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Development of an Algorithm to Detect Screw Threads in Planar Point Clouds

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Measurements in production must be rapid, robust and automated. In this paper a new method is proposed to automatically extract features and parameters of screw threads via Hough transformation from 2D point clouds acquired from profile measuring machines. The described method can be used to automate many operations during screw thread prealignment and drastically reduce operator's influence on the measurement process resulting in lower measurement times and increased repeatability.

Keywords: **screw thread; Hough transformation; feature extraction.**

1. Introduction

Coordinate measuring machines and devices of different type are widely used for screw thread inspection during recent decades [1]. Calibration and inspection of screw threads on coordinate measuring machines (CMM) is time consuming and costly in terms of operators' skill. Usually CMM operator has to specify locations of screw thread features (i.e. crests) manually to perform measurements, or he has to configure the measurement software in particular way for every different threaded workpiece. This can be very time consuming especially when sizes of measured screw threads vary greatly. Different measurement software allows automatic recognition of patterns to some degree. However most of it requires significant preparation to be done by the operator for every specific type of pattern or workpiece and none of them works out of the box for screw threads.

The method presented in this paper allows automatic detection of screw thread parameters in 2D images obtained from coordinate profile measuring machines, both tactile and optical. Enabling fully automatic screw thread prealignment and drastically reducing operator's influence on the measurement process resulting in lower measurement times and increased repeatability. The proposed experimental results include evaluation of a thread pitch from a scanned profile data.

This paper is organized as follows: an overview of previous work is given in Section 2. A Hough transformation is explained in Section 3, followed by Section 4 explaining the hardware used to aquire thread profile data and Section 5 where our detection algorithm is presented. Particular implementation details are highlighted in Section 6. The limitations of the proposed algorithm and its comparison to other pattern recognition methods are analyzed in Section 7. We conclude with a summary of the obtained results and ideas presented in this paper and outline topics for future research in Sections 8 and 9.

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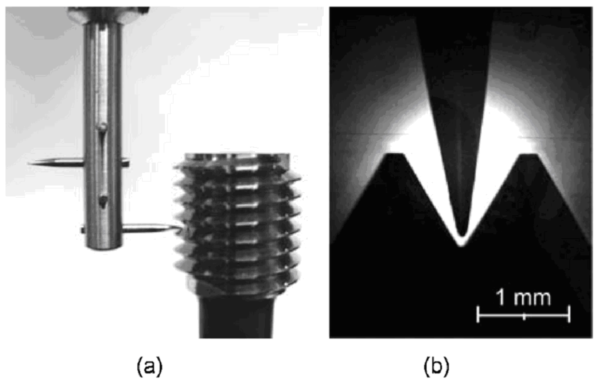

Fig. 1: Needle-like probe: (a) four needles on a stem in contact with a M20 thread gauge; (b) close-up of needle and thread [2]

2. Related Work

Development of new screw thread inspection techniques using optical and tactile methods recently became relevant. Carmignato and Chiffre [2] proposed a screw inspection method with a special needle-like probe fitted on a coordinate measuring machine (fig. 1).

In [3] authors perform optical inspection of damaged screw threads using CCD camera. The profile section of their sample is presented in fig. 2.

Many techniques usually involve different shape analysis algorithms from the field of computer vision and pattern recognition. Robertson and Fisher [4] experimented with 3D scanners and their application to large thread measurement (fig. 3). They examined that it is possible to extract parameters of screw threads from 3D scanned data. However they deal only with inner and outer radii of the thread.

Optical non-contact measurement methods involving di-

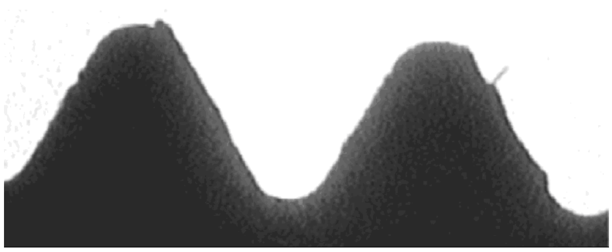

Fig. 2: Damaged cone thread [3]

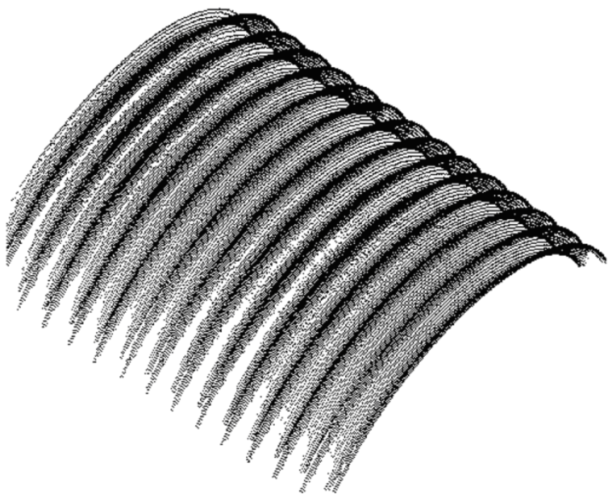

Fig. 3: Thread surface obtained from a 3D scanner [4]

mensional measurements and image analysis algorithms are also being actively developed. In [5] a coordinate measuring machine vision system is designed to implement automation of initial workpiece alignment. Their system uses one fixed position camera to detect the positions of the probe and the workpiece. In [6] authors apply image recognition techniques to crack width measurement. They use images obtained from CCD cameras (fig. 4).

In [7] a software system is presented capable of optical measurement of sixteen most common parameters of screw threads.

In [8] statistical image analysis method is proposed, capable of measuring thread pitch and pitch diameter. However evaluation method is not based on well established industrial practices described in [9].

The method proposed in this paper is based on the Hough transformation which is described thoroughly in the work [10] and in technical notes [11]. A large body of work had been undertaken by many researchers to use Hough transformation

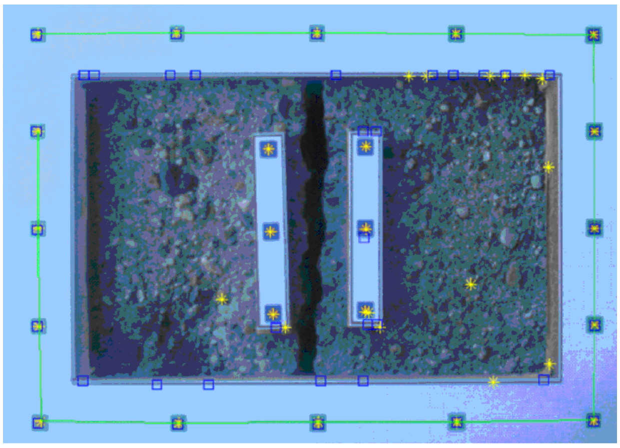

Fig. 4: Crack measurement using image recognition [6]

in many real-world tasks. Recently Tarek et al. [12] implemented a planar surface extraction from massive unstructured 3D point clouds using modified version of RANSAC (random sample consensus) algorithm. One of the major applications of RANSAC and point clouds processing and segmentation methods are LIDAR geomeasurements [13], however this topic will be left outside the scope of our paper.

3. Hough transformation overview

One of the well known solutions to the feature extraction problem in image analysis and computer vision is the Hough transformation [14]. The original Hough transformation was implied to detect lines in digitized raster images, and particularly subatomic particle tracks passing through a viewing field [14]. Later it was improved to became what is now known as the “generalized Hough transformation”.

To extract features from the source image one can perform a voting procedure in feature parameter space — n-tuple, where n depends on the certain class of the shapes to be extracted (line, circle etc.).

A straight line on a plane can be parametrized by the direction of its normal θ and its algebraic distance ρ from the origin. This yields the equation of the line

$$x \cos\theta + y \sin\theta = \rho. \tag{1}$$

Typically θ is restricted to the interval $[0, \pi)$ so that normal parameters for a line are unique and every line in the $x-y$ plane corresponds to a unique point in the $\theta-\rho$ plane [11].

To find the lines that fit a set of N points one should transform these points (x_i, y_i) from the $x-y$ plane into the curves in the $\theta-\rho$ plane defined by equation

$$\rho = x_i \cos\theta + y_i \sin\theta. \tag{2}$$

It is obvious [11] that the curves corresponding to collinear points have a common point of intersection. The coordi-

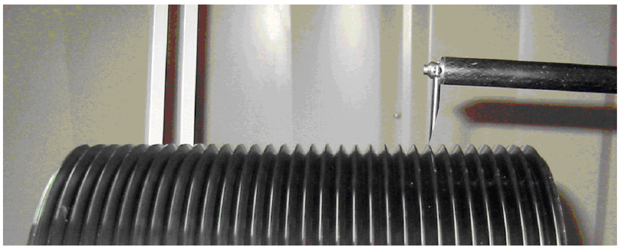

Fig. 5: Experimental setup [16]

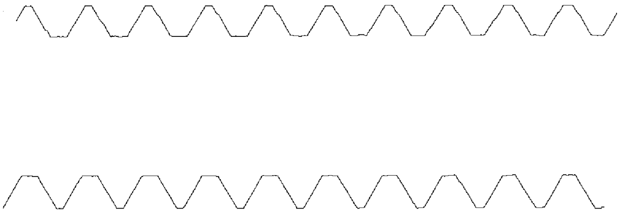

Fig. 6: Scanned profile of M27x3-6g screw thread

nates (ρ_0, θ_0) of this point define the line passing trough the collinear points.

The properties of the described point-to-curve transformation can be summarized as follows [11]:

- an image point corresponds to a sinusoidal curve in the parameter plane;
- a point in the parameter plane corresponds to a straight line in the image;
- points lying on the same straight line in the image correspond to curves through a common point in the parameter plane;
- points lying on the same curve in the parameter plane correspond to lines through the same point in the image.

Numerical results of line detection can be obtained by the quantization of the parameters on a two-dimensional grid. Each cell of the grid is an accumulator which is incremented every time a curve (2) passes through the cell (considering quantization). Maximal accumulated values represent the detected lines in such a way that if the value of an accumulator (θ_i, ρ_i) is k then exactly k points of the image is lying on the line $x\cos\theta_i + y\sin\theta_i = \rho_i$.

By picking N grid cells with maximal values one can obtain N lines passing through the maximal number of points in the image.

4. Experimental setup

Screw thread data collection was performed using 2D coordinate profile measuring machine Mahr Perthometer Concept XC20 (MPE = $2 + \frac{L}{50}\,\mu m)^1$, where L is the measuring length, mm. The parallel screw thread M27x3-6g was placed on the device's X/Y table so that the thread axis can be aligned along the measuring stylus traveling line (fig. 5). See [16] for an in-depth assessment of the alignment procedure. The resulting scanned raster profile is presented in fig. 6.

[1] Maximal Permissible Error (MPE) — error of measuring linear dimensions according to ISO 10360-2:2009 [15].

5. Screw thread recognition

A general overview of our screw thread detection algorithm is as follows:

- **Aquire 2-dimensional profile point cloud.** The profile points can be obtained from a profile measuring machine as in our experimental framework or any other coordinate measuring devices, i.e. CMMs, laser trackers and scanners, etc.
- **Extract lines from obtained points.** Straight lines representing flanks of the thread are obtained via Hough transformation.
- **Sort obtained lines and find intersection points.** Intersection points closest to the profile average line are used to fit circles into screw thread groves.
- **Fit circles into the groves.** Radii of the circles are chosen so that circles contact the profile close to the pitch diameter, as in the three-wires method.
- **Evaluate thread pitch and pitch diameter.** Distances between the fitted circles are used for assessment of screw thread parameters.

The procedure described above requires only nominal thread pitch to be specified by the user — this is necessary to calculate radii of the circles. Consider the raster profile (fig. 6) obtained by longitudinal scanning of the thread and digitized as a raster image 2048x2048.

To extract lines from this image we need to transform pixels (x_i, y_i) from the raster profile space to the line parameter space defined by the equation (2).

The resulting Hough-image is presented in fig. 7. Extraction of N local maximums from the Hough-image gives N straight lines that correspond to flanks of the screw thread. Though measured profile is of non-ideal shape the extreme points are smoothed into a region. A two-dimensional Gaussian filter (3) is used to filter this region and extract the peak point

$$g(x,y) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right). \tag{3}$$

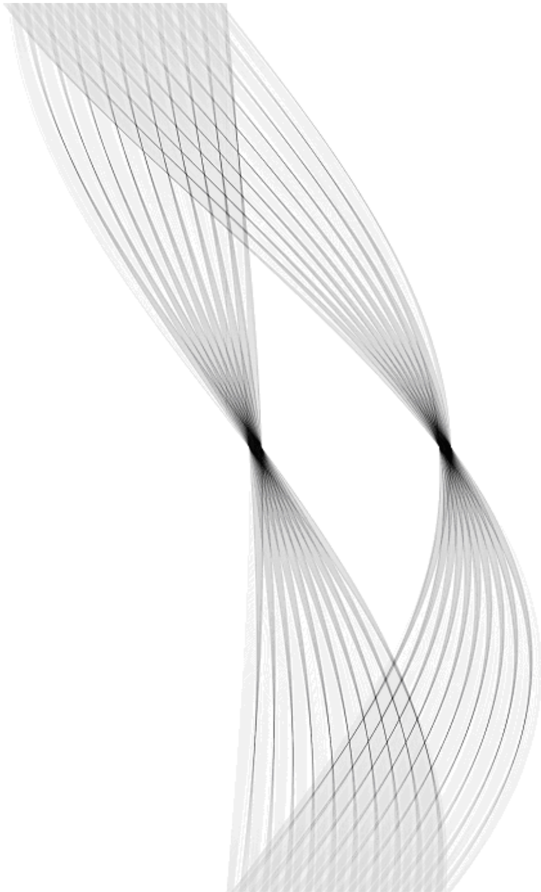

Fig. 7: Hough-image of the scanned M27x3-6g screw thread profile

An implementation of the kernel-based Hough transformation for detecting straight lines in binary images — KHT Sandbox (`https://sourceforge.net/projects/khtsandbox`) [17] — was used in our evaluation. It allows to achieve real-time performance even on relatively large images.

6. Prealignment and assessment of screw thread parameters

The flanks extraction from the top profile was done with KHT Sandbox and presented in fig. 8. To limit the extraction process to a useful number of lines an empiric rule is applied — as the line normal angle θ is below $\frac{1}{4}$ of the nominal thread angle the extraction is stopped and all previously detected straight lines considered to be the thread's flanks.

From the Hough-image fig. 7 it is clear that thread profile consists of 4 sets of lines — left and right flanks for lower and upper profile.

To separate left and right thread flanks the angles θ can be used directly, where positive angles give right flanks and negative angles give left flanks.

Hereafter the intersection points of the detected lines

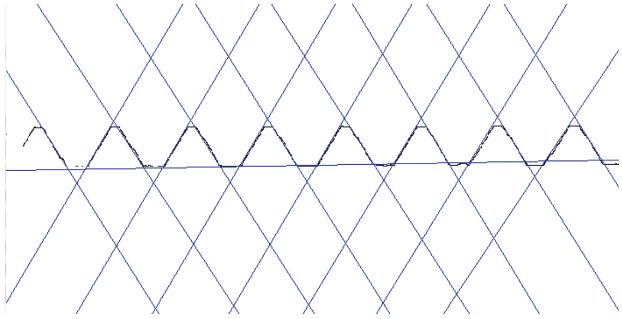

Fig. 8: Extraction of thread flanks

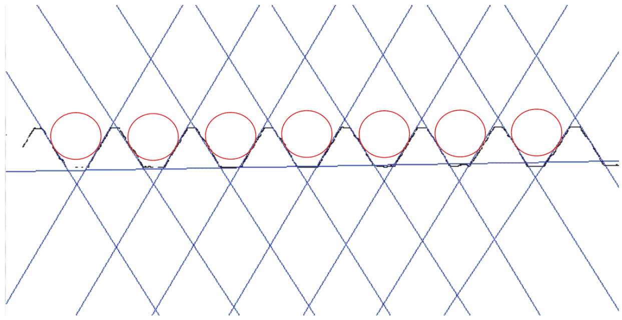

Fig. 9: Inscribed circles to allow pitch measurement

should be found. Once the intersection points are sorted by their y-coordinate they can be separated into two groups — points in-space and points in-material. Where the first group is above the profile average line and the second one is below it. The first n in-space points (S_n) next to the profile average line are lying directly above the thread groves. To fit the circles into the groves an initial fitting direction should be found. These points can be used together with the first n in-material points (M_n) below them as an initial values of circles fitting vector $\vec{r}_n = M_n - S_n$. Thereafter contact points of fitted circles and scanned profile can be established using binary search (fig. 9). The search procedure is stopped as the distance between the circle and the profile is below significantly small $\delta = 0.0001$ mm. Radii of the circles are chosen according to [9, Eq.(9)]

$$r_d = \frac{P}{4} \frac{1}{\cos\frac{\alpha}{2}}, \tag{4}$$

so that circles contact the profile close to the pitch diameter where P is the nominal thread pitch and α is the nominal thread angle.

The contact points are evaluated as the circle-to-profile contacts and not as the circle-to-line contacts, hence eliminating the uncertainties introduced by the presented prealignment procedure.

The prealignment can now be done using fitted circles according to any specific measurement task. For example, it is trivial to obtain the thread pitch — projections of distances

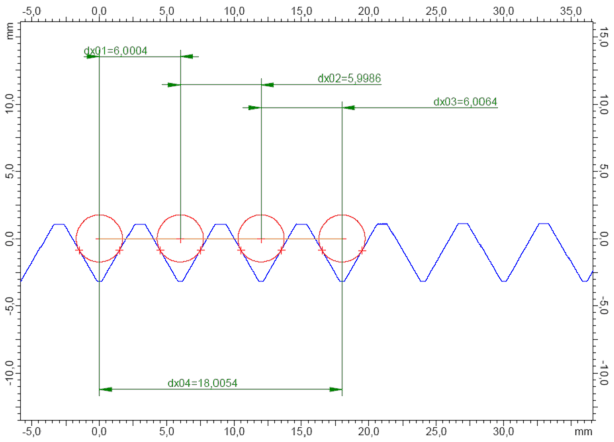

Fig. 10: Reference measurement of the M170x6-6g thread pitch via MarSurf XC 20

between the neighbor circles onto the thread axis can be used for this purpose. The pitch diameter of the thread can be calculated according to [9]:

$$D = m \mp \frac{2r_d}{\sin\frac{\alpha}{2}} \pm \frac{P}{2}\cot\frac{\alpha}{2} \mp A_1, \tag{5}$$

where m is the distance between circles on the opposite sides; P is the nominal thread pitch; α – nominal thread angle; A_1 is the rake correction [18]. The upper sign applies to external thread and the lower sign to internal threads. No measurement force correction is applied as the profile points are treated as being already CAA-corrected.

7. Results

The results obtained in this work were compared with the results of M27x3-6g thread profile evaluation in MarSurf XC 20 V1.50-5 measurement software (fig. 10) in terms of the measurement time and repeatability. The comparison results are summarized in tables 1 and 2. Standard deviations of ten different reevaluations (operator induced uncertainty) and ten different remeasurements are provided for both methods.

Two evaluation modes of MarSurf XC 20 were studied. Manual evaluation (first column) requires operator to mark features on the profile every time. “Quick & easy” (QEZ) evaluation mode requires preparations to be done by the operator for every different size of measured screw thread to develop so called “quick & easy program” which can be applied to a measured profile. The third column represents results evaluated in a fully automatic way with no information about nominal thread parameters provided to the software. The evaluation time in the first case was about ten minutes per experiment limited to the speed of the user. In the second case it was below one minute (operator had to select an appropriate QEZ program) plus ten minutes for preparation needed to create and save measurement program. In our algorithm evaluation

Table 1: Comparison of M27x3-6g profile reevaluation

	MarSurf	MarSurf (QEZ)	Our method
Min pitch [mm]	2.994	2.995	2.995
Max pitch [mm]	3.007	3.006	3.006
Std deviation [mm]	0.004	≈ 0.000	≈ 0.000
Time [s]	10	1	≈ 0

Table 2: Comparison of M27x3-6g profile re-measurement

	MarSurf	MarSurf (QEZ)	Our method
Min pitch [mm]	2.993	2.994	2.994
Max pitch [mm]	3.009	3.009	3.009
Std deviation [mm]	0.006	0.005	0.005

time can be neglected (operator had to load scanned profile in our software but is can be entirely avoided if the method proposed is integrated into measurement software) without any additional time required for preparation. The measurement time in our implementation is limited purely by the scanning speed of the measuring machine. Even so the results of QEZ mode during reevaluation are as stable as the results of our automatic reevaluation for a given profile an operator’s influence should still be considered since a QEZ program has to be created manually using a curtain scanned screw thread profile. Automatic evaluation procedure is free from this shortcoming.

8. Conclusions and future work

The results obtained in this work show that proposed method of screw threads detection is stable and faster than manual profile evaluation in typical measurement software.

The proposed profile processing method allows fast automatic extraction of screw threads’ pitch. Thread angle can be determined in a similar fashion. The main benefits from the automatic procedure are lower inspection time of screw threads and reduces operator influence on the measurement results.

In this paper only 2D images are considered, however the generalized Hough transform can be applied to the images of large dimensions, i.e. as proposed by Khoshelham [19]. Different object recognition techniques are of great importance in metrological application as the metrotomography technology is emerging as an industry field. In practice this will allow recognition of screw threads from 3D density grids obtained from computer tomography devices.

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