國立交通大學

工業工程與管理學系碩士班

碩士論文

應用電腦視覺於微型鑽頭與鍍膜銑刀的量測

An AOI System for Microdrill and Coated Router Measurement

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中華民國九十四年六月

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摘要

在印刷電路板產業中，如何快速精準的量測微型鑽頭的外徑與刃長是非常關鍵的課題。本論文發表的機器視覺系統針對微型鑽頭，發展了一套硬體系統與軟體演算法，可以自動地同時量測微型鑽頭的外徑與刃長。本論文所提出的軟體演算法擁有不需定位與高偏轉寬容值兩大優點，每支微型鑽頭可在兩秒內同時完成外徑與刃長的量測。在經過不同類型與大小數百支微型鑽頭的實際生產線測試後，證實了本論文所發展的自動視覺量測系統非常的有效率而且穩定。除此之外，經過一些演算法上的修改之後，本視覺系統也可應用在銑刀外徑的量測。

關鍵字： 機器視覺；自動量測；微型鑽頭；鍍膜銑刀

An AOI System for Microdrill and Coated Router Measurement

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Abstract

In this thesis, we developed a machine vision system for the measurement of microdrill. The issue about the speed and accuracy in measuring both the diameter and the length of microdrill is crucial. We proposed and implemented a machine vision system, including a set of AOI hardware and software algorithm, for auto-measuring the microdrill. The measuring algorithm is position-invariant and has a wide rotation-tolerance when a microdrill is loaded. The above measurement process can be completed within two seconds for each microdrill. And, the proposed system operates effectively and robustly when hundreds of different types and sizes of microdrill are tested. Also, the proposed measurement system can be applied to routers after some revision of the algorithm.

Keywords:
Machine Vision; Auto-Measurement; Microdrill; Coated Router

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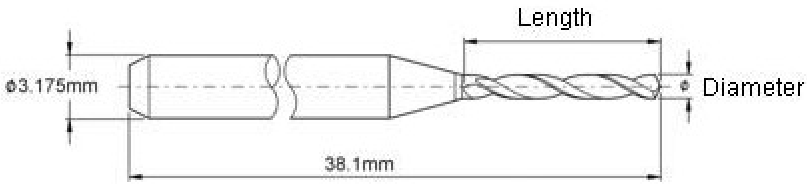
Chapter 1

1 Introduction

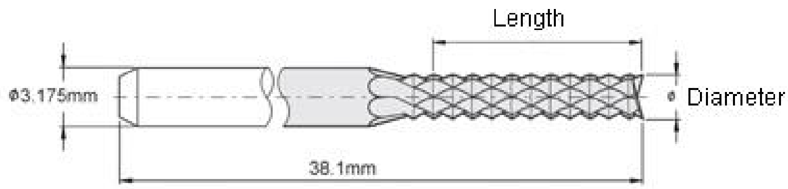
1.1 Introduction to the problem

The rapid growth in PCB production has led to the rapid growth of microdrilling and milling, too. The microdrill drills many intensive small holes through the PCB so as to create electricity connections between multiple layers of the PCB. Routers are designed for chip removal and accurate cutting. The technology of coating on the router increases the hardness of the tool surface to increase effectiveness and life cycle. Hundreds of different sizes of microdrills and routers have been developed to meet the high precision requirement of PCBs. Similar but different sizes of microdrills might be mixed up casually in the production line. However, it is essential to use every microdrill of accurate diameter when drilling. Even just one incorrect drilling might have one PCB be destroyed. As the circuit density on PCBs is getting higher, the diameter of a microdrill is getting finer, and the manufacturing cost is higher, too. Besides the diameter, the length of a microdrill is another critical point. A microdrill needs to be reground often to keep its sharpness, and hence the length of a microdrill will decrease gradually after each grinding process. Drilling a PCB with an insufficient length of a microdrill might cause danger or unexpected damage.

The side views of a typical microdrill and a coated router are illustrated in Figure 1. The overall length is fixed to 38.1mm and the diameter of the shank is fixed to 3.175mm. The lower diameter limit for a microdrill is about 0.1mm, the length is up to 12mm. And, the lower diameter limit for a coated router is about 0.6mm, the length is up to 9.5mm.



(a) Microdrill



(b) Coated Router

Figure 1: The side views of a typical microdrill and a coated router.

1.2 Objective and main contributions

Currently, the vernier and a laser system are commonly used to measure the diameter of a microdrill. The vernier is poor in its precision and easy to have a fine microdrill be broken when in measuring. Laser system is quite expensive and difficult to be adjusted or aligned automatically. Besides, laser system can not be used to measure the length of a microdrill simultaneously. Both the vernier and the laser system still cannot meet the requirement of measuring every microdrill in a short time. The outward appearance defects of coated routers, such as collapse, particle and lack of coated uniformity, are commonly inspected by human. But it is slow and unstable.

This thesis presents a machine vision system, including a set of AOI hardware and software algorithm, for inspection and auto-measuring both the diameter and the length of microdrill and coated router, which can be completed in a short time. The low cost, high speed and robustness of the system is the objective and expect that it can be applied in on-line measurement and inspection of microdrill and coated router.

1.3 Organization of the dissertation

The thesis is organized as follows. In the section 2, we present some related researches about the measurement or inspection of the microdrill. The proposed hardware mechanism and measurement algorithms are described in section 3 and section 4. Section 5 describes the experimental results of the measurement. Some conclusions of this thesis are given in section 6. The expect works to complete in the future are listed at final.

Chapter 2

2 Literature Review

In the pass few years, some researches on microdrill inspection have been published. Hinds and Treanor [7] used the finite-element method to analyze the stresses occurring in microdrills. Three-dimensional models of drills were defined by setting node points of the drill geometry. Gille et al. [10] developed ultrafine hardmetals for PCB microdrills that reduced the failure probability of the microdrills. Hazra et al. [5] presented a computer-aided inspection system for drills by using a contact probe-type instrument. Harza et al. [11] later proposed a method that could estimate five parameters which describing the geometry of microdrills by using three charge-coupled device (CCD) cameras to obtain the silhouette of flank surfaces. Kuang [8] used machine vision approach to inspect the defects of microdrills, but the proposed method requires a precise alignment. Tien et al. [12] proposed a position and orientation invariant method to inspect the defects of microdrills and claimed that the method can reliably achieve precise inspection. All the above researches only discussed with the inspection of top view of microdrills, none of them discussed about the coated router and the diameter and length measurement of microdrills. In this thesis, we proposed a system which can measure both the diameter and the length of microdrills effectively and robustly.

Chapter 3

3 The Measurement System

3.1 The hardware system

3.1.1 Mechanism

The hardware system for microdrill measurement is illustrated in Fig 2. It consists of a CCD camera, a fixture and an LED matrix. The CCD camera is used to extract a high resolution image of microdrill. The fixture is designed for convenient loading and unloading of the microdrill. The LED matrix is designed and used as backlight illumination mechanism. For convenient description in the following chapters, the extracted microdrill image is shown after rotating 90 degree to the right.

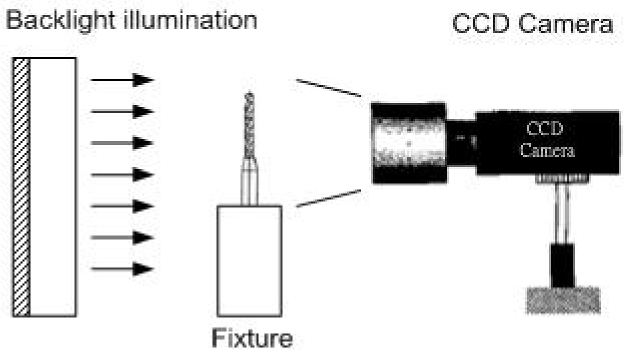
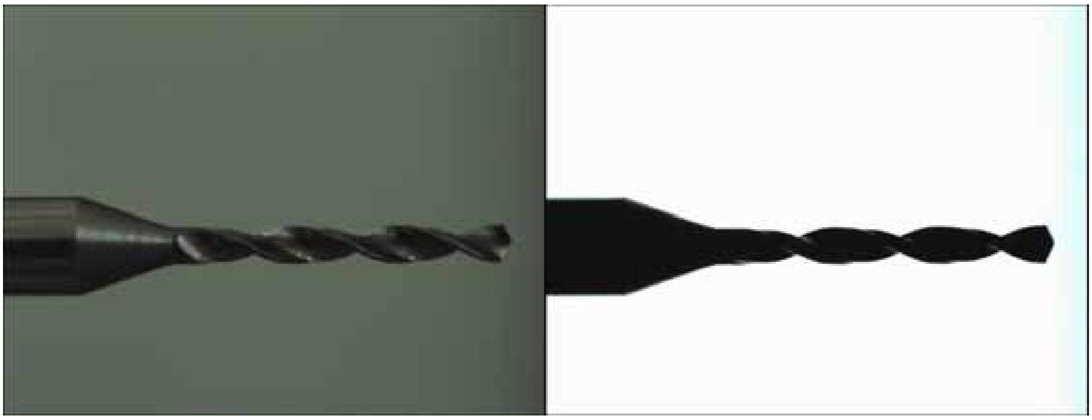


Figure 2: The illustration of hardware system

3.1.2 Lighting environment

To measure the microdrill accurately, an image of the microdrill with clear silhouette is required. However, the natural, environmental light would have some unexpected light on the microdrill be reflected onto the camera. Such reflection will destroy the shape image of the microdrill, as shown in Figure 3 (a). A properly designed high intensity backlight could highlight the silhouette of the object (Batchelor, [2]). So, an LED matrix is designed and adopted as the backlight in this research. The silhouette of a microdrill can then be highlighted without any reflection or noise, as shown in Figure 3 (b).



(a) (b)

Figure 3: The image of the microdrill extracted under
(a) natural, environmental light; (b) an LED matrix as backlighting environment.

3.2 Algorithm for Measurement

3.2.1 Image pre-processing

For the obtained gray-level image, the microdrill has to be separated from its background. The Otsu's auto- thresholding method [1] is used. After thresholding, two morphological operators of open and close are applied to eliminate unexpected noise. The image of microdrill after such pre-processing is shown in Figure 4.

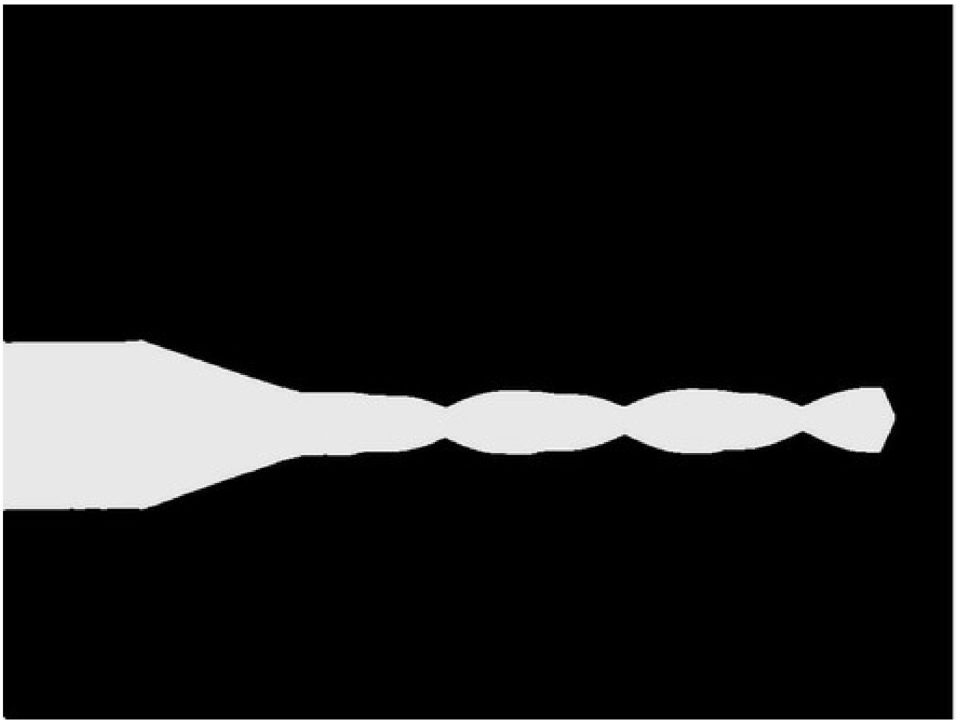


Figure 4: Clear microdrill image obtained after pre-processing is applied on Figure 3 (b).

3.2.2 Projection

Projection method is common and useful for edge detection and has been applied widely in machine vision. By projecting the image on the X-axis, we can have the accumulative pixel values of the image along the projected direction as shown in Figure 5. Horizontal axis of Figure 5 represents the positions corresponding to the projected direction, while vertical axis represents the intensity levels. With the projection method, the range of flute length can be obtained and is shown in Figure 5. The diameter of the microdrill can also be obtained from the projection diagram, but its precision level is still not always satisfied. The projection algorithm is position-invariant that no adjustment is need before the measurement.

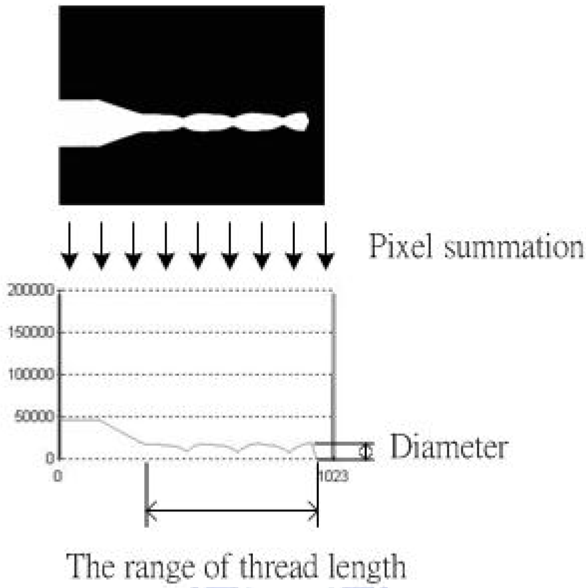


Figure 5: Illustration of the projection image of microdrill on X-axis. Both length and diameter of the microdrill can be obtained from the projection diagram.

3.2.3 Edge detection with subpixel accuracy

In order to obtain accurate edge measurement, it is necessary to determine the location of an edge to a higher resolution than the spacing between the pixels of the image sensor. This technique which is accurate to the subpixel level makes it possible for us to relax the limitation of resolution imposed by the pixel size of CCD. Many subpixel edge detection techniques ([6, 9]) have been proposed. Li et al. [3] presented a two-stage approach on edge detection and had a comparison of subpixel accuracy of several edge estimation methods. Kisworo et al. [4] proposed a new technique for 1-D and 2-D edge feature extraction to subpixel accuracy by using edge model and local energy approach. The previous subpixel approaches might ensure subpixel edge detection. But their approaches require huge amount of computation and are difficult to be applied for high-speed and on-line measurement. In this study, a fast and simple subpixel method for 1-D edge detection was proposed for microdrills measurement.

In many cases, the gray level of an edge changes gradually, and the real position of edge is difficult to be detected. Assumed the gray level change of edge of the microdrill flute can be sampled by a scan line perpendicular to it as shown in Figure 6. Then the real edge position of this flute can be estimated by processing every pixel on the scan line through the range of flute length of the microdrill by interpolation method. Such method is so fast that it can also be applied in on-line edge detection.

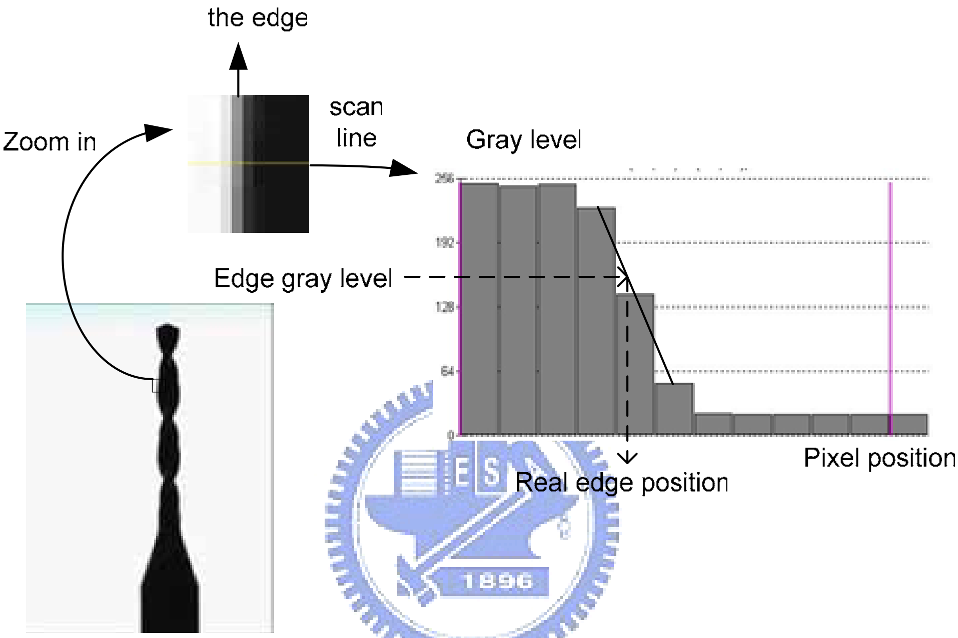


Figure 6: Illustration of the proposed 1-D subpixel edge detection method. Horizontal axis represents the positions of edge pixel, while vertical axis represents the corresponding gray levels of edge scan line.

3.2.4 Adjustment of slanting by software

The fixture is designed for convenient loading and unloading of microdrill. When a microdrill is loading on, it may not be fixed on the fixture firmly every time. The captured image of such microdrill might be slightly slanting and cause some measuring error. Hence, it has to take the slanting of microdrill into account. We use software solution for this situation. Each center point (x_i ,y_i) of the flute of microdrill is found by the upper and lower edge. Afterwards, the tilt angle of the microdrill can be estimated by the method of least square linear regression to fit the center line of the microdrill, as indicated in Equation (1) and shown in Figure 7. The measuring results are rectified by the estimated tilt angle θ, as indicated in Equations (2) and (3). Such procedure makes the measurement result still can be acknowledged when a microdrill is loaded on the fixture with a larger slanting tolerance.

$$\theta = \tan^{-1}\left(\frac{\sum x_i y_i - n\overline{X}\overline{Y}}{\sum x_i^{\ 2} - n\overline{X}^{\,2}}\right) \tag{1}$$

, where x_i and y_i respectively is the coordinate value of center point of the microdrill.

Adjusted diameter = Original diameter × cosθ (2)

Adjusted length = Original length × secθ (3)

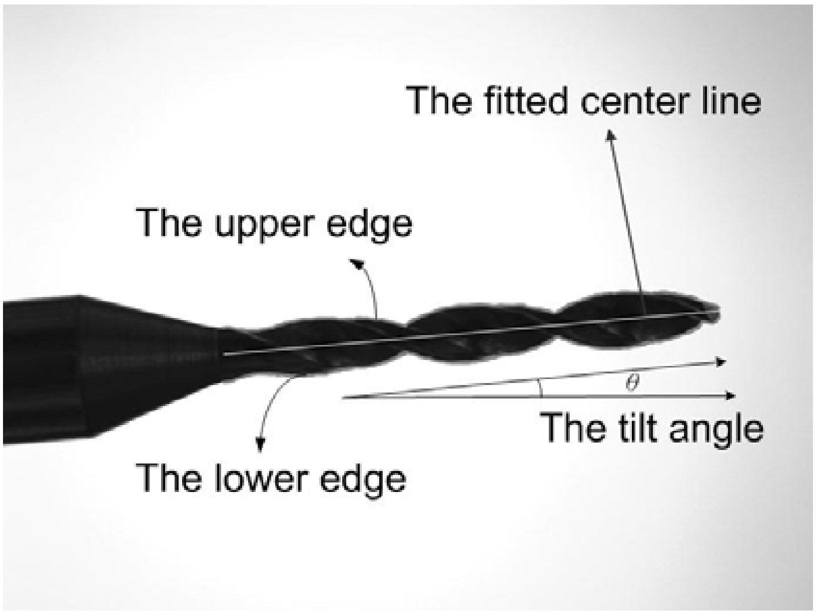


Figure 7: Illustration of the estimated tilt angle by least square linear regression to fit the center line of the microdrill.

3.2.5 Outlier elimination

Using the proposed measurement algorithm, the diameter of each point is acquired in the flute length of a microdrill. Generally, the maximum of these values can symbolize the diameter if the microdrill is clean and without any particle on it. The real diameter of the microdrill is found after some procedure for eliminating the outlier values, as shown in Figure 7. The procedure is necessary especially in dirty environment while measuring.

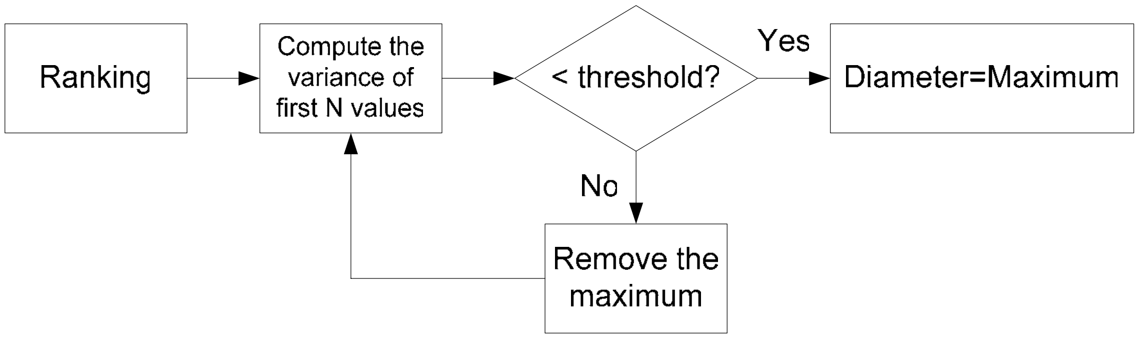


Figure 8: The procedures for eliminating the outlier values

3.2.6 ST and UC classification

Generally, microdrills can be classified into standard (ST) type and undercut (UC) type. A microdrill with undercut type costs more but can perform an excellent hole-wall quality than the one with standard type. An UC type microdrill is characterized with a slightly larger diameter on the flute tip, as shown in Figure 9.

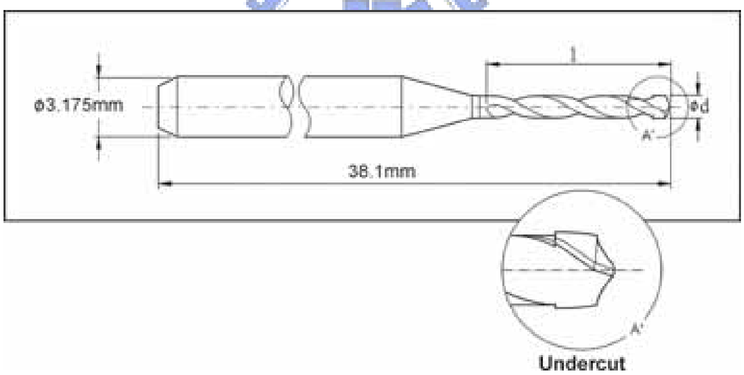


Figure 9: The side view of a microdrill with undercut type.

The difference between ST and UC is so small that it is extremely difficult for human eyes to classify it accurately. Therefore ST and UC microdrills are likely to be mixed up in the production line. Using the proposed measurement algorithm, the diameter of each point is acquired in the flute length of a microdrill. After comparing the maximal diameter between the tip and the body in the flute length of a microdrill, the proposed vision system performs well in the recognition of ST and UC.

3.3 Algorithm for Router Measurement

The most obvious difference between microdrill and router is the asymmetric silhouette in the side view of the router, as shown in Figure 10. Using the measurement algorithm of microdrill would undervalue the actual diameter of the router seriously, as shown in Figure 11. The maximum one-point value of the router can not symbolize the real diameter of it. So, some revision of the algorithm is required before the proposed microdrill measurement system applied to routers.

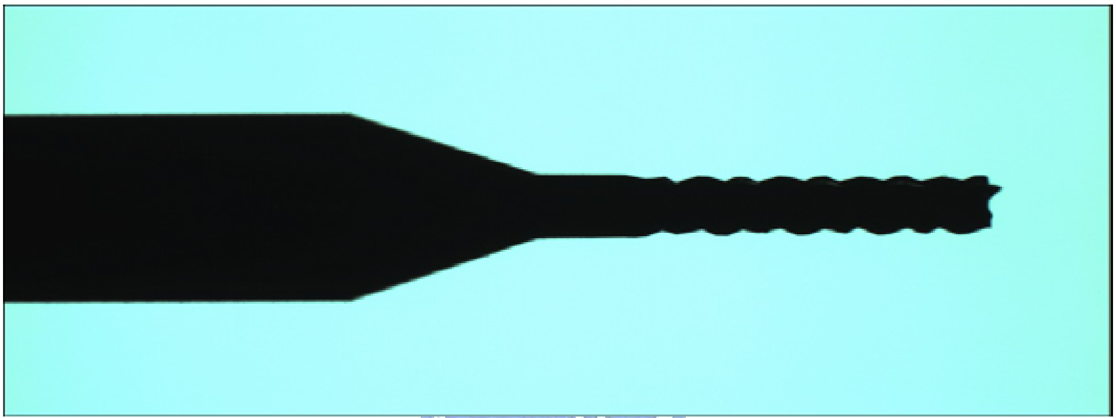


Figure 10: The illustration of the router with asymmetric silhouette.

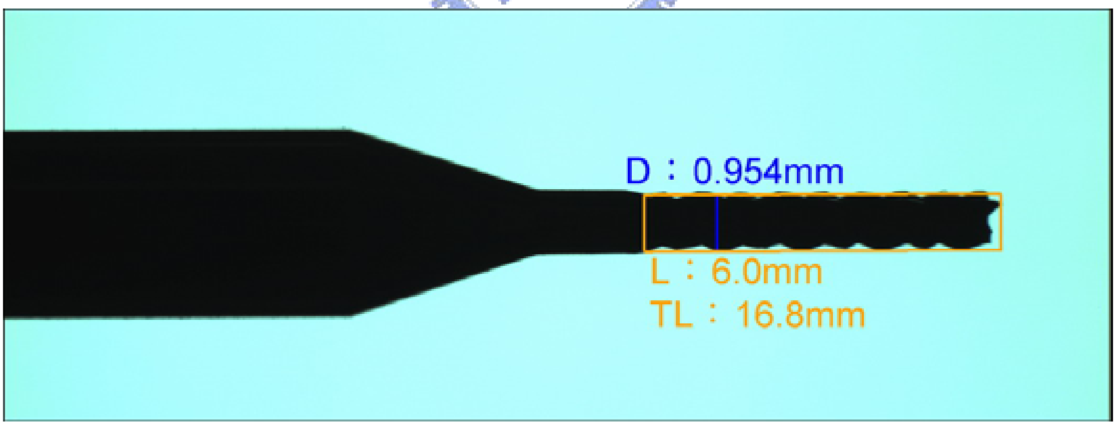


Figure 11: The illustration of the wrong algorithm undervalues seriously.

The proposed scan line is processed through the router, and then the highest and lowest edge points (x_1, y_1) and (x_2, y_2) of the router are found by the proposed algorithm. Taking the slanting of router into account, we compute the angle β as indicated in Equation (4) and estimate the tilt angle α by the method of least square linear regression, as shown in Figure 12. The diameter D of the router is rectified as indicated in Equations (5).

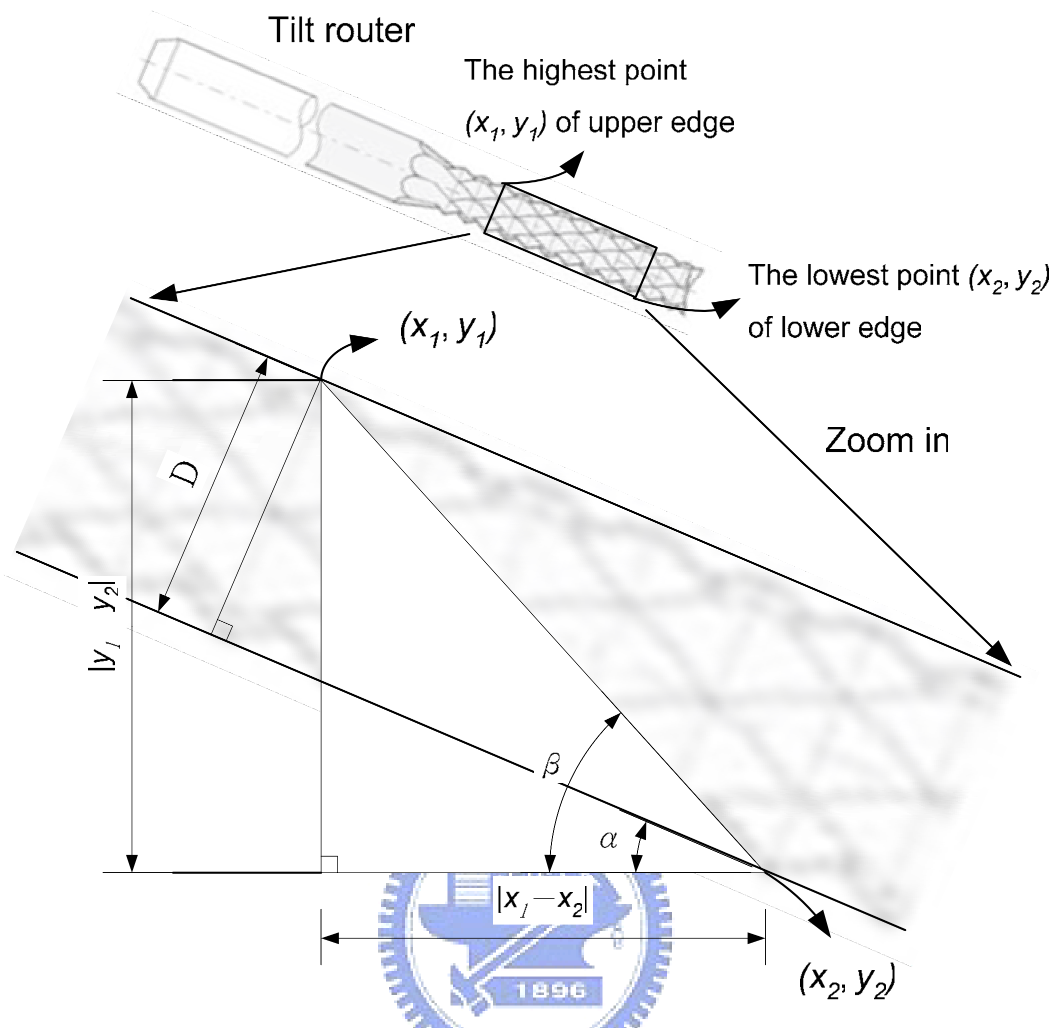


Figure 12: The illustration of the router measurement algorithm.

$$\beta = \tan^{-1}\left(\frac{|y_1 - y_2|}{|x_1 - x_2|}\right) \tag{4}$$

Where, (x_1, y_1) and (x_2, y_2) respectively is the coordinate value of highest and lowest point on the edge.

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \times \sin(\beta - \alpha) \tag{5}$$

Where, α denotes the tilt angle and D denotes the diameter of the router.

Such procedure makes the measurement result still can be acknowledged when a router is loaded on the fixture with a larger slanting tolerance. After revision of the algorithm, the rectified measurement result is shown in Figure 13.

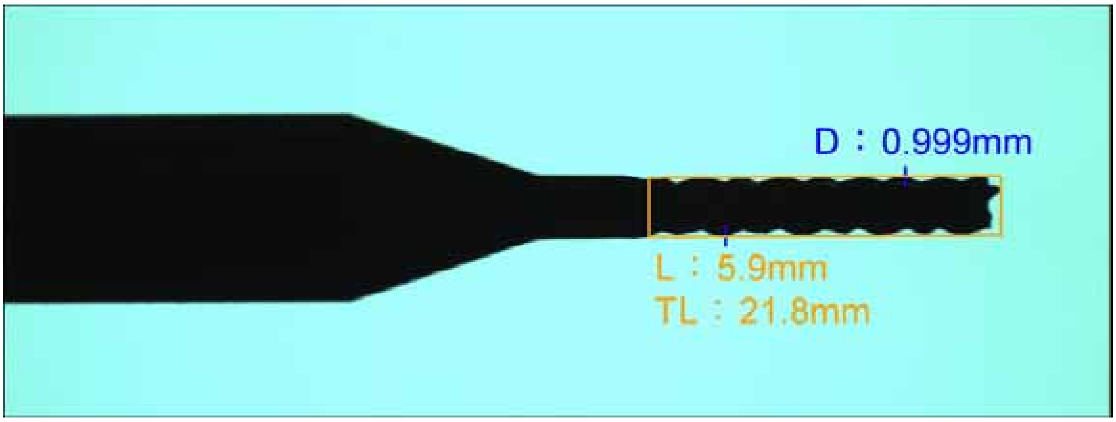


Figure 13: The rectified measurement result after revision of the algorithm.

Chapter 4

4 Experimental Results

4.1 Experimental equipments

In this section we presented some experimentations about the microdrill measurement. Figure 14 is a photo of the implemented prototype. All the images of the microdrill were grabbed by using a high resolution CCD camera of 2048×1536. The size of an image window is 17.6mm×13.2mm. The physical width of one pixel is about 8.6um. The measurement algorithms are programmed by Microsoft Visual Basic.NET. The experimental computer is powered by an Intel Pentium IV 1500M CPU.

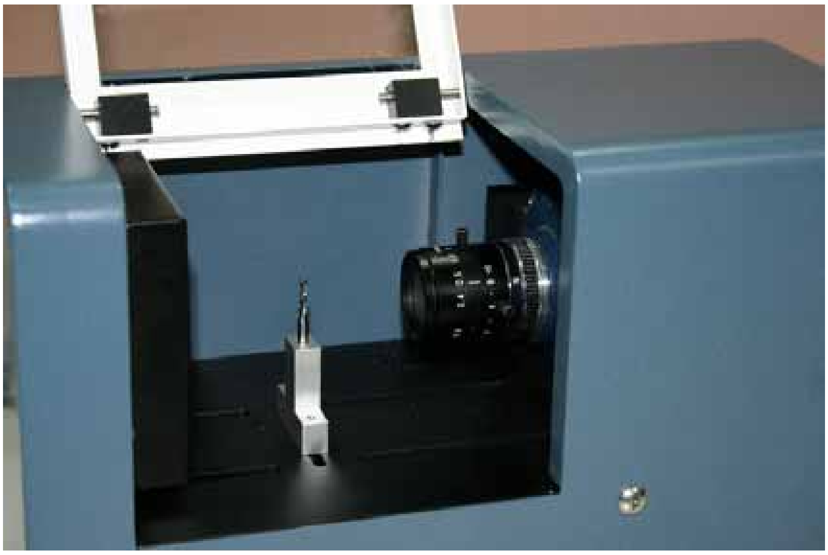


Figure 14: The implemented prototype for microdrill auto-measurement.

4.2 System performance

4.2.1 System performance for microdrill measurement

The user interface designed by VB.NET is easy use and friendly to user. Both the diameter and the length of each microdrill can be measured correctly and effectively, and are displayed as shown in Figure 15.

We selected three samples to verify the accuracy and robustness of the proposed system. Each sample is measured five times in one orientation and the measurement data is recorded in Table I.

Sample No.	Actual size and type	Experimental data	Difference	Variance
1	Diameter：0.293 ST	0.293, ST	0	2×10^{-7}
		0.292, ST	-0.001	
		0.293, ST	0	
		0.293, ST	0	
		0.293, ST	0	
	Length：5.7	5.7	0	2×10^{-3}
		5.7	0	
		5.7	0	
		5.8	0.1	
		5.7	0	
2	Diameter：0.305 UC	0.306, UC	0.001	5×10^{-7}
		0.305, UC	0	
		0.305, UC	0	
		0.305, UC	0	
		0.304, UC	-0.001	
	Length：6.4	6.4	0	0
		6.4	0	
		6.4	0	
		6.4	0	
		6.4	0	
3	Diameter：1.707 Large	1.706, Large	-0.001	2.8×10^{-6}
		1.705, Large	-0.002	
		1.705, Large	-0.002	
		1.707, Large	0	
		1.709, Large	0.002	

Table I： The experimental results data of three microdrill samples.

(Unit：mm)

After testing over hundreds of different types and sizes of microdrill, we can assure that the proposed system operates effectively and robustly. The measurement system achieved the accuracy of ±2μm for a microdrill in one orientation, which is better than a general laser system. The measurement of each microdrill can be completed within two seconds. The low cost, high speed and robustness of the system is practical to be applied in on-line measurement of microdrill.

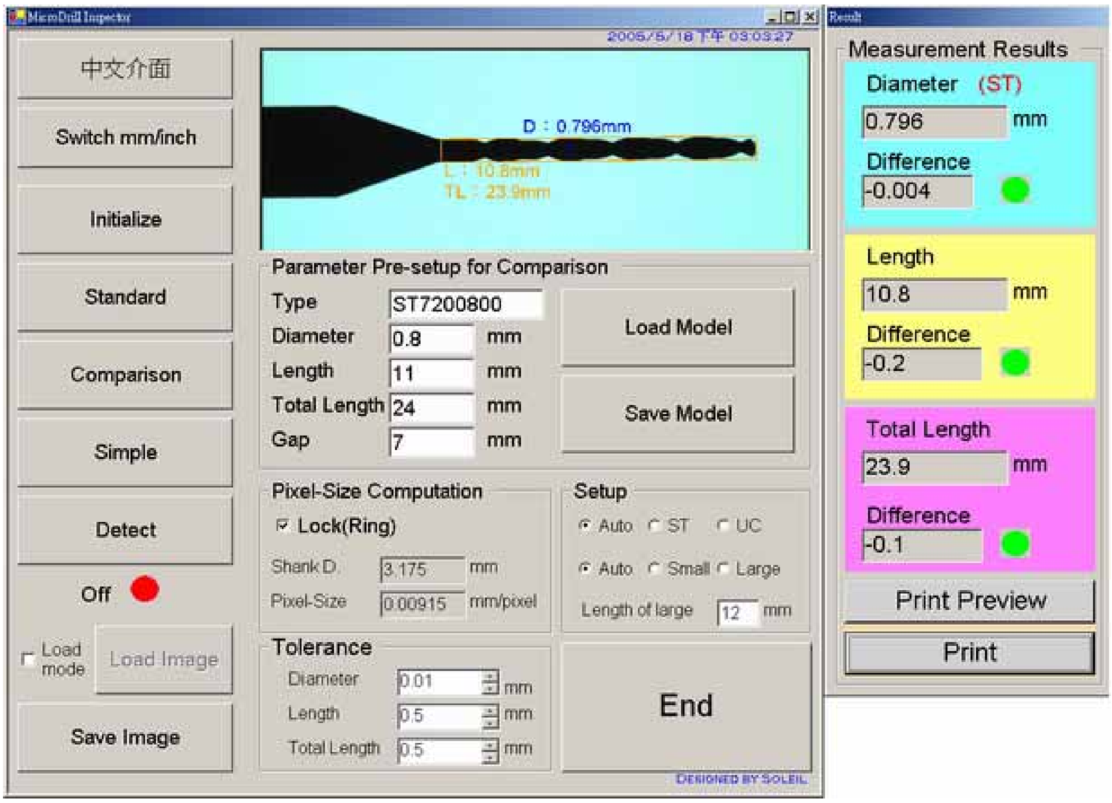


Figure 15: The user interface designed by VB.NET for microdrill measurement.

4.2.2 System performance for coated router measurement

The proposed system for router measurement can perform accurate and robust results in one orientation, but in different orientations, it has larger variance because of the asymmetric structure.

We selected three samples to verify the accuracy and robustness of the proposed system. Each sample is measured five times in one orientation and the measurement data is recorded in Table II.

Sample No.	Actual size and type	Experimental data	Difference	Variance
1	Diameter：0.985	0.984	-0.001	1.7×10^{-7}
		0.986	0.001	
		0.986	0.001	
		0.985	0	
		0.983	-0.002	
2	Diameter：0.995	0.996	0.001	2.8×10^{-6}
		0.994	-0.001	
		0.994	-0.001	
		0.995	0	
		0.998	0.003	
3	Diameter：0.990	0.988	-0.002	4.7×10^{-6}
		0.987	-0.003	
		0.988	-0.002	
		0.992	0.002	
		0.991	0.001	

Table II： The experimental results data of three coated router samples. (Unit：mm)

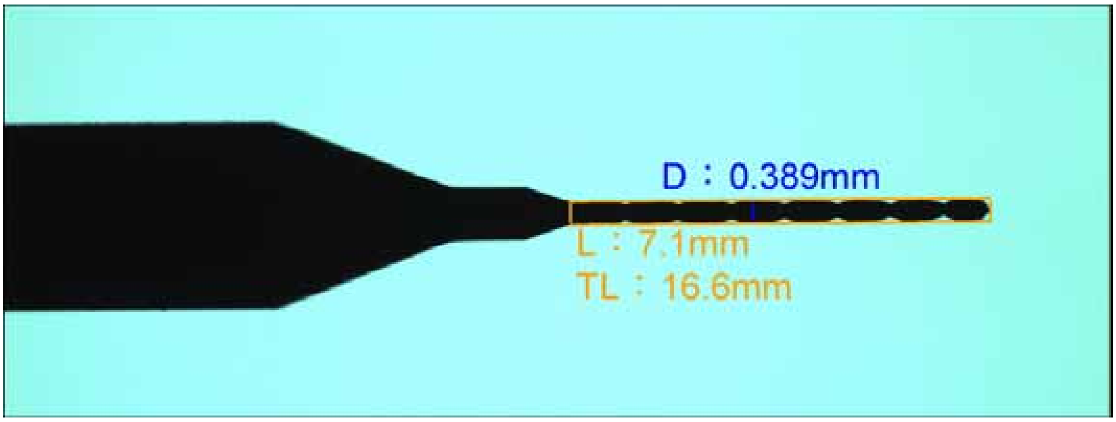
The proposed measurement system can achieve the accuracy of ±3μm for a coated router in one orientation. The measurement of each coated router can be completed within two seconds.

The coated router is different from the microdrill with the asymmetric structure. Therefore, the diameter of router has a larger variation than microdrill in different orientations. In the future, a spin hardware system might give assistance for more accurate measurement and taper inspection.

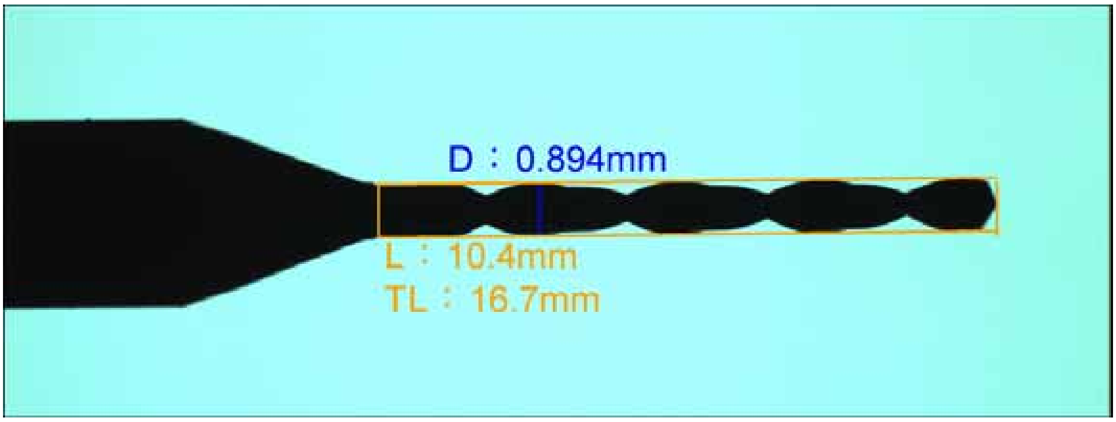
4.3 Discussion

The microdrills with different sizes, such as the standard fine microdrill, the two-phase fine microdrill and the large type microdrill are shown in Figure 10. In this research, the flute length range of a fine microdrill which are shown in Figure 16 (a) and (b) can be defined by the projection method described in

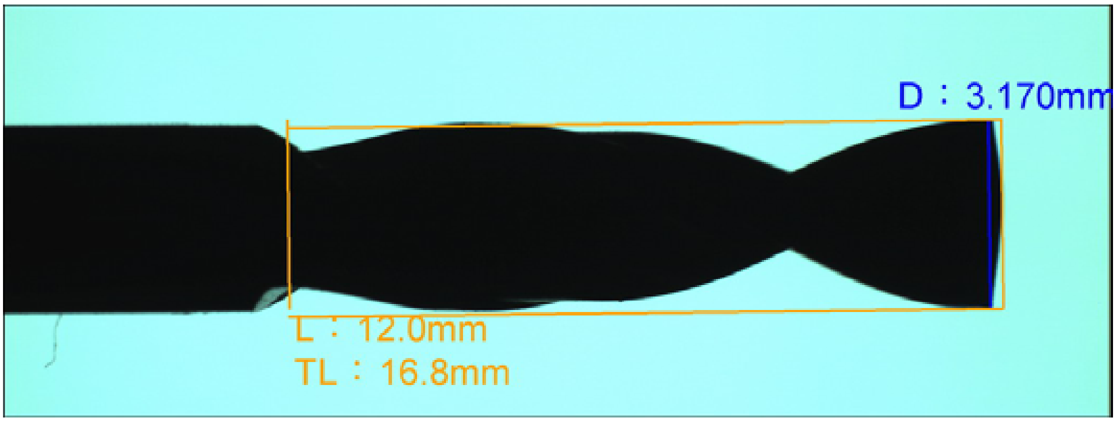
Section 4.2. However, it is difficult to define the flute length range of a large type microdrill such as shown in Figure 16 (c). The large type microdrill has a large variation in its shape in different orientations. Fortunately, most large type microdrills have been designed with fixed length. Thus the diameter still can be measured if its length is given before the measurement.



(a)



(b)



(c)

Figure 16: Illustration of the microdrill measurements with different types and sizes.

Chapter 5

5 Conclusion

This thesis presents a machine vision system, including a set of AOI hardware and software algorithm, for auto-measuring both the diameter and the length of microdrill. The measurement algorithm is position-invariant and has a wide rotation-tolerance of microdrill. The measurement of both the diameter and the length of each microdrill can be completed within two seconds. And, the proposed system operates well and robustly when hundreds of different types and sizes of microdrill are tested. Also, the proposed measurement system can be applied to coated routers after some revision of the algorithm. The issue about the inspection of outward appearance of coated routers will be studied further.

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