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Review

Welding joint detection by calibrated mosaicking with laser scanner systems

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ABSTRACT

Nowadays laser scanners are increasingly being used in laser welding. Because of deviations between the theoretical welding path and the actual contours of the workpiece, the welding result often does not meet the quality requirements. This problem can be solved using industrial imaging. Metrical information about the workpiece can be obtained from a camera attached to the laser scanner, which uses the same optical path as the laser beam. For this the entire camera application must be calibrated. The necessary calibration routines are described in this paper and validated by means of a practical example.

Contents

Introduction

Laser welding is an established method for mass production. Since the flexibility of production systems has become more and more important, today laser scanners are preferably used instead of fixed optics in numerous applications. These scanner optics apply a laser beam to a workpiece by deflecting the beam using movably mounted, galvo-driven mirrors and a focusing unit, forming the beam to a laser spot at a defined position within the scan field ([1], see Fig. 1).

An essential requirement for these welding systems is that the laser spot is applied very precisely at the joint location. Due to manufacturing tolerances of the joining partners and the small spot diameter, typically much smaller than 1 mm, the trajectories to be welded vary from component to component. Consequently, the theoretical trajectory is defined in the technical drawing, but the actual trajectory is commonly unknown. If manufacturing or positioning inaccuracies occur, the actual coordinates differ from the nominal coordinates, leading to a processing failure, which may result in the workpiece being discarded. For this reason an advanced offset correction for the welding path is desirable, which accounts for the actual, component-specific position and geometry. To make an offset correction possible, the offset firstly needs to be measured by a sensor.

This paper addresses the integration of such a sensor into a laser scanning system. An industrial camera is suggested for the sensing task. A beam splitter enables that camera to view through the same optical path as the laser beam (see Fig. 1). While the mirrors of the

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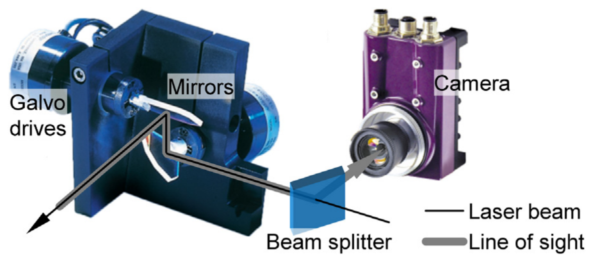

Fig. 1. Deflecting unit of a laser scanner in combination with a camera (according to [2,3]).

scanner are used to vary the detection area, the image sensor captures pictures. A view with a dedicated position of the mirrors is called camera pose, because it can be generated by a defined position of the camera without using the mirrors. The current view can be used for seam tracking [4,5], but the sequentially recorded single images contain much more information. They can further be aggregated into a global picture using a mosaicking process. With this global picture it is now possible to measure metrical workpiece features in the whole scan field and derive a component-specific welding trajectory. Since the optical path used during the measuring operation is the reverse path of the laser beam, the optical conditions are the same. A calibration routine for the camera has to deal with these conditions. There are two fundamentally different setups of scanner optics, which are explained in the following section.

Fundamentals of laser scanner optics

Zaeh et al. [3] describe two different types of scanner optics, the post- and the pre-objective scanner. In the first case, the raw laser beam is focused with a shifting lens and then deflected by the mirrors (see Fig. 2, left). The second type of scanner does it in the opposite manner. Here the focusing unit is typically built as a flat field lens. This means that the laser beam is always focused into a plane parallel to the objective and at a defined distance from the objective. This second concept can further be split up into entocentric and telecentric optics.

In entocentric optics only the central beam is parallel to the main axis. From the viewpoint of the camera, it comes perpendicularly from the object to be imaged (see Fig. 2, right). All lines of sight that differ from the central axis are no longer parallel to the main axis. Thus, the camera sees the object at an angle unequal to 90°. The result is a perspective image.

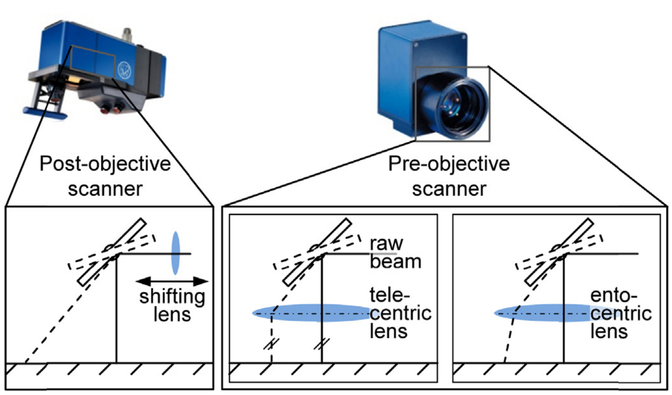

Fig. 2. Schematic representation of different concepts of scanner optics: post-objective scanner (left) and pre-objective scanner with telecentric (middle) and entocentric (right) flat field lens (according to [3]).

Using a telecentric lens, all lines of sight are parallel to the central axis (see Fig. 2, centre). However, the dimensions of the lens must always be equal to or greater than the scan field, which is a major drawback, since either the scan field is small or the lens becomes bulky and expensive.

Any lenses have aberrations, due to manufacturing inaccuracies, resulting in a distortion of the image. This typically results in a non-uniform radial projection of the lines of sight with an increasing distance from the centre of distortion. In combination with a perspective view, this results in the mapping of a point in the world (3D) onto a projection surface (2D, e.g. the camera chip). A mosaicking method has to compensate for these effects in order to get a metrical and homogeneous image. In the following a first and already existing approach is presented, for which the mosaicking process is done with pictures taken through telecentric laser scanner systems.

State of the art and need for action

Rombach [6] uses the combination of a laser scanner and a camera for manipulating the joint location, based on a template matching algorithm. As this method neither involves a field calibration, nor allows for a metrical measurement in the acquired images, it is only suitable for a positioning correction (translation, rotation) of the welding trajectory, but not for a geometrical trajectory adaption. However, Stache et al. [7,8] have developed a method for the field calibration of telecentric scanner systems with an integrated camera. Here, at the beginning, a thermal paper is positioned in the scan field and is marked with the laser beam at 81 defined points, arranged in a 9×9 matrix. Each marking is recorded through the optical path of the scanner, which is without any perspective deformation, due to the telecentric lens. In each captured image an offset vector from the applied marking to the centre of the image is calculated. Afterwards all frames are put together according to their image centre to form a global picture. An affine transformation is searched and applied to the global image so that the square sum of the lengths of the offset vectors from the measured marking positions to their real positions becomes minimal. This corresponds to a stretching, rotating or scaling, but not to a bending of the global image. By using one affine transformation for the global picture and therefore for all single pictures, it is not possible to react on a possible discontinuous imaging of the lens. Additionally, the distortion errors of the lens are not corrected. Consequently, this method can only be applied when using a telecentric lens; otherwise each frame would have a perspective deformation.

Thus, a general method to provide a calibrated global picture is needed which can be applied for all types of scanner optics. It has to include systems with entocentric lenses whose scan field, in contrast to the telecentric lenses, can be larger than the lens itself, which is typical in macro laser material processing. Thus it must be possible to apply the method even with perspectively deformed and distorted single images.

Machine vision through arbitrary laser scanners by calibrated mosaicking

Hereinafter, a method is presented to correct any perspectively deformed and distorted single pictures, captured through the laser scanner, to undeformed and undistorted ones and to arrange them to an undeformed and undistorted global picture. This method is known as calibrated mosaicking.

The necessary process suggested in this paper is made up of several sequential steps, which are depicted in the following Nassi–Shneiderman diagram (Fig. 3):