Toward an automatic measurement of micro cutting tool

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Abstract

Micro manufacturing is becoming more diffused due to its important for new application product. Micro machining plays an important role for such process [1]. As a consequence, metrology of micro cutting tool is demanding. Non-contact measurement instrument is preferable for micro tool compared to tactile instrument due to better accessibility and faster data acquisition [2]. In machining, rake angle is a very important quantity. As such, this study develops algorithm for automatic rake angle measurement of micro-turning tool from their acquired points. The algorithm is important to ensure repeatability of the measurement, which is not provided by most instruments' software. In addition, it is useful for the estimation of task-specific uncertainty (ISO15530-4) and automatic in-line inspection systems.

1. Automatic Measuring Algorithm development

Unlike micro-milling, the tool size of micro-turning is not necessaraly in micro-scale. As such, small insert tool is still used for micro-turning with dimension in mm [1] and is used for the case study. The system used is focus variation non-contact instrument (Fig. 1). The algorithm steps are: 1. Point normal vector and curvature estimation, 2. Reference plane and cutting plane construction, 3. Point segmentation and line fitting, 4. Rake angle calculation. Triangle-mesh of the points cloud is utilized as input for the algorithm.

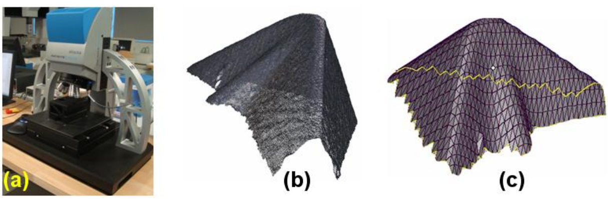

Figure 1: (a) The instrument, (b) Points cloud, (c) Triangle-mesh of the points cloud.

STEP 1: Point normal vector and curvature estimation. $\forall point P_i$, its normal vector $\vec{n}$ is estimated by $\sum_{i=1}^{n} \vec{n}_i / N$ where $\vec{n}_i$ normal of all adjacent faces and N is number of adjacent faces at the point (Fig. 2 left). Subsequently, the mean curvature $H = (k_1 + k_2)/2$ is calculated $\forall point P_i$. k_1, k_2 are two principal curvatures of P_i. Points on edge will have significant value of H (Fig. 2 center). k_1, k_2 are determined from the platelets, which are all the points adjacent to point P_i (Fig 2 right). These k_1, k_2 are the root of $k^2 - (c_1 + c_3)k + c_1 c_3 - c_2^2$, where c values are determined from the solution of:

$$\begin{bmatrix} p_1^2 & 2p_1q_1 & v_1^2 \\ \vdots & \vdots & \vdots \\ p_n^2 & 2p_nq_n & v_n^2 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} = \begin{bmatrix} d_1 \\ \vdots \\ d_n \end{bmatrix} \text{ where: } \begin{aligned} &(p_j, q_j)^T = (\vec{d}_j \bullet \vec{u}, \vec{d}_j \bullet \vec{v})^T; \\ &\vec{d}_j = Platelet_j^P - P_i; \\ &Platelet_j^P = Platelet_j - d_j \vec{n}; \end{aligned} \tag{1}$$

L is a plane having point P_i and unit normal $\mathbf{n_i}$. p_j, q_j are the absisca value of the local coordinate **u,v**. Distance of $Platelet_j$ to plane **L** is defind as d_j. $Platelet_j^P$ is the projection point of $Platelet_j$ on **L**.

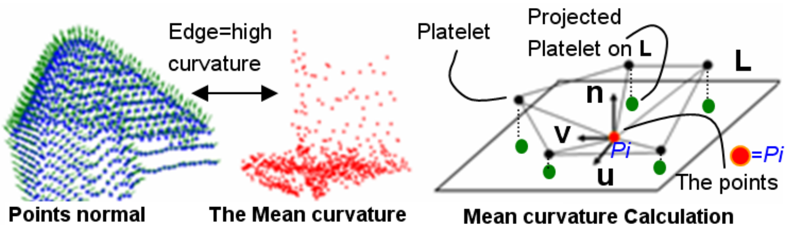

Figure 2: Normal and mean curvature of the points.

STEP 2: Reference plane **Pr** and cutting plane **P** construction. The **Pr** is determined from the points on edge. It can be done by selecting the points having significant value (above determined threshold=10) of H. The plane is constructed by a point on plane and its normal direction. Orthogonal fitting is used by finding the eigen vector correspond to the minimum eigen values of M, which is a $n \times 3$ matrix containing the edge points P_i coordinates. While, point on plane is the centroid (mean) of all considered points. The plane equation used, from $\vec{n} \bullet (P_i - \overline{P_i}) = 0$, is:

$$n_x(x)+n_y(y)+n_z(z)-(n_x\bar{x}+n_y\bar{y}+n_z\bar{z}) = Ax+By+Cz+D=0 \qquad (2)$$

The plane **Pr** (plane lie on the cutting edge) is used to determined plane **P** which is perpendicular to plane **Pr**. The unit normal of Plane **P** is obtained by rotating unit normal of plane **Pr** 90^0 around an axis, which is orthogonal to the cutting edge line, and the point on **P** is identical with the point on **Pr** (Fig. 3 left).

STEP 3: Point segmentation and line fitting. Segmentation is applied to the intersection points between the cutting plane **P** and the triangle-mesh model of the tool (Fig. 3 center). In this algorithm, paramateric equation of line is used. A line from two points $\vec{p}_{t1}, \vec{p}_{t2}$ is defined as $\vec{p}_t = \vec{p}_{t1} + t(\vec{p}_{t2} - \vec{p}_{t1})$ where t is a scalar quantity (scale) used to define the point on the line. By subtituting this parameteric equation to plane equation (eq. 2), then, t can be calculated as:

$$t = \frac{-[Ap_{t1x} + Bp_{t1y} + Cp_{t1z} + D]}{A(p_{t2x} - p_{t1x}) + A(p_{t2y} - p_{t1y}) + A(p_{t2z} - p_{t1z})} \qquad (3)$$

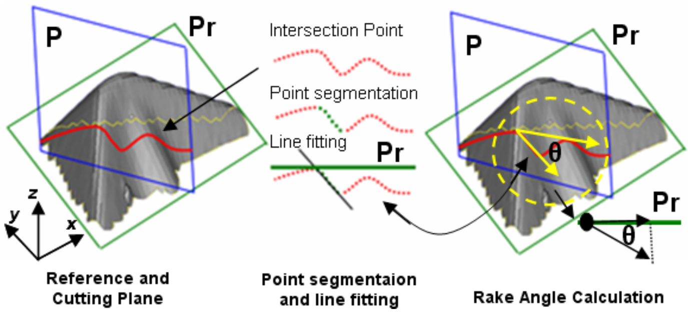

Figure 3: Constructed planes, point segmentation and fitting, rake angle calculation.

After obtaining t , intersection points between cutting plane **P** and the triangles can be obtained. Subsequently, point segmentation can be carried out. First, the points far from **Pr** are deleted.Then, the intersection points are sorted (ascending) with regard to *x*- and then y-coordinate position by using selection sort algorithm. Finally, the points are scanned starting from the left-edge point (Fig. 3 center). This point is identified by checking the point which has the minimum *y*-coordinate. The first 15 points are scanned and a line is orthogonally fitted. Then, the scanning is continued for the next point and the sigma of the error σ of the fitting is calculated, if $\sigma_{new} < \sigma$,then the point is stored. This step is carried out until there are three consecutive points contribute to have $\sigma_{new} > \sigma$, when the line is re-fitted.

STEP 4: Rake angle calculation. Rake angle θ is angle between line of segmented point and line projected to Pr (Fig 3 center). To calculate this angle, the unit normal of the fitted-line $\vec{n}_{line}$ from STEP 3 is projected into **Pr** (Fig. 3 right). The projected normal is calculated as:

$$\vec{n}_{Line\_proj} = \vec{n}_{line} - \vec{n}_{Plane\mathrm{Pr}} \left\| \vec{n}_{Plane\mathrm{Pr}} \left[\vec{n}_{line} \bullet \vec{n}_{Plane\mathrm{Pr}} \right] \right\| \qquad (4)$$

Finally, the rake angle θ is calculated as the angle between $\vec{n}_{line}$ and $\vec{n}_{line\_proj}$.

2. Algorithm Implementation: a case study

In this implementation, Insert tool for micro-turning was used and measured by the focus variation instrument (Fig. 4). To test the algorithm, 100 simulation runs were carried. In each simulation, every point was perturbed about 1 µm and rake angle is automatically calculated and stored. The results statistic of the rake angle are mean = 11.329^0 and sigma=0.9^0(Fig. 4 right). The algorithm will be improved to achieved sigma=0.6^0 , according to "golden rule limit" such that the measurement is efficient.

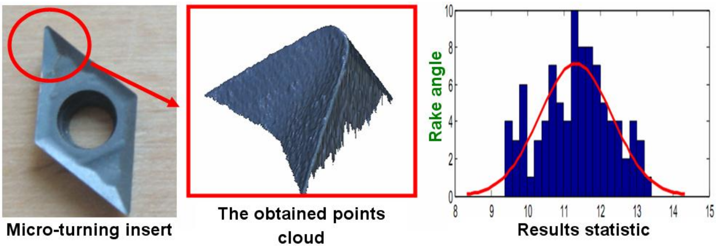

Figure 4: Micro-turning insert, points cloud obtained, results statistic.

3. Concluding Remarks

Non-contact instruments are able to capture many points. Then, these points should be processed. We proposed and demonstrate an algorithm for automatic rake angle measurement, ensuring repeatability, of which many instruments' software are still lacking.

References:

[1] Dornfeld D, Min S, Takeuchi Y 2006 Recent Advances in Mechanical Micromachining *CIRP Annals Manufacturing Technology* Vol 55 pp.745-768.
[2] Hansen HN, Carneiro K., Haitjema H, De Chiffre L 2006 Dimensional Micro and Nano Metrology *CIRP Annals Manufacturing Technology* Vol 55 pp.721-743.