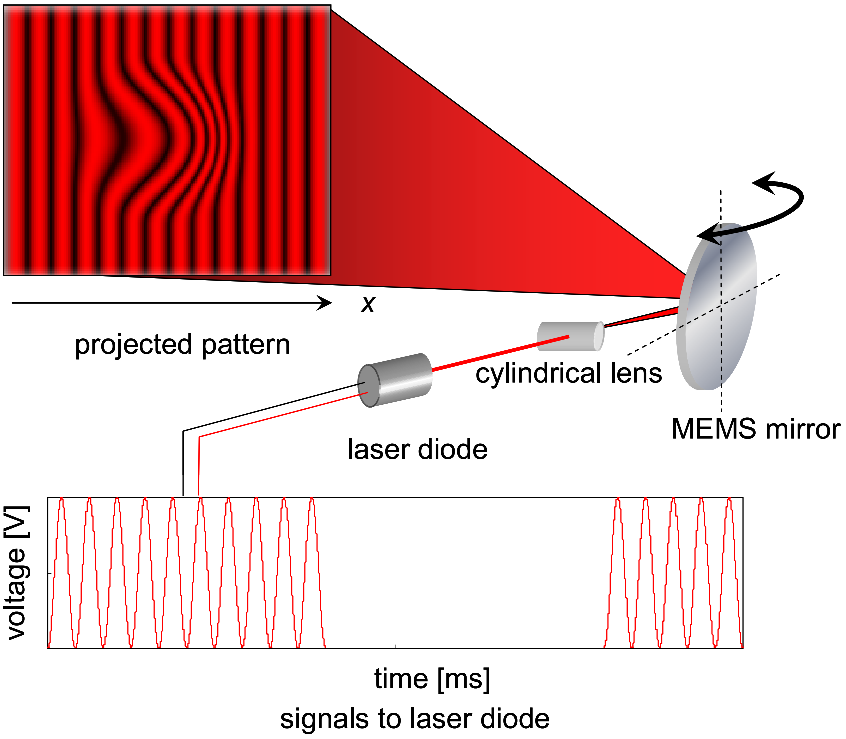


Fig. 1: MEMS scanner which we developed using a single MEMS mirror and a laser diode

Optical setup of the compact camera for 3D measurement

Figure 2 shows the optical setup of a compact camera for 3D profilometry incorporating a MEMS scanner and a CCD. The MEMS scanner as shown in Fig.1 is located at the point

A(0, *b*, *a*) in Fig.2. A lens of CCD camera is set at the point B(0, *0*, *a*) and the CCD is dislocated with the distance *c* to z direction from the point B and the point P is located at (0, b,0). The angle θ_N gives ∠PAT.

We can capture the intensity distribution $I_i(x, y)$ using the CCD camera when we apply the voltage like the sinusoidal voltage along a time. *i* indicates the number (*i*=0, 1, 2, 3) of the intensity distribution. The intensity distribution $I_i(x, y)$ can be written including the phase distribution $\phi(x,y)$. Here, $\phi(x,y)$ gives sample's phase distribution including the height information.

$$I_1(x,y) = A(x,y) + B(x,y)\cos[\phi(x,y)] \tag{1.1}$$

$$I_2(x,y) = A(x,y) + B(x,y)\cos\left[\phi(x,y) + \frac{\pi}{2}\right] \tag{1.2}$$

$$I_3(x,y) = A(x,y) + B(x,y)\cos[\phi(x,y) + \pi] \tag{1.3}$$

$$I_4(x,y) = A(x,y) + B(x,y)\cos\left[\phi(x,y) + \frac{3\pi}{2}\right] \tag{1.4}$$

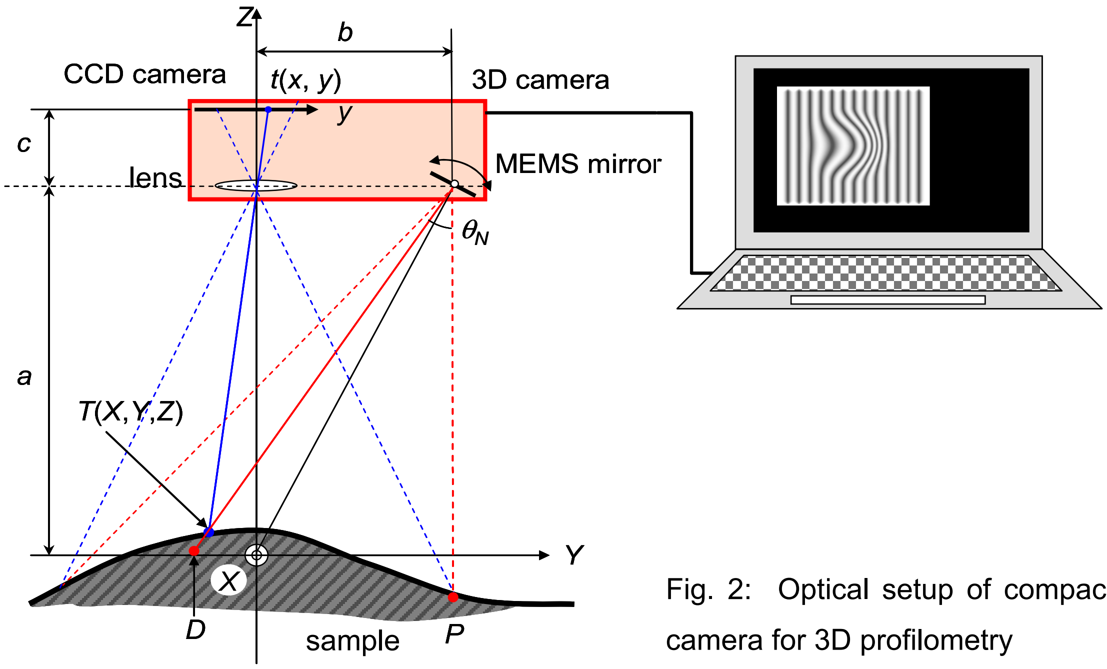


Fig. 2: Optical setup of compact camera for 3D profilometry

Fig. 3: Compact camera for 3D profile measurement

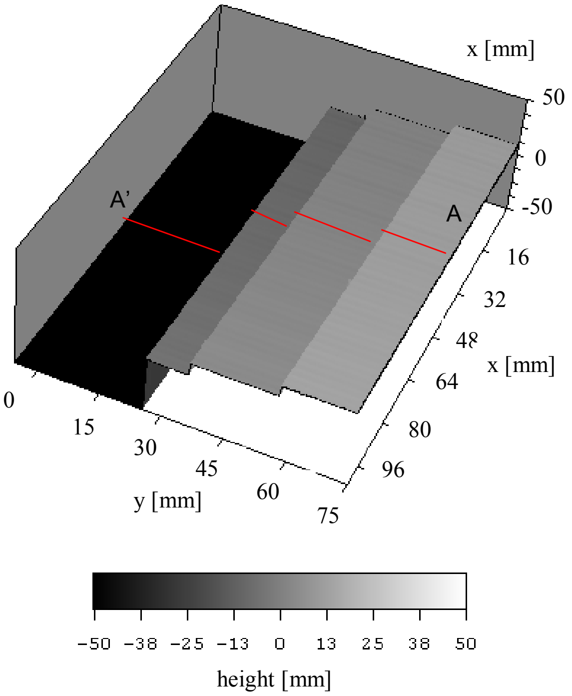
Here, $A(x,y)$ and $B(x,y)$ are a bias component and an amplitude components, respectively. In this stage, we have used four-step phase shifting algorithm to determine the phase distribution $\phi(x,y)$. Hence, we can get the phase distribution including sample's height information.

$$\phi(x,y)=\tan^{-1}\frac{I_4(x,y)-I_2(x,y)}{I_1(x,y)-I_3(x,y)} \tag{2}$$

From the above equations, we can determine sample's coordinates (X, Y, Z) [6].

Experimental Results

We developed a compact camera for 3D profilometry as shown in Fig.3. The size of this camera is 53mm×130mm×38mm and the weight of this camera is 320 g. We employed a CCD camera which has 10 bit gray scale of the monochromatic camera. The focus length of the camera lens is 16mm and we can capture 73mm×95mm. The optics of projection system is employed a laser diode (ADL66z01-HU, ARIMA Co.Ltd.) as a light source and a resonant scanner (LSM 500, Venture Forum Mie Ltd.) as the single MEMS mirror in this system. We employed a laser diode with 60mW output power and 650nm wavelengths. However, we adjusted so that the output of the beam may be some 3mW from the palm-top camera, temporally. We used a resonant scanner (f = 500Hz, θ=40˚) as a MEMS scanner. The size of the single MEMS mirror incorporated in the resonant scanner is ϕ3 mm in diameter. In this trial, the control unit of the laser diode, the MEMS scanner and the circuit of the functional



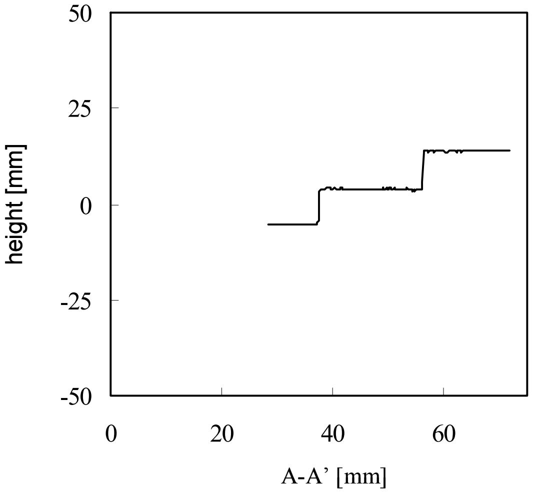


Fig. 4 (a): 3D profile of stepped gauge

Fig. 4 (b): Cross-sectioning diagram

generator are set outside of the camera unit. In this measurement, we applied the sinusoidal voltage (*f* = 40 kHz, *E* = 0~5 V) to the laser diode. The MEMS mirror can be returned signals (0 and 5 V) by the going way and the returning way. During the time of the going, the laser diode is applied the voltage using the functional generator. On the other hand, the laser diode is switched off during the returning time as shown in Fig.1. Theoretically, it is possible to shift the phase of the projected pattern up to the maximum frequency of a MEMS mirror from 2 kHz to 8kHz.

The CCD camera is connected to the note book computer (CF-Y8, Panasonic Co., Ltd., Intel (R) Core (TM) 2 Duo CPU L7800@2.00GHz, 777MHz, 1.99GB RAM) by way of the camera captured card (Frame Link VCE-CLB01, Imperx Co.,Ltd.) The time lag of the phase shift of the projected pattern is 0.1 sec. It takes 0.4 seconds to capture four images. The time from “capturing” to “display” including the analyzing process is about 0.6 seconds in this stage. Theoretically, it is possible to capture four images up to 10 milliseconds in this system.

We measured the references to check the performance of the palm-top camera for three-dimensional measurement. Three test gauges were arranged like stairs. The two gaps of the steps are 10mm and 8.5mm, respectively. Figure 4(a) shows three-dimensional surface profile of the test pieces. Figure 4(b) gives the cross sectioned profile A-A’. The random variation in the result was 0.3mm. To achieve the highly accurate measurement, we have only to project the fine periodical pattern. To show an experimental example, we measured an engraved model of human face. Figure 5 shows the 3D profile of this engraving shown from three directions.

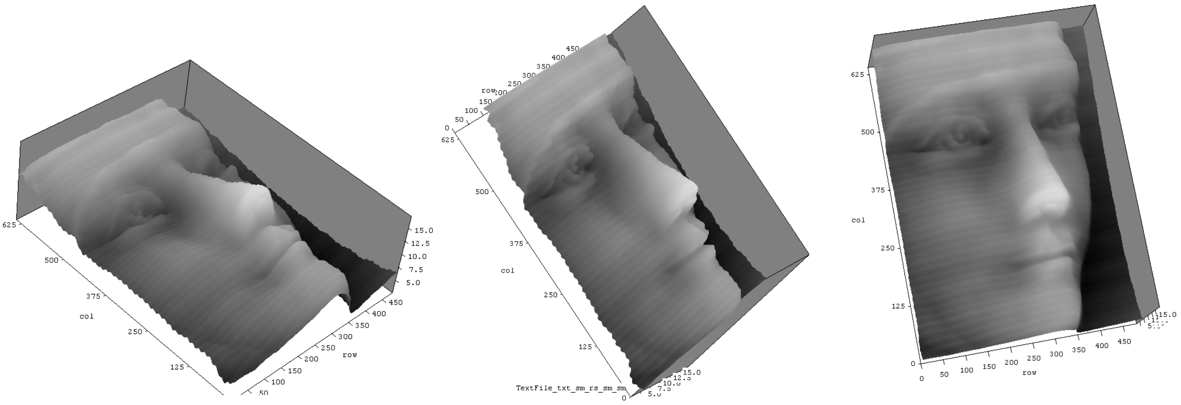


Fig. 5: 3D profile of the engraved model of human face

Conclusions

We have developed a compact camera for three dimensional profilometry and showed its performance and applications. The key technology to this measurement is a digital device “a single MEMS mirror” for pattern projection, not “DLP” nor “LC grating”. The camera is as small as a photographic digital camera in size. Using four stepped phase shifting algorithm, we have achieved to measure three dimensional profile of a sample in 0.6 seconds in this stage. We are expecting that our method will become most compact camera with the function of the high speed 3D measurement.

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