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Application of optical switch in precision measurement system based on multi-collimated beams

Yong Lv [a,b,*], Qibo Feng [a,1], Lishuang Liu [b,2], Qingrui Yi [b,2], Yueqiang Li [b,2]

[a] School of Science, Beijing Jiaotong University, Beijing 100044, China
[b] School of Instrumentation Science and Opto-electronics Engineering, Beijing Information Science & Technology University, Beijing 100192, China

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ABSTRACT

A collimated light test system based on the optical switch was built to test if an optical switch can meet homology and high stability requirements for precision measurement systems. An optical switch was used to split a Light Emitting Diode (LED) light source to obtain collimated beams. A Charge-Coupled Device (CCD) camera was then used to sample the collimated beams. Homology of these collimated beams was analyzed, and spot positions were calculated based on the threshold gray centroid method. Test results show that these collimated beams are highly homologous. Compared to a light source with no optical switch, which has a standard deviation of 0.03 pixels in 1 h, the stability of the collimated beams obtained from an optical switch is better, with a standard deviation of up to 0.02 pixels in 1 h, regardless of whether the optical switch is working in static or dynamic condition. A dual-path compensation test system based on the optical switch was constructed to further improve the long-term stability of the collimated beams. These tests show that an optical switch is an effective light dispersion device to get multi-collimated beams. An optical switch can also simplify the structure and improve the controllability and flexibility of the precision measurement system. We have successfully applied an optical switch in our novel 6-degree-of-freedom measurement system based on 4 collimated beams.

1. Introduction

Collimated beam measurement is based on straight-line propagation of light. The intensity center of the light beam is calculated as the straight-line basis. It has been widely used in the measurement of straightness, concentricity, parallelism and multiple degrees-of-freedom (DOF) [1]. Multi-collimated beams are often needed when the number of measured parameters increases [2–6]. Light dispersion devices such as beam splitters, mirrors and holographic gratings are traditionally used to obtain multi-collimated beams. But sometimes traditional light dispersion methods cannot meet the high requirements of the new multi-degree-of-freedom measurement system. For example, as shown in Fig. 1, in our simple and novel 6 DOF measurement system, four collimated beams project on a detector that is fixed to and moving along with the measured object. Changes in the position and orientation of the measured object will lead to a position change of the 4 light spots on the detector. For this system, easy adjustment of the spatial incident angle of each collimated beams is required to allow for different measuring ranges and accuracies. To simplify the system, only one detector is used, requiring the four

* Corresponding author at: School of Science, Beijing Jiaotong University, Beijing 100044, China. Tel.: +86 10 82426917; fax: +86 10 82426915.
E-mail addresses: lvyong@bistu.edu.cn (L. Yong), qbfeng@bjtu.edu.cn (F. Qibo), liulishuang@bistu.edu.cn (L. Lishuang), ruirui712@sohu.com (Y. Qingrui), liyafeng20062010@126.com (L. Yueqiang).
[1] Tel.: +86 10 51688313; fax: +86 10 51684843.
[2] Tel.: +86 10 82426917; fax: +86 10 82426915.

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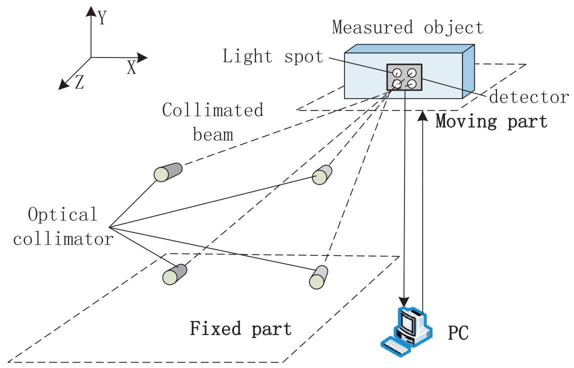

Fig. 1. 6 DOF measurement system based on 4 collimated beams.

collimated beams to be controlled to project on it. All these requirements cannot be realized by traditional light dispersion devices.

The optical switch can achieve light conversion and transmission among different optical paths. Each optical channel of the optical switch is time-multiplexed and independent of each other. The optical switch is characterized by its small size, complete controllability, high speed, low loss, and long life. Multi-collimated beams can be obtained by combining optical switch and fiber collimating technologies. Because of the coupling effect of a single-mode fiber, displacement drift and angle drift of the light source only affects the coupling efficiency, resulting in a change of the output power. However, this does not affect the intensity distribution, which plays a key role in the stability of the collimated beams [7]. By taking advantage of optical switch technology, the complexity of a precision measurement system based on collimated beams reduces, while the system's flexibility increases. The on–off status of each channel can also be controlled completely by the optical switch.

In this paper we have studied the feasibility of using an optical switch in a precision measurement system based on multi-collimated beams prior to applying one to our 6 DOF measurement system. An optical switch is used to split the light source. Then fiber-collimators are used to obtain multi-collimated beams that are sampled by the CCD camera. The center position of the light spots is calculated based on the threshold gray centroid method. Test results show that stability of the collimated beams from the optical switch is high enough to meet the requirements of a precision measurement system based on multi-collimated beams. Furthermore, long-term drift suppression of collimated beams based on an optical switch has been effectively achieved.

2. Feasibility of the optical switch for light splitting

A multi-collimated beam test system based on an optical switch was constructed. Light spots were sampled by the CCD camera and processed by software to obtain information such as the center coordinates and gray distribution. Further analysis of the stability and correlation of the collimated beams was carried out to test the feasibility of using an optical switch for splitting light in a precision measurement system.

2.1. Test system

As shown in Fig. 2, the system consists of an LED light source [8], 1×4 optical switch, optical collimators, area array CCD, and an industrial computer. Through the fiber pigtail, the light emitted from the LED light source is coupled into the optical switch. With the help of the optical collimator, collimated beams are obtained and projected onto the area array CCD. Position of the collimator and detector is fixed at a distance of 1.2 m. The collimator can be freely connected directly to the light source or to any channel of the optical switch.

This test system works in the lab environment and in natural conditions (non-isothermal conditions).The area array CCD used in the system was AVT Guppy F-146B, which has a pixel size of 4.65 μm $*$ 4.65 μm and resolution of 1392 $*$ 1040. The employed optical switch was SERCALO $1 \times$ 4MEMS optical switch (typical insert loss is 1 dB, switching time is 2 ms and cross talk is 55 dB). By controlling the movement of the micro-mirror array constructed on a semiconductor substrate, the optical switch can couple the input light to different output channels. The host computer can send out high or low level transistor-transistor logic (TTL) signals through a General Purpose Input/Output (GPIO) port to control the light switch.

2.2. Software algorithm

2.2.1. Threshold gray centroid method

The location of the light spot center is calculated based on the threshold gray centroid method. For a image of the light spot, its size is X $\times$ Y and $B[i,j]$ is the pixel gray value of the *i-th* row and *j-th* column. Then its gray gravity center is (x_0, y_0).

$$x_0 = \frac{\sum_{i=1}^{X}\sum_{j=1}^{Y}[B(i,j) - T] \times i}{\sum_{i=1}^{X}\sum_{j=1}^{Y}B(i,j)},$$
$$y_0 = \frac{\sum_{i=1}^{X}\sum_{j=1}^{Y}[B(i,j) - T] \times j}{\sum_{i=1}^{X}\sum_{j=1}^{Y}B(i,j)} \quad (1)$$

where T is the threshold of the background.

The gray gravity center is calculated after the background threshold has been subtracted. This method is simple and can improve the positioning accuracy and anti-interference ability.

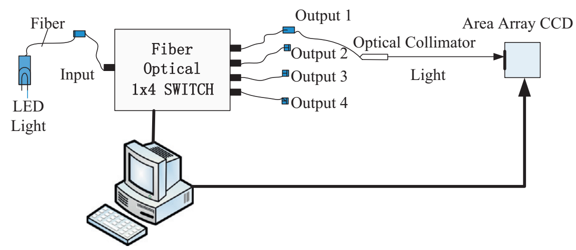

Fig. 2. Structure of the test system.