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Reducing field distortion for galvanometer scanning system using a vision system

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ABSTRACT

Laser galvanometer scanning systems are well-established devices for material processing, medical imaging and laser projection. Besides all the advantages of these devices like high resolution, repeatability and processing velocity, they are always affected by field distortions. Different pre-compensating techniques using iterative marking and measuring methods are applied in order to reduce such field distortions and increase in some extends the accuracy of the scanning systems. High-tech devices, temperature control systems and self-adjusting galvanometers are some expensive possibilities for reducing these deviations. This contribution presents a method for reducing field distortions using a coaxially coupled vision device and a self-designed calibration plate; this avoids, among others, the necessity of repetitive marking and measuring phases.

1. Introduction

Laser galvanometer scanning is an essential machining method in which the laser beam is deflected by means of mirrors attached to high-precision galvanometers. Different processes and laser sources make this machining approach a high-flexible method for diverse scientific areas. Such systems are capable to achieve very high processing velocities and spot sizes of tens of microns. The overall accuracy and finishing of the processing are directly influenced mainly by the accuracy of scanner system, coordinates table as well as optical distortions. For specific applications a compromise among accuracy, velocity and such distortions must be reached. In this work is presented a new method using a self-designed calibration plate and a coaxial vision system in order to reduce inherent deviations.

1.1. Mechanical and inherent deviations in galvanometer laser systems

Mechanical deviations are described essentially as building and mounting errors. They normally appear by incorrectly assembling the scanner unit, lenses or mirrors. Thermal effects are also another type of mechanical influenced deviations because the position of the laser spot changes because of the variation of temperature in the optics and electromechanical devices.

Mechanical deviations cause the working field to deform in a non-symmetric way while temperature changes cause the laser beam to drift while it is being scanned. In addition, there are also inherent deviations in the galvanometer scanning systems which are caused by the proper characteristics of used optical elements.

When the mirror rotates at a constant velocity (the variation of the angle θ_x of the mirror is constant), the relationship between the rotation of the mirror and the position of the laser spot when it is focused by a spherical lens is given by

$$h_x = f_t \cdot \tan \theta_x \quad (1)$$

where f_t is the focal distance of the lens, h_x the position over the working field and $\theta_x$the rotation angle. The position of the spot changes non-lineally and increases proportionally to the tangent of the angle. In addition, the position of the focal plane does not remain constant causing the image in the working area to blur, see Fig. 1(a).

The common way of solving these problems is using a special lens so-called flat field objective or f-theta objective. Its special design permits that the velocity of the spot and the focal plane remain constant over the complete working field, see Fig. 1(b). The position over the working field becomes

$$h_x = f_t \cdot \theta_x \quad (2)$$

The principal disadvantage of using these lenses is the introduction of geometrical aberrations. These aberrations do not cause the image to blur, but misshape. Finally, the deviation of the

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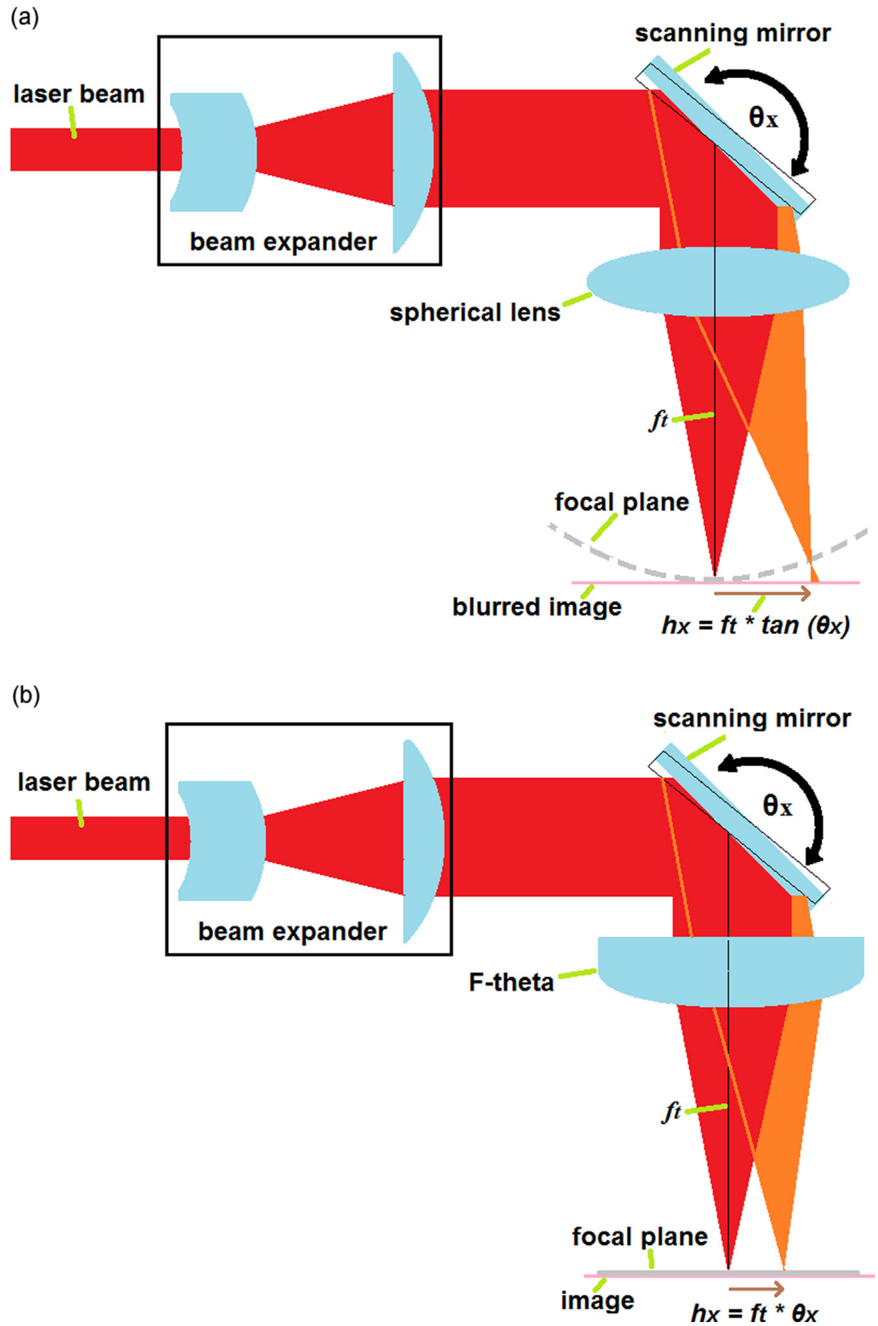

Fig. 1. General illustration of a laser scanning system. (a) Common spherical lens. (b) F-theta focusing lens.

complete working field can be represented as a combination of diverse distortions as depicted in Fig. 2.

1.2. Conventional correction of field distortion

Different strategies have been developed for reducing inherent deviations for laser scanning systems [14,2,3]. Improved devices, temperature control systems and self-adjusting galvanometers are some possibilities for reducing these deviations. The common way for reducing the inherent deviations in scanning systems is using the so-called compensating techniques. Basically, the scanning field is approximated to a linear function of two variables $F_s = f(x, y) = (\theta_x, \theta_y)$ in the focus plane. This approximation must be corrected using a multivariate interpolation method. Commonly, a bilinear interpolation or a bicubic interpolation is used for finding a solution for the two dimensional function.

The purpose is to find the value of scanning angles (galvanometers of axis X and Y) at a known point (x, y). That means to calculate the value of the function $F_u = f(x, y)$. The assumption is that the value of the function is already known in four controlling points (see Fig. 3), accordingly $f(P_{11}) = f(P_{x1,y1}) = (\theta_{x1}, \theta_{y1})$, $f(P_{21}) = f(P_{x2,y1}) = (\theta_{x2}, \theta_{y1})$, $f(P_{12}) = f(P_{x1,y2}) = (\theta_{x1}, \theta_{y2})$ and $f(P_{22}) = f(P_{x2,y2}) = (\theta_{x2}, \theta_{y2})$.

In order to approximate the function the interpolations are calculated over each direction. The order of these interpolations yields the same results. For convention, the X-direction is chosen as initial direction

$$f(x, y_1) = \frac{x_2 - x}{x_2 - x_1} f(P_{11}) + \frac{x - x_1}{x_2 - x_1} f(P_{21}) \tag{3}$$