# PROCEDURE OF DISTANCES EVALUATION FOR SURFACE INSPECTION

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**Abstract:** In the context of developing automated optical inspection system, this work brings into focus the aspect of de-velopment of evaluation algorithms for thickness distribution extraction from the object model reconstructed after surface scanning. Within this work an algorithm for the evaluation of local differences between two triangle meshes is presented. The pair of triangular meshes is representing the front and backside of a scanned 3D-object. The resulting array of differences vector corresponds to the shortest local distances (i.e. local thickness) between sides of object.

## 1. INTRODUCTION

To guarantee the quality of parts produced by sheet metal forming the inspection of products geometrical form, surface defects, thickness and possible tearing is needed. The strong demands for cost reduction, shortened development cycle and high quality involve the necessity of a fast, exact and robust measurement procedure at the stages of forming tool development, procedure and product optimisation and during mass production. Especially, the inspection at production starts lead to important conclusions on the production process (e.g., the influence of tool modifications on the manufactured parts). Used in the industry visual inspection by trained personnel can't satisfy recent requirements to the accuracy and objectivity of inspection procedure. Moreover, many relevant surface defects on sheet metal parts are not visible to the human eye. For successful surface defects detection using machine vision inspection instruments a great number of points with high spatial density as well with required evaluation precision is needed. Existing coordinate measuring machine not always satisfy demands for scanning velocity caused by the necessity of online inspection. Instrumentation for fast, automated, user-independent, with high density of measuring points thickness estimation of sheet metal parts is currently not available. It is known optical instrumentation using photogrammetry and grid analysis method (Höflin and Feldmann, 2002; Schmidt et al., 2004). Regular grid (usually circles) is applied on a sheet metal part before forming. Strain and thickness changes are evaluated from the grid analysis (analysis of marks form changing after forming). The resolution for such method is restricted by mark raster and there is some methodical error due to indirect thickness estimation. Most of instrumentation for formed sheet metal inspection specialised for one or two parameters evaluation and instruments combining the geometrical form parameters inspection, defect detection and thickness estimation currently are not available.

## 2. INSTRUMENTATION FOR SURFACE INSPECTION

Optical measuring technologies in sheet metal forming and tooling have been used more and more in the industry during recent years. Using optical systems considerably decreases the development time for products and production while improving the quality. Good prospects for application for the inspection of sheet metal parts have fringe projection optical systems. The availability of highly capable three-dimensional optical sensor systems based on the image triangulation principle using fringe projection method creates the possibility of fast digitising of object surface resulting in a large set of measuring points with high resolution. Existing on the market fringe projection systems enable check up of geometrical form and examination of surface structure of digitised object (Ernst et al., 2003).

The highly accurate and fast sensor system reliably detects even the smallest relevant surface defects such as dents, bumps, sink marks, waviness, constrictions and cracks etc. with a defect resolution down to 10 µm (Steinbichler Optotechnik GmbH). To assure the stability of formed sheet metal parts, additionally to form and surface structure the thickness fluctuations in the critical zones of formed component and defects like necking, thinning (with the future risk of tear) or wrinkling should be considered. New possibilities of defect detection reveals with the elaboration of measuring procedure enabling two-side surface scanning and creation of digital object model (Weckenmann et al., 2004). To realise the evaluation of thickness fluctuations an algorithm for distances between surfaces estimation is to be elaborated.

## 3. ALGORITHM DESCRIPTION

### 3.1. Definitions

To ensure the stability of a part created by sheet metal forming procedure is very important to guarantee that the minimal local thickness of a part is greater as the defined (for concrete material and work load conditions) critical value. From this point of view we define evaluated distance as the closest distance in local surrounding of an analysed surface point. Note that after a surface scanning an object is represented in form of point clouds (3D-data sets). As is the convention in coordinate metrology, thickness is estimated as length of the perpendicular from a point of one work piece surface side to the nearest interpolated surface element at the opposite side. The special feature of surface data is that the nearest point at the opposite side is included in several surface elements, so it is needed to find the surface element perpendicular on which is the shortest. Given a point *p* at one side of object surface and surface element *S* at opposite side, we define the distance *c(p,S)* as

$$c(p,S) = \min_{p' \in S} d(p,p') , \qquad (1)$$

where *d()* is the Euclidean distance between two points in $R^3$ and *p'* - the projection of *p* onto surface element *S*. In local surrounding of surface elements $S_1$, $S_2$ (for two object sides, correspondingly) the one-directional distance *E* is defined as

$$E(S_1,S_2) = \min_{p \in S_1} c(p,S_2) . \qquad (2)$$

Note that often in such way estimated distance is not symmetric, i.e. $E(S_1,S_2) \neq E(S_2,S_1)$. A two-sided distance may be obtained taking the minimum of $E(S_1,S_2)$ and $E(S_2,S_1)$ in local neighbouring of surface elements.

### 3.2. Evaluation procedure

The process of nearest element searching is complicated for data sets obtained by optical systems due to large number of scanning point presence. These data are non-sorted sets, i.e. without information about neighbouring relations between data points. So the first step in evaluation procedure (Fig. 1) is the estimation of topology information of 3D-data. Such information allows fast searching of the neighbouring elements and creates the necessary prerequisites for surface modelling (in current work a linear interpolation of triangle meshes is used). For topology estimation the Delaunay triangulation is used. The Delaunay triangulation realises space division with the following merging
of nearest points in triangles and demonstrates the optimal properties after circumscribed circles and angle maximization criteria. Moreover, there is a possibility to approximate a plane through each three nearest points and in such way to create a surface model (Fig. 2).

Using of Delaunay triangulation gives an opportunity to significantly reduce the number of searching operations and increase the efficiency of data processing algorithm. By means of such a structure, for point of one side, it is possible to quickly find a nearest point at the opposite side. But such a point can belong to several triangles. So, to find a triangle, projection on which gives the shortest distance, the algorithm for nearest point searching should be extended to the nearest element searching by the following steps:

– searching for adjacent triangles, containing the found nearest point;
– evaluation of projection points onto planes of adjacent triangles;
– rejection of the planes if projected point is not inside of triangle;
– estimation of the shortest perpendicular length, which corresponds to the local one-directional distance *E*.

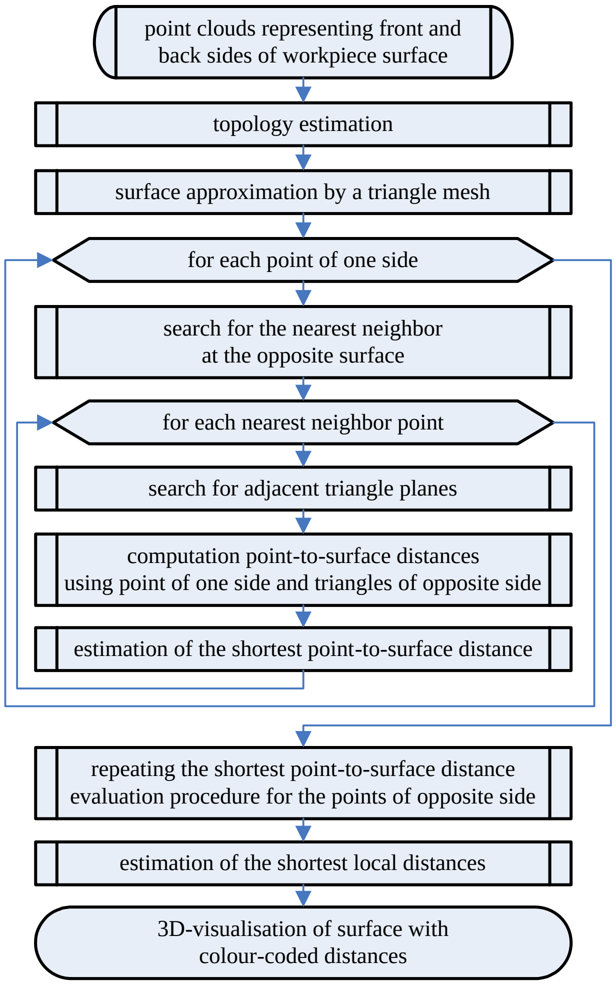


**Fig. 1.** Procedure for evaluation of distances between surfaces

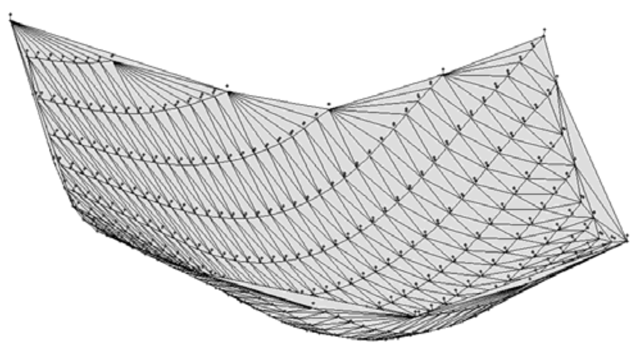

**Fig. 2.** Example of surface triangulation

For the efficiency of shortest element searching pointer indication triangles, containing current point is created.

For each triangle with points *P1*, *P2*, *P3* described by 3D-coordinates the normal vector is calculated from cross product of two triangle edges (Fig. 3)

$$\vec{n} = \left[(P2 - P1) \times (P3 - P1)\right]. \quad (3)$$

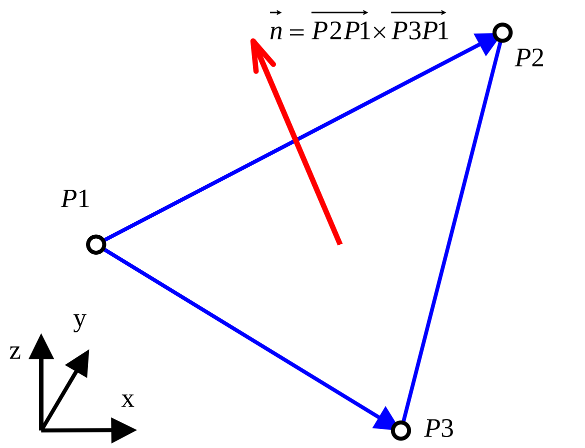


**Fig. 3.** Computation of normal vector for a triangular surface element

The elements of normal vector $\vec{n} = \{A; B; C\}$ are the coefficients of plane equation $Ax + By + Cz + D = 0$, where the coefficient *D* means the plane offset from the coordinate origin in the line of plane normal. If coefficients *A*, *B* and *C* are known the *D* is easy to find if put the coordinates of one of triangle points into the line equation. This operation can be described by dot product of vectors $\vec{n} = \{A; B; C\}$ and $P1 = \{x_1; y_1; z_1\}$

$$D = -(n \cdot P1). \quad (4)$$

Now it is possible to evaluate the distances from each point of one side $P_{1i}$ to the triangle plane at opposite side (to the corresponding projection point) containing the found nearest point. We evaluate this distance as difference between projection of $P_{1i}$ to the normal of triangle plane (corresponding to the distance to the origin) and distance from triangle plane to the origin:

$$d = \text{proj}_n P_{1i} - D = (n \cdot P_{1i}) - D. \quad (5)$$

At the next step the similar procedure in inverse direction, i.e. from the work piece opposite side, is run out. Analysing the results of the bi-directional procedures we find the smaller one of the above calculated distances located nearby defined points.

### 3.3. Procedure realisation

The elaborated algorithm realizes the method for estimation of local closest distances between sides of digitised formed sheet metal part. An example of measured part with colour-coded thickness information is shown at the Fig. 4.

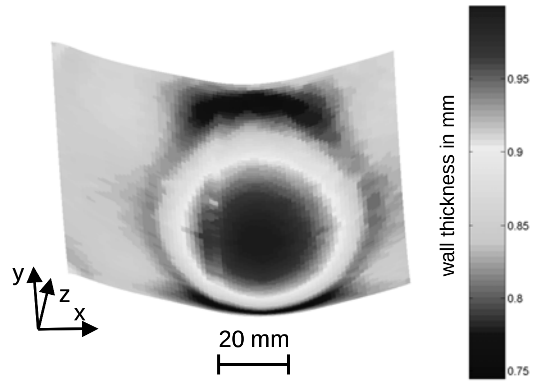


**Fig. 4.** Colour-coded distances distribution

## 4. SUMMARY

The evaluation module returns both numerical (array of local distances vectors) and visual results in form of coloured reference surface according to the estimated local distances. The estimated area-wise thickness is visualized over the one of measured surfaces as a colour-coded map. This kind of representation enables easy localization and documentation of the smallest wall thickness. Furthermore, the direct visualization helps to find reference of the wall thickness corresponding to the measured surface zone.

## REFERENCES


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