

Automatic Recognition of Internal Features of Axisymmetric Parts from 2-D Images

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Abstract

Objectives: This paper presents the development of a software package for Automatic Extraction of Geometrical Data (AEGD) and Recognition of Internal Turning Features (RITF). **Methods/Analysis:** The developed algorithms used to extract geometrical data and recognize internal features from the 2-D gray scale images and analyzed the recognized features. The expert system is developed using Java Advanced Image packages. The extracted test examples geometrical data analyzed with known geometrical data of a CAD model of the same axisymmetric component. **Findings:** The present research work deals with the development of a feature-based approach to automatically extract geometrical data and recognize the internal features of the workpiece from an image database without any human intervention. The geometrical data extracted from the sample images and the extracted data used to recognize turned features with the developed algorithms. It is found that the average percentage variation of extracting geometrical data not more than 0.09. **Applications/Improvement:** The proposed system is novel approach to extract geometrical data from the image files and use this data to recognize turned features. This information is required for downstream applications i.e. generation of process plans, production schedules, NC code generation etc.

Keywords: 2-D Drawing Images, Feature Recognition, Geometric Data Extraction, Image Processing, Rotational Parts

1. Introduction

Now a day's, with the use of computer based technologies in the manufacturing industries, manual and semi-automatic methods are largely being replaced by Computer Aided Design and manufacturing systems. The large scope of CAD/CAM systems will lead to reduce human intervention and the result would be reduced costs, increased production and better quality of the finished product. Since 1970's the extraction of geometric features from drawing data base has received considerable amount. The ability to automatically recognize turned features from an image database system is paramount to integrate CAD/CAM. The axisymmetric components are represented by a single-view 2D drawing images. These components are subset of all characteristic components manufactured in industry; it includes a group of relatively

important and frequently produced components such as spindles, shafts, axles, etc¹.

Several researchers have approached automatic recognition of features from different approaches for the past two decades. In literature, many systems are described for the design and manufacture of turned components and methods to evaluate parts that require turning. Many works are described in literature related to manufacturing feature recognition and its application in design.

Several researchers developed feature recognition modules for axisymmetric components that are machined on CNC lathes only². They have also discussed the different data exchange formats. They used DXF file format to extract the geometric data of axisymmetric parts in 2D, which was represented by boundary representation (B-rep) database. Standard oriented form-feature extraction system that converts lower level geometrical and

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topological data specified in a STEP file into relevant manufacturing data³.

The generation of the optimal process sequence⁴ through Hybrid approach considered. This approach consisting of the genetic algorithm, neural network and analytical process (AHP). By adopting the best satisfaction of manufacturing sequence rules to minimize manufacturing cost having the shortest time for production.⁵ Developed an automatic feature recognition system using the IGES data exchange format as input for rotationally symmetric parts. A feature-based design system that can be applied in the concept-to-manufacturing stages of the machining process⁶. Several Researchers explained that how they can extract data from DXF file and convert it into a graphical format and tabular format⁷. They also explained manufacturing feature recognition of a rotational component using DXF file. Liu reported a new approach for a component framework for feature-based design and process planning (CFACA) in order to provide a productive and a powerful development mode⁸.

Developed a system that recognizes design and manufacturing features from the lower level geometry and topology available in the STEP file⁹. Proposed three modules, namely, structured modeling, feature recognition and feature sequencing for machining rotational components¹⁰. Seamless integration technique of CAD/CAPP/CAM is intended to extract the geometric information of rotational parts from STEP file, and utilize this information to recognize the turning features¹¹. A generalized Java code has been written to extract the data from STEP file and to recognize the features. Anovel method for automated recognition of external surface features for turning components from the 2D images developed for four algorithms based on 2D drawing image files^{12,13}. The first algorithm deals with the extraction of geometrical data, the second algorithm used to recognize turned features from the extracted geometrical database. Recognized features are then passed to third and fourth algorithms for the generation of process plans and NC part programs respectively. Developed Algorithms for design feature data extraction from DXF files¹⁴. Developed a hint-based machining feature recognition system for 2.5D parts with arbitrary feature interactions¹⁵. A pre-processor is used to screen out invalid 2.5D parts automatically and calculate the possible machining directions. Two algorithms based on 2D drawing files developed^{15,16}. The first algorithm deals with surface feature recognition on turning parts. Recognized features are then passed to the second

algorithm for NC part program generation. Yang and Lee presented a geometry, setup and operation oriented decomposition based feature modification framework for the generation of alternative process plans. The authors found the method effective with grooved and profile features where tool changes were necessary. Developed an automatic feature recognition and CNC code generation (AFR/ACCG) system for rotational parts. This system was prepared using Delphi 7 programming languages¹⁷. The data input to the system is done by DXF prepared in any CAD program. Greyscale and RGB images are considered and used a median filter for image enhancement and segmentation for extraction of the diseased portion which is used to identify the disease level¹⁸. Presented an image retrieval system using hand drawn sketches of images¹⁹. The sketch is one of the convenient ways to represent the abstract shape of an object. The main objective is to perform retrieval of images using edge content by prioritizing the blocks based on the information.

It is observed from the literature review that based on many of researchers extracting geometrical data from the standard formats like IGES, DXF, STEP, etc., there is no literature reporting the study of how to extract internal geometrical data from the 2D drawing images. Therefore, there is a vital need to make an attempt to extract internally turned features from the image files. This paper addresses the algorithms developed for AEGD and RITF for axisymmetric part drawing images.

2. Feature Recognition

The feature recognition process can be performed with reference to the symmetrical axis why because all the rotational parts are symmetrical along their axis, designing their processes can be done according to the symmetry axis. According to machining attributes all features including rotational parts could be classified as outside features and inside features. These features are also classified to sub-features of the system such as long turning and grooving according to machining attributes.¹⁷ Automatic use of feature recognition minimizes the need to manually analyze and manipulate part geometry to prepare it for machining. Automated feature recognition can best be facilitated by CAD systems capable of generating the product geometry based on features exist. In the present work, eight internal features as shown in Figure 1 are considered, namely, Drilling, Boring, Groove turning,

Left-hand and Right-hand taper turning, Concave and Convex Contour turning, thread cutting.

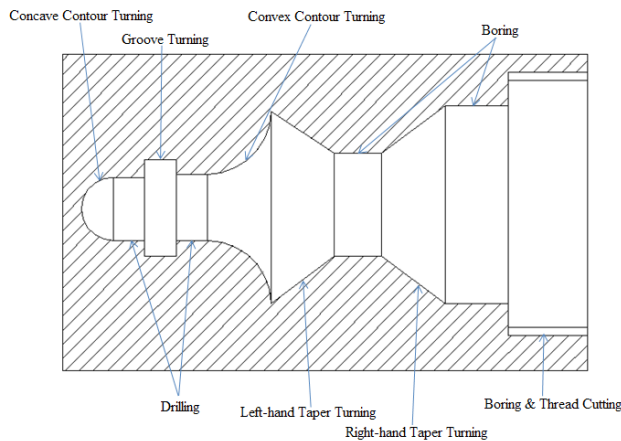


Figure 1. Typical axis-symmetric component showing internal turned features.

3. Proposed Algorithms

The present expert system has been developed using the advanced features of JAI package. The following steps of algorithm for the overall procedure of the system is explained and shown in Figure 2.

Step 1: After executing the Java program the main window will be displayed as shown in Figure 8. Choose options by using the mouse to execute those options.

Step 2: Enter the image filename and size of raw material available then click basic data button. Based on the size of raw material, the software automatically decides suitable scale factor for computing all the dimensions of the part.

Step 3: Click the geometrical data button, then the software can be extracted all the salient point coordinates and stored in a file.

Step 4: Turning features and their geometrical data will be generated and displayed as shown in Figure 9 after clicking the Turning features button.

Step 5: Exit option makes physical termination of the system.

3.1 Basic Data Extraction Algorithm

In this algorithm, first compute the Y-coordinate of the center axis of the part by scanning the image, pixel by pixel and extract, black color (based on RGB values, for

black color R=0, G=0, B=0) pixel coordinates starting from left top to right bottom of the image.

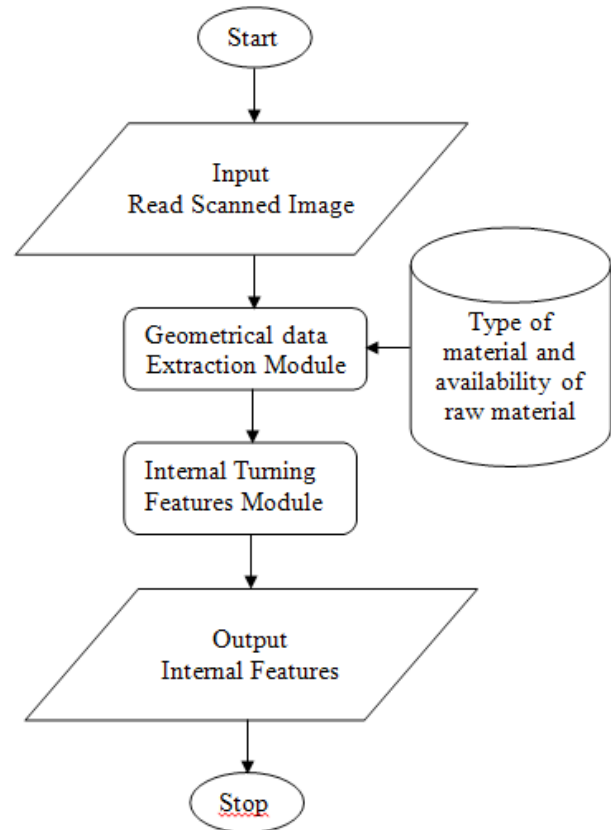


Figure 2. Flow chart depict the overall structure of the system.

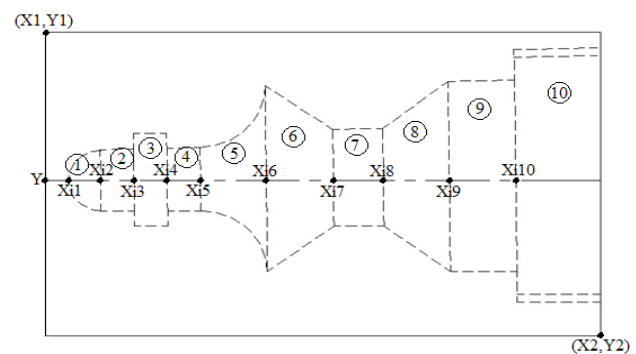


Figure 3. Segment numbers and basic points.

This Y-coordinate, as shown in Figure 3, is required to get the X-coordinates of all the segments of the part. The algorithm for basic data extraction is explained through the following steps.

Enter the image file name in .jpg/bmp format and click the extract button.

- Scan the image, pixel by pixel and extracts black colour pixel coordinates starting from left top to right bottom of the image.
- The first-pixel X-coordinate is assigned to $X1$ and Y-coordinate is assigned to $Y1$.
- If extracting particular row pixels repeatedly the same number of black colour pixels, then it will recognize as dashed lines and count the number of black pixels for one dash and assigned to 'd' and similarly count the number of white pixels for one gap and assigned to 'g' as shown in Figure 4.
- While extracting last row pixels, Y-coordinate of that pixel is assigned to $Y2$ and the last pixel X-coordinate is assigned to $X2$.
- If X-coordinate is less than the width of the image, go to the second step, otherwise, go to the next step.
- If the Y-coordinate is less than the height of the image, go to the second step, otherwise stop.

Calculate the Y-coordinate of the center axis of the part, $Y = Y1 + (Y2 - Y1)/2$.

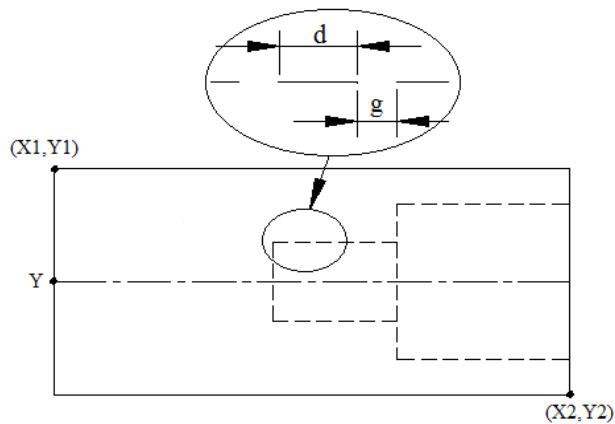


Figure 4. Length properties of dashed line.

3.2 Geometrical Data Extraction Algorithm

The algorithm for extracting salient points (A, B, C, D, E, F, G and H) coordinates of the different segments as shown in Table 1 is described in this section. For example, consider an image as shown in Figure 3 marked by ten segment numbers. The points A, B, C, D and E are assigned to start, $1/4^{\text{th}}$, $1/2$, $3/4^{\text{th}}$ length of the segment and end point of the segment respectively. The points F, G and H are taken at $1/4^{\text{th}}$, $1/2$, $3/4^{\text{th}}$ length of the segment

but at different Y values. These three points require for recognizing thread features.

- Enter the size of raw material available, and then click the geometrical data button.
- Scan the image again, pixel by pixel and extract, black colour pixel coordinates starting from left top to right bottom of the image.
- If the Y-coordinate of the pixel equal to $(Y+g+d/2)$ or $(Y+g/2+d/2)$ or $(Y+d/2)$ as shown in Figure 5(a), then increase counter 'c' by one (1).
- If c equals 2, assign X-coordinate of the pixel to $Xi1$, if c equals 3, assign X-coordinate of the pixel to $Xi2$ and so on. And also assign a number of internal segments of the part $n=(c-2)$.
- If X-coordinate of the pixel equal to $(Xij+g+d/2)$ or $(Xij+g/2+d/2)$ or $(Xij+d/2)$ as shown in Figure 5(b), corresponding X-coordinate is assigned to $Xij1$ and Y-coordinate is assigned to $Yij1$. Where i denote any numerical value and j equal to the number of the segment.
- Calculate intermediate X-coordinates of the j^{th} segment at $1/4^{\text{th}}$ length $Xij1+(Xi(j+1)-Xij1)/4$ and assigned to $Xij2$; at $1/2$ length $Xij2+(Xi(j+1)-Xij1)/4$, assigned to $Xij3$; and at $3/4^{\text{th}}$ length $Xij3+(Xi(j+1)-Xij1)/4$, assigned to $Xij4$; Substitute $j=1,2,3,\dots,n$ to get the intermediate X-coordinates of all the segments
- The intermediate Y-coordinates of the j^{th} segment is obtained as follows.

- If $Xij2$ equals X-coordinate of the pixel, corresponding Y-coordinate is assigned to $Yij2$. Increase counter 'p' by one (1). If p equals 1, corresponding Y-coordinate of the pixel is assigned to $Yij6$.
- If $Xij3$ equals X-coordinate of the pixel, corresponding Y-coordinate is assigned to $Yij3$. Increase counter 'q' by one (1). If q equals 1, corresponding Y-coordinate of the pixel is assigned to $Yij7$.
- If $Xij4$ equals X-coordinate of the pixel, corresponding Y-coordinate is assigned to $Yij4$. Increase counter 'r' by one (1). If r equals 1, corresponding Y-coordinate of the pixel is assigned to $Yij8$.

Substitute $j=1, 2, 3 \dots n$ to get the intermediate Y-coordinates of all the segments.

- (a) If X-co-ordinate is less than the width of the image, go to the second step, otherwise, go to next step.
 (b) If Y-co-ordinate is less than the height of the image, go to the second step, otherwise stop.

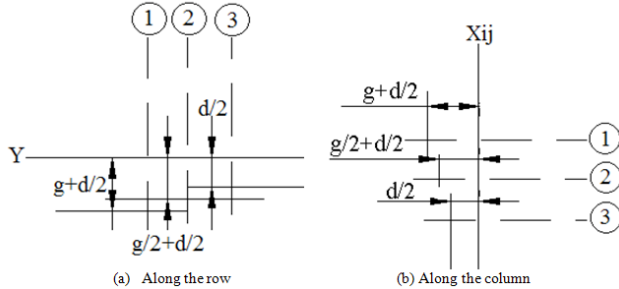


Figure 5. Scan the image pixel by pixel from left top to right bottom.

Table 1. Critical points of the segment

Sl.No.	Point	X-coordinate	Y-coordinate
1	A _{ij}	X _{ij1}	Y _{ij1}
2	B _{ij}	X _{ij2}	Y _{ij2}
3	C _{ij}	X _{ij3}	Y _{ij3}
4	D _{ij}	X _{ij4}	Y _{ij4}
5	E _{ij}	X _{ij5}	Y _{ij5}
6	F _{ij}	X _{ij6}	Y _{ij6}
7	G _{ij}	X _{ij7}	Y _{ij7}
8	H _{ij}	X _{ij8}	Y _{ij8}

3.3 Feature Recognition Algorithm

The exact size of the part is obtained only if the image is in the normal position. In all other positions (zoom in or zoom out), the size may vary. To overcome this problem, the scale factor is considered in the algorithm. The system will compute scale factor automatically based on the size of raw workpieces available. This scale factor is used to compute all the dimensions proportionately to the size of raw work piece Srinivasa Rao 12. Table 2 presents the logics used to recognize different internal turned features of the axisymmetric parts. As shown in the first row of Table 2, if the value of Y coordinates of all the salient points is equal and Y coordinate of the first point is greater than first and fifth points of next segment then recognizes the feature as a drilling. Similarly, compare Y coordinates of different points of the segment and recognize other features as shown in Table 2. For all the features, the length of the feature is computed by using the formula $L = (X_{i(j+1)} - X_{ij})/SF$, where 'SF' is the scale factor. The radius of curved

surfaces is computed by considering any three points on the curved surface as shown in Figure 6.

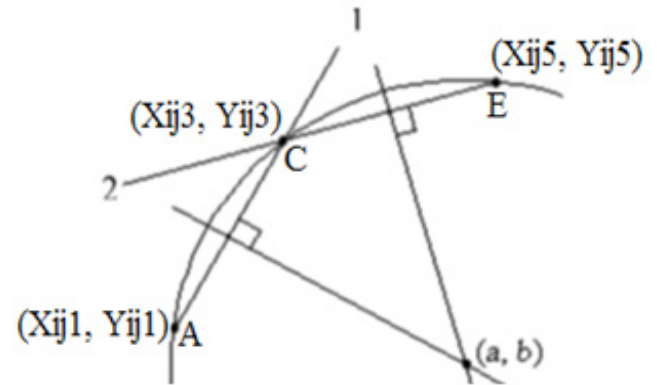


Figure 6. Computation radius of curvature.

$$\text{Slope of the first line } m_1 = \frac{(Y_{ij3} - Y_{ij1})}{(X_{ij3} - X_{ij1})}$$

$$\text{Slope of the second line } m_2 = \frac{(Y_{ij5} - Y_{ij3})}{(X_{ij5} - X_{ij3})}$$

The X coordinate of the centre of the curve

$$a = \frac{m_1 \times m_2 \times (Y_{ij1} - Y_{ij5}) + m_2 \times (X_{ij1} + X_{ij3}) - m_1 (X_{ij3} + X_{ij5})}{2(m_2 - m_1)}$$

The Y coordinate of the centre of the curve b=

$$(X_{ij1} - X_{ij5}) + m_1 \times (Y_{ij1} + Y_{ij3}) - m_2 \times (Y_{ij3} + Y_{ij5}) \\ 2(m_1 - m_2)$$

Radius of the curvature R =

$$\frac{\sqrt{(a - X_{ij1})^2 + (b - Y_{ij1})^2}}{SF}$$

In the present work considered ISO general-purpose metric screw threads and compute

$$\text{Major diameter } D_{\text{Major}} = 2 \times (Y_{ij1} - Y)/SF;$$

$$\text{Minor diameter } D_{\text{Minor}} = 2 \times (Y_{ij6} - Y)/SF$$

The pitch of the thread $p = H/0.866$, where H is the height of the thread.

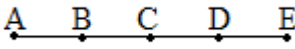
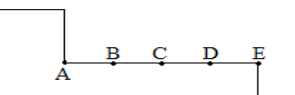
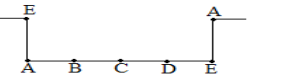
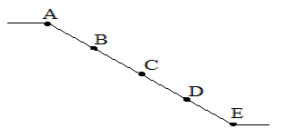
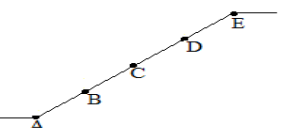
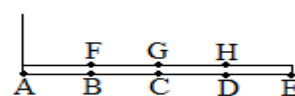
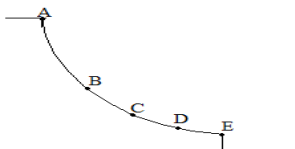
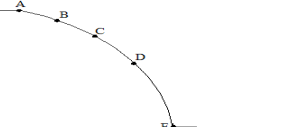
$$\text{Pitch of the thread } p = (Y_{ij1} - Y_{ij6})/(0.866 \times SF);$$

$$\text{Length of the thread } L = (X_{i(j+1)} - X_{ij})/SF$$

4. Results and Discussions

The applicability of the software to extract geometrical data and recognize internal features for turning parts is discussed below. The following example illustrates and

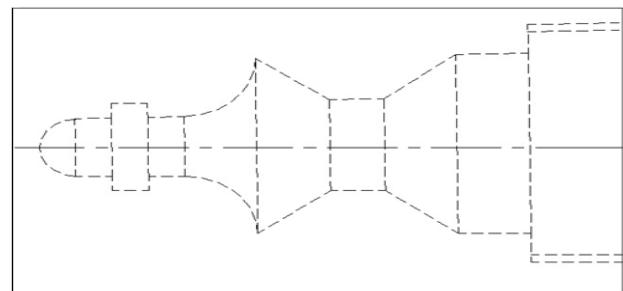
Table 2. Different logics used to recognize internal turned features

Sl.No.	Logic	Shape of the feature	Name of the internal feature	Geometrical Data
1	If $((Y_{ij1}=Y_{ij2}=Y_{ij3}=Y_{ij4}=Y_{ij5}=Y_{ij6}) \& (Y_{ij1}>Y_{i(j+1)1} \& Y_{i(j+1)5}))$		Drilling	$D = 2 \times (Y_{ij1} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$
2	If $((Y_{ij1}=Y_{ij2}=Y_{ij3}=Y_{ij4}=Y_{ij5}=Y_{ij6}) \& (Y_{i(j-1)5} < Y_{ij1} \& (Y_{ij5} < Y_{i(j+1)1})))$		Step Turning/ Boring	$D = 2 \times (Y_{ij1} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$
3	If $((Y_{ij1}=Y_{ij2}=Y_{ij3}=Y_{ij4}=Y_{ij5}=Y_{ij6}) \& (Y_{i(j-1)5} < Y_{ij1} \& (Y_{ij5} > Y_{i(j+1)1})))$		Groove Turning	$D = 2 \times (Y_{ij1} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$
4	If $((Y_{ij2}+Y_{ij4})/2=Y_{ij3}) \& (Y_{ij2} < Y_{ij3} < Y_{ij5})$		Right-hand Taper Turning	$D_L = 2 \times (Y_{ij1} - Y) / SF$ $D_R = 2 \times (Y_{ij5} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$
5	If $((Y_{ij2}+Y_{ij4})/2=Y_{ij3}) \& (Y_{ij2} > Y_{ij3} > Y_{ij5})$		Left-hand Taper Turning	$D_L = 2 \times (Y_{ij1} - Y) / SF$ $D_R = 2 \times (Y_{ij5} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$
6	If $((Y_{ij1}=Y_{ij2}=Y_{ij3}=Y_{ij4}=Y_{ij5}) \& (Y_{ij6}=Y_{ij7}=Y_{ij8}) \& (Y_{ij6} < Y_{ij1}))$		Thread Cutting	$D_{Major} = 2 \times (Y_{ij1} - Y) / SF$ $D_{Minor} = 2 \times (Y_{ij6} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$
7	If $((Y_{ij3} \& Y_{ij4} > (Y_{ij1} + Y_{ij5})/2 \& (Y_{ij1} \neq Y_{ij2}))$		Concave Contour Turning	$D_L = 2 \times (Y_{ij1} - Y) / SF$ $D_R = 2 \times (Y_{ij5} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$ $R = \text{Radius of curvature}$
8	If $((Y_{ij3} \& Y_{ij4} < (Y_{ij1} + Y_{ij5})/2 \& (Y_{ij1} \neq Y_{ij2}))$		Convex Contour Turning	$D_L = 2 \times (Y_{ij1} - Y) / SF$ $D_R = 2 \times (Y_{ij5} - Y) / SF$ $L = (X_{i(j+1)} - X_{ij}) / SF$ $R = \text{Radius of curvature}$

explains the procedure for extracting geometrical data and recognizing internal turning features for a typical axisymmetric part.

4.1 Example

An example of the sample workpiece 2D drawing, the image file is shown in Figure 7. When the software is made to execute, it displays the main window as shown in Figure 8. After entering the image file name and size of raw material available, by pressing basic data button the centre Y coordinate of the part is determined from the image and is assigned to the variable Y for further

**Figure 7.** Example part for 2D Image (job 1.jpg).

processing. By pressing Geometrical data button, the system will scan the image again and extracts all the coor-

Table 3. Comparison of geometrical attributes of test component job1

Feature No.	Name of the feature	Attributes	Extracted Values	Actual Values	% variation
1	Concave contour turning	Left Dia	0	0	0
		Right Dia	19.96	20	0.2
		Radius	9.97	10	0.3
		Length	10	10	0
2	Drilling	Diameter	20	20	0
		Length	10	10	0
3	Groove Turning	Diameter	30	30	0
		Length	10	10	0
4	Drilling	Diameter	20	20	0
		Length	10	10	0
5	Concave contour turning	Left Dia	19.98	20	0.1
		Right Dia	61.03	61	0.05
		Radius	20.02	20	0.1
		Length	20	20	0
6	Left-hand taper turning	Left Dia	61.05	61	0.08
		Right Dia	31.97	32	0.09
		Length	20	20	0
		Length	20	20	0
7	Boring	Diameter	32	32	0
		Length	15	15	0
8	Right-hand taper turning	Left Dia	31.98	32	0.06
		Right Dia	62.97	63	0.05
		Length	20	20	0
		Length	20	20	0
9	Boring	Diameter	63	63	0
		Length	20	20	0
10	Threading	Major Dia	84.03	84	0.04
		Minor Dia	80.99	81	0.01
		Length	25	25	0

dinates and assigns respective variable segment-wise and the results are stored in a separate file. By pressing, turning features button, the turning features of the image from left to right are recognized and displayed as shown in Figure 9.

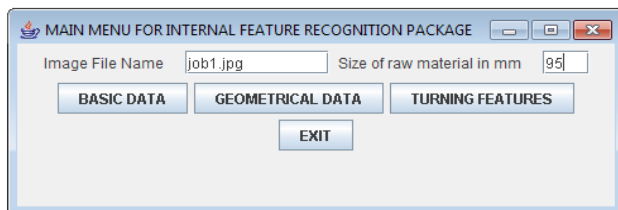
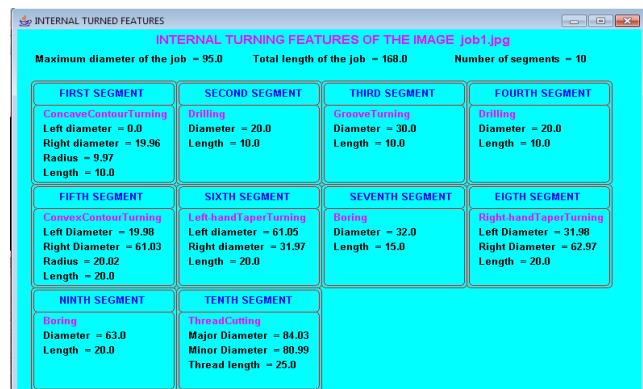
**Figure 8.** Shows the Image file name and size of raw material entered.

Table 3 shows the extracted geometrical results along with actual drawing values of the example part. The results

**Figure 9.** The extracted internal turning features of the 2D drawing image.

are stored in a separate file which will be required for generating process plans. In order to validate, the extracted dimensional results are compared with the actual drawing

dimensions. It is observed from the table that the percentage variation between extracted dimensional values and actual drawing dimensional values are less than 0.3, it is also observed that most of the variation of extracting and drawing dimensional values is almost nearer to 0 percentages. Therefore, this system can be used to recognize internally turned features from the dimensionless drawing images and gives better results.

5. Conclusions

The present work shows an attempt to design and develop a software package for axisymmetric parts. The package developed can be applied to auxiliary industrial parts like shafts, spindles, axles, etc. This package facilitates to extract geometrical data and recognize internal turning features of axisymmetric parts. The developed modules are implemented on a micro computer and the way of implementation is explained with a specific example in the paper. Hence this software package is very much useful to recognize internal turning features and their geometrical data through the scanned image of the product drawing, where the dimensional data is not available. All the developed algorithms are implemented on a microcomputer and the results are satisfactory. The proposed package has been developed in 'Java' language and has the following limitations.

- It is applied to the axisymmetric turned parts
- The modules work with the internal turning features.
- Black and White 2D drawing images.

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