eu**spen**'s 23rd International Conference &
Exhibition, Copenhagen, DK, June 2023
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Combined computer-aided part inspection and fixture planning

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Abstract

Coordinate measuring machines (CMMs) are widely used in the inspection process because of their high accuracy. With the increase in part complexity and the fact that tolerances have become tighter, there is a need for well-defined strategies to effectively plan the inspection process and fixture of parts on CMMs. This paper proposes a novel approach that integrates computer-aided part inspection and fixture planning on CMMs to achieve effective measurements. This work begins with feature extraction from the CAD model of the part. Optimal part positioning is then obtained based on accessibility analysis and minimization of part setup. Then, the generation of minimum probe orientations for each part setup is performed in terms of ease of fixtures and accessibility of inspection surfaces. A series of techniques and algorithms were used to achieve efficient inspection on the CMM. The effectiveness of the proposed strategies was confirmed through part case studies.

Inspection, Fixture, Coordinate Measuring Machine (CMM), Touch probe, Accessibility, Setup, Planning.

1. Introduction

With advances in computer systems and production automation, the accuracy of production quality control has seen a significant increase. In recent years, dimensional inspection is widely used as a monitoring and evaluation activity to determine if the manufactured part meets defined standards and design requirements. Indeed, coordinate measuring machines (CMMs) are widely used to perform consistent and efficient inspection. Contact sensors, such as touch probes mounted on CMMs, are typically used. These sensors are known for their accuracy and repeatability. Nevertheless, a well-planned inspection process leads to increase measurement accuracy.

The overall inspection planning process can be divided into two steps: high-level inspection planning and low-level inspection planning [1, 2]. A high-level inspection plan involves tasks such as determining the optimal part setup and probe orientation, while a low-level inspection plan involves determining the number and location of measuring points for each surface and the optimal probe travel path.

The inspection process requires a fixture system that can hold the inspected part while providing accessibility to the inspected surfaces. The fixture may not allow access to all surfaces to be inspected. In this case, multiple positioning of the part is required. The number of orientations should be kept to a minimum to ensure optimum accuracy and save inspection time.

In general, conventional inspection processes are often human-driven, as opposed to automated or intelligent systems. Due to human involvement, conventional inspection methods are error-prone, time-consuming and may involve unnecessary efforts that ultimately contribute to increased inspection costs. Therefore, automation of the inspection planning and fixture process offers an excellent alternative to overcome the limitations of conventional measures [3]. In the case of a large number of similar components, automation of inspection and fixture planning can significantly reduce inspection time.

The planning process is based on the geometrical and metrological data of the part. This information is stored in the CAD model of the part. For computer-aided planning, the recognition of inspection data from the CAD model is an important task to automatically generate inspection plans.

In the literature, it has been shown that the problems of inspection data recognition, inspection process planning and fixture planning have been treated as separate problems. There is a need to develop an integrated system that can automatically and continuously communicate information between inspection and fixture activities.

The remainder of the paper is organized as follows: Section 2 describes the combination of inspection and fixture planning. Inspection data recognition is detailed in Section 3. Section 4 explains the proposed method for part setup planning. Section 5 discusses the generation of inspection and fixture plans for the resulting part setups. Applications and discussions are presented in Section 6.

2. Combined inspection and fixture planning approach

The inspection planning concerns several tasks: part setup planning, probe orientation generation and measuring points distribution [4]. Through the literature review, it was noted that inspection has not been analyzed as a complete system. Therefore, CMM inspection should be performed by secession of operations including:

- Part setup.
- Probe orientation determination .
- Surface accessibility analysis.
- Measuring points determination and distribution.

The first three operations are dependent. Thus, a new approach that takes into account the part setup with the accessibility analysis and the sensor orientation generation becomes essential. The functionality of the part is first analyzed to determine the datum and tolerance features. These data will be included in the CAD model of the part. The datum features are then used to set up the part. The primary, secondary and tertiary datum features are used to define the measurement reference system. Thus, the part will be set up in a way that facilitates the measurement of the reference system.

On the other hand, the fixture planning is a critical task either for inspection or machining process. It includes three steps: fixture planning, fixture layout and fixture assembly [5]. The first involves the identification of candidate features for location and clamping. The second concerns the position of locating elements and clamps on the identified features. The third step involves the assembly of the previous fixture with the part.

In the literature, previous works treat inspection and fixture planning separately. Recently, more attention has been paid to the integration of inspection and fixture planning. In the work proposed by Nasr et al. [5], setup planning is treated separately in the inspection and fixture processes. However, the setup planning in the inspection process can directly affect the fixture planning and vice versa. In this work, a novel method that integrates part setup planning for inspection and fixture is proposed.

Using several setup of the part means that it will be removed and reoriented to perform measurement. This will lead to add more position errors on the measurement, which can affect measuring results. Thus, this work proposes an approach that permit to reduce part setup ensuring best access to the inspection feature.

The flowchart of the proposed method is detailed in Figure 1.

First, the inspection data is extracted from the CAD model and a database is created. Then, the part setup planning is performed taking into consideration the inspection and fixture issues. Finally, for inspection planning, the probe path is determined, while for the fixture, the support, clamping and locating elements and their positions are established.

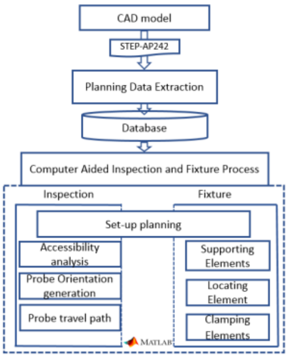


Figure 1. Framework of the proposed approach.

The approach is applied to the test part shown in Figure 2. The three geometrical tolerances to be controlled are: flatness, perpendicularity with respect to the reference A and localization with respect to the reference B.

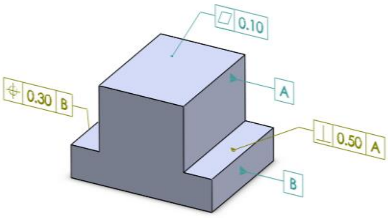


Figure 2. CAD model of the case study part.

3. Inspection data extraction

The automatic planning of the inspection process requires a database containing the necessary information to perform the planning tasks. This information includes geometrical and metrological data. The concept of inspection feature and non-inspection feature is used as explained in [6]. The inspection feature is a feature that has an associated specification that needs to be evaluated. It is composed of surfaces and inspection data such as tolerance types and intervals. Furthermore, a surface is defined by its normal vector and its contour which is composed of several vertex points defined by their coordinates (xyz).

The STEP AP242 file is a standard exchange neutral format commonly used to extract inspection information [4]. A parser is developed to retrieve this information and store them into the database. The relational scheme of the database is given in Figure 3.

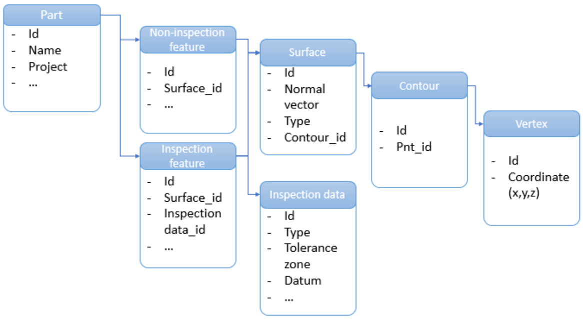


Figure 3. Relational scheme of the database.

The application of the inspection data extraction process on the case study part allows to identify 3 inspection features. Each of them is composed of the corresponding surfaces as shown in Figure 4 and Figure 5.

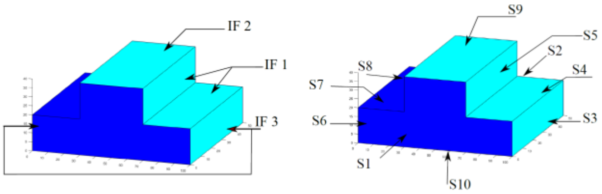
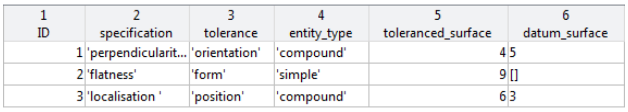


Figure 4. Inspection features and inspection surfaces.



1 ID	2 specification	3 tolerance	4 entity_type	5 toleranced_surface	6 datum_surface
1	'perpendicularit...	'orientation'	'compound'	4	5
2	'flatness'	'form'	'simple'	9	[]
3	'localisation '	'position'	'compound'	6	3

Figure 5. Extracted inspection data.

4. Part setup planning method

The planning of the part setup concerns the definition of the base faces. A base face is defined as the face on which the part must be placed to perform the measurement. The proposed setup planning study should generate the minimum number of base faces to measure all inspection features. For each base face, it should be possible to inspect the maximum number of surfaces using a reduced number of probe orientations and allow the part to be easily fixed without interfering with the measurement of the inspection features.

First, the planning begins with the generation of candidate faces that can be base faces. These candidates are ordered according to the number of inspection surfaces contained on the face. A face is preferred as a candidate base face if it contains no inspection surfaces and therefore the part can be fixed on it.

Then, for each candidate base face, the number of inspection features measured when the part is positioned on that base face, the number of required probe orientations and the fixture surfaces are identified. Candidate base faces are ranked according to these three criteria respectively. The first criterion is the most important to increase measurement accuracy.

Finally, the face selected for part setup is the first candidate base face. This process is applied to all inspection surfaces of the part. If other inspection surfaces cannot be measured considering the obtained base face, the same steps are repeated on the non-measured inspection surfaces. The steps of the part setup planning are presented in Algorithm 1.

4.1. Part setup in terms of inspection features

The study of the part setup in terms of presence of inspection features in a face is a primary analysis to identify potential candidates base faces.

4.1.1. Part Face Identification

The base face is obtained from one of the faces surrounding the part. Initially, the faces of the part and their normal vectors must be identified by analyzing the surfaces of the part. For prismatic parts, the identified faces are 6 and this can increase for non-prismatic parts.

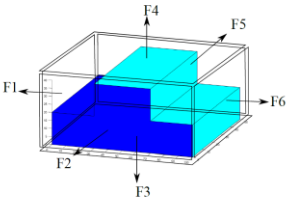
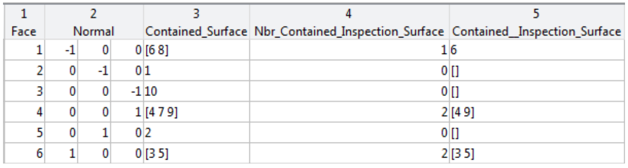


Figure 6. Part face identification

The surfaces that belong to each face are gathered. For example, surfaces 6 and 8 are associated with face F1, while surfaces 4, 7 and 9 are associated with face F4. The other surfaces of the test part are shown in Figure 6 and Figure 7.



1 Face	2 Normal			3 Contained_Surface	4 Nbr_Contained_Inspection_Surface	5 Contained__Inspection_Surface
1	-1	0	0	[6 8]	1	6
2	0	-1	0	1	0	[]
3	0	0	-1	10	0	[]
4	0	0	1	[4 7 9]	2	[4 9]
5	0	1	0	2	0	[]
6	1	0	0	[3 5]	2	[3 5]

Figure 7. Identified faces with their corresponding information.

4.1.2. Candidate base face identification

The setup study in terms of inspection features consists of ordering the identified faces according to the number of inspection surfaces present in each face. The face that contains inspection surfaces will have a lower priority because it prevents the measurement of these surfaces. The ordered faces are denoted as "candidate base faces".

4.2. Part setup in terms of accessibility and fixture ease

The geometric data of the part are expressed in the part coordinate system. In order to analyze the accessibility of the probe in each configuration where the part is positioned on a candidate base face, the geometrical data must be expressed in terms of the studied candidate base face. Thus, it is necessary to find the rotation matrix for each candidate base face. The normal vector of the candidate base face in the machine coordinate system is always oriented downward along the Z axis**.**

Each base face of normal n is rotated to have a normal vector of b=(0 0 -1) in the machine frame. Thus, a rotation matrix should be evaluated. In order to study the accessibility of the probe for a given candidate base face, the point coordinates and the normal vectors are thus multiplied by the rotation matrix m.

The CMM machine probe consists of a stylus and a head. The motorized spherical head allows the stylus to be oriented in 673 different positions by rotating it around the vertical and horizontal axes. Each probe orientation $\overrightarrow{N_l}$ is described by the two angles α and β. The rotation range of α is from 0 to 105° with a step of 7.5 and β from -180 to 180° with a step of 7.5, as presented in Figure 8.

$$\overrightarrow{N_l} = \begin{Bmatrix} -\sin(\alpha).\cos(\beta) \\ -\sin(\alpha).\sin(\beta) \\ -\cos(\alpha) \end{Bmatrix}$$

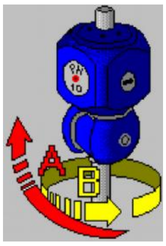
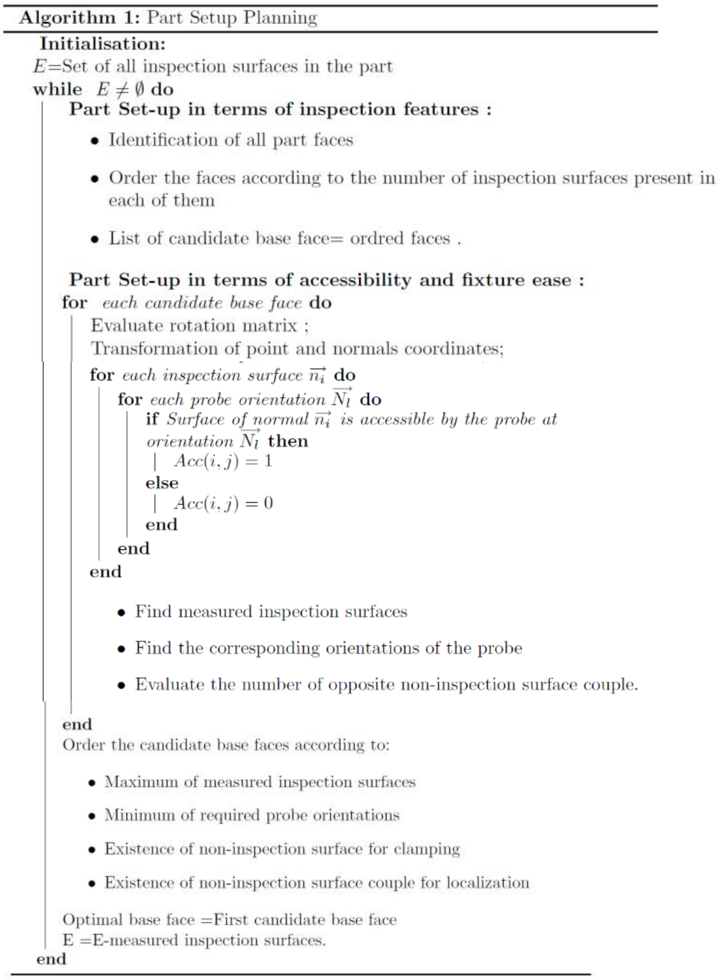


Figure 8. Touch probe orientation calculation.

The probe accessibility study is usually divided into local and global accessibility studies [7]. In this paper, the focus is on the local reachability, which is to check locally whether the probe can access the surface. This can be expressed as the scalar product between the surface normal vector and the orientation of the probe. A surface with normal **n** is accessible by the probe at orientation $\overrightarrow{N_l}$ if the scalar product is negative. In the case where the product is null, the length of the probe must be compared to the length of the surface to check for collision problems [4].



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Algorithm 1: Part Setup Planning
  Initialisation:
  $E$=Set of all inspection surfaces in the part
  while $E \neq \emptyset$ do
      Part Set-up in terms of inspection features :
        • Identification of all part faces
        • Order the faces according to the number of inspection surfaces present in
          each of them
        • List of candidate base face= ordred faces .
      Part Set-up in terms of accessibility and fixture ease :
      for each candidate base face do
          Evaluate rotation matrix ;
          Transformation of point and normals coordinates;
          for each inspection surface $\overrightarrow{n_i}$ do
              for each probe orientation $\overrightarrow{N_l}$ do
                  if Surface of normal $\overrightarrow{n_i}$ is accessible by the probe at
                  orientation $\overrightarrow{N_l}$ then
                      $Acc(i,j) = 1$
                  else
                      $Acc(i,j) = 0$
                  end
              end
          end
            • Find measured inspection surfaces
            • Find the corresponding orientations of the probe
            • Evaluate the number of opposite non-inspection surface couple.
      end
      Order the candidate base faces according to:
        • Maximum of measured inspection surfaces
        • Minimum of required probe orientations
        • Existence of non-inspection surface for clamping
        • Existence of non-inspection surface couple for localization
      Optimal base face =First candidate base face
      E =E-measured inspection surfaces.
  end
```

Part fixture involves four types of elements, which are baseplates, locators, supports and clamps [5]. These devices are placed on the locator surface, the support surface and the clamp surface. The baseplates and supports concern mostly the base face. In this work, locator and clamp surfaces are only considered.

The clamping surface is generally defined as the parallel surface to the base face to eliminate the degree of freedom along the z axis. The selected surface must be a non-inspection surface and the furthest away from the inspection ones. Locator surfaces are generally two opposite faces in which locator will be positioned.

In this paper, the easy fixture is ensured by the presence of non-inspection surface that is parallel to the candidate base face and the presence of a coupe of non-inspection surfaces that are opposite and will be used for locators.

5. Inspection and fixture plan generation

Once the optimal base face is determined, the inspection and fixture plans are processed. The inspection plans consist of defining the probe travel paths, since the probe orientations have already been determined. For this, an approach was proposed by Stojadinovic et al. [8] for optimal distribution of the measuring points in inspection surfaces. For the fixture plans, the support elements, location, clamping and their positions are determined.

6. Applications and discussions

All the steps of the combined inspection and fixture planning approach are implemented in Matlab. This approach is carried out on the test part shown in Figure 2. First, part faces are identified and ranked to form the candidate base faces. The proposed approach to part setup planning is then applied. The results are shown in Figure 12. Faces 2, 3 and 5 contain no inspection surfaces. In addition, the number of measured surfaces is the same for these faces. Face 2 is then selected because it requires a minimum number of probe orientations and it presents fixture surfaces. Inspection surfaces and non-inspection surfaces of the part are presented in Figure 9. Figure 10 and Figure 11 show the resulting base face and probe orientation. The proposed technique reveals that the test part requires only one setup and one probe orientation to measure all inspection features.

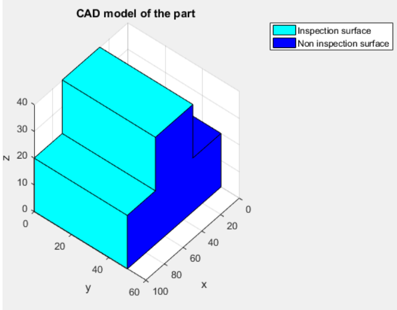


Figure 9. Inspection surfaces and non-inspection surfaces of the part.

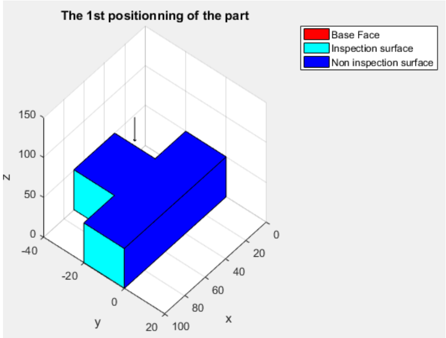


Figure 10. Results of part setup planning (view 1).

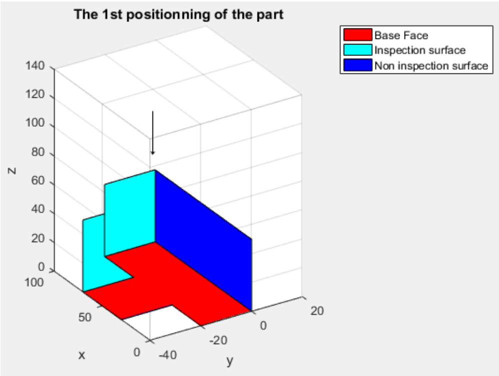
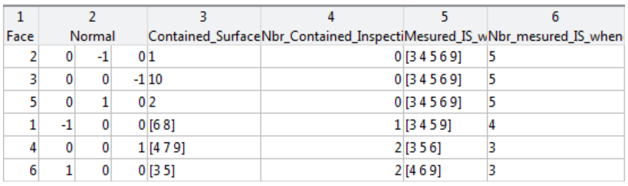


Figure 11. Results of part setup planning (view 2).



1	2			3	4	5	6
Face	Normal			Contained_Surface	Nbr_Contained_Inspecti	Mesured_IS_w	Nbr_mesured_IS_when
2	0	-1	0	1	0	[3 4 5 6 9]	5
3	0	0	-1	10	0	[3 4 5 6 9]	5
5	0	1	0	2	0	[3 4 5 6 9]	5
1	-1	0	0	[6 8]	1	[3 4 5 9]	4
4	0	0	1	[4 7 9]	2	[3 5 6]	3
6	1	0	0	[3 5]	2	[4 6 9]	3

Figure 12. Ordered candidate base faces

7. Conclusion

The combination of inspection and fixture planning is a complex issue, while part positioning is a common task in both processes. In this paper, a new method for generating part setup is developed. The optimal number of setup can be found, allowing to measure all inspection features of the part with a minimal number of probe orientations. This results in high performance measurements and reduced measurement costs.

In the future, this approach will be applied to other test parts with internal shapes such as slots.

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