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A Web-based on-machine mould matching and measurement system based on CAD/CAM/CAI integration*

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Abstract: The purpose of this study is to develop a Web-based on-machine mould identification and measurement system. The Web-based mould identification system matches obtained vision information with CAD database. Developed Web-based system is to exchange messages between a server and a client by making of ActiveX control, and the result of mould identification is shown on Web-browser at remote site. For effective feature classification and extraction, the signature method is used to make meaningful information from obtained image data. For on-machine measurement of the matched mould, inspection database is constructed from CAD database using developed inspection planning methods. The results are simulated and analyzed using developed system to verify the effectiveness of the proposed methods.

Key words: E-manufacturing, CAD/CAM/CAI integration, On-machine measurement, Mould identification, Vision system
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INTRODUCTION

Today, the manufacturing industry makes constant effort in order to construct an E-manufacturing system using information technology for effective production control, and then, it offers the integrated production control to the workers, the production managers, and the consumers, etc. (Lee, 2003; Choi, 2004). In the mould manufacturing industry, the process managers often request paperwork to know the information of the processes on CNC machine tools or they visit the shop floor (Cho *et al*., 2003). Those ineffective activities cause the worker's complain, the delay of the processes, and the quality problems. Even the point of production control using the bar code technique also burdens the worker on the shop floor. Muto (2003) proposed the production control system by installing cameras on the shop floor, but, it only shows the machining status of machine tool. The detailed information cannot be acquired by his method. Though the reverse engineering system using 3D vision information can be used for the purpose, the amount of its data generated is too much to be dealt with in a real time Web-based system (Cho *et al*., 2000; Choi, 2003).

In the developed system of this research, a Web camera monitors the processing and takes an image of a machined mould, features are recognized from the image, and they are matched with the features which are acquired in CAD database, then, a mould can be identified. Using the system, the mould and its processing information can be shared with workers, the more appropriate decision making by the control manager is possible for the effective production, and the remote customer monitors the ordered mould parts visually through the Web.

After mould identification process is performed,

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on-machine measurement for the mould can be performed to check the accuracy of the machined parts by request from the remote site. For this purpose, inspection planning database is constructed for each mould from CAD database.

Each feature is decomposed into its constituent geometric elements such as plane, circle, etc. Then, a series of tasks are processed such as (1) suitable number of measuring points, (2) their locations, and (3) optimum probing path, to minimize measuring errors and times. Finally, the proposed methods are simulated using developed system to verify their effectiveness in real process. Fig.1 illustrates the proposed system in this research.

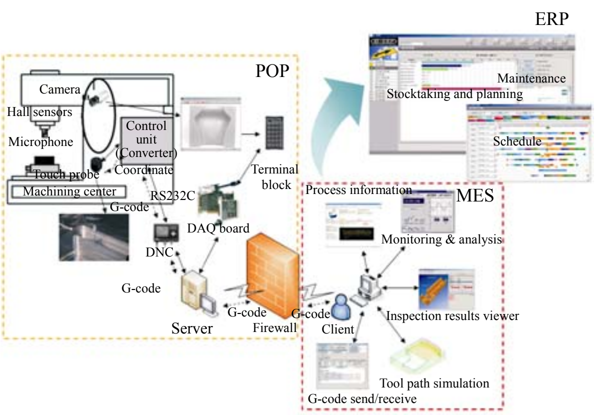


Fig.1 A Web-based mould identification and measurement system

FEATURE CLASSIFICAITON AND DATABASE CONSTRUCTION

Database for mould matching

The developed system in this research constructs a database for the 3D CAD model and matches the feature information from visual image with the database. The visual image represents the top view from the orthogonal direction on the partitioned surface of the mould cavity. The database is comprised of the top views of the CAD data files of the mould cavities. The geometrical object information is extracted using UG API, and it is stored in a database according to the predefined feature standards. The standard features have to be simply defined geometrically in visual images and acquired in a CAD data file conveniently. The structure is represented in Fig.2. The information of its area, perimeter and the coordinates of the center are used in order to differentiate each geometric object in feature.

The structure of the database is constructed as an MDB (Manufacturing Database) in Fig.3. It consists of a main DB and its sub-DBs corresponding to moulds respectively. The types of the feature and their numbers are stored in the main DB. If the combination of the features of a mould is very different from that of the target mould, it would be ignored. The sub-DBs consist of the information of the area, perimeter and the coordinates of the center, and are used to match the candidate moulds selected using the main DB with the target mould. The matching process with the feature information from the visual image is performed using SQL.

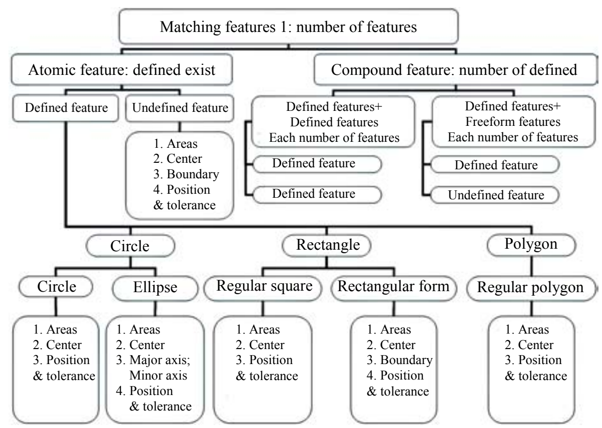


Fig.2 Classification of the matching features

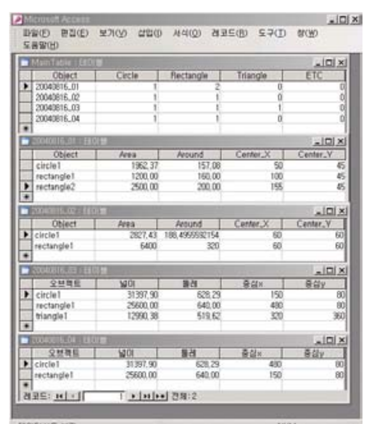


Fig.3 Structure of a database for mould matching

Database for OMM

For the measuring process using OMM, a touch-type probe is generally used, which performs point-to-point motions to get dimensional data of the target surface, usually one point at a time (Cho and

Seo, 2002). Although the target workpiece is very complicated and has many machining features, it is composed of many geometric primitives such as planes, cylinders, and sculptured surfaces, etc. as shown in Fig.4 (Cho and Kim, 1995; Cho *et al*., 1995; Mäntylä *et al*., 1994; Rogers, 1994). Also, when using a touch type probe, the probe repeats identical point-to-point motions to get point data of the primitives. The geometric tolerance evaluation, such as parallelism, squareness, etc., can be determined by manipulating the obtained point data set. Thus, it is necessary to decompose the features into easy-to-handle primitives for effective inspection planning (Chang and Wysk, 1985).

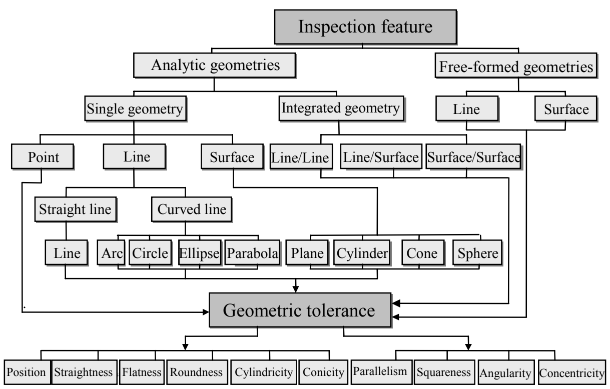


Fig.4 Geometric feature classification for OMM process decomposed features

As shown in Fig.5, the feature decomposition procedure is composed of two steps: decomposition into (1) inspection features and (2) primitives for local inspection planning. In the first step of the decomposition into inspection features, the object is decomposed into the features for inspection such as pockets, planes and islands, etc. (Fig.5a). In this step, the decomposed features are very similar to machining features. As shown in Fig.5b, the features obtained form the first step can be decomposed into the geometric primitives such as planes, cylinders, etc. Since the inspection process using OMM with a touch-type probe performs point-to-point motions to get the dimensional data of the target surface, such decomposition process makes it easier to build an inspection plan for complicated objects.

MOULD IDENTIFICATION SYSTEM

Web-based matching system

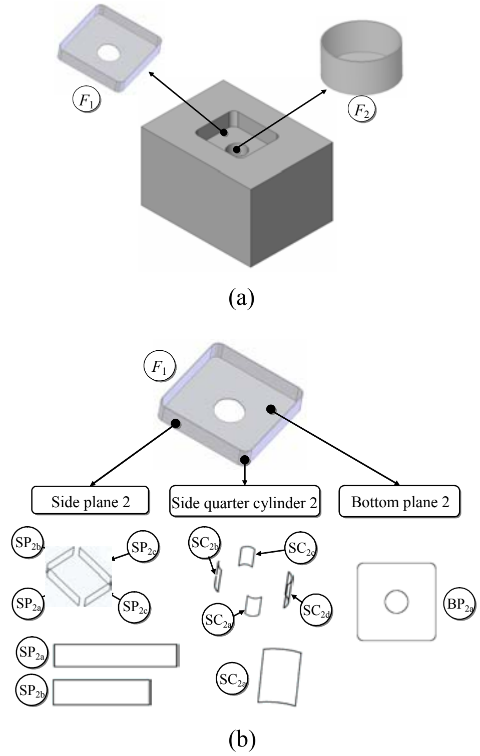


Fig.5 Decomposition of features for inspection
(a) Step 1: Decomposition into inspection features; (b) Step 2: Decomposition into primitive

A Web server and client system is constructed for this research, and the socket communication is implemented for the effective message exchange between the server and the client (Jung *et al*., 2001). An ActiveX control is made using VC++ for the smooth and prompt connection with the server and the mutual communication; it is downloaded automatically to the first connected client.

The socket communication carries out the following three events for the mould identification request as shown in Fig.6. First, the client requests the server to send the image by the Web camera installed on the machine. After the server sends the requested image stored in it, the client displays the image on the client program made of ActiveX. Second, the coordinates of the cropped portion by the client are sent to the server. The server performs the image processing of the vision system in the cropped image by the Web camera using the received coordinates, and then, feature information is created. The feature information is matched with the database constructed using UG-API, and the most similar mould is selected. Third, the server sends out the information of the selected mould, and the client displays the information. Then, the socket communication ends.

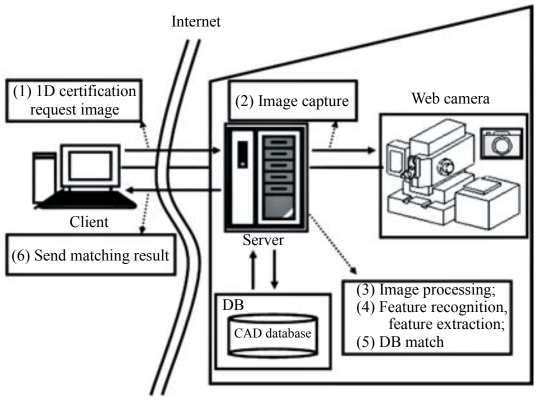
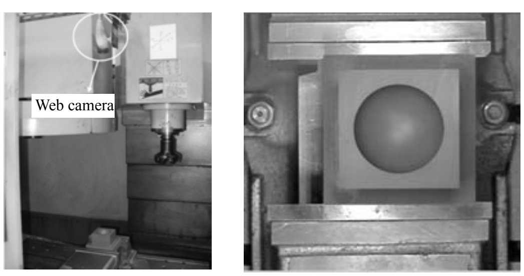


Fig.6 Proposed Web-based matching system

Vision system and image processing

The visual image for the mould matching is shown in Fig.7. The edge detection algorithm and the edge slimming operation are applied to the smoothed and enhanced image to acquire the feature information. If the length of the perimeter of a feature exceeds a predetermined value, the feature is excluded. The signature method (Ahn and Cho, 1996) which calculates the centroid of a feature and the distance to the edge from the centroid is used to calculate the coordinates of the center, the length of the perimeter, and the area.



(a) (b)

Fig.7 Vision system setup. (a) Initial setting; (b) Captured image

The matching process of the image data acquired by the vision system and the database is shown in Fig.8. In the process, because 3D image requires much more calculation than 2D image, the 2D image is used for the image acquisition and processing. Preprocessing including the cleaning process for noise reduction is performed on the 2D image by the Web camera, and the essential information is acquired for the predetermined features. The high pass filter, low pass filter, blurring filter, median filter, and the histogram equalizer are used for the pre-processing; the blurring filter; the combination of binary processing; the combination of dilation and erosion techniques are used for the cleaning process.

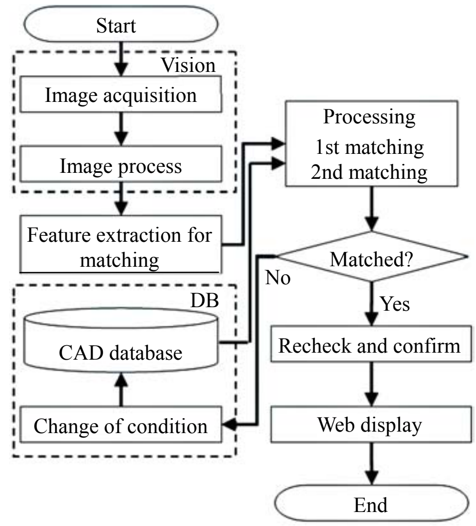


Fig.8 Flowchart of the vision system

The extracted feature information is used for the two stage matching processes with the CAD database. The corresponding mould is selected and the extracted features are compared in detail to confirm as the target mould. Because this process relies on matching, not the dimensional information, the result can be obtained rapidly and easily using the feature information of low precision level.

The signature method can represent the information of the 2D boundary points as 1D functions as shown in Fig.9. It plots the distance to the boundary from the centroid, then, it can describe the characteristics of a geometrical figure. In this study, the 2D boundary information is represented as the 1D information for each predefined feature. The degree of an angle is represented as θ and the distance to the boundary from the centroid is represented as $r(\theta)$. The points where the differentiation of $r(\theta)$ changes from a positive value to a negative one are detected and they are represented as the vertices. The feature can be recognized by the vertices information.

Experiments for mould matching

Four mould samples are manufactured to verify

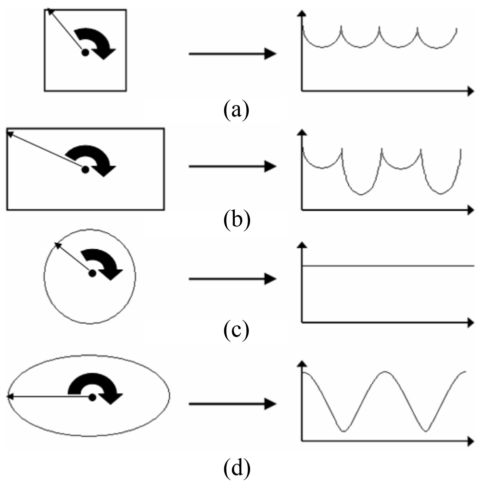
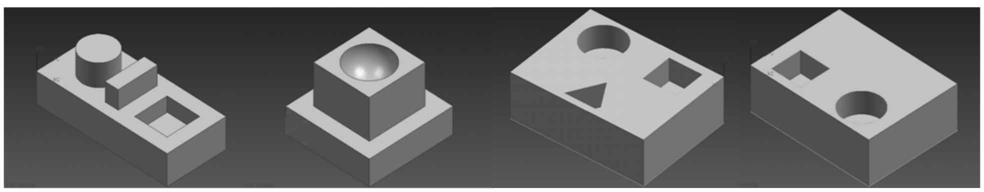


Fig.9 Graph of the signature method
(a) Regular square; (b) Rectangle; (c) Circle; (d) Ellipse

the developed system as shown in Fig.10. The feature information captured and processed by the vision system is shown in Fig.11.

The 2D feature information extracted from the 3D CAD data file is stored in a database. The developed mould identification is applied to the moulds in Figs.10a and 10b, and the result is as follows.

The matching process of the mould in the Fig.10a with the main DB is comprised of the search of the feature pattern in the database corresponding to one circle and two rectangles. The outermost rectangle is ignored. The search result is found and it is DB1 only, then, it is finally rechecked using the feature information in the sub-DB. But in this process, the exact coincidence value may not be acquired because

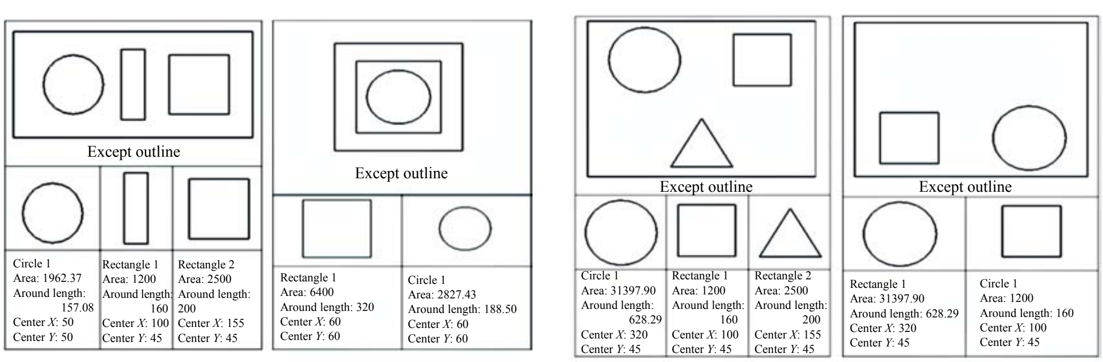


(a) (b) (c) (d)

Fig.10 Mould samples. (a) Model A; (b) Model B; (c) Model C; (d) Model D

Table 1 Recheck result of Fig.10a

	Area			Area ratio		
	Circle 1	Rect 1	Rect 2	C1/R1	C1/R2	R1/R2
Experiment	8237	5082	9091	1.620819	0.90606	0.55901
DB 1	1962.37	1200	2500	1.635308	0.78495	0.48000
Recheck (%)				99.113990	115.42900	116.46100
	Length			Length ratio		
	Circle 1	Rect 1	Rect 2	C1/R1	C1/R2	R1/R2
Experiment	338.3	326.7	378.5	1.03551	0.89379	0.86314
DB 1	157.08	160	200	0.98175	0.78540	0.80000
Recheck (%)				105.47600	113.80100	107.89300



(a) (b) (c) (d)

Fig.11 Classification of features for matching. (a) Model A; (b) Model B; (c) Model C; (d) Model D

the lack of the information of the height of each object and the height of the camera. The ratio of the features is used in this research to avoid the problem. The ratio of two geometrical objects is calculated and the approximately matched features with the ratio are looked for. Shown in Table 1, the ratios of the area and the perimeter of features are represented in percentage, and the recheck values are calculated by comparing the results of experiments and the values in the database.

In the case of the mould in Fig.10b, the feature pattern comprised of one circle and two rectangles is searched in the database. DB2 and DB4 are matched at first, and they are rechecked using the sub-DBs. Each of them has its own object in the sub-DB, and it is matched with the feature information of the visual image.

The ratios of the area and the perimeter of two objects of the visual images are shown in Tables 2 and 3. In Table 2 for the area ratio, the ratios of Circle 1 and Rect 1 are 0.45 in the experiment, 0.44 in DB2, and 1.23 in DB4. Based on the recheck values of the ratio of the ratios, the DB2 of 102.2% is far more coincident than the DB4 of 36.0%. In Table 3 for the perimeter length ratio, the ratios of Circle 1 and Rect 1 are 0.63 in the image, 0.59 in DB2 and 0.98 in DB4. Based on the recheck values, the DB2 of 106.7% is far more coincident than the DB4 of 60.0%. Therefore, it can be concluded that DB2 is the matched mould because of the higher coincident degrees.

Table 2 Area ratio of Fig.10b

	Circle 1	Rect 1	Ratio	Ratio of ratio (%)
Experiment	21996.50	48709	0.451590055	–
DB2	2827.43	6400	0.441785938	102.219201
DB4	31397.90	25600	1.226480469	36.020626

Table 3 Perimeter length ratio of Fig.10b

	Circle 1	Rect 1	Ratio	Ratio of ratio (%)
Experiment	554.600	882.5	0.628441926	–
DB2	188.496	320.0	0.589050000	106.6873654
DB4	628.290	640.0	0.981703125	60.00286492

Fig.12 is the Web display of the client after the mould identification. Then, the various mould information is supplied to the user and the matching process ends successfully.

Fig.12 Result of the matching process

ON-MACHINE MEASUREMENT

After mould identification process is done, OMM process can be performed by request from remote site. The OMM is carried out using pre-defined inspection planning database. This inspection planning database includes necessary inspection parameters such as the suitable number of measuring points for each surface, the optimum locations of the points, and the probing path to minimize the total inspection time.

Number of measuring points

The reliability of measured results using the OMM strongly depends on the number of sampling points (Caskey *et al*., 1990). More reliable results can be achieved as the number of measuring point increases. However, since the increase of the number of measuring points usually requires more measuring time, optimum number of measuring points has to be determined for each feature by considering tolerance levels, geometric characteristics and desired confidence levels. In this research, a fuzzy system is applied to optimize the number of measuring points as shown in Fig.13. In this system, the surface area of the target surface, the degree of design tolerance and the volumetric error of the machine tool are used as input parameters.

Measuring point locations

In this research, Hammersley's algorithm is applied to determine the locations since it can achieve the nearly quadratic reduction of measuring points to satisfy the equal level of measuring accuracy compared to the equi-interval sampling method (Lee *et al*., 1997; Woo and Liang, 1993).

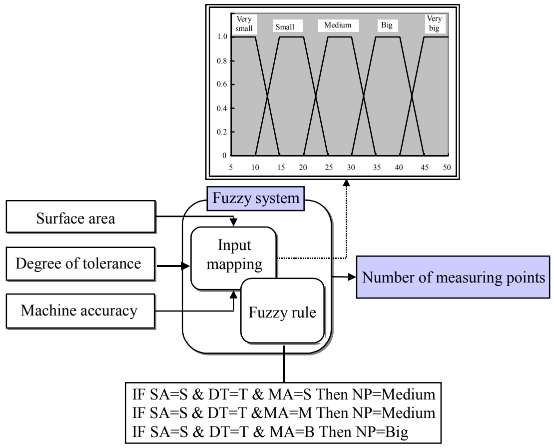


Fig.13 Fuzzy system to determine the number of measuring points

Since the decomposed primitives may contain holes, slots and/or pockets, the measuring point locations obtained by applying the Hammersley's method onto the surface should be relocated. An example of non-contacting point relocation result is shown in Fig.14.

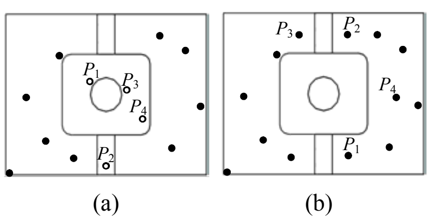


Fig.14 An example of non-contacting points relocation
(a) Before relocation; (b) After relocation

Measuring sequence

Since the measuring process uses a touch-type probe as a discrete type measurement, the measuring order of the points does not affect the inspection results. However, if the probe moves randomly between the measuring points, it may take an inefficient duration of time to inspect the entire surface. Thus, the measuring order of the points has to be determined to minimize total inspection time. In this research, the TSP (travelling salesperson problem) algorithm based on the simulated annealing method is implemented to generate the probe path between the measuring points (Lee *et al*., 1994) as shown in Fig.15.

Simulation results

Simulation works are performed to verify the effectiveness of the proposed feature-based inspection planning method. The simulated result for the example part considering each machining step, including measuring point locations and probing paths, is shown in Fig.16.

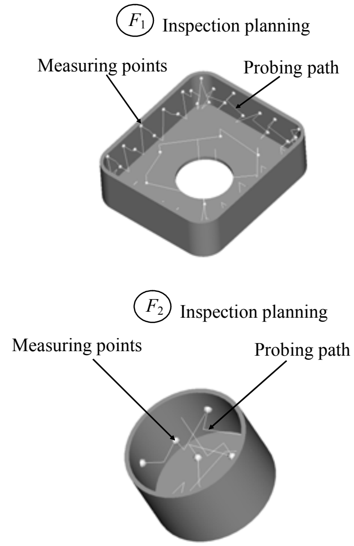


Fig.15 Generated probe path for inspection feature

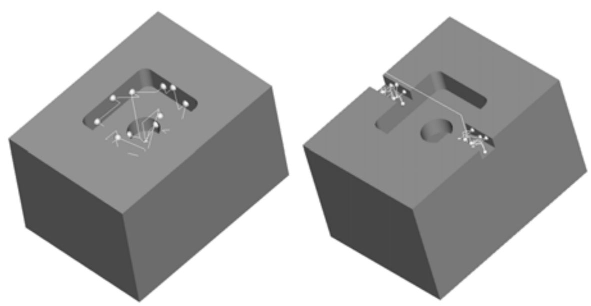


Fig.16 Inspection planning results for the example part

CONCLUSION

A on-machine mould matching and measurement system is constructed in this research by developing the Web-based system, the vision processes, the feature recognition and classification method, the databases, and the matching algorithm for the application on the shop floor of the mould manufacturing industry. The developed system is easily applicable to the actual production to monitor, track, and make decisions in the mould manufacturing processes. The results and conclusions acquired by the experiments are as follows:

(1) The features and their characteristics are classified in the CAD database for the use in the mould identification, and the result is stored in a database. The developed Web-based mould identification system carries out the matching between the information acquired from the visual image and the database.

(2) The system uses 2D image information, with fast processing and is suitable for a Web-based system; in addition, the remote monitoring and the control of the mould identification process are effective.

(3) The matching technique is devised and verified in experiments. It can be used in general for common moulds to the extent that the distortion of the camera-taken image and the difference of the mould heights are not serious.

(4) Efficient OMM planning methods are suggested including a series of tasks such as suitable number of measuring points, their locations, and optimum probing paths to minimize measuring errors and times.

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