

Three-Beam Triangulating Sensor

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Abstract. The new high precision triangulating sensor for measuring distance and/or inclination angle with high temperature stability for a wide range of technical and technological applications is proposed. The corresponding measurement algorithm is considered and hardware allowing its implementation is developed. The preferable embodiment of three beam triangulating sensor comprises three laser radiation sources, CCD-array based image sensor including optical system, and control electronic unit.

1. Introduction

Measurement of the distance between objects, or to an object is an actual problem in many industrial and technology applications in geodesy, echolocation, robotics, military applications, etc.

To solve this problem the radio, ultrasonic or optical waves may be used. Measurement of the distance is based on the emission signal in direction of the object and then receiving and processing the reflected or scattered signals.

Ultrasonic waves are widely used in non-destructive testing (NDT) of solid objects, in diagnostics of multiphase objects [1, 2] as well as in of underwater sonar. When measuring the distance or position of remote objects is preferable to use optical or radio waves.

The main advantages of optical sources is a high focusing accuracy, the independence of propagation velocity of the ambient temperature and the relative simplicity of the design.

Optical distance measurement methods can technically be put into three categories: interferometry, time-of-flight and triangulation methods [3].

In time-of-flight pulsed laser rangefinders, a laser pulse is emitted to the target, and range is measured as the time delay between the emitted pulse and the echo received from the target.

This method was used in the following devices [4, 5]. For short-range applications, this technique presents the disadvantage of requiring the measurement of extremely short times for good range accuracy [6]. For example, to obtain 1 mm accuracy, the accuracy of the time interval measurement should be 6.7 ps [7].

The next group is laser phase-shift rangefinders. In a phase-shift rangefinder, the optical power is modulated with a constant frequency. This method is also known as amplitude modulation continuous wave (AMCW). A sine wave of this frequency generated by the main oscillator modulates the dc current of the laser diode. After reflection from the target, a photodiode collects a part of the laser



beam. Measurement of the distance is deduced from the phase shift between the photoelectric current and the modulated emitted signal [7]. A couple devices using this principle presented in [8, 9].

Distance measurement by the phase-shift technique provides resolution of some millimeters in 1 to 20 m ranges and with high-frequency modulation the resolution can be better than 50 μm . The main disadvantage of this method is the complexity of circuit realization.

Another continuous wave technique uses frequency modulation (FMCW) of the radio frequency subcarrier used to amplitude modulate a laser diode output. In these systems, the range is measured as an intermediate frequency. The main advantage of this technique over AMCW is its ability to resolve multiple targets, which is important in scenes where a main target is obscured by objects in front of it [6, 10].

Some devices provide this method described in [11, 12]. The main disadvantage of this method is that frequency modulation response of a laser diode is nonuniform against the modulation frequency. So that a linear optical frequency sweep cannot be realized by a linear modulation of the control current. In addition, the frequency versus control current characteristic is also in general nonlinear [7].

Many technological and technical application imposes contradistinguished requirements of high accuracy and ease of use, in the field of rangefinders it means that it should have high accuracy and tolerance to misalignment. One of the possible way to meet these opposed requirements is described in the present paper. More specifically, in this paper a method for measuring the distance to the object and its geometrical arrangement in some technical and technological applications using three distributed laser sources is proposed. The additional advantages of this method is possibility to measure inclination angle of the surface under test and to take into account this angle to obtain correct value of distance.

2. Three beam laser triangulating method

In the introduction has been shown that one of the main problem is difficulties caused by requirements of fine alignment of a triangulating sensor in relation to object under test. It is obvious that in many cases such measurements become inconvenient or inaccurate (for example, when object changes orientation during measurement procedures).

To solve this problem three beam laser triangulating method has been proposed (Figure 1). The method uses laser beams generated by three spatially distributed sources (1, 2 and 3). Each beam produces an image on surface of object under test (6) in the form of small dot. The images of three dots are perceived by light sensitive matrix equipped by optical system. Different distances to the object are corresponds to different positions of dots on image similarly to the conventional laser triangulating method [3].

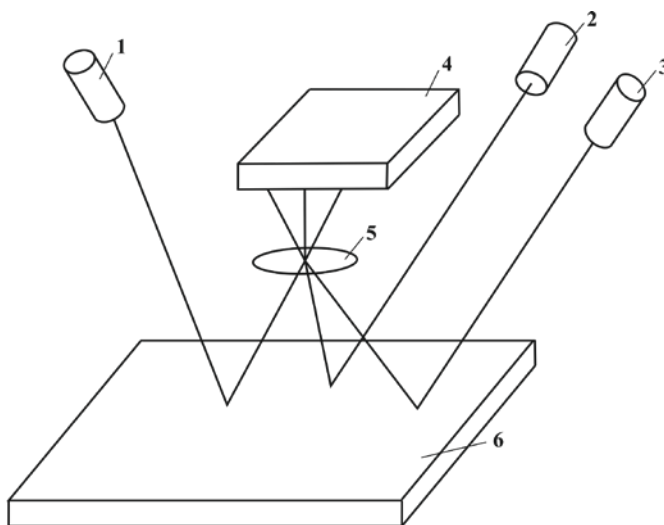


Figure 1. Three beam laser triangulating method: 1, 2, 3 is laser beam sources, 4 is light sensitive matrix, 5 is optical system, 6 is an object under test.

It makes possible to increase accuracy of distance measurement and to provide measurement of inclination angle of the object when taking into account measurements of distances to an object from three different points with the predetermined positions (laser sources outputs).

Let's consider the proposed method for the two-dimensional case (Figure 2).

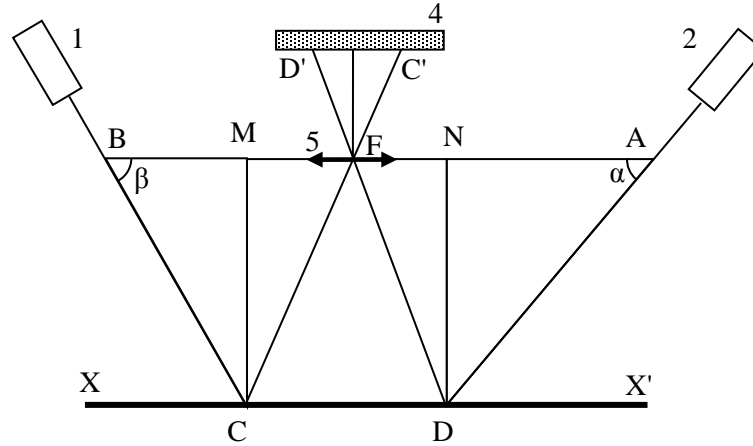


Figure 2. Two-dimensional illustration of three beam laser triangulating method: 1, 2 is laser beam sources, 4 is light sensitive matrix, 5 is optical system.

1) Line AB goes through the external principal plane of the lens system 5 and intersections of the line AB with laser beams are denoted by points A and B.

2) The points of intersection of beams of the laser sources 1 and 2 with plane X-X' of the object under test are designated as C and D correspondingly;

3) Points M and N are projections on the line AB of points C and D correspondingly;

4) F is the optical center of the lens. f is the distance from the lens to the image sensor 4 (light sensitive matrix);

5) C' and D' are images of points C and D on the surface of light sensitive matrix 4;

6) For triangle ADO, we can write

$$\frac{AD}{\sin \gamma_A} = \frac{L_A}{\sin(180^\circ - \alpha - \gamma_A)}, \quad (1)$$

where L_A – length of the segment AB. In this case

$$AD = \frac{L_A \sin \gamma_A}{\sin(\alpha + \gamma_A)}. \quad (2)$$

7) The height ND we find as

$$ND = AD \cos \alpha = \frac{L_A \sin \gamma_A \cos \alpha}{\sin(\alpha + \gamma_A)}. \quad (3)$$

8) Then cathetus ON of a right triangle NDO is equal to

$$ON = \frac{MD}{\tan \gamma_\alpha} = \frac{L_A \sin \gamma_A \cos \alpha}{\sin(\alpha + \gamma_A) \tan \gamma_\alpha}. \quad (4)$$

9) Similarly, for triangle BCO

$$MF = \frac{L_B \sin \gamma_B \cos \beta}{\sin(\beta + \gamma_B)}, \quad (5)$$

$$CM = \frac{L_B \cos \gamma_B \cos \beta}{\sin(\beta + \gamma_B)}. \quad (6)$$

10) The inclination angle of the plane can be found from the following equation (see Figure 3)

$$\tan \theta = \frac{LD}{CL} = \frac{DN - MC}{MN}. \quad (7)$$

These calculations are presented for the two-dimensional case. However, they can be easily generalized to three-dimensional space.

Experimental investigation of the proposed method had been carried out using conventional digital camera Defender G-lens 2693 and three laser pointer has shown that this simple implementation of method allows to obtain instrumental error less than 1% for distance measurement in the range 0,2-2 m, and about 2% for inclination angle measurement at distance 1 m. However, the accuracy can be significantly improved by more precise manufacturing of the sensor and by sensor components selection and adjustment.

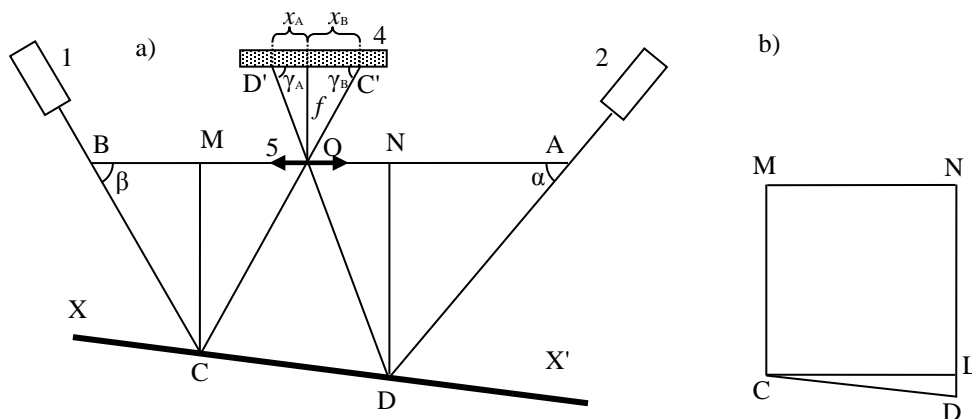


Figure 3. Determination of inclination angle: 1, 2 is laser beam sources, 4 is light sensitive matrix, 5 is optical system.

It is obvious that information on the inclination angle of surface of the object under test could be used for improvement accuracy and usability of sensor. In case of using the proposed method the correct distance to the surface can be measured taking into account the inclination angle of the surface. Further the method provides possibility to not use exact alignment of the sensor since it could make automatic correction procedures eliminating effect of misalignment.

3. Three-beam laser triangulating sensor

The three-beam laser triangulating method described above has effective realization in form of sensor. A proposed three-beam sensor contains three spatially separated laser sources (LS) configured to generate narrow beams, a receiver of optical radiation on the basis of the light sensitive charge-coupled device (CCD) array.

Block diagram of the sensor is presented in Figure 4 according to which sensor comprises three units: Laser Radiation Generator, Light Receiver and Digital Control and Processing Unit. Laser Radiation Generator including three laser drivers (LD) and three laser sources (LS) are adapted to produce three spaced laser beams. Laser Receiver comprises light sensitive CCD-array (LCA),

preprocessing unit (PU), control unit (CU), and Memory Unit (MU). LCM forms image with dots corresponding to laser track on the object's surface. PU are intended to perform preliminary processing of image, such as operations of color correction, white-balance, etc. MU stores image before transferring to microcontroller. CU controls operation of whole Laser Receiver. Digital Control and Processing Unit comprises two main units: microcontroller (μC) and interface unit (IU). μC is configured to control operation of whole sensor and to process measuring data, particularly to

- determine positions of beams centers on the image;
- calculate distances to each of laser sources;
- calculate inclination angle of the object under test;
- estimate corrected value of distance between sensor and the object under test.

IU allows to transmit data to computer, global or local network, indicator, etc.

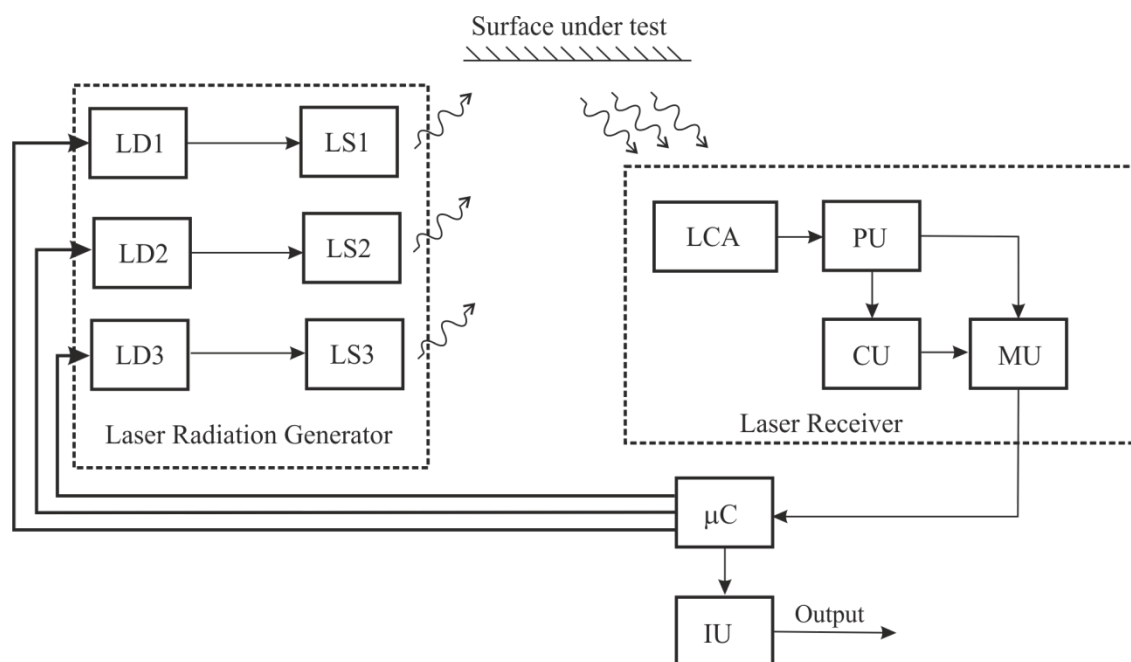


Figure 4. Block diagram of the three-beam laser triangulating sensor.

One of technical problem for this type of sensor is differentiation of beams on the image. Here light sources with different wavelengths (colors) or operation of each LS in its specific period of time (frequency and time separations correspondingly) can be used.

The main advantages of this implementation of sensor is in that it requires not expensive components and the sensor could provide functionality of digital camera between or/and during measurement procedure.

This approach allows to increase accuracy and usability since the sensor is able to take into account inclination angle during distance measuring.

4. Conclusion

The original approach for developing triangulating sensor is proposed. The sensor uses three laser beams to measure distance and inclination angle with excellent temperature stability. This approach allows to increase accuracy and usability of measuring equipment. It can be used effectively in many technological processes (such as control of thickness, distance measurement, etc.), in automotive control systems, in robot orientation systems, and in other applications requiring contactless measurement of distance or inclination angle.

The corresponding measurement algorithm is considered and hardware allowing its implementation is developed. Design of three beam triangulating sensor comprises at least three laser radiation sources, CCD-matrix based image sensor including optical system, and control electronic unit which provides signals for configuring and actuating sensor's elements and processes measuring signals.

To recognize images of different laser beams on the surface of photosensitive CCD-matrix two different methods could be used in dependence on the user and environment requirements: 1. actuating laser-sources in different moments of time; 2. using laser sources with different wave lengths (different colors). Therefore the proposed sensor can be manufactured from inexpensive parts and is very cost effective.

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