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Verification of New Sampling Methods On Small Scale Free Form Surfaces

Suleiman M. Obeidat*[,a] , Rami H. Fouad[a] and Nabeel Mandahawi[a]

[a]Hashemite university, Industrial Engineering Department, P.O. Box 330127, Zarqa 13115, Jordan

Abstract

The three recently developed algorithms by Obeidat and Raman in 2009 for sampling free form surfaces are applied on small scale parts created using milling machine. The three proposed algorithms and the two existing algorithms (equiparametric approach, and the patch-size-based sampling method) are applied in sampling the measuring points. A Browne & Sharpe MicroVal PFX™ 454 CMM was used in the measuring process. The comparison between the five algorithms shows that a reduction in the number of points of 73% with reduction in the accuracy of 7.5 % can be achieved in very complicated surfaces. A low inspection time is achieved using the proposed algorithms.

Keywords: CMM; Inspection; Free Form Surfaces; Adaptive sampling; patch sampling; small scale parts sampling

1. Introduction

Sampling is a fundamental step in measurement. To verify that the part within tolerances specified, an inspection process is necessary. To accept the part or reject it, you need some criteria. One of the most important criterions is verifying that the part is close enough from the designed model. All parts created using any kind of manufacturing processes have errors; those errors need to be revealed using one of inspection methods, such as Visual inspection, scanning methods by laser, by X-Ray, by Coordinate Measuring Machine (CMM) or using any other convenient way.

For this purpose, the algorithms developed by Obeidat and Raman [1], applied on theoretical proposed Free Form surfaces, are applied in this work on actual created surfaces. In the proposed algorithms, Obeidat and Raman [1] assumed that there is a theoretical error on the surface and they proposed that error is affected by the curvature of the surface being created and then they made a comparison between the three proposed algorithms and the existing ones. In this work, the error is actual. Some free form surfaces are created using milling machine, and those surfaces are small compared to the surfaces used by obeidat and Raman[1], so the manufacturing parameters effect on the dimensional error is high, so the effect of the surface curvature is more on the manufacturing error in this case. The created surfaces were made using CNC milling machine. AL 7075-T6 was used as a workpiece material, and a HSS ball end mill cutter of diameter 0.5 inch was used. The parameters used in making those parts are the same in all parts to be easier in comparison between the tolerance zones: step over: 0.025 inch, cut angle: 180°, spindle speed: 7500 rpm, and the cut type was climb cut type.

The three proposed algorithms by Obeidat and Raman [1] and the two existing algorithms (equiparametric and the patch-size-based sampling techniques) are applied in sampling the measuring points. In milling operation, the cutter affects the surface by cutting force, and so the surface affects the cutter by a force in the opposite direction resulting in a cutter deflection as shown in Figure 1 .This deflection is proportional to the surface gradient in the direction of the cutting operation. There is an effect from the gradient of the surface in the vertical direction to the cutting direction but that effect is very small compared to the gradient in the cutting direction. Hence, the effect of the gradient that is significant is the gradient in the direction of the cutting operation.

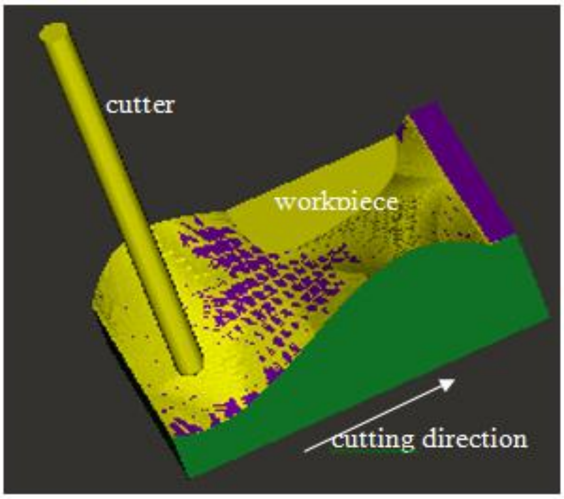

Figure 1: Free form surface created using end milling.

* Corresponding author. e-mail: sulobeidat@ou.edu

Based on the proposed algorithms by Obeidat and Raman [1], in inspecting free form surfaces, critical points are obtained. The critical points are ranging from the points of highest Gaussian curvature to the points of the mean Gaussian curvature. And so, one of our objectives in this work is minimizing the number of inspection points using the critical points that represent the surface accurately.

2. Coordinate Measuring Machines

Measurement of free-form surfaces is a very critical issue because of the shape ,complexity, the lack of adequate datums and the large number of measurements that is needed to accurately represent free form surfaces, Ristic et al. [2]. Before inspection process, an alignment between the machine coordinate and the part to be inspected is made. this process has been studied by many researchers. Li and Gu [3] developed an automatic system that performs general localization and point – point localization between the measured part and the design model. Huang et al. [4] created algorithms for 3D feature localization and quantitative comparison. They applied their algorithms on free form surfaces. They created a very effective pseudoinverse algorithm for the localization process for two free form surfaces that are created using measurement data. Ainsworth et al. [5] developed an inspection system that depends and employs at each step of an inspection process the CAD model. Their system consists of a registration process, defining the measurement points on the surface, probe path generation, path optimization and verification and probe radius compensation. In the sampling process some sampling criteria have been used such as: uniform sampling, chord length, maximum sample density of the sampling points on the surface, and parameterization-based sampling criteria. Pahk et al. [6] developed an integrated precision inspection system for manufacturing molds that has CAD defined features. In their system they used a CAD environment to choose the feature to be inspected and then an inspection planning for each feature is performed. Some sampling techniques are used in their system, such as: uniform distribution, curvature dependent distribution and hybrid distribution of the two depending on the complexity of the sculptured surface.

All measurement processes have some extent of uncertainty, Feng et al. [7]. Many researchers have studied the factors that affect uncertainty in coordinate measuring machines and how that uncertainty can be reduced ((Schwenke et al.[8]), (Weckenmann et al. [9]), (Edgeworth and Wilhelm [10]), and (Shen and Duffie [11])), studied the factors that affect the measurement process.

The measurements obtained using the CMM include the manufacturing error, CMM errors and the measurement errors which include the errors in measuring the probe diameter, the error in measuring the probe length, etc.

In this study, the CMM error will not be detailed, nor the localization process. The manufacturing error is the most significant factor in this work.

3. Inspection Path Planning

Modern manufacturing can be characterized by low-volume, high variety production and close tolerance high quality products, Diaa et al. [12]. For any product there is a need for an inspection plan which is suitable for a specific part and its complexity. Yau and Menq [13] stated that, to achieve higher automation level in dimensional inspection, an intelligent and computer integrated inspection environment is needed. Hence, the inspection plan should be integrated with that system to ensure high accuracy. Many researchers have worked in the area of computer aided inspection planning. Consequently, many algorithms for computer aided inspection planning using CMM have been proposed. Some of them are detailed here.

Lin and Murugappan [14] developed a new algorithm for optimum collision free CMM probe path. In this algorithm ray tracing technique was used to detect the collision of the probe with the part. This algorithm used a mechanical desktop and its run time extension (ARX) as the application programming interface, which runs on Windows NT 4.0 platform. This algorithm used a querying CAD data base for the part geometry. This algorithm is useful in simple prismatic solids but doesn’t work for solids with curved surfaces and free form surfaces.

Chan and Gu [15]developed an object oriented inspection plan (OOIP) to be used as a tool for integration of CAD and CMMs using knowledge - based system techniques. They introduced some tools that can be used to classify inspection items into manual and machine inspection based on feature geometry and tolerance type. Some features or tolerances not crucial in terms of tolerances or are not economical when inspected by CMM, are inspected manually. Ketan et al. [16] generated automated inspection process plans based on feature based (FB)-computer aided inspection planning. They developed a computer internal model for a product to achieve direct integration between CAD and CAIP without requiring interface communication system. From this system they developed an NC code which can be generated for inspection process for only prismatic parts. Limaiem and Elmaraghy [17] used the Dijkistras shortest path algorithm combined with collision detection routines to develop a path planning module. Fan and Leu [18] introduced an integrated system for intelligent inspection path planning of CMM probes for feature-based objects for three types of surfaces: planar, cylindrical and conical. They developed a system that generates the measuring points automatically by linking with AutoCAD modeling of the surface model. They used a swept-volume method for probe collision detection and they developed a program to generate the measuring points of an object created by AutoCAD. A technique for collision detection and avoidance was created. Marefat and Kashyap [19] also developed an inspection planning program based on a CAD model. The information about the part including its edges, faces, slots and holes were extracted from the CAD model. They developed an interface between the CAD model and the inspection system. Tannock et al. [20] developed a Computer Aided Inspection Work station (CAIW) approach to shop-floor inspection. It is low-cost and more flexible than the systems based on (CMMs). In (CAIW), an intelligent Inspection Planning System (IPS) was developed. Detailed inspection plans can be generated. By (IPS) and (CAIW) inspection plan procedures, selection of the instruments, gauges and fixtures instructions, and on - screen graphics can be performed. IPS is different from systems that use (CMMs) because by (IPS) the information about the part geometry, nominal and tolerance attributes can be conveyed directly, while in the systems based on (CMMs) (DMIS) is used to convey the information about the part to (CMM). Merat and Radack [21]introduced an automated inspection planner that depends on the linking between geometric dimensioning and tolerancing (GD&T) feature class and an Inspection Plan Fragment (IPF). Tang and Davies [22] developed an inspection planning system called (INSPEX) based on knowledge transmitted from CAD systems. Fan et al. [23] developed software called "Auto Probe" to create the measurement path of the Probe. Also, they developed a software called "Auto-Wire" to create 3D-wireframe view of the part from its 2D projection views. From the 3-D wire frame created by "Auto-Wire", "Auto Probe" can be used to create the probe path by mouse, keyboard or a digitizer. Spitz et al. [24] introduced an algorithm for high level inspection planning using CMMs. High level planning means "to determine how to setup the work piece on the CMM table, which surfaces to inspect in each set up, which probes to use, and how to orient those probes". Menq et al. [25] introduced a method for determining the actual measured points by CMMs. This method was called optimal match algorithm.

Caulier and Bourennane [26] presented a general free-form surface inspection approach depending on the projection of a structured light pattern and the interpretation of the generated stripe structures by means of Fourier-based features. Xu and Li [27] presented a new way to match the coordinate system of measurement with CAD coordinate system.

4. Inspection Path Planning

Sampling is used to specify the number and the location of measuring points that give the best representation of the created surface, Obeidat and Raman [1].

In this paper three actual milled surfaces are used to demonstrate the methodology developed by Obeidat and Raman [1]. A comparison between those strategies and Equiparametric and patch size - based techniques, is performed.

The two well-known sampling methods for free form surfaces that were derived from literature to create a basis for comparison with the three sampling methods are:

1) Equiparametric Sampling: This method, as explained by Elkott et al. [28] distributes the sample points equally in the u-v space. It is simple and easy to apply. It is good for simple surfaces that do not have significant changes in curvatures. It is also insensitive to surface complexities such as sharp curvature changes and unequal surface-patch sizes. The algorithm is explained in figure 2.

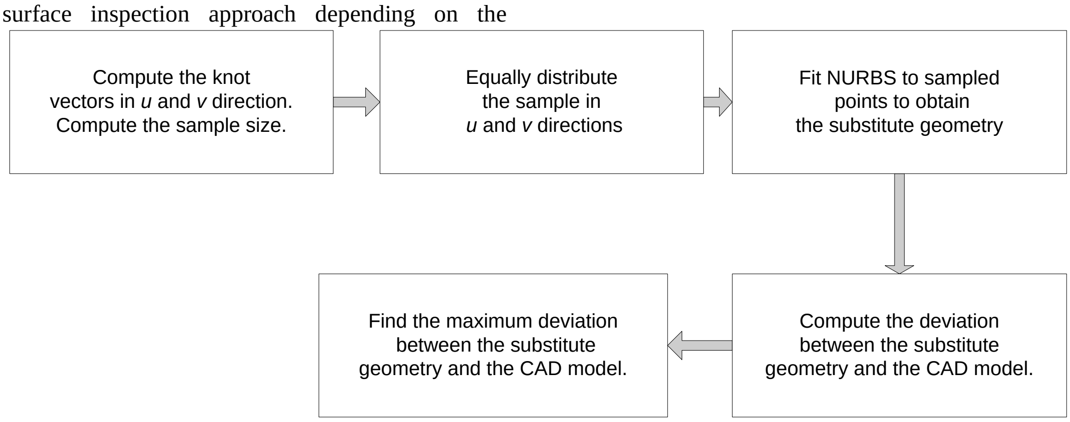

Figure 2: Flow diagram of the equiparametric sampling technique.

2) Patch size-based sampling: this method, as explained by Elkott et al. [28], divides the surface into its patches based on the knot vector. These patches are ranked based on their sizes, and the points are distributed based on the patches ranking, where the patch of higher rank has a high number of points proportional to its size. In this algorithm the very small patches are ignored which might have important variations in the surface curvature. Figure 3 explains the flow diagram of this sampling algorithm.

The three surfaces used for demonstration are different in complexity. Specific points are sampled using the developed algorithms by Obeidat and Raman [1]. NURBS are used to fit the data to obtain the substitute geometry from which the maximum difference between this resulting surface and the CAD model surface is obtained. The algorithms used are shown in figures 4, 5, and 6.

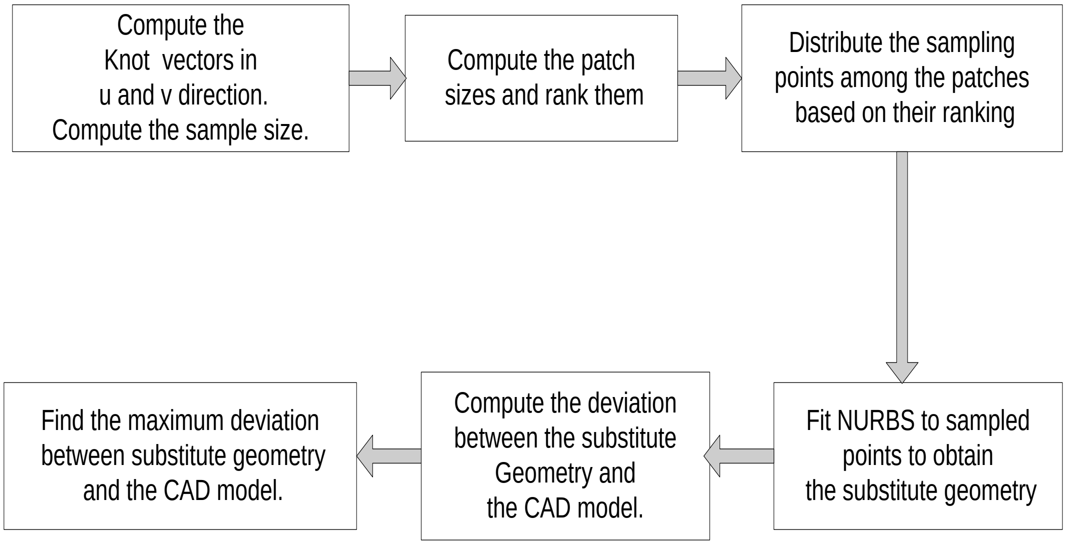

Figure 3: Patch size-based sampling flow diagram.

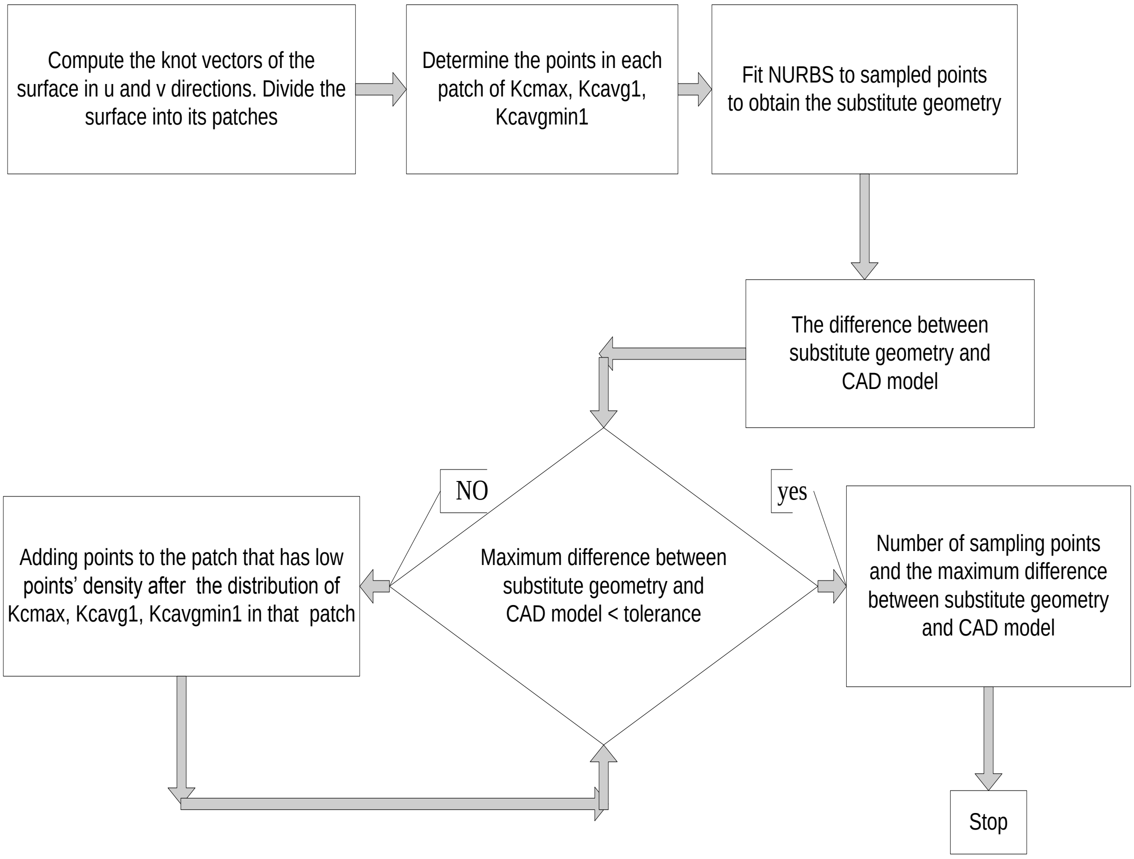

Figure 4: First algorithm, Obeidat and Raman [1]

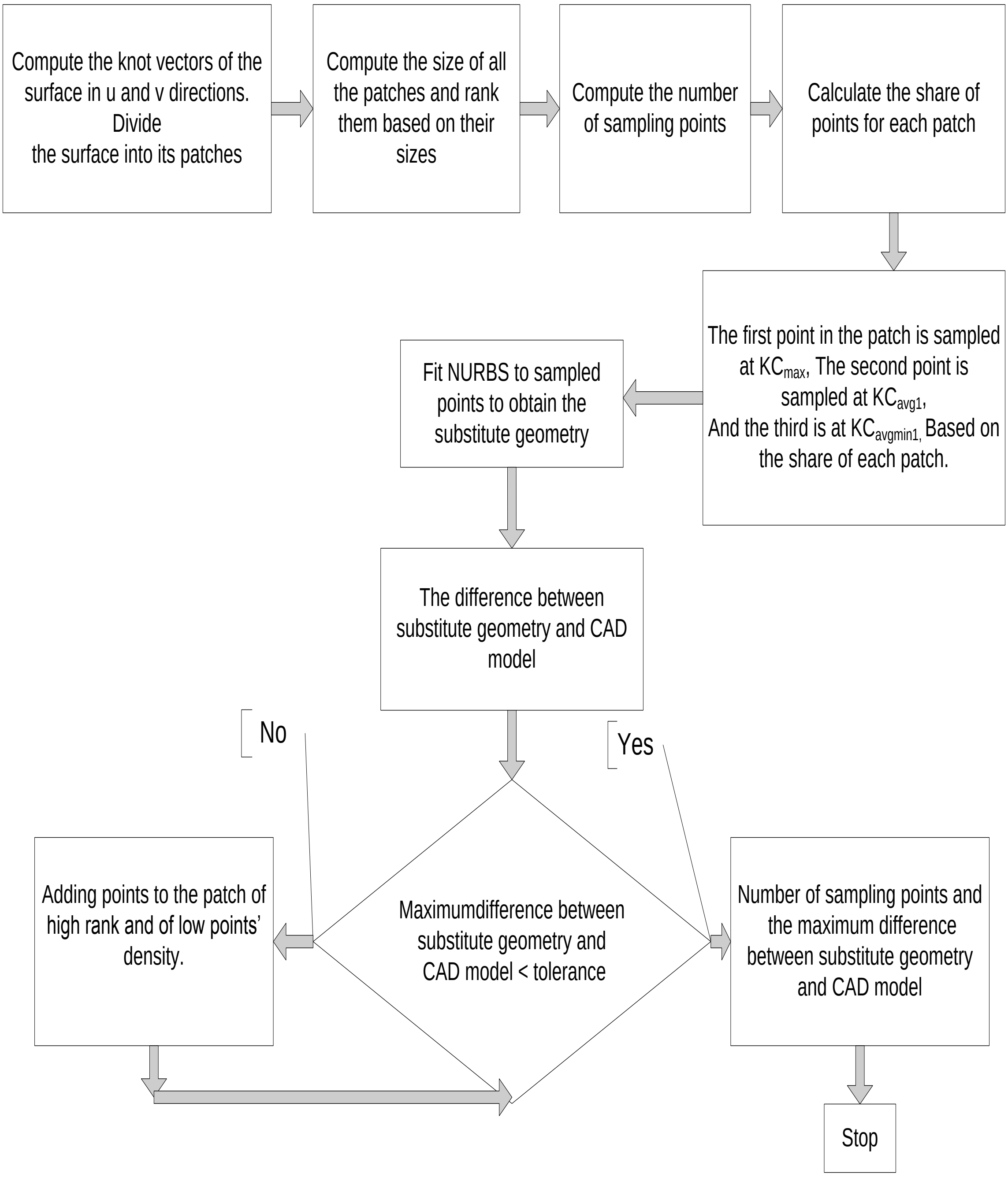

Figure 5: Second algorithm, Obeidat and Raman [1]

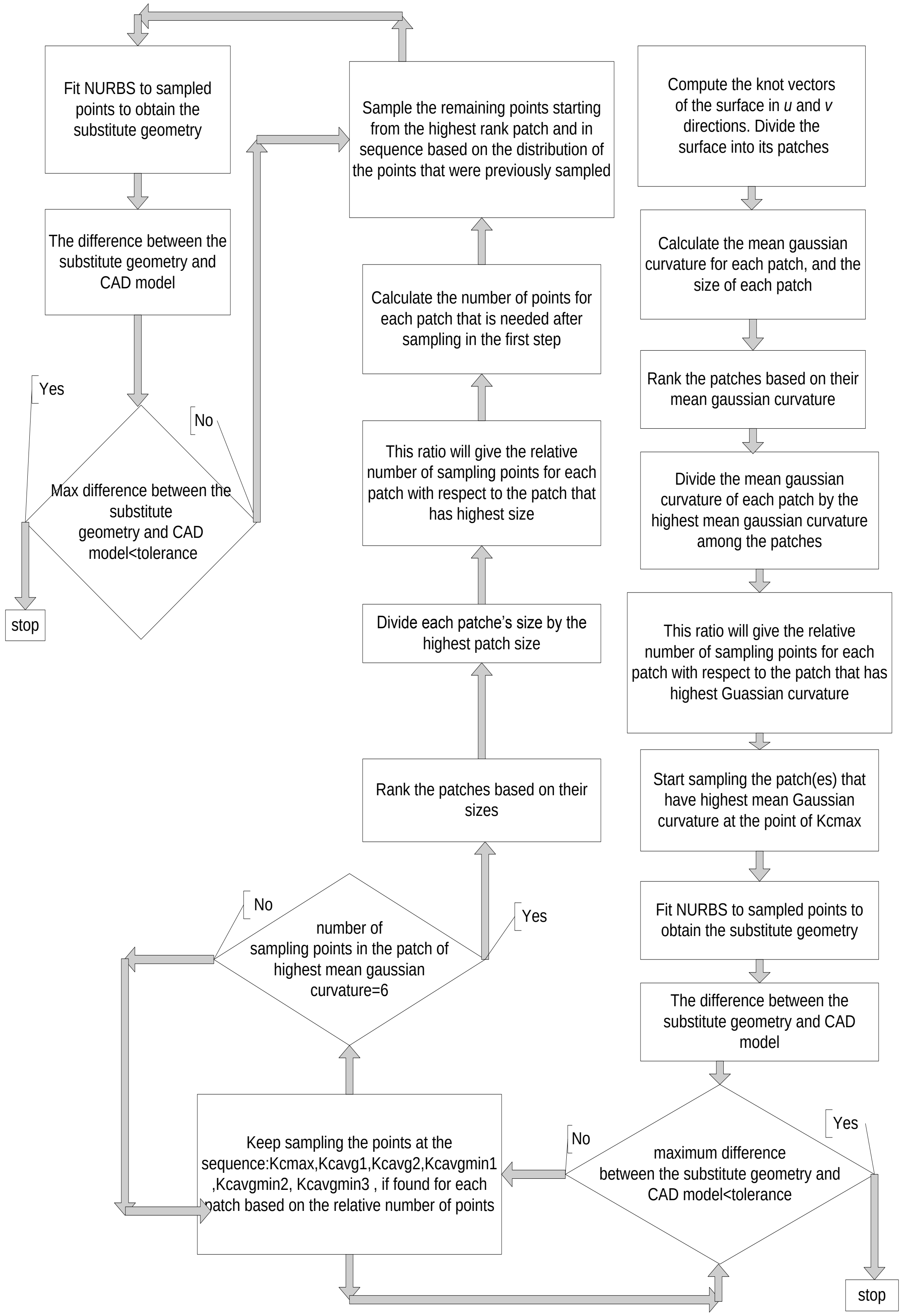

Figure 6**:** Third algorithm, Obeidat and Raman [1].

The surfaces that those algorithms were applied on are shown in figures 7, 8, and 9.

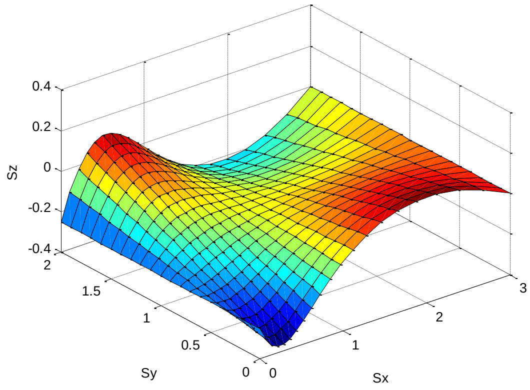

Figure 7: Surface part1.

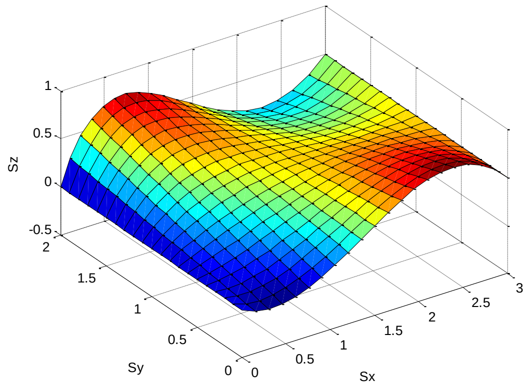

Figure 8: Surface part2.

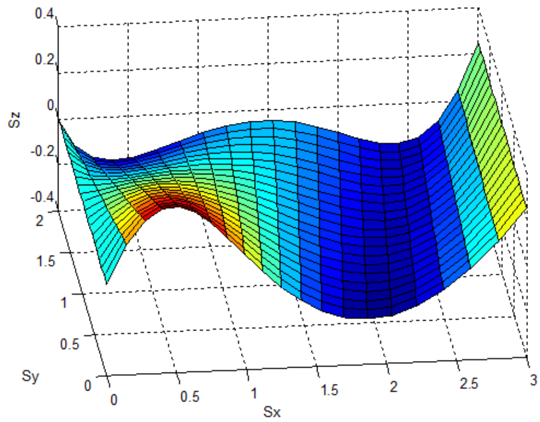

Figure 9: Surface part3.

5. Results and Discussion

As mentioned above, an inspection process has been performed on three surfaces made using milling machine. A Browne & Sharpe MicroVal PFX™ 454 CMM was used in the measuring process. The three algorithms developed by Obeidat and Raman [1] have been used in sampling the inspection points. The results obtained have been compared with those obtained using two existing sampling techniques (Equiparametric and Patch – size based). The surfaces made are ranging from simple to complicated surfaces.

The tolerance zones obtained using Equiparametric and patch size – based sampling techniques are used as basis for comparison. It is assumed that the correct tolerance zone is the one obtained using the two existing sampling techniques. This is acceptable assumption because 121 points are used in sampling the points using the two existing techniques.

Table 1 gives the tolerance zones and the number of points needed to get those tolerance zones for each sampling technique.

For surface part1 (least complexity), it can be noticed from Table 1 and figure 10 that the third algorithm using 30 points, gives the closest tolerance zone to those obtained using Equiparametric and patch – size based techniques with 121 points. This reveals the strength of the third algorithm in sampling simple surfaces. A reduction in number of points of 75% reduces the accuracy by 10% is a great development because this will reduce the inspection time by around 75%. This is because Equiparametric and patch size – based methods don't take into consideration the complexity of the surface, and so there is no need for this huge number of sampling points (121) as suggested by the new developed algorithms.

For surface part2 (moderate complexity), it can be noticed from Table 1 and figure 11 that the first algorithm using 22 points, gives the closest tolerance zone to those obtained using Equiparametric and patch – size based techniques with 121 points. This reveals the strength of the first algorithm in sampling moderate complexity surfaces.

For surface part3 (high complexity), it can be noticed from Table 1 and figure 12 that the first algorithm (29 points), second algorithm (29 points) and third algorithm (33 points), give great results. The three developed algorithms give tolerance zones that are very close to those obtained using Equiparametric and patch – size based techniques. By reducing the number of points by 73 % a reduction in accuracy of 7.5% is achieved is a great achievement. This will reduce the inspection time by 73 % if this amount of accuracy is ignored in very complicated surfaces. Also this reveals that the developed algorithms by Obeidat and Raman [1] are applicable for small size surfaces as well as for large scale surfaces. More over those algorithms can catch the maximum error faster and using less number of points compared to Equiparametric and patch – size based techniques.

Table 1: Comparison between the five sampling algorithms when applied on surface part1, surface part2, and surface part3.

Surface	Algorithm	Tolerance Zone (inch)	Number of points
Part 1	First	0.1405	22
	Second	0.1147	22
	Third	0.1872	30
	Equiparametric	0.2076	121
	Patch - size based	0.1897	121
Part 2	First	0.0448	22
	Second	0.0382	22
	Third	0.0357	30
	Equiparametric	0.0602	121
	Patch - size based	0.0567	121
Part 3	First	0.3859	29
	Second	0.3810	29
	Third	0.3812	33
	Equiparametric	0.3498	121
	Patch - size based	0.3356	121

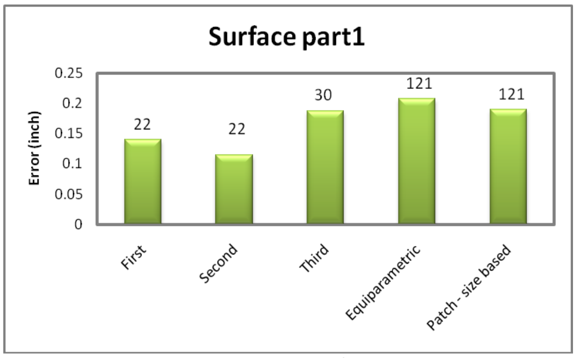

Figure 9: Dimensional error when the five algorithms are applied on surface part1.

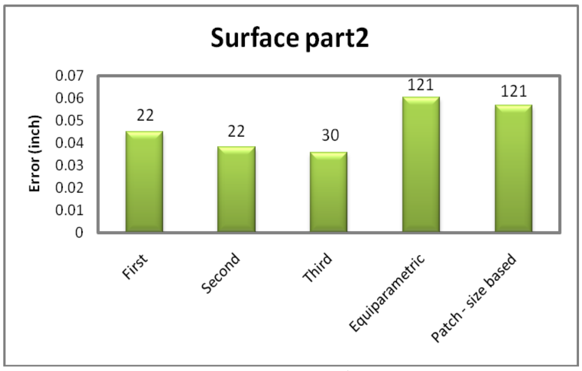

Figure 10: Dimensional error when the five algorithms are applied on surface part2.

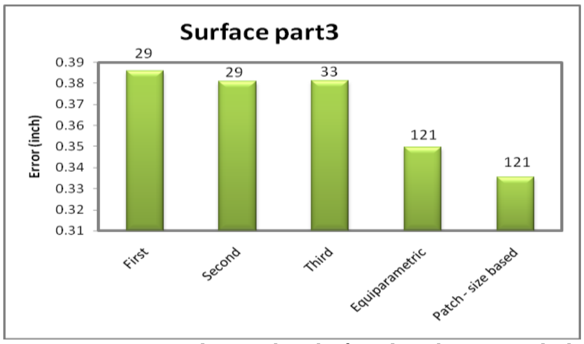

Figure 11: Dimensional error when the five algorithms are applied on surface part3.

6. Conclusion

In this work the three algorithms developed by Obeidat and Raman [1] were used. They were applied on actual surfaces made by end milling. The error is actual and is not proposed .The three kinds of surfaces are of small scale compared to those used by Obeidat and Raman [1].Three kinds of surfaces ranging in complexity from simple to very complicated surfaces, were used. The inspection points were obtained using the three developed algorithms and two existing sampling techniques (Equiparametric and patch – size based techniques).

It can be concluded that, the first algorithm is the best for simple surfaces giving a reduction in number of points of 75 % with a reduction in accuracy of 10%. Also, the three algorithms are better than Equiparametric and patch – size based techniques for very complicated surfaces with a reduction in number of points of 73% with a reduction in accuracy of 7.5%. A reduction in an inspection time is achieved which leads to big reduction in measurement cost.

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