Measurement 73 (2015) 304–312

Contents lists available at ScienceDirect

Measurement

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

A model to transform a commercial flatbed scanner into a two-coordinates measuring machine

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ARTICLE INFO

Article history:
Received 27 March 2015
Received in revised form 9 May 2015
Accepted 29 May 2015
Available online 6 June 2015

Keywords:
Optical dimensional metrology
Measurement uncertainty
Flatbed scanner
Instruments calibration
Correlation

ABSTRACT

This paper describes a methodology which allows a commercial flatbed scanner to be transformed into a two-coordinate measuring machine which is capable of providing traceable measurements. This methodology requires an initial adjustment in order to convert the reference system of the flatbed scanner into a Cartesian reference system, thereafter calibrating it using standards with metrological traceability. Circle and line scales have been used in this case, but other alternative standards may also be employed by merely adapting the calculation algorithms. Once the equipment has been calibrated, the characterisation process of a relatively complex part and the results obtained for different critical dimensions are indicated as an example. The criteria used to determine and propagate the uncertainties in measurement, as recommended in Supplements 1 and 2 to the "Guide to the expression of uncertainty in measurement" (GUM), are also indicated.

1. Introduction

The scientific literature contains different works which indicate the use of commercial flatbed scanners as measuring instruments in various fields, such as: engineering [1–3], biology [4], archaeology [5], mineralogy [6], biomedical sciences [7] and astronomy [8]. In all cases, the justification for their use is based on the speed, versatility and ease of this equipment for image acquisition. However, it is not always possible to ensure that the measurements taken with such equipment are metrologically traceable if they have not been previously adjusted and calibrated. Both phases are essential and necessary from a metrological point of view:

- Adjustment of a measuring system (VIM 3.11 [9]) also referred to, in this paper, as self-calibration of the flatbed scanner. This is performed with a standard not necessarily traceable, which allows the reference system of the flatbed scanner to be transformed into a Cartesian system.
- Calibration (VIM 2.39 [9]) using a traceable standard. Determines the uncertainty associated with the measurements made under certain conditions.

Using the flatbed scanner as a versatile measuring instrument capable of providing useful information to determine levels of complex parts requires an additional phase in order to truly obtain a measuring instrument capable of characterising 2D parts. This phase includes the following three stages:

- Writing of computer routines that enable the automatic detection of the edges of the part, that is, the measurement points based on the images generated by the flatbed scanner.

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http://dx.doi.org/10.1016/j.measurement.2015.05.029
0263-2241/

- Writing of computer routines which adjust geometric elements such as lines, circles, and ellipses. to the measurement points. This allows geometric operations between the elements, such as determining the angles between lines, distances between elements, and intersections.
- Writing of computer routines to estimate the uncertainties of the measurement results using the Monte Carlo method, as recommended in Supplement 1 [10] to the GUM [11].

In this paper, the image processing algorithms were developed based on the toolboxes of MatLab® [12]. The edge detection and image filtering procedures based on the Canny filter, contained in the scientific literature, can also be used [13–15].

The point is not to build an advanced and high precision dimensional metrology instrument. In fact, the expected benefits of this type of instrument are necessarily modest. This work only endeavours to show the capacity of a simple and very economical instrument to characterise and verify complex geometries when the tolerances are not overly demanding, for example greater than 30 μm.

The two phases described above are developed throughout this work. These are necessary so as to ensure the traceability of the measurements obtained using a very low cost commercial flatbed scanner, which was not designed as a measuring instrument. The experimental body and the mathematical developments set out in this paper help to clarify and establish the adjustment and calibration concepts that are very important in education and in industry.

The adjustment phase is a task usually performed by the manufacturer of the measuring equipment, which is often unknown to the end user. This paper describes a relatively simple linear model which allows an acceptable adjustment of the flatbed scanner as a measuring instrument, and we believe that this is of interest because it is transferable to other instruments. Naturally, the process described here would not be immediately applicable to 3D equipment, but the ideas, principles and basic concepts involved are applicable.

This work has made use of a multifunction Canon, model PIXMA MP630 (Fig. 1) flatbed scanner with a working area of 216 mm × 297 mm (approximately size A4) and an optical resolution of up to 4800 dot per inch (dpi) approximately equivalent to a resolution $E = 0.005$ mm. This paper encompasses work performed in a reduced area of 216 × 216 mm (Fig. 2), with an optical resolution of only 1200 dpi which generates digital images of 100 megapixels with $E_0 = 0.021$ mm resolution. Work has been performed in this reduced area, with a reduced resolution, in order to allow a flexible management of the images obtained using a PC with a quad-core processor and a frequency of 3 GHz and 4 GB of RAM. If the work had been performed using the entire area of the flatbed scanner, and with its maximum resolution, the size of the images would have been 2.3 gigapixel, which is a size that would have been completely unmanageable using the computer equipment described.

Fig. 1. Commercial flatbed scanner Canon PIXMA MP630.

2. Flatbed scanner adjustment of a measuring system

The adjustment of the flatbed scanner is performed using an uncalibrated artefact, and uses methods based on the *sel-calibration* concept [16,17]. For this, the artefact is measured in n positions (multi-step) (blue [1]dashed lines in Fig. 2) relative to the instrument. This allows the geometric errors of the equipment to be eliminated without the equipment being affected by the calibration results of the artefact.

The (p, q) coordinate system of the flatbed scanner, expressed in pixels, is not a Cartesian system. If the set of points of the flatbed scanner is such that $p = \text{constant}$ or $q = \text{constant}$, in general a curve, and not a straight line, is obtained, even when the curve appears as a straight line. Furthermore, it could be that:

- The $p = \text{constant}$ or $q = \text{constant}$ curves were not exactly parallel.
- The $p = \text{constant}$ and $q = \text{constant}$ do not intersect in a completely perpendicular form.
- The pixel dimensions were slightly different, according to the p and q directions.

Due to this, if the distance between two A and B points of a part is measured, the result $\sqrt{\Delta p^2 + \Delta q^2}$ (being $\Delta p = p_B - p_A$ and $\Delta q = q_B - q_A$) may vary by changing the orientation in which it is measured. However, this distance is constant if the part is dimensionally stable. That is, the application assigning the $\sqrt{\Delta p^2 + \Delta q^2}$ value to the "distance" between points A and B, it is not invariant to rotations and translation of the part with respect to the coordinate system of the flatbed scanner. To overcome this problem, we must find an $(x, y) = \mathbf{f}(p, q)$ application that transforms the non-Cartesian coordinates (p, q) into (x, y) coordinates, which are Cartesian coordinates (Figs. 3 and 4). That is, the $\sqrt{\Delta x^2 + \Delta y^2}$ distance is invariant to rotations and/or translation of the part with respect to the coordinate system of the flatbed scanner. If the $\mathbf{f}$ function is linearised, and:

[1] For interpretation of color in Fig. 2, the reader is referred to the web version of this article.