AI techniques in the programming of coordinate measuring machines

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Abstract: *The paper describes an off-line programming system for coordinate measuring machines based on a novel approach relying on the application of AI techniques. Input data to the system is the geometric model produced by a CAD system. Using the picture of the part, the user can select the surface elements to be inspected. He or she has to provide the tolerance data as additional information. First the workpiece setup is decided: the position and orientation, the accessibility of the part is deteremined using accessibility information derived from the model. Next the system automatically generates an optimal distribution of the measuring points for the surfaces to be inspected and the local probepath. Probe clusters are built together on an interactive way using a set of building blocks. A time optimal sequence of the inspection operations is computed using a heuristic algorithms. At this stage all information needed for the CMM programme is available and will be combined in a device independent DMIS format, which in turn can be converted into equipment specific programmes.*

Keywords:CMM programming, AI techniques, feature recognition,

1 Introduction

Coordinate measuring machines have made a dramatic impact on inspection in the last ten years. Their ability to slash inspection times and costs, greatly improved measuring capability and accuracy has been the main reason for that. The effectivity of a coordinate measuring device depends to a large extent on the software provided: the programmes to control the machine and to evaluate measuring data and the software to support the programming of the inspection operations.

Achivements in the field of computer aided geometric modelling and the automatic derivation of NC programmes based on the model of the final workpiece's nominal geometry and the rough material, triggered a rather similar development in coordinate measurement. The problem here is more complex, because the computer has to recognise the socalled inspection features (for example internal or external cylindrical surfaces, paralell planes, etc.) before it can associate an inspection strategy to the surface(s), build up an appropriate probe cluster and generate the measuring motions based on lower level information.

2 The structure of the programming system

The functions, a programming system for coordinate measuring machines should full fill, are given figure 1. The first task is the selection of the features to be inspected. It is an interactive process performed through the use of a graphical interface. The user may select with the cursor one or more surface elements from the geometric model visualized and then chose from the context dependent menu offered by the system a tolerance type. Hereby he or she has defined an inspection feature.

The next step in the process is the selection of the most appropriate measuring machine from a given library. Using the main parameters of the workpiece constraints for the measuring machine are derived and these constrains are used in the selection. The final decision is taken on the base of cost function. This is followed by a setup procedure. The result are the positions and orientations needed to inspect the part and the corresponding transformation matrices wich establish the correspondence between the machine's and the part's coordinate system.

The next step is followed by the selection of the various components of the probe cluster(s) to be used in the inspection process. Herefore the parts in the library attached to the particular measuring machine are displayed and the user may select the necessary components and build up the cluster(s) by selecting and attaching the components to eachother. He is assisted in this job by a small scale expert system giving advices based on the constrains impossed by the workpiece. A motion cycle for calibration is attached to each probe. Their results are the correction values used in the calculation of the respective surface point. After all the preparatore steps are take the following function are performed:

- selection of the inspection strategy
- selection of the probe and accessibility control
- generation of the measuring motions (local paths)
- determination of the optimal global path
- visual collision check and simulation
- output of the programme in an intermediate format

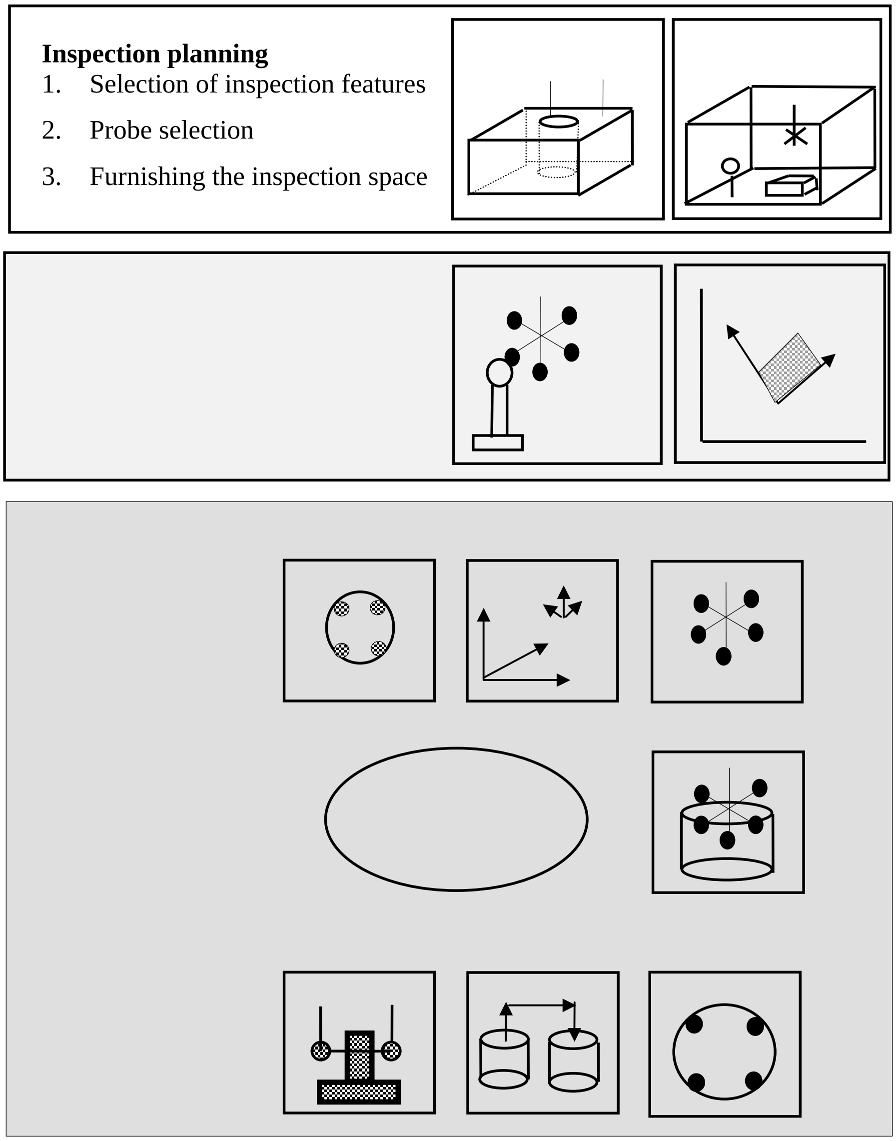

Fig.1 Functions of an off-line programming system for coordinate measuring machines

The workpiece model contains all the information relevante to the inspection as a subset: the macrogeometry of the part and the tolerances. Additional information needed for the definition of the inspection plan should be supplied by the programmer in an interactive session creating the socalled inspection features.

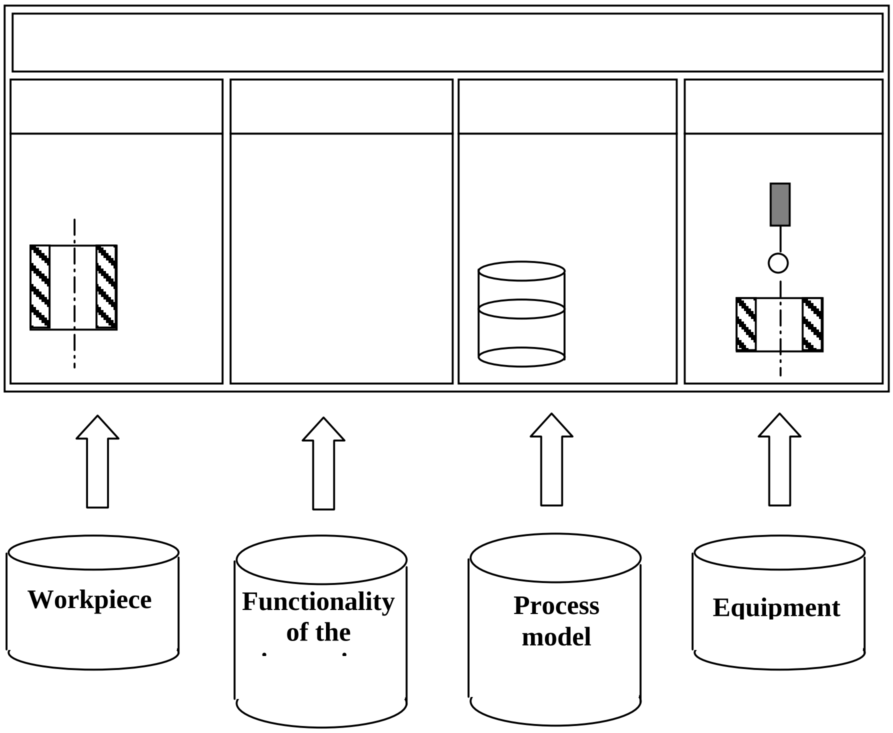

Fig. 2 The information flow and the contribution of
the different modells to the process

An inspection feature consists of one or more surface element, like a cylinder, plane face, circle, etc. their size or relative position to each other and the associated tolerance. In Fig. 3 a simple inspection feature is given.

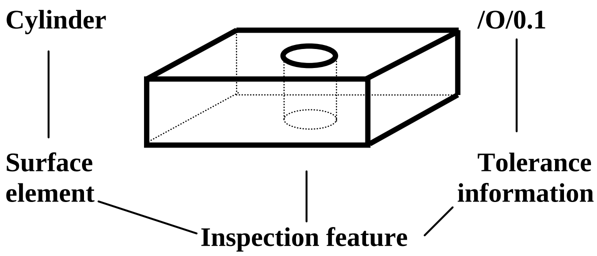

Fig. 3 A Simple inspection feature

3 The application of AI techniques

1.1 Setup procedure

The result of the setup procedure are the positions and orientations needed to inspect the part and the corresponding transformation matrices, which establish the correspondence between the machine's and the part's coordinate system.

The workpieces are categoriezed into:

- Single-sided 2.5 D
- Double-sided 2.5 D
- 3D
- five-sided and
- 5D part

depending on the number of approach directions needed to sense all surface elemets to be inspected. The determination of the group to which the workpiece in question belongs to a modified version of the algorithm developed by Murray and Yue is used. It is based on the direction of the surface normals and uses boolean operations between the different layers to detect overlap which results in a partly hidden face. The algorithm processes geometric models based on boundary representation.

1.2 Selection of the inspection strategy

The inspection process consists of two parts: the collection of surface point coordinate data from the geometric elements to be inspected and the evaluation of this data according to the prescribed tolerances.

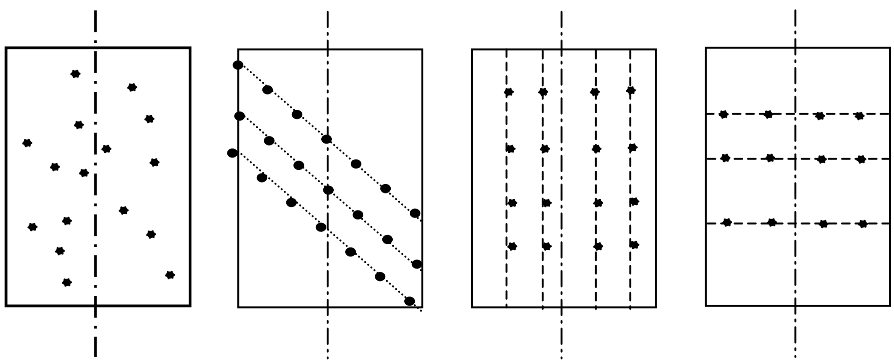

Fig. 4 A set of inspection strategies capturing extensive geometric information from a cylindrical surface

In order the collect the coordinate values the distribution of the measuring points on the surface, the corresponding sensing directions and the local measuring motions should be detemined. This set of information forms the inspection strategy.

As empirical investigations have shown when the inspection task is the determination of the distance between two boreholes then equidistant circles strategy provides the best results. The final selection depends on the surface- and tolerance type, the tolerance value and whether it is a basis or not. The decision is taken by a rule-based expert system, but the result might be overridden by the user. Plane faces are displayed one by one with the inspection points marked. Curved surfaces are first developed into the plane and then marked. If needed the user can modify the inspection points, delete some or insert new ones. Inspection feature taxonomy helps in the selection of the appropriate set of strategies.

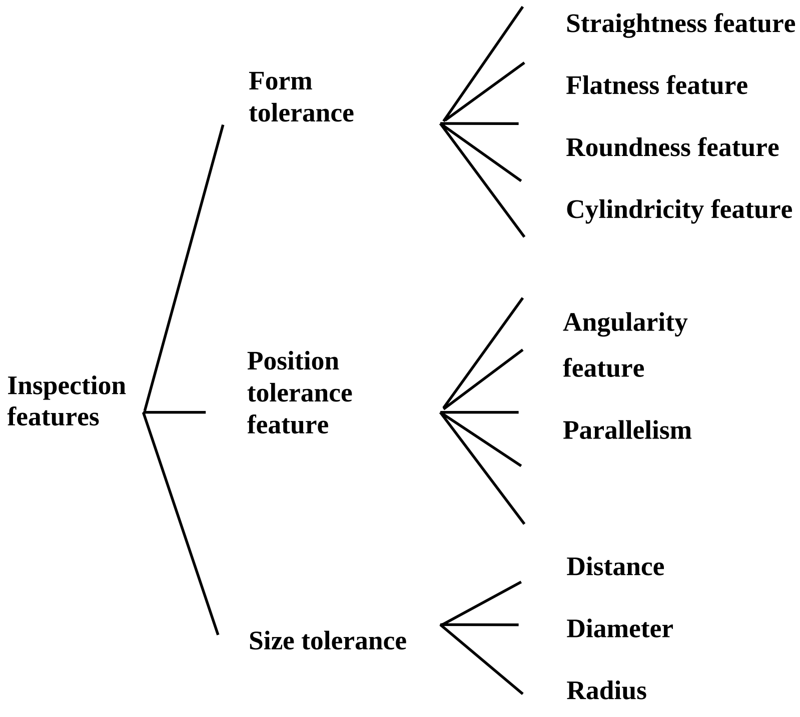

Fig. 5 Simplified inspection feature taxonomy

1.3 Accesibility of inspection features and probe selection

The optimal probe cluster is determined by the geometry of the inspection features. Our goal is to build clusters on such a way that the number of probes used for the inspection of the part remain minimal because probe change is a timeconsuming and costly operation. During the selection of the appropriate strategy the inspection points and the corresponding approach directions have been determined. Together with the constrains imposed by the surface elements they restrict our selection. First the distance between the inspection point and the closest surface point in the approach direction is determined by sending a ray from the inspection point into the approach direction and calculate the distance between the point of intersection of the ray and any surface element on the workpiece. This value is used later as a constrain together with others in the probetip selection.

On the next level these probetips are built together to form a cluster, which can be used to measure a number of inspection features. The building process is a manual one assisted by an advisory module.

1.4 Probe path generation

Probe path generation is multilevel process. As probe change is extremely timeconsuming compared with surface sensing in the first step the programme minimizes the number of probe changes by assigning those surface elements which can be inspected by the same probe to the same group. Then using either the socalled Manhatten or the Euclidian distance the programme tries to find a collision-free path close to the minimal one.

The task can be formulated on the following way: transform the a moving probe from it's current configuration to a specific end configuration using the following data:

- Geometric description of the measuring machine and the part in it's workspace
- The current configuration of the measuring machine and the workpiece and
- The desired final configuration

This step is performed by a heuristic algorithm. The following constrains shoul been taken into consideration:

- point belonging to the same inspection feature should be measured subsequently
- the inspection movements may not be modified, only the entry and exit point might be chosen freely

The notion of configuration is used here to refer to the combined position and orientation of the object to be inspected and the set of joint specifying the arrangements of the measuring machine. The geometric aspects of the path generation between to features can be formulated by the use of two fundamental spatial planning problem: Findspace and Findpath.

Findspace determines a safe configuration for the measuring machine in the workspace, that is a configuration where no inference with the part is detected. Findpath generates a path from starting to the final position on such a way that all configurations of the measuring head on the path are safe.

Once this has been done, the information generated by the computer upto this stage, describes every detail of the inspection program and it can be used to simulate the inspection process. The computer generates the measuring motions real time using either the wire-frame or the shaded picture model of the workpiece, measuring machine and the probe. The observer's position can be changed using soft keys on the screen. On this way the programmer may notice and can correct any mistakes done earlier in the programming process.

1.5 Conclusions

The results presented in this paper are part of a research program aimed at the developing an intelligent programming system for inspection planning on coordinate measuring machines. The aim was not to develop new techniques but to apply ideas from geometric modelling an d artificial intelligence. These application areas include measuring probe selection, workpiese setup, feature accessibility determination, inspection strategy and probe path generation. The system is truly generative one. It is implemented on a SUN workstation using an Intellicorp development system and the ACIS geometric modeller

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