Optics and Lasers in Engineering 105 (2018) 75–85

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Microscope self-calibration based on micro laser line imaging and soft computing algorithms

J. Apolinar Muñoz Rodríguez

Centro de Investigaciones en Optica A.C., Apartado Postal 1-948, León, GTO 37150, México

ARTICLE INFO

Keywords:
Microscope self-calibration
Approximation networks
Micro laser line imaging

ABSTRACT

A technique to perform microscope self-calibration via micro laser line and soft computing algorithms is presented. In this technique, the microscope vision parameters are computed by means of soft computing algorithms based on laser line projection. To implement the self-calibration, a microscope vision system is constructed by means of a CCD camera and a 38 µm laser line. From this arrangement, the microscope vision parameters are represented via Bezier approximation networks, which are accomplished through the laser line position. In this procedure, a genetic algorithm determines the microscope vision parameters by means of laser line imaging. Also, the approximation networks compute the three-dimensional vision by means of the laser line position. Additionally, the soft computing algorithms re-calibrate the vision parameters when the microscope vision system is modified during the vision task. The proposed self-calibration improves accuracy of the traditional microscope calibration, which is accomplished via external references to the microscope system. The capability of the self-calibration based on soft computing algorithms is determined by means of the calibration accuracy and the micro-scale measurement error. This contribution is corroborated by an evaluation based on the accuracy of the traditional microscope calibration.

1. Introduction

Nowadays, the microscope calibration plays an important role to compute micro-scale surface in research areas such as: micro-scale surface inspection [1], micro positioning [2], micro machining [3], and so on. These microscope vision systems perform the three-dimensional (3D) vision based on calibrated vision parameters and image processing of an intensity pattern [4]. Typically, the calibration of optical microscope systems is performed by means of perspective geometry and known references [5,6]. For instance, the stereo light microscope systems are calibrated via perspective geometry and known references such as: circle tie-points, glass-tube, and squared patterns [7–10]. These microscope systems compute the three-dimensional vision based on the stereo geometry, where a pixel pattern is detected in two images. Also, the monocular light microscope systems are calibrated via perspective geometry and known references such as: squared patterns [11,12]. These microscope systems compute the surface topography based on the microscope geometry. Moreover, the scanning probe microscope systems are calibrated via perspective geometry and known references such as: land-marked pyramid and circles matrix [13–15]. These microscope systems compute the 3D vision by means of an affine transformation and least squares approximation. Furthermore, the microscope systems based on fringe projection are calibrated via perspective geometry and known references [16,17]. These microscope systems compute the surface topography based on the microscope geometry and a phase detection algorithm. The calibration of the above mentioned microscope vision systems is accomplished by means of external references. Therefore, physical measurement errors are added to the calibration, which increases the surface measurement error. Additionally, the re-calibration is not achieved due to the missing of references when the microscope configuration is modified during the vision task. Moreover, the stereo light microscope, monocular light microscope and scanning probe microscope consume long time to determine the pixel pattern position without high accuracy. Furthermore, the microscope system based on fringe projection requires a high quality of alignment to obtain the fringe pattern. According to these criterions, it is established that the traditional microscope calibration still represents a challenge task. Therefore, the traditional microscope calibration should be improved by means of an automatic technique to avoid external references.

The proposed microscope self-calibration is performed by means of soft computing algorithms based on micro laser line projection. In this technique, the vision parameters are represented via Bezier approximation networks based on laser line position. From these networks, the vision parameters are computed by a genetic algorithm trough the laser line position. Thus, the microscope self-calibration is accomplished without physical measurements of external references. Also, the vision

E-mail addresses: munoza@foton.cio.mx, munoza@cio.mx

https://doi.org/10.1016/j.optlaseng.2017.12.010
Received 5 August 2017; Received in revised form 8 December 2017; Accepted 24 December 2017
0143-8166/

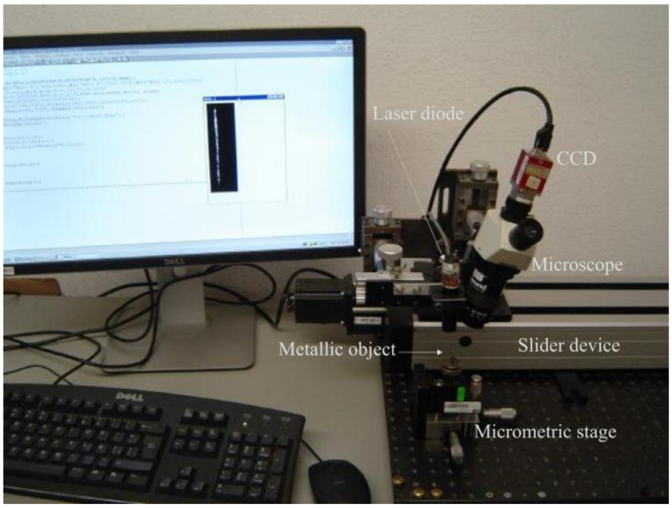

Fig. 1. Microscope setup to perform self-calibration via micro laser line projection.

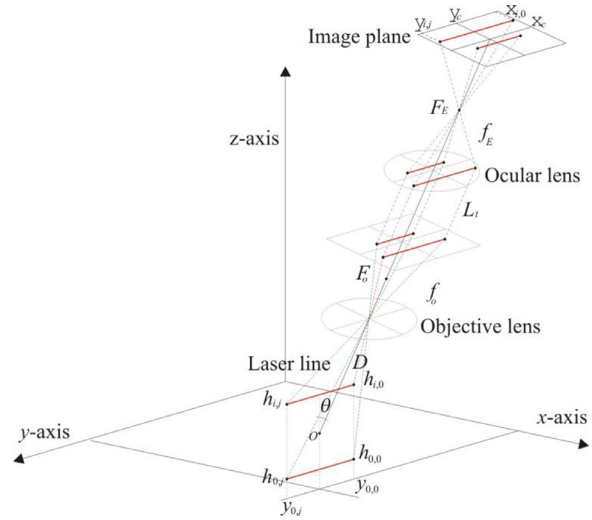

Fig. 2. Microscope geometry based on micro-laser line projection.

parameters are re-calibrated by means of the networks and the genetic algorithm when the microscope system is modified during the vision task. Thus, the soft computing algorithms improve the accuracy of the traditional microscope calibration and the surface measurements. It is because the approximation networks avoid errors of external references. The self-calibration is performed based on a microscope vision system, which projects a 38 μm laser line on the target surface and a CCD camera captures the laser line. Thus, the approximation networks compute the micro-scale surface through the line position, which is detected via Bezier curves [18]. Then, the microscope system is moved by means of a slider device to compute the complete micro-scale surface. Additionally, parameters such as: numerical aperture (*NA*), field of view (*FOV*), and axial resolution are determined based on the data provided by the self-calibration. The proposed microscope self-calibration improves the previous work of micro-laser scanning, which does not provide flexible calibration [19]. The previous work is performed based on a static calibration, which does not re-compute the vision parameters when the setup is modified during the vision task. It is because the previous method does not provide equations to re-compute the vision parameters during the vision process. The static calibration of the previous work is successfully applied when the setup geometry is not modified during the vision task. However, several times, the microscope configuration is adjusted during the vision process to improve the image of the surface to be profiled. Therefore, the proposed technique performs flexible calibration, which provides equations to re-compute the vision parameters during the vision task. This procedure is carried out by representing the vision parameters by means of the Bezier approximation networks based on the laser line position. Thus, the limitations of the previous work are overcome. The contribution of the proposed microscope self-calibration is corroborated by an evaluation based on the accuracy of the traditional calibration of optical microscope. The paper is organized as follow, the microscope system is described in Section 2, the microscope self-calibration is implemented in Section 3, and the micro-scale surface contouring is described in Section 4.

2. Basic description of optical microscope system

The proposed microscope self-calibration is performed based on the microscope vision system shown in Fig. 1. This microscope system includes a laser diode, a CCD camera, a slider device and a computer. The microscope arrangement consists of an optical microscope on which the CCD camera and the laser diode are mounted. In this setup, the surface to be profiled is located on the *x*–*y* plane, which is situated perpendicularly to *z*-axis. The micro laser line is projected perpendicularly on the target surface and the microscope is aligned at an angle. Thus, the CCD camera captures the laser line image through the optical microscope. The microscope system can be moved in *x*-axis, *y*-axis, and *z*-axis. Additionally, the microscope can be displaced toward or away from the diode laser. The geometry that describes the configuration of the optical microscope system is shown in Fig. 2. In this diagram, the angle between the laser line and the optical axis is indicated by the symbol θ. The distance from the point O to the objective lens is depicted by D. The focus of the objective lens is indicated by F_o and the focal length f_o represents the distance between the objective lens and the intermediate image plane. The distance from the intermediate image plane to the ocular lens is depicted by L_t. The focus of the ocular lens is indicated by F_E and the focal length f_E represents the distance between the CCD image plane and the ocular lens. In the CCD image plane, the laser line position is indicated by the coordinates ($x_{i,j}$, $y_{i,j}$), the image center is depicted by the coordinates (x_c, y_c) and the pixel size is represented by η. The length of the laser line in *y*-axis is determined by the distance from the point $y_{i,0}$ to the point $y_{i,j}$. The surface coordinate $x_{i,j}$ represents the position where the laser line is projected on the target surface in *x*-axis. This coordinate is provided by the slider device. The surface depth $h_{i,j}$ represents the distance between the point "*O*" and the surface contour in *z*-axis. Based on the geometry shown in Fig. 2, the surface $h_{i,j}$ is calculated by means of the expression $h_{i,j} = (x_c - x_{i,j})\mathcal{M}/[Q + (x_c - x_{i,j})\mathcal{L}]$ and the surface coordinate $ly_{i,j}$ is computed by means of the expression $ly_{i,j} = Fd_{i,j}(D - h_{i,j}\cos\theta)(y_{i,j} - y_c)$, where, $\mathcal{M} = \eta L_t D$, $Q = f_E f_o \sin\theta$, $\mathcal{L} = \eta L_t \cos\theta$, and $F = \eta L_t / f_E f_o$, and $d_{i,j} = D - h_{i,j}\cos\theta$. In this case, the parameters (η, x_c, y_c, L_t, D, f_E, f_o, θ) are constants. This means that the surface coordinates are determined by means of the laser line coordinates. From this relationship, the self-calibration is performed by representing the surface coordinates ($h_{i,j}$, $ly_{i,j}$) via laser line coordinates by means of the Bezier approximation networks $h(u,v)$ and $ly(u,v)$, respectively. These approximation networks are implemented by the summation of Bezier basis functions $B(u)$ and $B(v)$, which are multiplied by the surface coordinates and a weight. In these networks, the surface coordinates ($h_{i,j}$, $ly_{i,j}$) are substituted by the terms $(x_c - x_{i,j})\mathcal{M}/[Q + (x_c - x_{i,j})\mathcal{L}]$ and $Fd_{i,j}(D - h_{i,j}\cos\theta)(y_{i,j} - y_c)$, respectively. Thus, the next networks are obtained

$$h(u,v) = \sum_{i=0}^{n}\sum_{j=0}^{m} \frac{B_i(u)B_j(v)w_{i,j}(x_c - x_{i,j})\mathcal{M}}{Q + (x_c - x_{i,j})\mathcal{L}}, \quad 0 \le u \le 1, \quad 0 \le v \le 1. \quad (1)$$

$$ly(u,v) = \sum_{i=0}^{n}\sum_{j=0}^{m} B_i(u)B_j(v)W_{i,j}F\left(y_{i,j} - y_c\right)d_{i,j}, \quad 0 \le u \le 1, \quad 0 \le v \le 1. \quad (2)$$

These networks are accomplished by computing the Bezier basis functions $B_i(u)$, $B_j(v)$ and the weights ($w_{i,j}$, $W_{i,j}$). The weights are com-