VOL. 9, NO. 5, MAY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PART LOCALIZATION FOR CNC MACHINING USING DISCRETE POINT SET APPROACH

M. Chandranath, Raghavendra, R. Suresh and S. Ravishankar
Centre for Civil Aircraft Design and Development, CSIR-National Aerospace Laboratories, Bangalore, India
E-Mail: chandranath@ccadd.cmmacs.ernet.in

ABSTRACT

Machining of components on CNC machining centres without any datum reference or tooling hole details is a challenge and requires mapping of the CAD reference system with the CNC Machine reference system. Applying best fit alignment approach to position and orient CNC coordinate system for parts with free-form features is a subject that can be widely employed for machining of components in automobile and aircraft industry. The localization of part and fixing the coordinate system needs 3D point data set obtained from the CNC machining centre using a touch signal probe. This paper focuses on establishing the CNC coordinate system for machining of components with 3D free form surface whose datum coordinate system cannot be established because of the non availability of planar and straight surfaces for reference. The method adopted in this paper helps in accurately machining of such parts without the usage of any special fixtures. The research work aims to report some strategies that provide guidelines to select appropriate best fit techniques for achieving the machining quality in the shortest time. The best fit method adopted on CAD models for fixing of CNC Coordinate system is done using CATIA software. A shorter surface mapping time and better fitting results can be achieved by adopting the recommended techniques.

Keywords: best fit, free-form surface, 3D point data set, localization.

INTRODUCTION

Localization is a subject of extensive research having immense application in various fields viz., Bio-medical engineering, Image processing, Machine Vision, Object recognition, Reverse Engineering, Metrology etc,. Part localization in the field of Production Engineering is an important problem that is being addressed to resolve many manufacturing concerns. Workpiece localization refers to the following problem: A rigid workpiece when placed arbitrarily on a machine table necessitates determining the position and orientation of the workpiece coordinate frame relative to known reference coordinate frame [1], so as to establish the correspondence between the two coordinate systems. Machining involves arresting all the six degrees of freedom of a part on a CNC machine with proper fixtures. This requires the part to be located on the machine with predefined positioning information (program zero, from CAM Software) and accuracy using planar faces of the lugs as datum. But in a rework scenario, which is very common during prototype development stage, particularly in aircraft industry, in most cases the datum planes/ lug pads would be cut-off and hence the positioning of such parts on a CNC machine for rework is quite a challenge considering the need to meet design demands for close tolerances.

Accurate machining and reworking of large, complex or flexible components on CNC Machining Centres needs accurate datum features to define the program zero or the CNC machining coordinate reference system. If these parts do not have any in built datum features viz., planar surfaces, tooling holes, etc., then CNC machining needs special fixtures on such parts to satisfy 3-2-1 datum principle to define the program zero, which is not only time consuming but cost inefficient. For such parts without any datum reference or tooling holes, this research work proposes fitting techniques to carryout localization of part with program reference systems so as to define the program zero datum. This is carried out by application of well known CAD/CAM software viz., CATIA, thus enabling CNC machining of components without any known datum reference system and eliminating the usage of any special work holding devices so as to achieve the required part tolerances demanded by design.

By adopting the technique described in this research work, the part localization method provides the ability to establish bespoke CAM toolpaths to the actual position of the part, rather than having to ensure that the work piece is exactly at the predefined known nominal location specified in the CAM system. This capability is achieved by using the machine tool controller much more efficiently and effectively than placing and holding the part in exactly the specified position using specially designed dedicated fixtures.

LITERATURE SURVEY

Li, Gou and Chu [2] compares different techniques to achieve localization of work piece for CNC machining of a part. The technique requires standard (planar) surfaces to be probed to determine the position and orientation of work piece and the paper emphasizes that when dealing with sculptured surfaces proper initial conditions are required to compute nearest home surface points. Fan and Senthil Kumar [3] carries out a fixture locating layout with robust design approach by combining Taguchi Method and Monte-Carlo statistical method in order to increase the quality of final machining of work pieces, so that the layout can be robust and insensitive to errors. In this paper, the Taguchi Method is employed to study the locating effect of the locator’s position at

ARPN Journal of Engineering and Applied Sciences

different levels and the Monte-Carlo method is applied to simulate the variation of coordinates of the locating contact points. Yau, Chen and Wilhelm [4], proposes a surface registration algorithm for application in the area of reverse engineering to solve the problem using a nonlinear minimization approach. Multiple data sets with different orientations are aligned and integrated to construct complete 3D data set. Chu *et al.* [1] analyses and compares the performance of three localization algorithms based on robustness with respect to variations in initial conditions, accuracy of computed results and computational efficiency towards developing an approach for improving the robustness of the algorithms for workpieces with sculptured surfaces for which region of convergence is typically small. Xiong *et al*. [5] addresses an optimal planning problem for workpiece localization with coordinate measurements by finding the best probing locations and a suitable sampling size, such that the uncertainty of the localization error is within a predefined limited bound. Gunnarsson K T and Prinz B [6] present a solution to the problem of determining the location of a part in a robotic manufacturing situation. The problem is solved by matching a database surface description of the part with discrete points measured on its surface. The matching is accomplished through the calculation of a transformation. The transformation specifies the position and orientation of the part as it appears in front of the robot. The method was developed for use in flexible manufacturing where low precision, general purpose fixtures and positioners are employed wherein the knowledge of the approximate location of the part is used.

This paper reports a part localization procedure in the manufacturing of typical aircraft components. Different types of alignment techniques are supported by the CAD software viz., three point / three sphere alignment, 3-2-1 principle, six point/free form alignment, etc., all of which require definite datum surfaces on the part or provision for external special holding fixtures. The point cloud alignment technique discussed here can be used for alignment of parts with no definite datum surfaces. The part considered here does not have any datum surface for reference and hence the point cloud alignment technique is adopted.

LOCALIZATION PROCEDURE

General localization procedure as shown in Figure-2 consists of the following primary steps.

i. **Part placement:** The part is located/clamped arbitrarily in the machining envelope of the CNC machining center. It is firmly clamped at suitable place with general shop fixtures (Figure-1).

Figure-1. Part clamped arbitrarily on the CNC machining center.

ii. **Point data set generation:** The program zero reference datum is taken arbitrarily in space and stored under local coordinate systems using specific G codes viz., G54-G59. In general, the datum point is taken above the middle area of the part so that the origin is approximately symmetrical about the part profile. This minimizes the error distribution across the part surface. The necessary points set or cloud of points data set are obtained from component geometry by two methods:

a) using the touch signal probe fitted onto the machine spindle for 3D free form surfaces
b) using a portable articulated arm (Figure-3) for complex surfaces with negative draft angles.

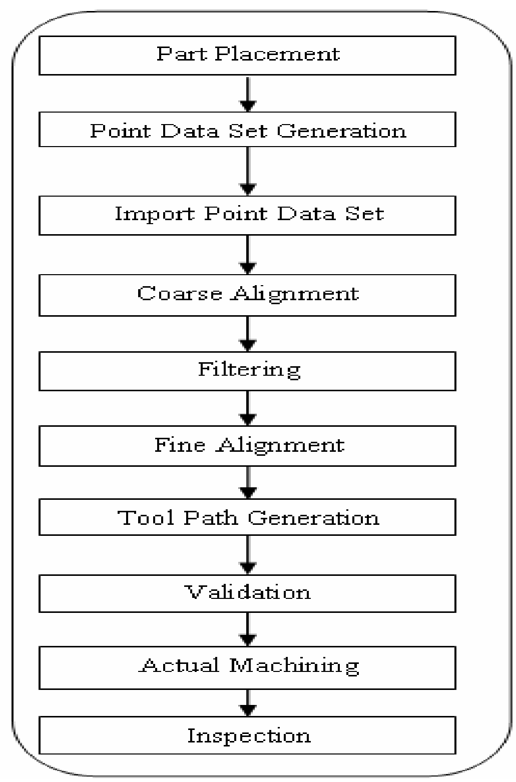

Figure-2. Localization procedure.

VOL. 9, NO. 5, MAY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

When we capture points through tactile/non contact approach using articulated arm the basic features has to be probed for setting the datum. The point data set from the component has to be taken from at least three sides to carryout best fit with the CAD model. Taking large number of points on more number of sides, i.e. a well distributed point cloud will provide better results with best fit and thus help in achieving a higher accuracy.

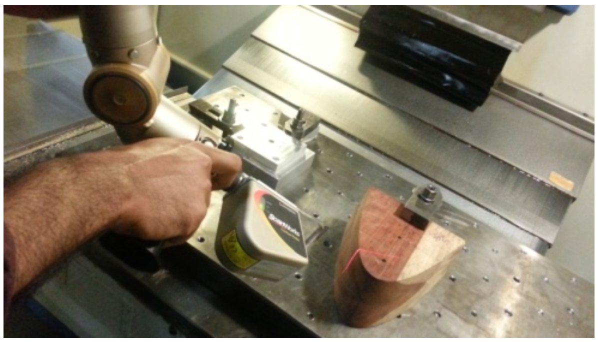

Figure-3. Capturing of points using portable articulated arm - scanner configuration.

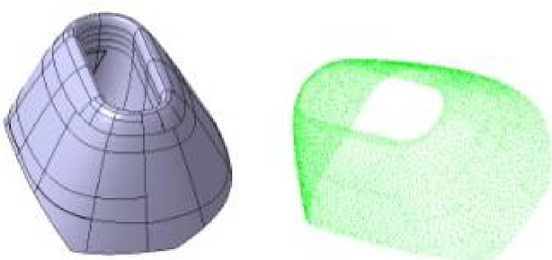

Figure-4(a). CAD model and point cloud data of a De-icing tool.

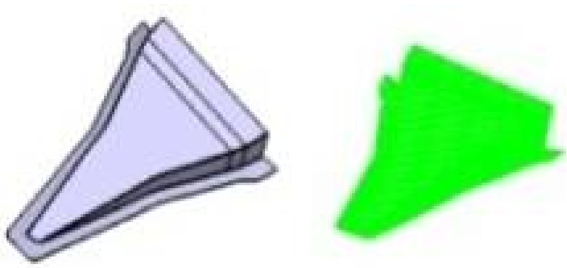

Figure-4(b). CAD model and point cloud data of an oil cooler inlet duct.

iii. **Import point data set:** The captured cloud of points is imported into CAD software in any of the supported formats (Figures 4a and 4b). The probed data is offset by an amount equal to the radius of the probe and hence the surfaces of the part in CAD should also be offset by the same value before starting the alignment procedures.

iv. **Coarse alignment stage:** The CAD geometry of the part is imported in the software. Rough alignment of the part (Figure-5) with the cloud of points has to be done by manual alignment using the compass feature of CATIA software so as to reduce the computation time for the best fit alignment.

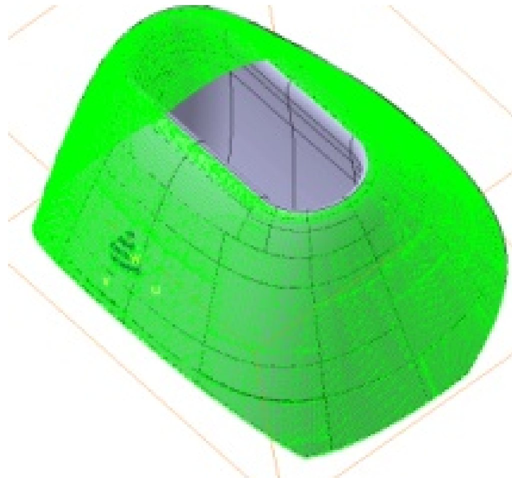

Figure-5. Initial coarse alignment stage using compass feature.

v. **Filtering:** Certain unwanted points or outliers are filtered off as noise so that the alignment is done with the points of interest (Figure-6). As alignment involves averaging of the deviations of all points from the target surface, hence unwanted points are removed prior to applying best fit alignment so as to reduce the time for computation and get accurate results.

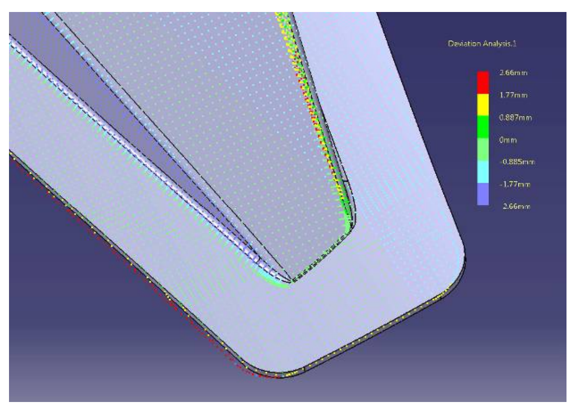

Figure-6. Filtering of points by distance analysis.

vi. **Fine alignment stage:** There are a variety of best-fit techniques that is adopted to achieve fine alignment of the two point data sets. Some of them are three point/three sphere, 3-2-1 principle; six point/free form techniques. All the above techniques require at least one or more datum surfaces as reference. For parts without any datum reference surface point cloud alignment technique is applied to get accurate results. A best fit alignment of the model to the point cloud is done (Figure-7).

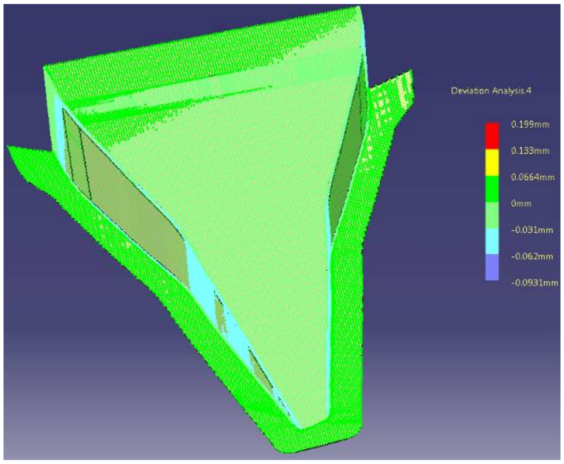

Figure-7. Final aligned surface to the cloud of points.

vii. **Tool path generation:** Once the alignment is achieved with in the required tolerance, distance analysis is carried to confirm the same. Now a CNC toolpath for machining the required surface is generated with the axis of import of the cloud points as the origin.
viii. **Validation:** The generated toolpath is verified in VERICUT software.
ix. **Actual machining:** The validated toolpath is then transferred to the CNC machining center with the origin as the one recorded from the second step and CNC machining is carried out.
x. **Inspection:** The final machined part is then probed with points at the machined surface and then compared with native CAD model geometry and inspection is completed.

CASE STUDY

A typical Wing/Fuselage bracket is arbitrarily loaded on a CNC machining center. A series of scanned points are captured at distributed positions (Figure-8) and imported as a cloud of points within the CATIA software as shown in Figure-9.

Figure-8. On machine capture of points by probe.

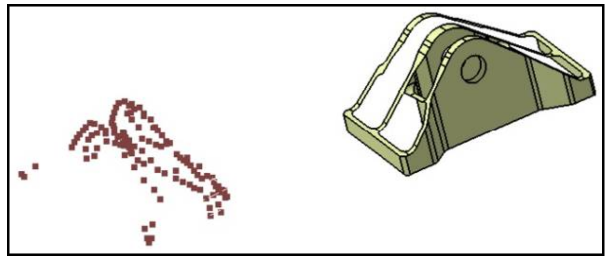

Figure-9. Point cloud import to CATIA software.

The CAD model is initially coarsely aligned near the cloud of points for ease of alignment as shown in Figure-10.

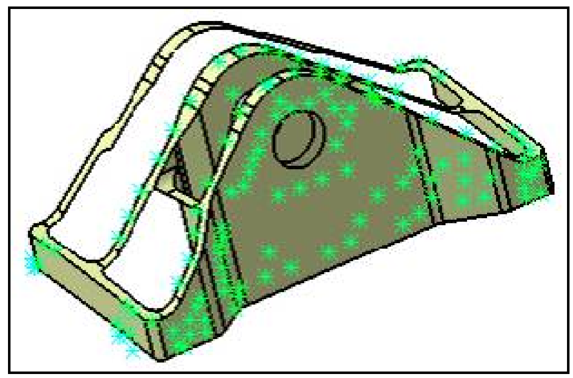

Figure-10. Coarse alignment stage.

A range of best-fit routines are applied within the software to locate the CAD model at exact position by transformations to match the imported cloud of points. Any mismatch between the nominal position used in the CAM system to the actual position of the part are calculated. After completion of the coarse alignment stage, best fit is enforced with appropriate translations and rotations to align the part to the existing imported cloud of points (Figure-11) thereby capturing the transformation axis system.

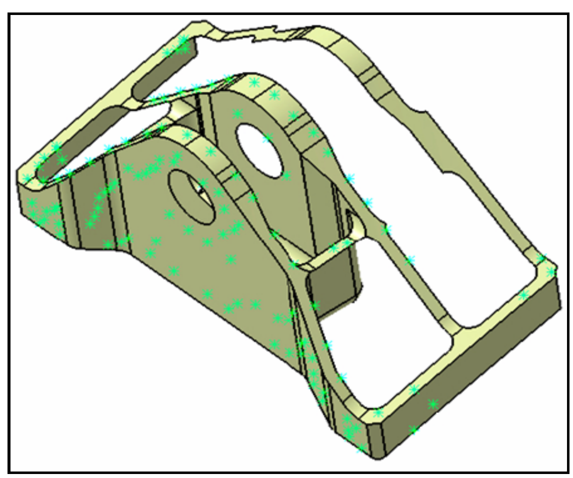

Figure-11. Fine alignment stage.

This transformation axis system gives the datum shift or the required rotations/translations to compensate for the differences in location and alignment. The Absolute axis system which uses Local coordinate system (G54-G59) of CNC machining controller is then taken as the program origin for CNC tool path generations. The generated tool path is then validated in VERICUT software. The validated programs are then transferred on to the machine with the origin of the initial scan as the machining origin / machining datum and machining of the surface requiring rework or re-machining is carried out. This approach is much faster than trying to locate a heavy block of complex shaped part into exactly the position specified, which can often involve many hours of manual adjustment and is error prone. The inspection results of the deviation are shown in Figure-12 and are well within the acceptable tolerance standards [7], thus validating the localization method adopted in this research work.

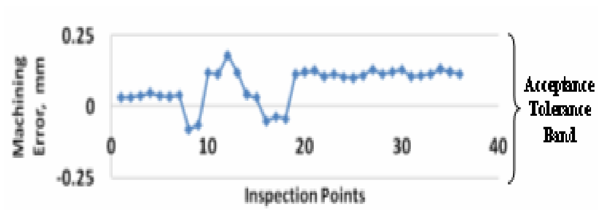

Figure-12. Inspection results.

CONCLUSIONS

The CNC Part localization technique discussed in this paper can be extensively used for the machining and reworking of tools and components which do not have a known datum reference. By using the NC-Part localization technique, the surface of the component can thus be mapped even with basic fixturing and thereby provides more reliable results. This method is also useful to carry out secondary operation on parts which have warpages and cumulative errors due to earlier in-correct machining operations or change in design. These secondary operation problems can be overcome with NC-part localization technique by probing part surfaces and realigning once again and quantifying any distortion of the part by probing and additionally defining the axis for reworking operations accordingly.

NC-Part Location technique using best fit can also be used to prevent tolerance build-up when undertaking a series of machining operations. For example, if a series of holes are to be produced and surfaces have to be machined around a standard bore and faces, the location of the bore and faces can be confirmed before starting of the operations. Again, using the actual positions of the features that have already been machined will give more accurate results than using the nominal positions from the CAD file.

The proposed procedure in this paper concentrates on initial origin capturing and coarse alignment of the CAD model to the imported cloud of points. The initial origin recorded at approximately symmetric location in the part gives an equal error distribution which is then moderated by the best-fit technique. The coarse alignment stage reduces unwanted computations for transformations and the fine alignment stage gives a quick and accurate localization of the part. It should also be noted that the general practice to fix datum for rework or re-machining of such parts is with the usage of fixtures for locating the part which is time consuming, expensive and error prone. The cumulative effect of fixture errors also will further reduce the accuracy of the machined part. Thus the part localization methods discussed here not only offer potential savings in time and cost but also enable reworking and usage of expensive machined parts which are hitherto not machinable because of lack of known reference system.

ACKNOWLEDGEMENT

The authors express their sincere thanks to Director, CSIR-NAL, Head, Centre for Civil Aircraft Design and Development, CSIR-NAL for their consistent support for this research work. The staff and facilities at APMF are greatly acknowledged.

REFERENCES

[1] Chu Y X, J B Gou J B, B Kang, Woo K T and Li Z X. 1997. Performance Analysis of Localization Algorithms. IEEE International Conference on Robotics and Automation, April 20-25, Albuquerque, New Mexico. Vol.4.

[2] Li Z, Gou J and Chu Y. 1998. Geometric Algorithms for work piece localization. IEEE Trans. On Robotics and Automation. 14(6):864-878.

[3] Fan L and Senthil Kumar A. 2010. Development of robust fixture locating layout for machining work pieces. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, December. 224(12): 1792-1803. DOI:1 0.1243/09544054JEM1686.

[4] Yau H T, Chen C Y and Wilhelm R G. 2000. Registration and integration of multiple laser scanned data for reverse engineering of complex 3D models. International Journal of Production Research. 38(2): 269-285.

[5] Xiong Z, Wang M Y and Li Z. 2004. A Near-Optimal Probing Strategy for Workpiece Localization. IEEE Transactions on Robotics. 20(4), August.

[6] Gunnarson K T and Prinz F B. 1987. CAD model-based localization of parts in Manufacturing. IEEE Computer. pp. 64-67, August.

[7] 2011. NAL report: Standard for general manufacturing tolerances, NAP-016 'B', February.