International Journal of Innovative Engineering Applications

Journal homepage: https://dergipark.org.tr/ijiea

A COMPARISON STUDY IN TERMS OF DIMENSIONAL ACCURACY AND PRECISION OF 3D MODELING

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Abstract

Original scientific paper

In this study, the differences in the dimensions of the 3D models produced by Polyjet and FDM (Fused Deposition Modeling) methods as Auto surface modeling (AS_m) and Parametric modeling (P_m) were investigated. Here, our purpose is to demonstrate the effects of the modeling methods on the dimensional accuracy and precision. A component having cylindrical, plane and amorphous surfaces have been selected as a sample material. Polyjet and FDM methods have been used in 3D printer using the nominal data of this component. Then a 3D scanner have been used to scan those aforementioned parts. These scans have been remodeled with two different modeling methods, namely, AS_m and P_m. After modeling, the measured (scan) data has been compared with the nominal data. Differences in terms of the size of the results were revealed mathematically. According to the results obtained, when we compare the parts produced by Polyjet by AS_m and P_m methods, we observe that AS_m gives better results all over the surface than P_m. Also, the former one has less maximum error norm than the later one. On the other hand the samples produced by FDM using both AS_m and P_m give better results all over the surface, but the former one has relatively less maximum error norm than the later one.

Keywords: *3D scanning, 3D printing, accuracy, auto surface modeling, parametric modeling, reverse engineering.*

3D MODELLEMELERİN BOYUTSAL DOĞRULUK VE HASSASİYET AÇISINDAN BİR KARŞILAŞTIRMA ÇALIŞMASI

Özet

Orijinal bilimsel makale

Bu çalışmada, Otomatik yüzey modelleme (ASm) ve Parametrik modelleme (Pm) olarak Polyjet ve FDM (Fused Deposition Modeling) yöntemleri ile üretilen 3D modellerin boyutlarındaki farklılıklar araştırılmıştır. Burada amaç modelleme yöntemlerinin boyutsal doğruluk ve hassasiyet üzerindeki etkilerini ortaya koymaktır. Malzeme olarak silindirik, düz ve amorf yüzeylere sahip bir bileşen seçilmiştir. Bu bileşenin nominal verileri kullanılarak 3D yazıcıda Polyjet ve FDM yöntemleri kullanılmıştır. Daha sonra, yukarıda belirtilen parçaları taramak için bir 3D tarayıcı kullanılmıştır. Bu taramalar ASm ve Pm olmak üzere iki farklı modelleme yöntemi ile yeniden modellenmiştir. Modellemeden sonra ölçülen (tarama) veriler nominal verilerle karşılaştırılmıştır. Sonuçların büyüklüğü açısından farklılıklar matematiksel olarak ortaya konmuştur. Elde edilen sonuçlara göre Polyjet' in ASm ve Pm yöntemleriyle ürettiği parçaları karşılaştırdığımızda ASm' nin tüm yüzeyde Pm'ye göre daha iyi sonuçlar verdiğini gözlemliyoruz. Ayrıca ASm' nin tüm yüzeyde Pm'ye göre daha az maksimum hata normuna sahiptir. Öte yandan, FDM tarafından hem ASm hem de Pm kullanılarak üretilen numuneler tüm yüzeyde daha iyi sonuçlar vermiş, ancak ASm, Pm'ye göre nispeten daha az maksimum hata normuna sahiptir.

Anahtar Kelimeler: *3D tarama, 3D yazıcı, hassasiyet, otomatik yüzey modelleme, parametrik modelleme, tersine mühendislik.*

1 Introduction

Reverse engineering (RE) can be defined as the redesign of the design process based on the shape or geometry of the products. RE, which plays an important role in the remodeling of medical and mechanical products, provides an ease access to Computer Aided Design (CAD) data products in engineering. In this way, an efficient process occurred by digitizing the product geometry using contact (probe) and non-contact (laser).

Traditional measurement methods in industry have been used for decades. Although classical CMM systems are relatively responsive to the industry's need, high accuracy/precision is now required with fewer deviations and measurement errors. The modeling of the data obtained at the end of the scanning processes is also extremely

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Received 19 October 2021; Received in revised form 28 December 2021; Accepted 08 January 2022

 Doi: https://doi.org/10.46460/ijiea.1012067

important. The structure and limitations of the surface play an important role in this context.

There have been some studies by researchers on issues about RE. Boschetto et al. designed a 3D model and then made measurements by producing a prototype of this model. They found that this profile is effective on the surface of FDM technology [1]. Dietrich et al. produced 20 different prototypes and re-scanned these parts and found that there was a significant difference between these two prototyping methods with the Polyjet and SLS method [2]. Mallepree et al. created a 3D model based on CT images. They have achieved very important measurement proximity [3]. Jonhson et al. produced a model containing different geometries with both CNC and FDM method. They then re-scan these comparison models by scanning. In their study, they concluded that the CNC method is relatively inexpensive and higher in size than FDM [4]. Armillotta et al. re-scan the ABS 3D model produced by the FDM method to detect edge, surface forms and position errors. In their study, parameters yielded effective results on edge structure [5]. Cheng et al. conducted an experimental and theoretical study for an efficient optimization of the density of cellular structure in layered production. They also proposed a homogenized model in their study and confirmed the optimization by comparison with the experiments in Ref. [6]. Anwer et al., in their study, have demonstrated how to use reverse engineering in product development processes and how they can be developed using curves [7]. Eijnatten et al. examined the effects of CT data on product STL data. They also have found that there were 3 methods of MDCT (Multi detector row computed tomography) that gave the best results in terms of accuracy in terms of 3 different CT methods [8]. Chiu et al. minimized time for repeatability productions by optimizing 3D production parameters. As a result, they showed that the process time, light flux, curing time and platform moving velocity have been affected [9]. Aroca et al., in their work, have recognized the 3D parts of the finished parts of a robot with a robot to allow serial production. In this way, they have created a series production system in low-cost components [10].

Anwer et al., on the product simulations, developed computer aided tolerance systems for modeling the effects of tolerances and were able to obtain realistic solutions as a result [11]. Villiers et al. developed a real inferential model for rapid prototyping of graphics models. This study using the C ++ program has demonstrated rapid and effective solutions for graphical models [12]. Doubenskaia et al. used a comprehensive optical monitoring method for the parametric analysis of the Selective Laser Melting (SLM) method. As a result of the different screening methods used in the study, the microstructure and product properties of the products were also found to be effective and different [13]. Wang and Yu have done modeling with quadratic curve and surface fitting with minimization management in squared distance. They also achieved effective results due to repetition of the method [14]. Schleich et al. developed a model in which the deviations in the surface are examined in the geometric shapes of the products. In the study, the results showed significant differences in the geometry of the products and the validation of the design measures [15]. Pattnaik et al. studied rapid prototyping techniques and at the same time evaluated the advantages and disadvantages of their limitations during production. As a result, they demonstrated that long and costly processes can be overcome by rapid prototyping in industry and health sectors [16]. Salmi et al. examined the completeness of measurement in medical models of additive manufacturing method. They produced 3 different skull models with SLS, Polyjet and 3DP methods. According to the results, they found that Polyjet is better than other methods [17]. Majstorovic et al. presented a new method of anatomical features through X-ray images of human bones. With this method, they managed to form a complete bone geometry within the required surgical margins [18]. Stark et al. developed a reverse engineering process based on 3D scans of 3D models for maintenance repair and renewal processes. In their work, they demonstrated the successful results of data processing approaches for automatic separation, identification and mapping of assembly structures in product data management systems in 3D assembly scans [19]. İsa and Lazoglu designed a laser scanner that works in a global structure. With this design, measurement uncertainties and deviations have been tried to be minimized [20]. Molleda et al. in the study of the properties of 2-dimensional rolled products such as flatness and width have been examined in a 3-dimensional method. This method is intended to reduce unwanted surface defects [21]. Popov et al. developed a high speed and resolution non-contact scanning method. In their study, they found two types of errors in surface scans and they reduced the random errors linearly [22]. Isheil et al., examined the parameters of the distance d, the incidence angle α and the projected angle using a non-contact scanning method and contributed to the reduction of systematic screening errors [23]. In Xi et al., demonstrated an empirical formula for compensating for errors caused by laser scanning lines [24]. In their study, Wang and Feng examined the measurement errors resulting from reflective surfaces that significantly affected the quality of point cloud data in the scanning of complex surfaces. They have produced two different models that give effective results for these contradictions [25]. In another study, Wang and Feng also examined the effects of the scanning direction on 3D laser scanning of reflective surfaces. In the present study, they investigated empirically the effects of the scanning direction on contradictory formations [26]. Besic et al. CMM also examined the effects of laser scanner lines on measurements. They also conducted a series of tests using contact and non-contact scanning systems [27]. Iuliano et al. examined the performance of these systems by considering the dimensional and geometrical tolerances as well as their quantitative and qualitative criteria in 3D scanning systems [28]. Feng et al. analyzed the digitization errors of laser scanning systems. The empirical model, based on some parameters, such as scanning depth and laser angle, revealed very fine deviation values [29].

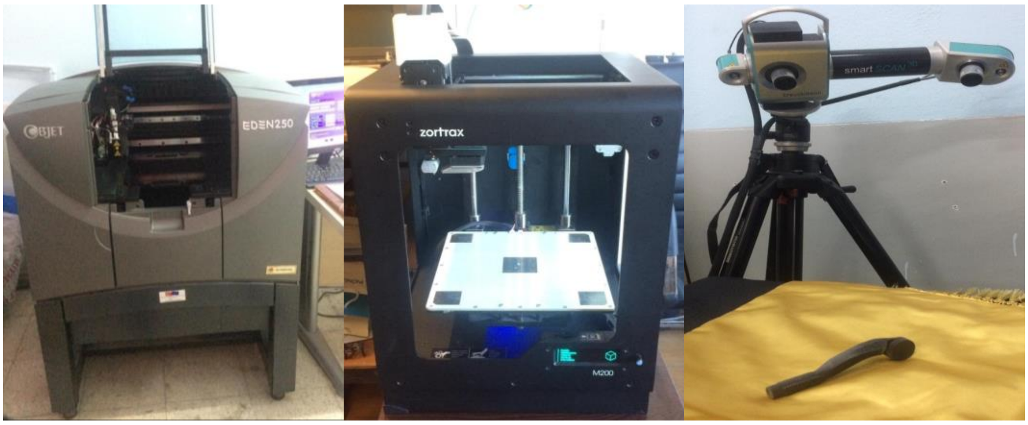
As it is understood from the literature, the studies on the efficiency of scanning methods and 3D prototypes on the dimensional accuracy and precision of the products are quite high. However, this study, the modeling of the end products' dimensional accuracy and precision is mathematically revealed through the error analysis. In this sense, it will contribute to RE studies as an experimental and theoretical study.

2 Materials and Method

2.1 3D Printing and 3D Scanning Process

To demonstrate the effects of the modeling method on dimensional accuracy and precision, 3D prototype models of the component selected for the study were produced by the EDEN 250 (Figure 1a) produced that uses Polyjet method and Zortrax M200 (Figure 1b) that uses FDM method. The scans of the produced parts have been made with Breuckmann 3D Smartscan (Figure 1c).

Each of the four samples has been scanned from 6 different directions and approximately 150 points in each scan and compared with the same points in each modeling. In the auto surface modeling of Polyjet samples 909 points (Figure 2a), and in P_m 898 points (Figure 2b) have been taken. In FDM AS_m 897 points (Figure 2c) and in P_m 901 points (Figure 2d) have been taken. These data are the differences between the nominal data and the scanned data given in millimeter (mm).



(a) (b) (c)

Figure 1. 3D Printers and Scanner (a) EDEN 250 3D printer (b) Zortrax M 200 3D printer (c) SmartSCAN 3D scanner.

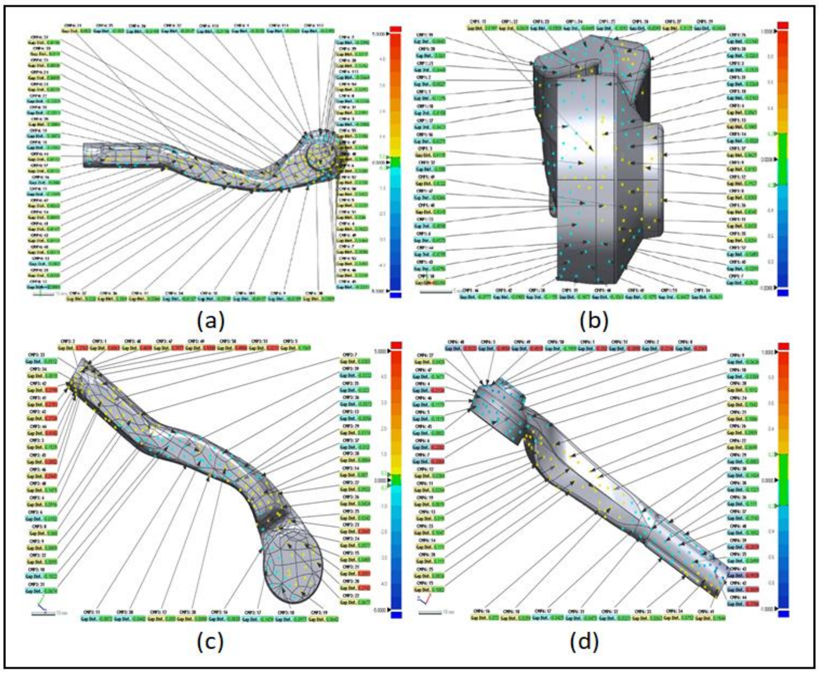


Figure 2. Some scan views a) AS_m Polyjet b) P_m Polyjet c) AS_m FDM d) P_m FDM.

2.2 Modeling Process

Rapid form XOR program has been used in modeling studies. Firstly, in the modeling, polygonal data of the part is obtained by scanning system on those data. Next, the sections have been obtained by using reverse engineering software. Sketches are created on those received sections. These sketches are formed by solids or surfaces, resulting in final results. Two methods have been applied according to the geometry of the parts, accuracy & precision, cost or application used for the modeling.

2.2.1 Parametric Modeling (Pm)

Sketch based modeling can also be used for P_m. Since the solids and surfaces can be obtained from the drafts, the changes made through the drafts are reflected to the entire design.

P_m refers to a modeling method that establishes a relationship between the model elements and the modeling objective in order to perform the control and dynamic update of geometry with mathematical variables and algorithms [30,31,32].

2.2.2 Auto Surface Modeling (ASm)

Data can be easily created by rapid surface modeling. This method is used to edit the scanned data. (Clearing the blanks, clearing the deformations, arranging the polygons, softening or sharpening the polygons) The program then automatically creates a surface on the polygon data.

The difference between these two processes is the fact that in the first one the data is obtained in a controlled manner and in the other one the data is generated according to the software's own algorithm. As a result, AS_m is a relatively quick method of obtaining geometry. P_m reconfigures design changes in the whole process, regardless of geometrics. However, this dependent and specific design method can be slower in RE processes. The argument discussed in this study is the error analysis between the AS_m, which is designed for high accuracy machining with lower accuracy, and the high accuracy of Pm, which leads to high computational time expenditure. However, the amorphous surface of the surface is also an important parameter in this context.

2.2.3 Mathematical Results

In order to measure how good the approximations are, the error norms L_2 and L_∞ defined as follows;

$$L_2 = \|u - u_{nm}\|_2 = \frac{\sqrt{\sum_{i=1}^{n_{ip}} |u_i - (u_{nm})_i|^2}}{\sqrt{\sum_{i=1}^{n_{ip}} |u_i|^2}}, \tag{1}$$

$$L_\infty = \|u - u_{nm}\|_\infty = \max_{0<i<n_{ip}} |u_i - (u_{nm})_i| \tag{2}$$

have been used using Microsoft Excel VBA language. Here n_{ip} is the number of inner points, u_i and $(u_{nm})_i$ are the exact and numerical solutions at the point i., respectively. The L_2 and L_∞ error norms are computed by taking the values u_i and $(u_{nm})_i$ at selected points obtained by dividing the region elements in the directions. As clearly seen from the formulae, the numerical solution becomes better as the number of points used increases.

3 Result and Discussion

Differences in the size of the nominal data and the deviations (Figures. 3,4) of the scanned data were compared with the results of the comparison of Polyjet and FDM samples with both AS_m and P_m. In order to test the accuracy and efficiency of the methods used in this manuscript, we have used the most commonly used error norms L_2 and L_∞ given as;

$$L_2 = \sqrt{\sum_{i=1}^{N} |U_{exact} - U_{approx}|^2} \tag{3}$$

$$L_\infty = max|U_{exact} - U_{approx}| \tag{4}$$

In Polyjet samples, while we have computed the error norms as L_2=1.722x10^{-3} and L_∞=0.2456 for n=909 measurements using AS_m, we have computed the error norms as L_2=2.2374x10^{-3} and L_∞=0.803 for n=898 measurements using P_m. In Polyjet samples, when we compare AS_m and P_m, we see that AS_m gives better results all over the surface than P_m. Also the former one has less maximum error norm than the later one.

In samples produced by FDM, again, we found out the error norms as L_2=6.48x10^{-3} and L_∞=0.0663 for n=897 measurements using AS_m, we have found out the error norms as L_2=6.676x10^{-3} and L_∞=0.9939 for n=901 measurements using P_m. In FDM samples, one can easily see that both AS_m and P_m give better results all over the surface, but the former one has relatively less maximum error norm than the later one.

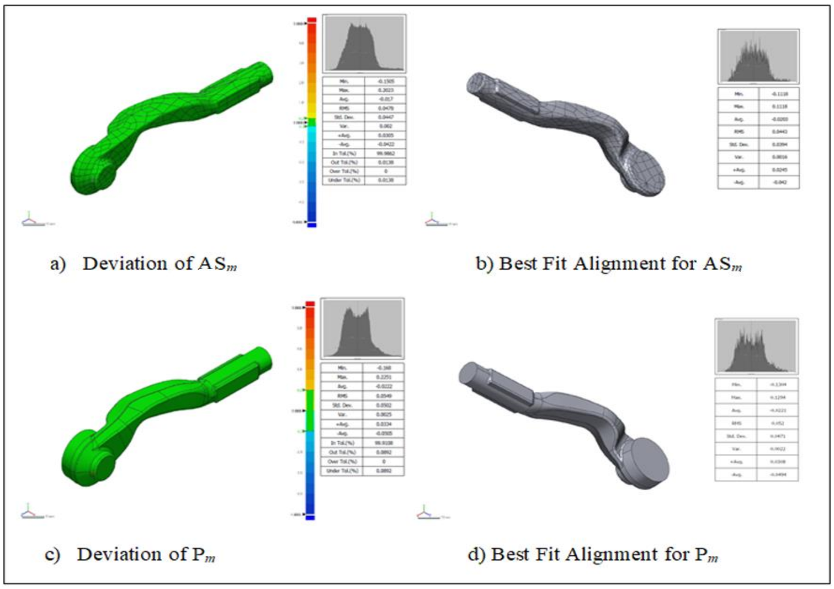


Figure 3. Deviation and Best Fit Alignment of the polyjet sample.

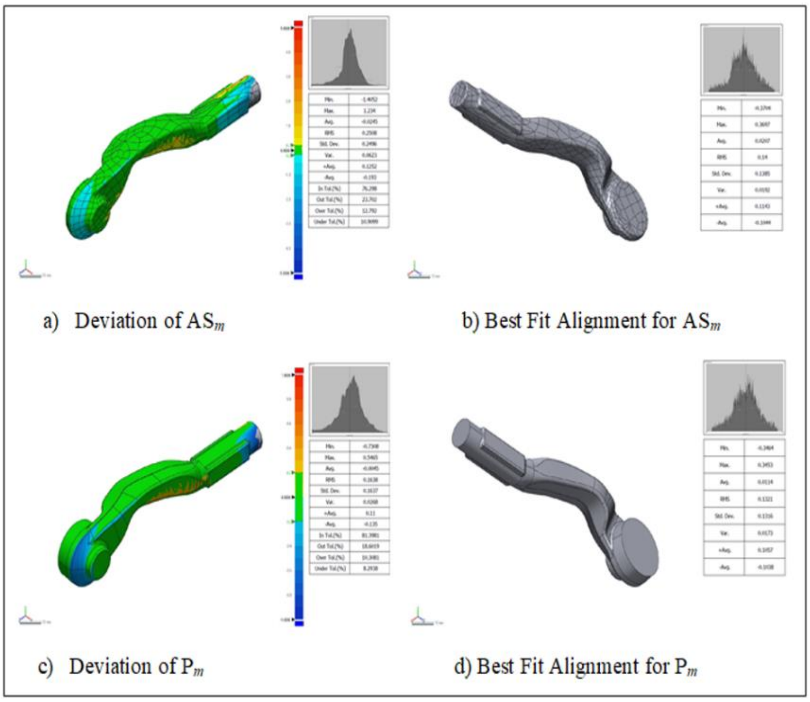


Figure 4. Deviation and Best Fit Alignment of the FDM sample.

4 Conclusion

The purpose of this study is to determine the effects of modeling method on dimensional accuracy and precision. The difference in the dimensions of the 3D models produced by Polyjet and FDM using AS$_m$ and P$_m$ have been examined. According to the error analysis after the scanning of the component having cylindrical, plane and amorphous, the following results have been reached.

We have found out the maximum error made in each model. We have also calculated be replaced with we also calculate the overall error throughout the surfaces. According to those results, we conclude the following points.

- For samples produced by Polyjet, AS$_m$ can be preferred P$_m$ due to the fact that error norm $L_2=1.722\text{x}10^{-3}$ of the former one is less than that of the latter one $L_2=2.2374\text{x}10^{-3}$ and at the same time the error norm of the former one $L_\infty=0.2456$ is also less than that of the latter one $L_\infty=0.803$.
- Again for samples produced by FDM, AS$_m$ can slightly be preferred P$_m$ due to the fact that error norm $L_2=6.480\text{x}10^{-3}$ of the former one is a little less than that of the latter one $L_2=6.676\text{x}10^{-3}$ and at the same time the error norm of the former one $L_\infty=0.0663$ is quiet less than that of the latter one $L_\infty=0.9939$.
- We concluded that while modeling components having amorphous surfaces, AS$_m$ is preferred to P$_m$.

Acknowledgements

Thanks to the "Poligon Engineering/Istanbul" for their support.

Declaration

Ethics committee approval is not required.

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