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COMPUTER VISION BASED INSPECTION OF MECHANICAL COMPONENTS

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Abstract In manufacturing environment, a frequent and common requirement has been oriented with the measurement of different dimensions of manufactured components. Measurement has been the generally accepted industrial term for inspection by variables, i.e., with the use of calibrated instruments to determine the actual dimensions of the product for comparison with the desired size. Variable types of inspection would generally take more time. The rapid development of computer technology, have made it possible to replace the traditional inspection methods by computer vision based inspection system backed with suitable image processing software. The automated computer vision system would provide a non-contact, non-destructive method of inspection at a faster rate. In this paper, machine vision based algorithms have been developed using the relevant expressions for inspection of mechanical components. The computer vision based inspection of two commonly used mechanical components, e.g., gears and threads have been considered under this inspection plan.

Keywords: Inspection, Mechanical components, Gear, Screw-threads.

INTRODUCTION

Measurement has been the fundamental activity of any inspection system. The intent of inspection has been to ensure that what have been manufactured would conform to the specifications of the product/part. Measurement has been the generally accepted term for inspection by variables, i.e., with the use of calibrated instruments to determine the actual dimensions of the product for comparison with the desired size. Variable types of inspection would generally take more time[Degarmo et al, 1984]. A common requirement in manufacturing is the automated measurement of the geometric properties of mechanical components [Toncich and Stefani, 1999]. The computer vision system would provide a non-contact, non-destructive method of inspection at a faster rate, thus enabling 100% inspection to be effectively implemented in industries. In this paper, computer vision based inspection using intelligent image processing for the measurement of geometrical properties of two commonly used manufactured parts consisting of curved profiles have been considered. First ,the inspection of gears have been considered and secondly, the inspection of screw threads have been taken into consideration. In this paper, only the planar profiles have been considered which could be obtained by the projection of three-dimensional manufactured parts on the two-dimensional inspection plane.

PLAN FOR GEAR INSPECTION

Basically, the dimensions of gear teeth in a spur gear can be expressed in two ways. Different gear dimensions can be estimated in terms of the diametral pitch (DP) where, DP would be the number of teeth (N) per unit of pitch circle diameter (D). Therefore, DP=N/D. The second method for measurement of gear dimensions would be by means of the module (m), which can be defined as the pitch diameter divided by the number of teeth or m=D/N, which would again be the reciprocal of the diametral pitch. The important tooth elements in a spur gear as highlighted in Fig 1. can be specified in terms of the diametral pitch or the module and have been given as follows:

i) Blank Diameter (also called as addendum diameter) : This is the diameter of the blank from which the gear has been cut out.

Blank diameter =D + 2m = mN + 2m = m(N+2)

where, m= module
and N= number of teeth.

ii) From the above relation, Blank diameter =m(N+2), hence,module, m = Blank diameter / (N+2)

iii) P.C.D., (D) =m x N;

iv) Circular Pitch, (cp) =Π D / N = Π m

v) Tooth thickness = Πm / 2

vi) Basic circular diameter = D x cos 20º (assuming pressure angle = 20º)

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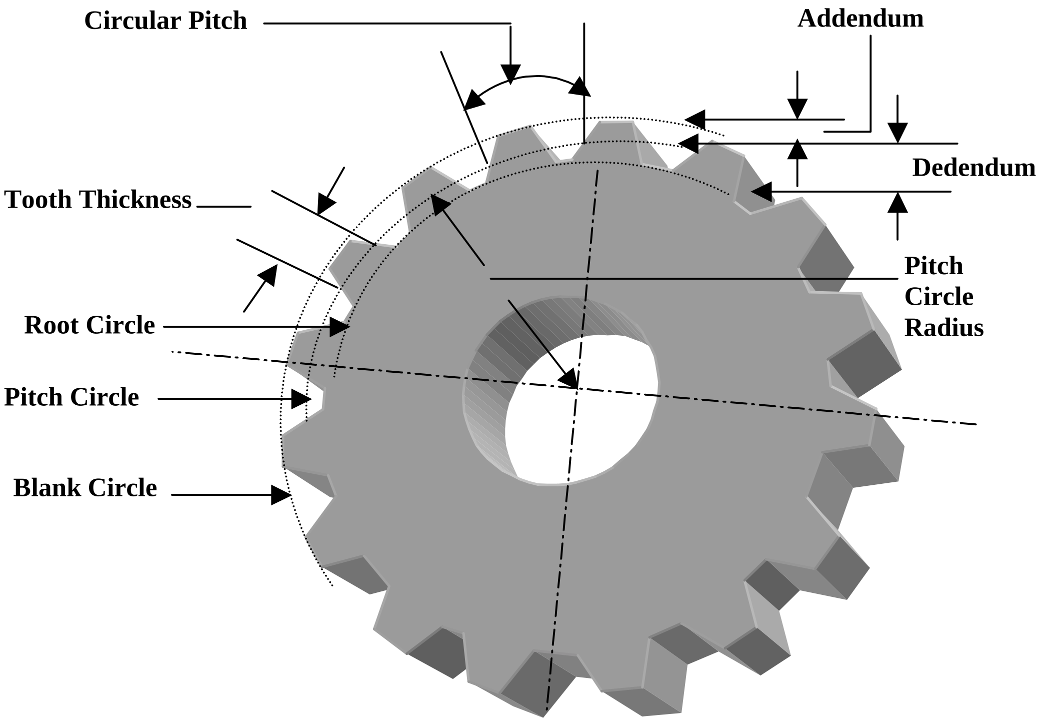

Fig. 1 Gear Tooth Nomenclature

For the measurement of the important tooth elements by computer vision based image processing system, if only the blank diameter and the number of teeth of the gear could be found out, then all the other dimensions could easily be calculated based on these two estimations and from the relations as already mentioned in this paper.

Determination Of The Blank Diameter And Number Of Teeth

Blank diameter would be the longest possible diameter considering all the points on the profile of the gear. To find the longest possible diameter, the image of the gear has to be processed following a number of steps, e.g., (i) the ordered sequence of the coordinates of all the profile points have to be found out [Rosenfeld and Kak, 1976 and Gongalez and Woods, 1993], (ii) the centroid of the profile points has to be estimated, (iii) the distances of the profile points from the centroid have to be found out and (iv) the maximum of these distances has to be computed. The double of this distance would correspond to the addendum diameter or the blank diameter of the gear.

The number of points on the image of the gear profile whose distance from the centroid would be the local maxima would give the number of teeth (N) for that gear.

PLAN FOR SCREW-THREAD INSPECTION

For measurement of the important thread elements and dimensional analysis, a magnified view of the image of the thread profile has been considered for processing and to get the exact dimensions, after processing, the dimensions have to be reduced by the same factor as those had been magnified before processing. The different elements as considered for the inspection have been the (i) pitch of the screw thread, (ii) depth of the screw thread, (iii) thread angle, (iv) flank angle, (v) root truncation and (vi) angular depth. Different thread elements have been highlighted in Fig. 2

For the purpose of processing for dimensional analysis, the image of the screw thread has been threshold by making the image black against the white background. The top leftmost point has been found out, then the image has been scanned until a white pixel would be detected. The midpoint of already traced black points has been found out which would correspond to the crest c_1. Then, the next crest has been found out in a similar way by scanning horizontally rightward until another black pixel has been detected and it would correspond to the crest c_2. The distance between c_1 and c_2 would be the pitch (P). Then, straight lines have been fitted through the straight portions $\mathbf{S_1}$ and $\mathbf{S_2}$ of the thread allowing them to intersect at a point 'r' as shown in the fig 2. Let, the slope of the straight line S_1 be m_1 and that of straight line S_2 be m_2. Then by the relation,

$$\theta = \tan^{-1}\frac{m_2 - m_1}{1 + m_1 m_2} \qquad (1)$$

the acute angle between $S_1$and S_2 has been found out. The value of θ would represent the thread angle. Therefore, the flank angle would be θ / 2. The midpoint of c_1 and c_2, i. e., c has to be determined and c_1c=pitch / 2. From c the image has been scanned vertically downward until a black pixel has been traced.

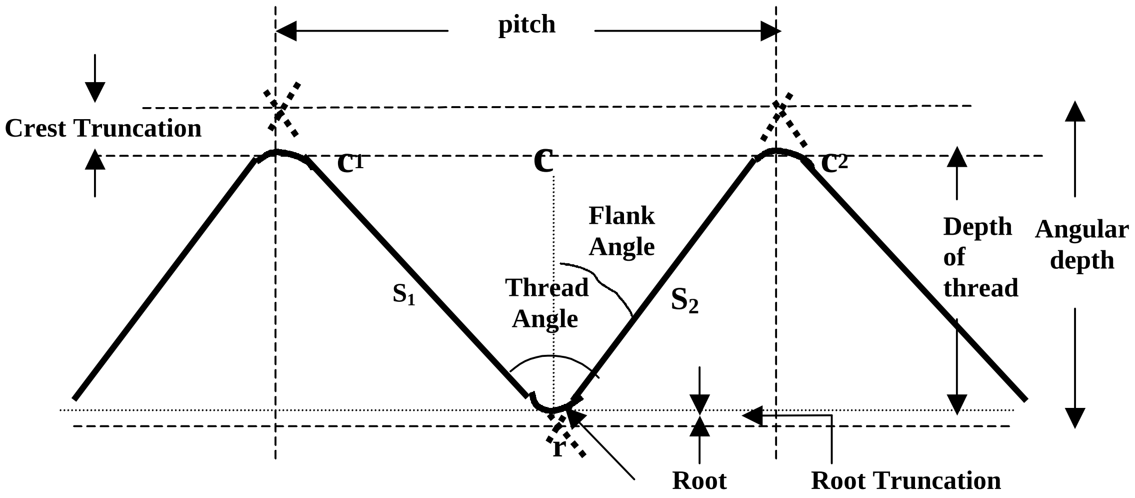

Fig.2 Different Thread Elements

The distance between this black pixel and c has been the depth of the thread. A straight line has been fitted through c and this black pixel. As r has already been determined, therefore, the distance rc can also be computed. The crest truncation can be determined by the following expression.

$$\text{Crest Truncation} = \frac{P/2 - rc\tan\frac{\theta}{2}}{\tan\frac{\theta}{2}} \qquad (2)$$

Again, Root Truncation = rc- Depth of thread. (3)
and Angular Depth = Crest Truncation +Depth of thread + Root Truncation . (4)

In the recognition part of this inspection plan, four different types of screw threads have been considered as follows:

(i) If a thread has D=(0.5 x P) ± tolerance, (where D is the P.C.D. and P is the pitch) and if in the pitch, the number of white pixels in a sequence would be equal to the number of black pixels in a sequence ± tolerance, then it would be a square thread.

(ii) If the thread angle has been 60º ± tolerance, then it would be an American screw thread.

(iii) If the thread angle has been 29º± tolerance and the depth has been (0.5 x P)± tolerance, then it would be an American Acme thread.

(iv.) If the thread angle has been 29º± tolerance and the depth has been (0.6866 x P) ± tolerance, then it would be a worm thread.

EXPERIMENTAL RESULTS FOR GEAR INSPECTION

With the help of the steps as already been described in the section for gear inspection of this paper, the addendum diameter and the number of gear teeth have been determined and represented in Table 1.With the help of the expressions as described in the plan for gear inspection of this paper, different dimensions of the gear have been determined both by the machine vision system and other measuring instruments and those have been compared through Table 2.

A comparative study of the machine vision data and data based on the variable type of measurement has been represented in Table 3. In this table, the percentage error has been defined as,

Percentage error=(Measured value- Value from machine vision)/ Measured value *100. (5)

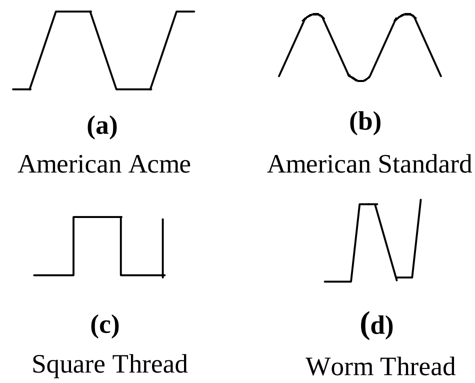

Fig.3 Screw Threads as Considered for Classification

EXPERIMENTAL RESULTS FOR THE INSPECTION OF SCREW THREADS

In this paper, four different types of screw threads have been considered for intelligent classification by the computer vision based inspection system. The screw threads as considered for classification based upon the measured parametric values and thread profiles have been as shown in Fig.3. Table 4 also shows the comparative results for various thread measurement parameters as obtained through the computer vision system and conventional measuring instruments.

CONCLUSION

Machine vision-based inspection of mechanical components has been a continually expanding area in the field of industrial inspection. In this paper, a machine vision based inspection system for mechanical components has been presented. Here, the three-dimensional mechanical components have been projected on the two-dimensional inspection plane and the recognition and analysis modules have been applied to these two-dimensional images. In this paper, machine vision algorithms have been developed using the relevant expressions for inspection of mechanical components. The inspection of two commonly used mechanical parts have been considered under the inspection plan. First, the inspection of spur gears has been considered and secondly, the inspection of screw threads has been taken into consideration. From the experimental results as obtained, it has been observed that high level of accuracy has been maintained for all the measured parameters of spur gear and screw threads.

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Table 1: **Experimental results for addendum diameter and number of teeth**

Gear	Addendum diameter by machine vision (mm)	Addendum diameter by Measurement (mm)	Relative error in %	Number of teeth by machine vision	Number of teeth by visual inspection
1	78.88	78.90	0.025	30	30
2	78.88	79.00	0.152	32	32

Table 2: Dimensional analysis for gear

Gear	Module (m) by machine vision	Module (m) by measu-rement	P.C.D. (D) by machine vision	P.C.D. (D) by measu-rement	Circular pitch by machine vision	Circular pitch by measu-rement	Outside diameter by machine vision	Outside diameter by measu-rement	Tooth thickness by machine vision	Tooth thickness by measu-rement	Base circle diameter by machine vision	Base circle diameter by measu-rement
1	2.46	2.465	73.95	73.95	7.74	7.74	78.87	78.88	3.87	3.87	69.49	69.49
2	2.32	2.320	74.24	74.24	7.29	7.29	83.52	83.52	3.64	3.64	69.76	69.76

Table 3: **A comparative study of machine vision data and data based on variable type of measurement for gear**

Gear	Percentage error for module	Percentage error for P.C.D.	Percentage error for circular pitch	Percentage error for outside dia.	Percentage error for tooth thickness	Percentage error for base circle diameter
1	0.20	0	0	0.01	0	0
2	0	0	0	0	0	0

Table 4: Results as obtained from the inspection of the screw threads as shown in Fig 3.

Fig.	Pitch of screw thread by vision (mm)	Pitch of screw thread by measu-rement (mm)	Depth of screw thread by vision (mm)	Depth of screw thread by measu-rement (mm)	Thread angle by vision (^{0})	Thread angle by measu-rement (^{0})	Flank angle by vision (^{0})	Flank angle by measu-rement (^{0})	Root Trunc-ation by vision	Root Trunc-ation by measu-rement (mm)	Angular depth by vision (mm)	Angular depth by measu-rement (mm)	Type Of Thread
(a)	1.512	1.60	0.756	0.800	28.75	29.00	14.38	14.50	2.777	2.857	6.310	6.513	American Acme
(b)	1.563	1.560	1.156	1.120	59.57	60.00	29.79	30.00	0.213	0.220	1.583	1.560	American Standard
(c)	1.536	1.600	0.768	0.800									Square Thread
(d)	1.536	1.600	1.055	1.099	28.51	29.00	14.26	14.50	1.028	0.959	3.111	3.016	Worm Thread