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DEVELOPMENT OF A COMPUTERIZED MULTI-MEASUREMENT SYSTEM FOR FINE MEASUREMENTS

استخدام الحاسب في تطوير نظام للقياسات الدقيقة المتنوعة

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الملخص:

تُستخدم أجهزة القياس الميكروسكوبية في كثير من التطبيقات الهندسية بغرض الفحص والقياس. وتحتوي هذه الأجهزة على ميكرومترين مثبتين على قاعدتين متحركتين تتحرك كل منهما في اتجاه عمودي على حركة الأخرى. وتتميز هذه الأجهزة بالدقة العالية، حيث تصل دقة القياس فيها إلى ١ ميكرون. ومن عيوب بعض الأجهزة الميكروسكوبية القديمة أن إمكانياتها مقتصرة على قياس طول الحركة التي تتحركها كل قاعدة من خلال الميكرومتر المثبت عليها، ولا تقوم هذه الأجهزة بإجراء أي عملية قياس مباشرة. ويُقدّم هذا البحث نظاما مطوّرا يمكن استخدامه لإجراء مجموعة من القياسات الدقيقة المختلفة، وذلك بتوصيل أحد أجهزة القياس الميكروسكوبية بالحاسب، وتصميم مجموعة من البرامج اللازمة لإجراء عمليات القياس المختلفة.

ويحتوي هذا النظام على ثلاثة وحدات للقياس: الوحدة الأولى تُستخدم لإجراء القياسات العامة، مثل قياس الأبعاد الطولية، وقياس الزوايا، وقياس أنصاف أقطار الأقواس وأقطار الثقوب، وقياس المسافات بين مراكز الثقوب. وتُستخدم وحدة القياس الثانية لقياس وتسجيل الأشكال الدقيقة غير المنتظمة، مثل العيوب والشروخ الموجودة في أسطح المعادن. ويمكن أيضا الحصول على بعض المعلومات الهامة عن الأشكال المقاسة مثل الطول والعرض والمساحة والمحيط. وتُستخدم وحدة القياس الثالثة لقياس وتسجيل أبعاد المنتجات الصغيرة التي تحتوي على أبعاد دقيقة ومنحنيات يصعب قياسها بالأساليب التقليدية. ومن مميزات وحدة القياس الثالثة أن المنتجات التي يتم قياسها يمكن إخراجها إلى برنامج الأوتوكاد على صورة رسم هندسي بحيث يمكن طباعته أو تعديله فيما بعد. ويمكن أن تخدم وحدة القياس الثالثة مجال الهندسة العكسية من ناحية قياس أبعاد المنتجات الموجودة بالفعل. وعند استخدام وحدتي القياس الثانية والثالثة تظهر الأشكال التي يتم قياسها على الشاشة مباشرة أثناء عملية القياس مما يساعد المستخدم على رؤية الأجزاء التي تم قياسها.

وقد تم تطوير النظام المقترح واختباره في معمل القياسات الدقيقة بكلية الهندسة جامعة المنصورة. وتم كتابة البرامج اللازمة له باستخدام أحد لغات البرمجة المتطورة، وهي لغة (Visual C++). وتم أيضا استخدام النظام في إجراء مجموعة من القياسات في التطبيقات المختلفة.

ABSTRACT

Microscopic instruments have been widely used in many applications for the purpose of inspection and measurement. Measurescopes are one of these microscopic instruments, which are used in micro measurements. Old 2-D measurescopes are limited to producing X and Y coordinates for individual points according to the movement of attached two micrometers. In this paper, a computerized 2-D measurement system has been developed using a Measurescope, personal computer and developed software. The software, named *MScope*, is fully written in lab using Microsoft Visual C++ 6.0 and is ready to run on any Windows environment. The system is capable of performing various types of measurements such as linear, angular, circular and radial measurements. In addition, the system is capable of tracing contours and freeform shapes in a manner, which could simulate a 2-D Coordinate Measuring

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Machine (CMM). This facility may help in the field of reverse engineering to measure small and complex products. The information of both the traced contours and the freeform shapes are calculated automatically and could be exported to AutoCAD as drawing files for further editing and modifications.

KEYWORDS

Metrology, Computer aided measurement, Micro measurements, Freeform shapes, Contours.

NOMENCLATURE

FSM = Freeform Shapes Module
GMM = General Measurements Module
MML = Multi Measurement List
TCM = Tracing Contours Module

1. INTRODUCTION

Measuring instruments are generally used for various measurements in industries and laboratories because the need of these instruments is more realized over verniers, micrometers, gauges etc. [1]. On the other hand, the small critical dimensions in modern products such as integrated circuits, materials microstructure and the other micro-devices make microscopic inspection and measurement essential. Microscopic measurements are used in many fields such as engineering, medicine and dentistry. Engineering applications include characterization of surface topography [2-5], determination of cracks [6, 7], investigation of grain orientation of ceramic [8], characterization of surface defects [9] and examination of the fractured surfaces [10]. Measurescopes are one of the instruments, which are used for microscopic measurements. Old Measurescopes are limited to produce X and Y coordinates for individual points through a digital display. Although modern measurescopes could be supplied by some accessories to extend its measurement capabilities, they are very expensive. In this work, an old Measurescope has been modified to develop a 2-D measuring system to perform various types of measurements.

2. PROBLEM DESCRIBTION

A Nikon-10 Measurescope has been established in the metrology lab in Mansoura University, faculty of engineering since 1991. It has the advantage of producing accurate readings, up to 1 μm, in both X and Y directions through two digital micrometers, which are connected to a X-Y table. The readings are displayed on a separate digital readout unit. In addition, it has a variety of magnification lenses to suite different application measurements. The main disadvantage of the measuring process is the limitation to measure X and Y coordinates of individual points. For example, to measure the length of a line, the coordinates of the two end points should be read individually and recorded manually to a piece of paper for further calculations. The aim of this paper is to extend the measurement capability of the Measurescope by connecting it to a personal computer and developing software capable of performing various types of measurements.

3. THE PROPOSED SYSTEM

Figure 1 shows a photograph for the proposed system. It consists of four parts: the Measurescope (1-6), a PC bus optically isolated I/O board (PCIO44) (7), personal computer (8) and the developed software (*Mscope*) (9). The PCIO44 card is installed inside the computer and it is used to acquire the readings of the Measurescope and converts it to a form readable by the computer. The digital display (6) has no interface with the computer. Therefore, an interface connection has been established between the digital display and the A/D card. The computer is an IBM compatible PC with the minimum specification of 200 MHz processor, 64 MB of RAM, 8 GB hard disk, 15" color monitor and VGA card with resolution of 800 x 600 pixels.

The proposed software, named *MScope*, is fully written in lab using Microsoft Visual C++ 6.0 as a 32-bit application. It is ready to run on any Windows environment. It is capable of acquiring and saving X and Y coordinates from the Measurescope and performing various types of measurements such as linear, angular, radial and circular measurements. In addition, it is capable of tracing contours and freeform shapes.

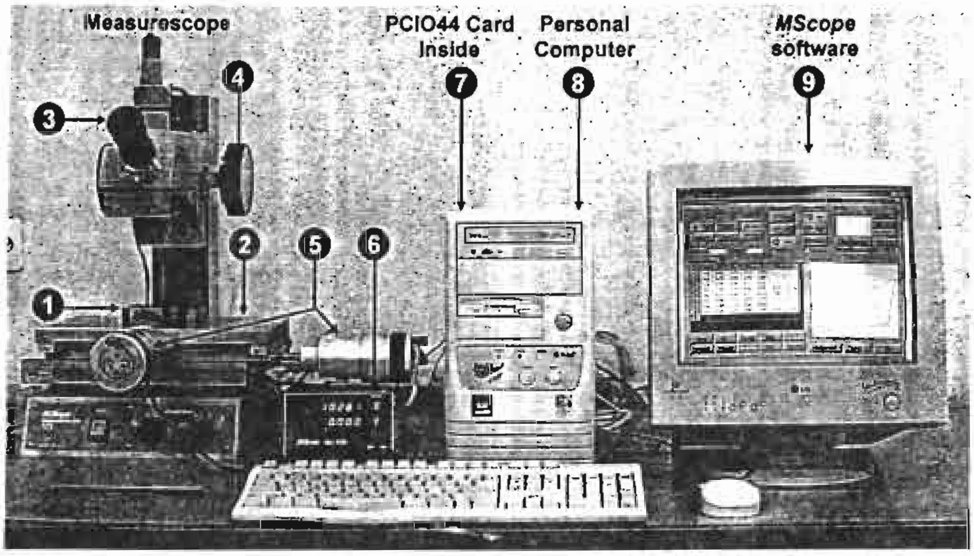


Fig. 1. Photograph of the proposed system

4. PROCEDURES OF WORKING

As shown in Fig. 1, the procedures of working can be summarized as follows:

1. Switching on the power of both the Measurescope and the PC.
2. Placing the object to be measured (1) on the X-Y table (2) and looking from the eyepiece (3) to adjust the focus using the wheel (4).
3. Executing the *MScope* software and selecting the suitable module to perform the required measurements.
4. Acquiring the desired points by moving the X-Y table to adjust each point under the crosshairs of the eyepiece, then clicking the *Add* button in the selected module.

5. MODULES OF THE *MSCOPE* SOFTWARE

The *MScope* software is divided into three modules, which are General Measurements Module (*GMM*), Tracing Contours Module (*TCM*), and Freeform Shapes Module (*FSM*). Figs. 2, 4 and 5 show the main interface of these modules, respectively. All modules have a fixed section called *Measure Scope*, which is located at the upper left of the dialog. This section is used to control the acquired readings from the Measurescope. Table (1) shows the function of each button in this section. The Measurescope is capable of moving the X-Y table for relatively long distances without rotating the micrometers by placing slip gauges between the micrometer anvil and the corresponding table. If slip gauges were used, its values should be entered to the *X Direction* and the *Y Direction* text boxes.

Table 1. Functions of the buttons used to control the acquired readings from the Measurescope

Button	Funetion
Start/Stop	(Toggle button) starts and stops acquiring readings from the Measurescope.
Reset X	Resetting X reading to zero
Reset Y	Resetting Y reading to zero
Reset XY	Resetting both X and Y readings to zero
Auto Show	Enable/Disable real-time displaying of the acquired readings
Show	To display the current readings (Enabled only if Auto Show is not selected)

5.1. The General Measurements Module

The General Measurements Module (*GMM*) is shown in Fig. 2. It is used to perform three types of measurements: linear, angular and radial/circular measurements. Each type can be performed by two methods as shown in Table 1. The measurement type and method is selected from the buttons shown at the bottom of the dialog. Readings can be acquired by clicking the *Add* button in the *Readings* section, or by pressing the Enter key or the space bar from the keyboard. The *preview* section helps the user to specify the required points for all measurements. The required point is marked by a small square, while the recorded points are marked by a filled small circle. Once the required points were acquired, the results are displayed in the *Measurements* section, which is updated automatically according to the selected measurement type and method. The results obtained by each type of measurements are shown in the last column of Table 2.

5.1.1. Mathematical calculation of the *GMM*

The *GMM* uses some mathematical formulas for each type of measurements. For linear measurements, length, slope, delta X and delta Y are calculated simply from the acquired two points. For angular measurements, the slopes of both lines, which conforming the angle, are determined then the angle between them is calculated. For circular and radial measurements, the center point and the radius are calculated from the acquired three points using equations (1-3). If (x_1,y_1), (x_2,y_2) and (x_3,y_3) are the coordinates of the three points, respectively, then the coordinates of the center point are calculated from equations 1 and 2.

$$c_x = \frac{(y_3-y_1)[(x_2-x_1)(x_2+x_1)+(y_2-y_1)(y_2+y_1)]-(y_2-y_1)[(x_3-x_1)(x_3+x_1)+(y_3-y_1)(y_3+y_1)]}{2[(x_2-x_1)(y_3-y_2)-(y_2-y_1)(x_3-x_2)]} \qquad (1)$$

$$c_y = \frac{(x_2-x_1)[(x_3-x_1)(x_3+x_1)+(y_3-y_1)(y_3+y_1)]-(x_3-x_1)[(x_2-x_1)(x_2+x_1)+(y_2-y_1)(y_2+y_1)]}{2[(x_2-x_1)(y_3-y_2)-(y_2-y_1)(x_3-x_2)]} \qquad (2)$$

where c_x *and* c_y are the x and y coordinates of the center point, respectively. The radius R of an arc or circle is calculated from equation 3:

$$R=\sqrt{(x_i-c_x)^2+(y_i-c_y)^2} \quad \text{...} (3)$$

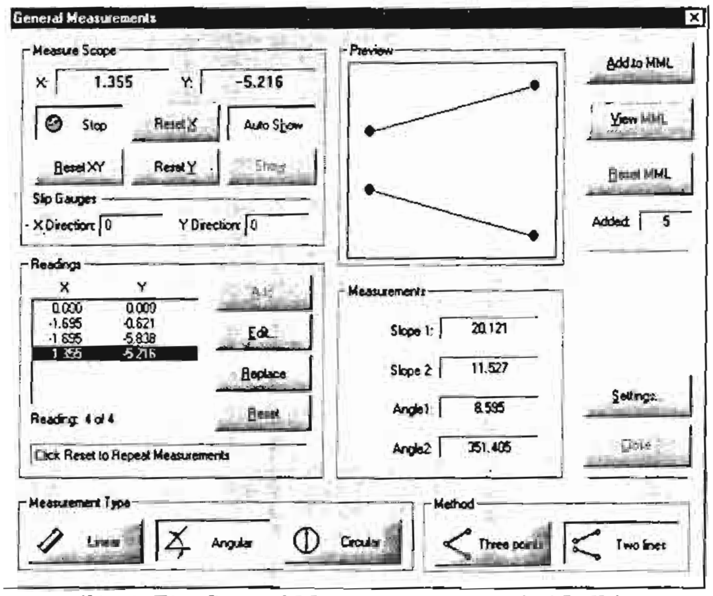


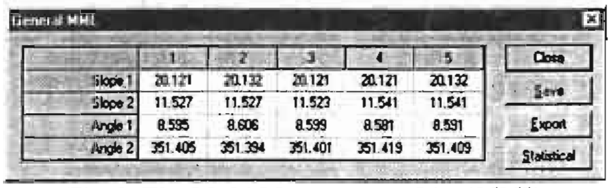
Fig. 2. The General Measurements module (*GMM*)

Table 2. Description of the three types of measurements used by the *GMM*

Type	Method	Required points		Results
		Number	Description	
Linear	Two points	2	Two end points of a line.	Length, slope, delta X and delta Y.
	Two centers	6	Three points on each circle or arc.	
Angular	Three points	3	The angle (apex) should be at the second point.	First line slope, second line slope, angle between the two lines and the opposite angle.
	Two lines	4	Two points on each edge of the angle.	
Circular	Arc	3	Two end points and any point in between.	Center point, radius, start angle and end angle.
	Circle	3	Any three points on the circle.	Center point and the radius or diameter.

5.1.2. Repeatability of measurements

In metrology, it is known that one measurement process is not enough to give accurate results. The term repeatability is used to perform successive measurements for the same object under the same conditions. The *GMM* has the facility of adding the results of measurements to a list called Multi Measurement List (*MML*), which can store up to 50 measurements. The *MML* is useful for calculating the most common statistical parameters of the repeated measurements such as minimum, maximum, average, range and standard deviation of the measurements. Fig. 3 shows the *MML* of five measurements for the same angle. The *MML* can be saved to a file or exported to MS Excel for further usage.



	1	2	3	4	5
Slope 1	20.121	20.132	20.121	20.121	20.132
Slope 2	11.527	11.527	11.523	11.541	11.541
Angle 1	8.595	8.606	8.599	8.581	8.591
Angle 2	351.405	351.394	351.401	351.419	351.409

Fig. 3. The Multi Measurement List (*MML*)

5.2. The Tracing Contours Module

The Tracing Contour Module (*TCM*) is shown in Fig. 4. This module is useful for tracing contours, which may be considered as a series of lines. The traced points are stored to an array for further calculations. Points can be acquired as described in section 5.1. Several editing operations can be applied to the acquired points such as modifying, replacing and deleting points. In addition, new points could be inserted before any recorded point.

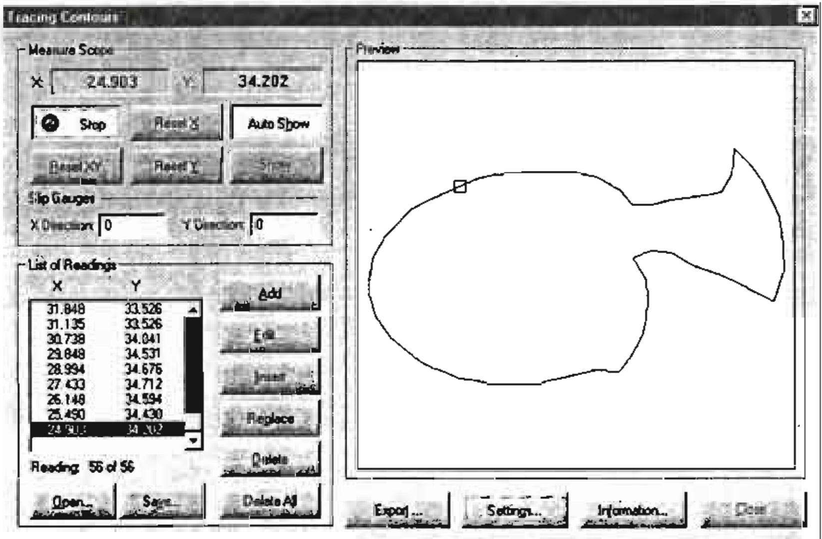


Fig. 4. The Tracing Contours Module (*TCM*)

The traced contour is displayed and adjusted automatically in the *Preview* section. Once the contour is traced, the acquired points can be saved to a file for future use. Useful information could be obtained for the traced contours such as width, height, area and perimeter. In addition, the traced contours can be exported to AutoCAD as a drawing file for further editing and usage.

5.3. The Freeform Shapes Module

The Freeform Shapes Module (*FSM*) is shown in Fig. 5. This module is useful for tracing small and complex 2-D freeform shapes. It could assist in the field of reverse engineering to measure dimensions of the existing products. The user selects the object to be traced (line, arc or circle) from the *Measuring Mode* section, and then acquires its coordinates through the *Readings* section. Two points are required for lines and three points are required for both arcs and circles. If the *Continuous* check box is checked, the last acquired point for lines and arcs is considered the start point for the next line or arc. In this case, one point is required for each line and two points are required for each arc. Once the required points for the object to be measured are acquired, the object is added automatically to the *Measured Objects* list and all necessary information for the object is calculated and stored to a database for further usages. Information about any traced object can be obtained by selecting the object and clicking the *Object Info* button. For example, information about traced arcs includes the center point, radius, include angle, start angle and end angle as shown in Fig. 6. During the tracing process, the traced shape is displayed and adjusted automatically in the *Preview* section. Traced shapes can be saved to files for future opening and modifications. In addition, it can be exported to AutoCAD as a drawing file to write its dimensions.

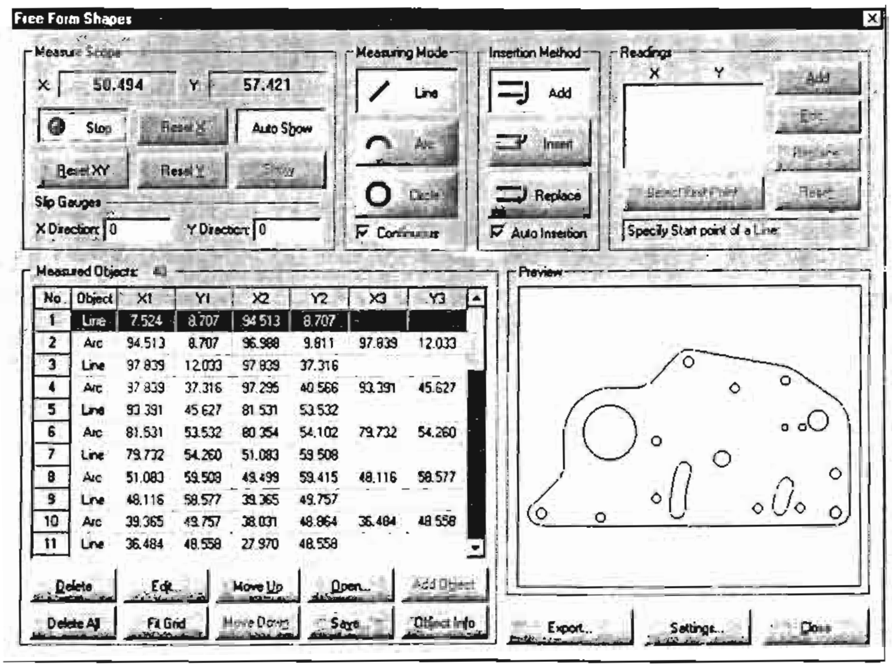


Fig. 5. The Freeform Shapes Module (*FSM*)

6. SYSTEM VERIFICATION

To verify the accuracy of the proposed system, the two micrometers were moved from their beginning to their ending strokes and the readings of the digital display were compared with the acquired readings every 5 mm. All readings were identical, except in some cases the acquired readings may be less than the digital display readings by 1 μm in either X or Y directions. This value can be neglected if compared with the total length of the micrometer strokes, which are 100 mm in X direction and 60 mm in Y direction. However, the accuracy of measurement depends on the accuracy of the user who specifies the points of the objects to be measured.

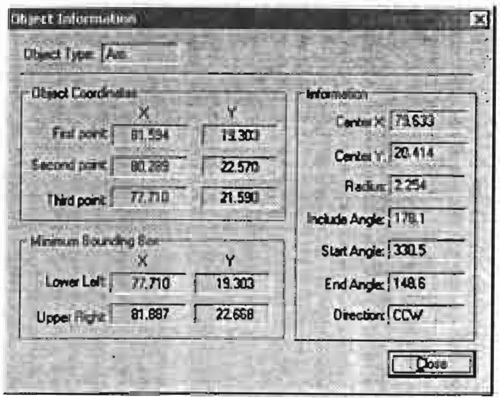
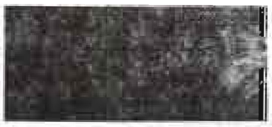


Fig. 6. Obtained Information about a traced arc using the *FSM*

7. APPLICATION OF THE PROPOSED SYSTEM

The *GMM* was used in metrology lab to measure lengths, angles and diameters of products in addition to the traditional methods (micrometers, verniers, bevel protractors, clinometers, sine bar, etc). In addition, the *TCM* and the *FSM* were used in many applications and an application for each module is described here. The *TCM* was used for tracing welding defects in radiographic films to obtain useful information about the defects such as the area and the perimeter of the defects as shown in Table 3. The *FSM* was used to trace the product shown in Fig. 6. The *preview* section in Fig. 5 shows the traced shape. Fig. 7 shows the engineering drawing of the product after exported to AutoCAD and writing some dimensions of the part. Once the engineering drawing is exported to AutoCAD, minor editing could be done to adjust the corner fillets. In addition, all dimensions can be written easily including distances between centers of holes, which are difficult to be measured by the traditional methods.

Table 3. Two welding defects traced from radiographic

Radiographic Defect Sample	Traced contour	Obtained Information
		Width: 14.987 Height: 8.396 Area: 77.264 Perimeter: 43.680
		Width: 1.528 Height: 47.767 Area: 70.613 Perimeter: 97.585

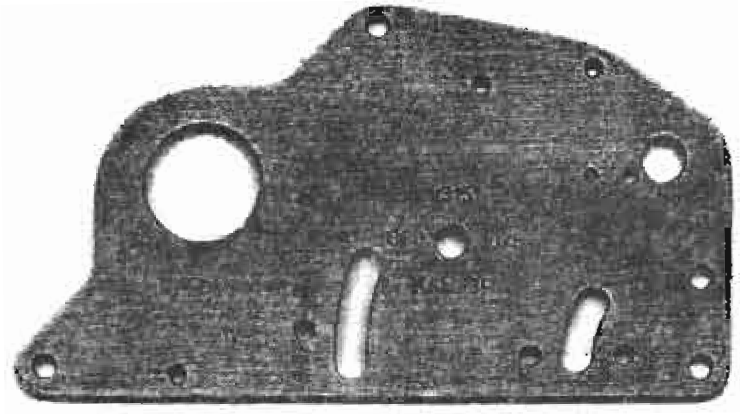


Fig. 7. The original product

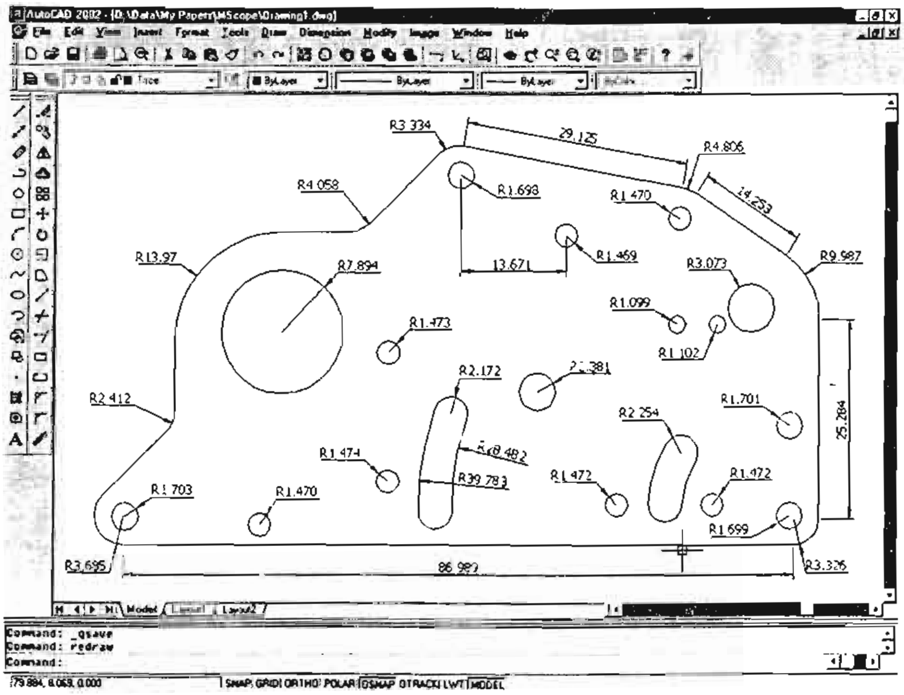


Fig. 8. The traced product after exported to AutoCAD

8. DISCUSSION

The accuracy of the proposed system proved to be very accurate. On the other hand, the accuracy of measurements depends on the accuracy of the user who specifies the points to be acquired. The sensitivity of the proposed system is considered relatively high because measuring small dimensions under high magnification increases the sensitivity of the measurement process. This problem could be overcome by repeating the measurements using the *MML*, then taking the average of the measurements.

9. CONCLUSIONS

A developed system has been introduced for microscopic measurements. The system could assist in the field of reverse engineering for measuring the dimensions of both small and complex products. The system is capable of performing general measurements such as linear, angular and circular measurements. General measurements could be repeated for the same object to ensure the measurements and to obtain useful statistical parameters such as minimum, maximum, average, range and standard deviation of the measurements. In addition, the system is capable of tracing 2-D contours and freeform shapes. These modules have been used successfully in many applications such as tracing products, measuring welding defects from radiographic films and measuring different objects from medicine and dentistry x-ray films. Traced contours and freeform shapes could be exported to AutoCAD as drawing files for further editing and for writing dimensions. The system was verified and tested for all modules and proved to be very accurate if measurements were carried out with care.

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