Automatic 3D Shape Measurement Noise Reduction for an Optical Profilometer

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Abstract: This paper presents a technique to automatically reduce the measurement noise of an optical profilometer. By approximating polynomials line-by-line horizontally and vertically, the bad measurement points are detected and fixed automatically.

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OCIS codes: (100.6890) Three-Dimensional Image Processing; (180.6900) Three-Dimensional Microscopy.

1. Introduction

The Alicona InfiniteFocus Microscope (IFM) is an optical 3D profile measurement device that operates in the micro- and nano-meter range based on focus variation [1]. It can measure steep flanks, materials with highly reflective properties, and large roughness with a vertical resolution down to 10 nanometers.

In this study, the tip of a screwdriver was measured at 45º by IFM. However, the measurement noise was found to be prohibitive for further data analysis. The software provided by Alicona requires an extremely time-consuming procedure to clean up the noise manually. Because of the huge size of data produced by the IFM, approximately 5GB per frame in *.Obj file format, conventional commercially available geometry processing tools such as Maya, GSI (Geometry System Inc), Solidworks, cannot handle such data well. Thus, a new means is needed for efficient processing of such 3D geometry data.

In this research, an automatic approach is developed to significantly reduce the measurement noise to an acceptable level. In particular, the data is processed row by row, and column by column. Each row is approximated as a polynomial function \(z(x)\), and each column is approximated as another polynomial function \(z(y)\). If the difference between the measured data point is beyond a pre-selected threshold, it is regarded as bad and discarded. Finally, those bad points are approximated by the polynomials obtained from the good data points row by row and column by column again. The orders of the polynomials are adjusted manually so that most of the bad points will be removed while good ones are kept untouched. Experiments are presented to verify the performance of the proposed algorithm.

2. Principle

We used the Alicona IFM to measure the tip of a screwdriver, and the measurement result is shown in Fig.1. The size of the scan is 4656×1028 pixels. The spatial resolution is approximately 1.6 \(\mu\)m per pixel, and the depth resolution is approximately 10 nm. This data clearly shows that the noise (spikes in this figure) is significantly large and the desired signal (the profile of the screwdriver tip) is hidden in the noisy surround. Therefore, it is extremely difficult to use the raw data for further processing and/or analysis.

For any measurement point \((i, j)\) of a 3D scan, it contains \(x_{ij}, y_{ij}, z_{ij}\) coordinates and the texture (color) information, where, \(i\) is the row number, and \(j\) the column number. For a given row, \(i = i_0\), the relationship between the \(z\) coordinates and the \(x\) coordinates is approximated as an \(n\)-th order polynomial, that is,

\[
\hat{z}(x) = \sum_{k=0}^{n} c_k x^k
\]

(1)

here, from the measurement points \(x_{1d}\) and \(z_{1d}(j = 1, 2, \ldots N)\), \(c_k\) is estimated using the least square algorithm.

Once the polynomial function is obtained, the difference between the approximated data and the actual data is
calculated. If the difference is beyond a given threshold \((th)\), this point is marked as bad point and eliminated, namely,

\[ |\hat{z}(x_{ij}) - z_{ij}| > th \Rightarrow (i,j) \text{ is bad.} \quad (2) \]

Figure 2 (a) shows a typical row data with a significant amount of bad points. Because horizontally the screw driver tip is relatively flat, a 1\(^{\text{st}}\)–order polynomial is used to approximate the data points, which is shown in the red curve. Figure 2(b) shows the difference between the measured data and the approximated result. If a threshold of 80 \(\mu\text{m}\) is used, the data points below the lower red line or above the topper red line will be treated as bad and should be eliminated. It can be seen that if the proper threshold is chosen, almost all the bad points can be removed.

![Figure 2](image.png)

Similar operations are applied to the remaining good points vertically line by line. Because vertically the screw driver tip is not flat, a 9\(^{\text{th}}\)–order polynomial was found to be appropriate to fit the curve. Figure 3 shows the corresponding to the plots of 2000\(^{\text{th}}\) row. It clearly shows that the 9\(^{\text{th}}\) order polynomial well represents the curve, and a threshold of 25 \(\mu\text{m}\) is sufficient to eliminate most of the bad points. After this operation, more bad points are removed and the data is further cleaned.

![Figure 3](image.png)

Figure 4 shows the result after removing all bad points. In this figure, removed bad points are depicted as black areas. This figure clearly shows that most of the bad points (spikes) in Fig. 1. are successfully removed. It should be noted that the same threshold is used for all horizontal lines (vertical lines), and the same order of polynomial is used for all horizontal lines (vertical lines). However, leaving holes in the measured geometry is not desirable for future data processing. Thus, we now will explain the method used to fill in those removed points.
To fill in the removed bad points, the remaining good points are used to generate polynomials line-by-line vertically and horizontally. The bad points are then replaced with the value calculated by the polynomial functions without touching the good points. Figure 5 shows the result after processing. All spiky bad points are removed, and the profile of the screwdriver tip is well represented.

To verify the influence of this processing algorithm, the difference in image between the raw 3D data and the resultant 3D data is calculated point by point. Figure 6 shows the plot of a typical cross section, 300th row and 2000th column, respectively. It clearly shows that the difference image contains mostly the spiky noisy points while remains the good points remain untouched.

Our experiments have demonstrated that by properly selecting the order numbers of polynomials and the thresholds, almost 100% bad points are found and eliminated without significantly affecting good points. In addition, this proposed algorithm is very fast, only taking approximately 6 seconds to process 4656x1028 data points with a dual core 2.66GHz Pentium 4 CPU Dell Optiplex 330 desktop computer.

3. Summary

This paper has presented a technique to automatically reduce the measurement noise in data obtained using an Alicona IFM. By approximating polynomials line-by-line horizontally and vertically, the bad measurement points are detected and fixed automatically. Experiments have shown that that by properly selecting the order numbers of polynomials and the thresholds, almost 100% of the bad points are found and eliminated without significantly affecting good points. The processing speed is really fast, it only takes approximately 6 second to process over 4.8 million data points under a dual-core 2.66GHz CPU computer.

4. Acknowledgements

This work was supported by the National Institute of Justice under contract 2004-IJ-R-088, and was performed in part at Ames Laboratory, which is operated under contract No. W-7405-Eng-82 by Iowa State University with the US Department of Energy.

5. References