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TOWARDS AUTOMATED CAPTURING OF CMM INSPECTION STRATEGIES

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Abstract: *In product quality testing, many systems for automated CMM inspection planning have been developed; most being in the form of expert systems using knowledge bases and rules extracted from documentation such as handbooks and manuals. However, in these studies, there is no explicitly formalized methodology on how to prepare CMM measurements, to help human planners to produce new inspection plans. Current systems are not capable of quickly and accurately capturing the expertise of experienced CMM programmers performing inspection planning and, consequently, the expert knowledge implied in these plans is lost. This work proposes a tool for capturing inspection strategies along with the knowledge generated by CMM programmers. Preliminary results from pilot studies are presented showing the benefits of such a methodology. The strategies captured could potentially be used in future inspection planner training or for automated CMM/robotic inspection programming, while the captured knowledge could be embedded in CAD-systems design-for-inspection routines.*

Key words: *CMM, Measurement strategies, Inspection planning, Knowledge capture.*

1. Introduction

Coordinate Metrology and Coordinate Measuring Machines (CMMs) are widely used to test product conformance to design intent. The concept of Computer Aided Inspection Planning (CAIP) has been developed to support engineers in planning measurements and generate CMM part programs. An extended range of CAIP systems has been proposed to facilitate the development of inspection plans [1]. While these systems use explicit knowledge, reported in documentation such as manuals and practical guides, they lack the rationale and expertise of the human planner. Also, there are no formal methods outlined in the literature for capturing, either manually or automatically, a CMM programmer's decision making process. Thus, the crucial thought process and rationale followed are lost which, if captured, could be reused in future either for the creation of new inspection plans or for training purposes. In this study a system for the automated capture of CMM inspection planning is proposed. A technical description and two pilot studies are presented in the following

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sections. The strategies captured can potentially be used for novice CMM operator training or automated CMM and robotic measurement programs.

2. State of the art

Attempts have been made at extracting human expertise for CMM inspection planning programming using manual methods. In [2] an informal model is structured for the development of a knowledge-based system. The MOKA methodology (**M**ethodology and tools **O**riented to **K**nowledge based engineering **A**pplications) was used to develop an IDEF0 ontology using extracted knowledge. This was extracted by interviewing CMM experts and analyzing technical documents (handbooks and manuals). Such manual knowledge elicitation techniques require too much time [3], while knowledge quality depends on subject-experts' capability to express their decision making clearly [4].

Barreiro et al. [5] proposed an ontology developed by an extension of MOKA to identify and represent inspection planning knowledge in the form of IDEF0 diagrams. This study is limited to knowledge capture from documents. Similar approaches are also applied to a series of related studies [6-8].

Alvarez et al. [9]aiming to extract inspection planning expertise and build decision rules for optimal CMM probing strategies, used a data mining tool PCPACK from documentation without any involvement of CMM programmers. As a consequence, the knowledge elicited does not include the human thought process for measurement planning.

In [10][11] the authors have formulated an ontology, aiming to build a knowledge base for an intelligent CMM inspection planning system. Similarly, in [12][13] the development of a knowledge base model for the inspection planning of prismatic parts is presented. However, in these works it is not stated what is the source of the knowledge captured or how this was acquired and modelled as presented into a knowledge base.

In the abovementioned papers, it can be seen that there is no known methodology or system for a quick and effective way to capture human expertise and rationale in the domain of inspection planning for CMMs. However, the existing literature indicate there are many techniques developed facilitating the capture of human expertise and engineering knowledge generated during the product life cycle [14] in order to be formalized in explicit forms for rapidly and effectively sharing and reuse.

From this review, there are two major technological gaps: (i) a lack of a methodology related to how implicit expert knowledge can be captured; (ii) a lack of an approach for formalizing human expertise and rationale captured for share and reuse purposes rapidly and more effectively. In this research the major aim is to present a methodology for direct expertise and rationale elicitation for CMM inspection planning strategies.

3. Proposed Methodology

To try and capture the process of inspection planning for CMMs a methodology has been proposed based on motion study-analysis. It has been shown previously [15] that this approach can be applied for the effective analysis of captured expertise. The decision making for a measurement strategy involves the thought process of a CMM programmer while observing the workpiece's geometry and tolerance specifications annotated on the drawing. This thought process is demonstrated through the actual task performing instead of being expressed verbally or scripted by the user. An effective way to capture the sequence of actions in the planning process is the utilisation of a motion capture system. Considering that the stylus moves around a workpiece simulate the motion of a real CMM stylus during a measurement task, a measurement planning process can be logged and stored. In the data logged, the expertôs tacit knowledge generated during the task is embedded and it can potentially be post-processed and structured in different representations for a range of applications depending on its use such as training, generation and comparison of alternative inspection strategies or even direct CMM programming. In this pilot study the data logged are structured in the format of chronocyclegraphs as this type of representation allows effective user actions interpretation for decision making analysis, knowledge capture and formalisation in engineering manufacture tasks [16].

3.1. System Description

The configuration of the motion capture system used (Figure 1) includes:

- A set of 12 infrared cameras (Res.: 1280 × 1024, frame rate: 30-120 FPS) [17].
- A set of retro-reflective markers placed on the stylus used to simulate the real inspection stylus.
- MOTIVE software package for data motion capture and post-processing.

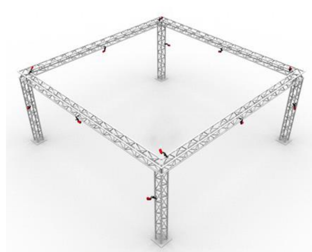


Fig. 1. Configuration of capture volume

The system is based on the detection of infrared light reflections (by the retro-reflective material on the markers). In cases where the stylus would have to touch internal features (Figure 2) which may be out of a cameraôs range of view, e.g. narrow or deep holes, the marker on the stylus-tip could not be detected by the cameras. To overcome this problem, a mathematical reconstruction of the non-detected markerôs 3D coordinates was employed using the coordinates of two other detectable markers located at known distances on the stylus.

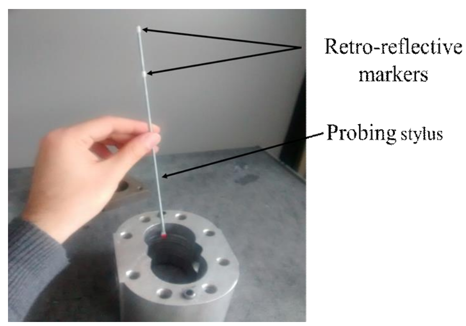


Fig. 2. Measuring an internal feature

3.2. Captured Strategy Analysis

The objective of the proposed methodology is to capture, analyse and identify the sequence of activities during the task of CMM inspection planning and consequently interpret the implied decision making of a CMM programmer. To meet this goal, a measurement planning strategy has to be processed in two planning stages: i) strategic and ii) tactical. In the former, an inspection planner makes decisions considering the whole geometry of the component [18]. Thus relative considerations to activities involved are:

- part orientation,
- stylus configuration/orientation,
- features grouping,
- features sequencing

In the tactical stage, local geometries, interactions between features and design specification should be considered for each feature selected for inspection [18]. The relative activities are:

- datum features used for each feature inspection,
- number and distribution of probing points,
- probing path on each feature

This kind of classification enables a detailed recognition and characterisation of actions for each step during a CMM measurement planning task.

4. Results and Discussion

To demonstrate the capabilities and potential of the system, two pilot studies were conducted with two components as shown in Figure 3.

Fig. 3. Pilot studies components

For the purpose of this study, only some key features were involved in the inspection planning scenarios. As shown, the total captured inspection paths are depicted for each of the selected parts. To analyse more effectively the planning strategies, the paths have been split into segments for better illustration.

4.1. Pilot Study 1: Prismatic part

In the first case a prismatic part is used as the object under inspection. Figure 4 shows the probing path for the definition of the part's coordinate system virtually aligned on the CMM table, as the typical first activity of an inspection strategy. For this step the top face is probed with 3 points to define the Z zero plane. On the front face two points are probed to construct a line and define X zero plane, perpendicular to Z plane. Finally, on the left face a point is probed to define Y zero plane, perpendicular to two previous planes. This constitutes the quickest and easiest way to align a part – known as 3-2-1 method or plane-line-point.

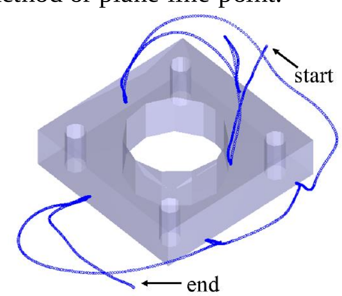


Fig. 4. Part alignment - probing path

In Figure 5 the whole inspection path is presented, followed by figures with the path segments for each sub-activity (Figures 6-9).

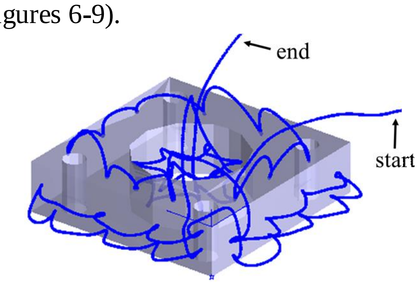


Fig. 5. Total probing path

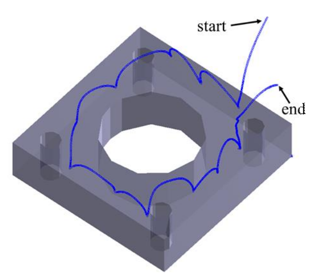


Fig. 6. Probing path – datum top face

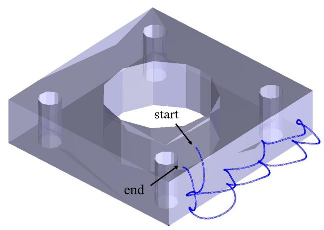


Fig. 7. Probing path – datum front face

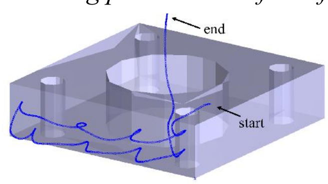


Fig. 8. Probing path – datum left face

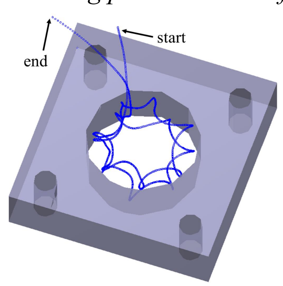
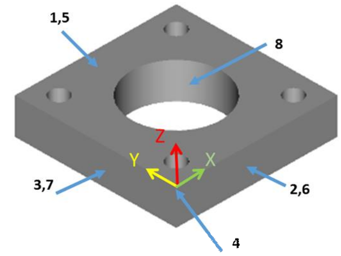


Fig. 9. Probing path – central bore

From the chronocyclegraphs, as strategic planning information, the sequence of features inspected (Figure 10) is extracted, as well as details of the tactical planning such as: the number of points and the type of distribution (Table 1).



1. Probing top face
2. Probing front face
3. Probing left face
4. Part alignment
5. Probing datum feature top face
6. Probing datum feature front face
7. Probing datum feature left face
8. Probing feature central hole

Fig. 10. Strategic plan – features sequence

From the strategy captured it can be observed that in the part alignment step, the features are probed with the minimum number of points so that the required substitute geometries are constructed (3 points for a plane, 2 for a line, 1 for a single point) while in the evaluation step where these features are probed as datums, more points are used.

Table 1, Interpretation of data to strategic and tactical planning activities

CSV data file	**Strategic**	**Tactical**			
	Actions sequence	**Feature**	**Points**	**Distribution**	**Use**
[40.13411,8.9139,21.80823] [68.69305,35.75986,22.02781] [32.64202,60.64999,22.08044]	Probing top face	Top face	3	Random, planar	Part align.
[59.31247,-7.28029,11.01693] [12.79093,-7.36034,10.90368]	Probing front face	Front face	2	Random, linear	Part align.
[-6.49211,37.6091,14.18235]	Probing left face	Left face	1	Random	Part align.
-	Part alignment	-	-	-	-
[20.75,6.33,17.75] [39.22,6.38,17.93] ...	Probing datum feature top face	Top face	12	Uniform	Datum
[4.75,-4.08,12.41] [25.69,-3.81,11.72]	Probing datum feature front face	Front face	8	Uniform	Datum
[-2.37,3.26,16.45] [-3.26,19.69,14.05] ...	Probing datum feature left face	Left face	8	Uniform	Datum
[39.37,19.52,12.59] [50.65,26.81,12.64] ...	Probing feature central hole	Central bore	14	Uniform, circular	Evaluation

4.2. Pilot Study 2: Elliptic part

In the second pilot study the chronocyclegraphs built, depict the general probing strategy followed with separate graphs for the path segments for each of the inspected features.

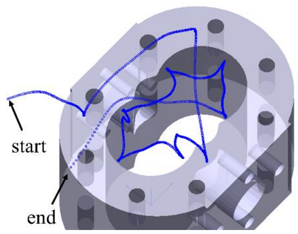


Fig. 11. Probing path – part alignment

Figure 11 above shows the part alignment method which includes probing of the top face to define the zero Z plane and two central circles (left and right). The centres of the two circles are used to construct a line and define Y axis origin and X zero plane, perpendicular to Z plane. The centre of the first circle probed is used as origin of X axis and Y zero plane, perpendicular to two previous planes.

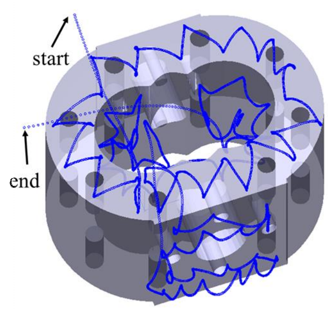


Fig. 12. Total probing path

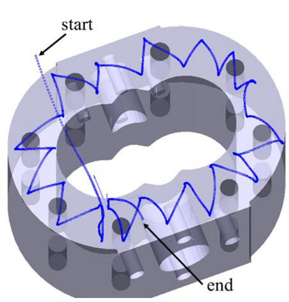


Fig. 13. Probing path - datum top face

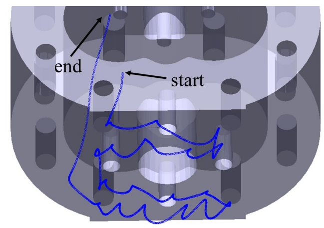


Fig. 14. Probing path - datum front face

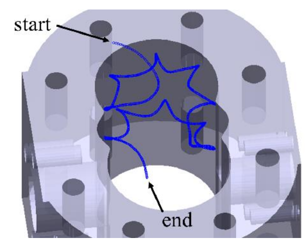


Fig. 15. Probing path - left central hole

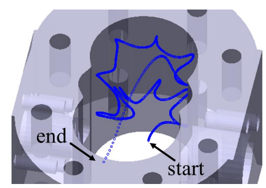
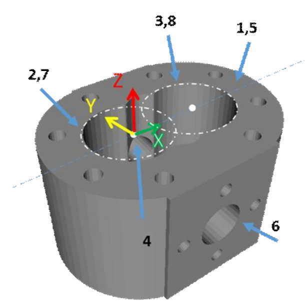


Fig. 16. Probing path - right central hole

Figures 12-16 show the stylus's path segments for the inspection of datums and the features to evaluate.



1.Probing top face
2.Probing left central circle
3.Probing right central circle
4.Part alignment/Coordinate System
5.Probing datum feature top face
6.Probing datum feature front face
7.Probing feature left central bore
8.Probing feature right central bore

Fig. 17. Strategic plan – features sequence

Table 2, Interpretation of data to strategic and tactical planning activities

CSV data file	**Strategic**	**Tactical**			
	Actions Sequence	**Feature**	**Points**	**Distribution**	**Use**
[-14.99,36.48,79.25] [66.31,25.29,78.65] [7.87,-33.99,79.75]	Probing top face	Top face	3	Random, planar	Part align.
[2.22,-21.56,73.85] [-21.71,5.45,74.05] [-2.76,18.64,73.75]	Probing left central circle	Left central circle	3	Uniform, circular	Part align.
[39.51,22.58,73.05] [64.84,2.44,74.55] [37.53,-22.12,72.35]	Probing right central circle	Right central circle	3	Uniform, circular	Part align.
-	Part alignment	-	-	-	-
[-20.03,-44.78,79.25] [-37.53,-28.34,79.25] ...	Probing datum feature top face	Top face	12	Uniform	Datum
[-4.65,-55.39,72.35] [10.93,-55.79,60.65] ...	Probing datum feature front face	Front face	8	Uniform	Datum
[4.65,-21.880,72.75] [-12.38,-17.60,73.45] ...	Probing feature left central bore	Left central bore	10	Uniform, cylindrical	Evaluation
[35.61,-22.28,70.75] [54.08,-21.30,70.75] ...	Probing feature right central bore	Right central bore	10	Uniform, cylindrical	Evaluation

Having captured the inspection planning process for the second component, the strategic and tactical planning details are provided in the Figure 17 and Table 2 respectively.

From the results and representations a difference in the probing strategies is apparent when a feature is inspected as a datum feature or part of the coordinate system. The same was observed in the first pilot study. Therefore it can be inferred that an important factor in the planning of probing strategy is how a feature is used, namely: in part alignment, as a datum feature and a feature to evaluate.

5. Conclusion

In this research a methodology for the quick and direct extraction of CMM measurement planning strategies is proposed. Two pilot studies were presented to prove the principles of the suggested technique and system. The strategies captured in each inspection scenario can be represented in a range of different forms (graphs, instructions, etc.) that can be used directly for training purposes or generation of new inspection plans. Additionally, new directions for further investigation have been identified. Firstly, how the use of a selected feature affects the planning of an inspection. Secondly, in the first pilot study one feature required inspection with 3 related datum features, while in the second, two features were to be inspected related to the same two datum features. In this aspect, relationships between the design specification and inspection complexity levels are uncovered, requiring more detailed study. In future studies the authors aim to address these issues.

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