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Point Clouds Pre-Processing and Surface Reconstruction Based on Tangent Continuity Algorithm Technique

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KEYWORDS

Point Clouds, Tangent Continuity, Surface Reconstruction.

ABSTRACT

Pre-processing is essential for processing the row data point clouds which acquired using a 3D laser scanner as a modern technique to digitize and reconstruct the surface of the 3D objects in reverse engineering applications. Due to the accuracy limitation of some 3D scanners and the environmental noise factors such as illumination and reflection, there are some noised data points associated with the row point clouds, so, in the present paper, a preprocessing algorithm has been proposed to determine and delete the unnecessary data as noised points and save the remaining data points for the surface reconstruction of 3D objects from its point clouds which acquired using the 3D laser scanner (Matter and Form). The proposed algorithm based on the assessment of tangent continuity as a geometrical feature and criteria for the contiguous points. A MATLAB software has been used to construct a program for the proposed point clouds pre-processing algorithm, the validity of the constructed program has been proved using geometrical case studies with different shapes. The application results of the proposed tangent algorithm and surface fitting process for the suggested case studies were proved the validity of the proposed algorithm for simplification of the point clouds, where the percent of noised data which removed according to the proposed tangent continuity algorithm which achieved a reduction of the total points to a percentage of (43.63%), and (32.01%) for the studied case studies, from the total number of data points in point cloud for first and second case study respectively.

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1. Introduction

In recent years using 3D laser scanners as modern technology in reverse engineering have more attention to acquiring the data information about the objects to create the database represented by a point cloud about these objects or needing to the development process. This process has some unnecessary data information in the form of noised data as a result of illumination or reflection problems and the limitation accuracy of the used 3D laser scanners, in addition to the problems of huge data points in the point cloud. So, the past researchers dedicated articles to manipulate these problems by proposing some simplification and surface reconstruction algorithms.

Wand et al. presented an algorithm for out of core outlier removal and geometrical filtering tool for multi-resolution data structure visualization, interactive selection, transformation, painting, of huge scanner data (point cloud) sets [1].

Xiao et al. were provided an algorithm for surface flattening, started with the surface reconstruction as a triangular mesh from the 3D point cloud data which acquired using laser scanners, then using the mechanics revision to locate the damage and collapse on the inner side of the tunnel to ensure the railroad of transportation operations [2].

Kisztner et al. introduced an algorithm based on image processing and remote sensing to create a software and procedure using cluster analysis and spectral behavior analysis to general use for vegetation separation from the 3D data cloud acquired by Terrestrial Laser Scanning [3].

Gauthier et al. have proposed a method to analyze a histogram of curvature for an actual object using a digitized 3D surface, also propose using the analysis of the curvature histogram to retrieve a CAD model for many steps of a reverse engineering process [4].

Lee and Bo were suggested a smooth reconstructs feature curves approach and refine incident approximation planes from the 3D point cloud based on intersections of developable strip pairs and approximation of the point cloud as linear segments to collect the features of the curves [5].

Min was presented a surface reconstruction approach, based on identifying the basic parts of the object surface and construct blinding surfaces to blends between these surface parts, the normal vectors were used to divide the part of the surface into triangular patches to obtaining the boundary representation and reconstruction of model [6].

Leal et al. presented a linear programming model to point cloud simplification, depending on the assessment of a local density for the point cloud, to detecting and deleting a noise and outlier points in the point cloud, then using the curvature value to define the point cloud set clustering and finding the noise points with a high curvature value to reduce the point cloud set [7].

In the present work, a new algorithm for simplification of the point cloud data will be established which based on the tangent continuity as one of the most important surfaces geometrical feature. The proposed algorithm is robust and not require an additional estimation procedure for the detection of the noise points in point clouds. The proposed algorithm has a methodology consist of three basic stages. The first stage was represented by a data acquisition as point clouds using the 3D laser scanner, fitting the acquire point clouds into a third-degree polynomial, and the instantaneous calculation of tangent continuity for each point in point clouds was established in the second stage. Finally, in the third stage, the noised points will be detected and removed from the set of the point clouds, arriving to obtain the mathematical representation equations which represent the surface of the intended case studies.

The present paper will be organized as follow, section 2 will be introduced the tangent continuity algorithm, then section 3 will be illustrated the methodology of tangent continuity algorithm, subsections 3.1 and 3.2 will be demonstrating the procedure of applying the tangent algorithm and the flowchart of the building program in MATLAB software respectively, section 4 will be showing the proposed case studies to ensure the validity of the proposed algorithm, in sections 5 the results and discussions will be present for the proposed case studies, finally a conclusion for the present work will be recorded and illustrate in section 6.

2. Tangent Continuity Pre-Processing Algorithm

Tangent or so-called first-order parametric continuity (C1) is the property for geometrical curve and surface, the tangent continuity means that the first parametric derivatives (tangent lines) of the coordinate functions. First-order continuity was used for drawings digitization and some design applications [8]. The tangent vector of a parametric curve at any point is given by the first derivative of the parametric equations for the curve. The length or magnitude of the tangent vector depends on the parameterization and affects the interior shape of the curve. When the tangent vector magnitudes exceed some multiple of the chord length between the endpoints of the curve segment, the curve exhibits unfavorable characteristics, such as loops and cusps [9]. Figure 1 shown a fixed-point X on the curve $f(u)$ and the moving point P on the same curve. The tangent vector constructed at point X by moving the point P toward X.

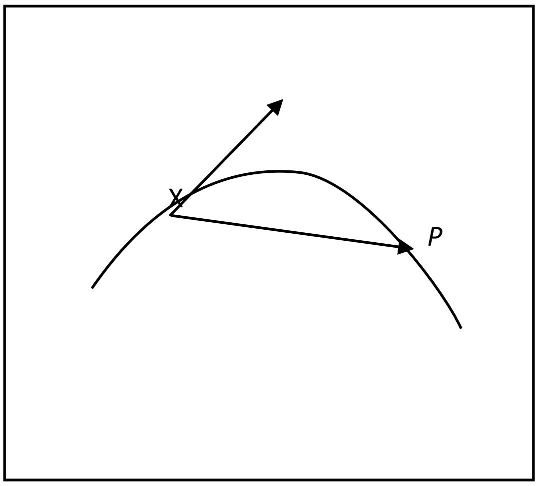

Figure 1: Curve tangent vector

The tangent vector magnitude at any point can be computed simplest by calculation of the first derivative at this point [10].
If the surface represented as

$$\boldsymbol{f}(x, y) = f1(x, y), f2(x, y), f3(x, y) \quad (1)$$

The partial derivatives

$$\boldsymbol{f}_x = \partial \boldsymbol{f} / \partial x \quad (2)$$

And

$$\boldsymbol{f}_y = \partial \boldsymbol{f} / \partial y \quad (3)$$

The partial derivatives are the changing rates of $\boldsymbol{f}$ with respect to changes in one of the variables while the other is held fixed, this concept illustrates in Figure 2 for the partial derivative (tangent) of the surface cross-section for one variable while the other variable is constant [11].

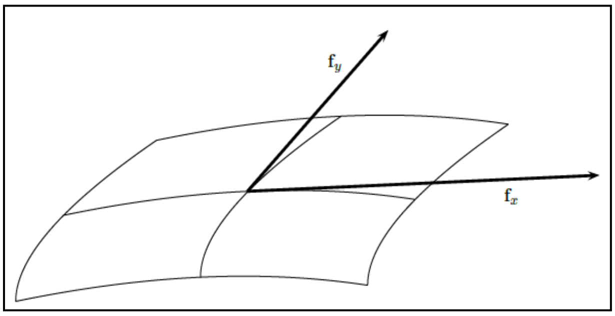

Figure 2: The surface tangent vectors

3. The methodology of the Tangent Pre-Processing Algorithm

The developed tangent pre-processing algorithm based on the tangent value calculation through the first derivative of the polynomial which produced from the surface fitting of the scanned point cloud. The algorithm supposes the value of the tangent difference (S) is constant between each adjacent point along the curve segment of the points streamline in the point cloud. So, the tangent value of the orthogonal coordinate axis will be computed for each point in the streamline of points and the tangent difference value will be computed, then this current value of tangent difference will be compared with pre-computed value (S) of the tangent difference. So, when the computed tangent difference value greater than (S) for any point, that identifies the point, maybe represent noise or unnecessary point which can be neglected in the final result of the streamline points of the curve segment. The value of (S) is a mean computed value for all tangent difference values. In such a way the noised points can be identified along the other curve segment, which belongs to the surface of the object, where these points don't represent the actual representation of the desired surface. The proposed tangent algorithm was mathematically simplest and precise for detecting the noise points and filtering the row point clouds.

3.1. Procedure to Apply the Tangent Pre-Processing Algorithm

To simplify the row point clouds using the methodology of the proposed tangent pre-processing algorithm, it can apply the sequence of the following steps:
Step 1: input the streamlines of set points $\{P_i, P_{i+1}, P_{i+2}, \ldots, P_n\}$
Step 2: find the polynomial equation (E_p) for the point cloud set using the surface fitting
Step 3: compute the first partial derivative of the polynomial (E_p) in the direction x-axis (∂E_{px}), and y-axis (∂E_{py}), separately.
Step 4: compute the pre-value of tangent difference (S_x), (S_y) in x and y axis respectively.
Step 5: calculate the value of tangent difference (ΔD_x) and (ΔD_x) using the formula:

$$\Delta D_x = \Delta D_{x(i+1)} - \Delta D_{x(i)} \quad (4)$$

$$\text{or } \Delta D_y = \Delta D_{y(i+1)} - \Delta D_{y(i)} \quad (5)$$

Step 6: compare the value of (ΔD_x) and (ΔD_x) with the value of (S_x), (S_y) respectively, and make the decisions
- If $|\Delta D| \leq S$. Therefore, the point (P_{i+1}) is within the data points which represent a point on the object's surface.
- If $|\Delta D| > S$, then the point P_{i+1} does not represent the data point for the object's surface and can be considerd as a noisy point which needs to remove from the final result of data points for object's surface. Then replace P_{i+1} with P_{i+2} and repeat steps 4 and 6. Step 7: repeat steps 5 and 6 until all data points cover the procedure. Step 8: save the needed data points and neglect the noisy point.

3.2. Proposed Algorithm Program

A MATLAB program has been built to perform the methodology of the proposed tangent continuity simplification algorithm. Figure 3 shows the basic steps of the adopted MATLAB program in the flowchart, where the building program started with importing the data points as a point cloud which acquired using the 3D laser scanner device, then fitting these points to generate the explicit parametric equation which represents the object's surface. The tangent value will be computed in the next step for each point in the point cloud, finally, the tangent difference value between each adjacent two points will be computed and compare to take the decision wherever the point represent the noisy point or the specific point on the object's surface.

4. Proposed Case Studies

To prove the proficiency of the adopted algorithm for simplification of the data points and detection of the noisy points in point clouds, two case studies were suggested with different shapes as shown in Figures 4 and 5.
These case studies have been 3D scanned using the (Matter and Form) 3D laser scan device. After complete the scanning process for the case studies the output file saved as a data point cloud with (x, y, z) format ('file name'. xyz) in three dimensions coordinate using the assisted software for the scanner device 'Matter and Form', then the file has been imported in 'Excel' program to re-arrange the data point cloud and save it in (.xlsx) format, after that the file has been opened in 'MATLAB' program to perform processing with the proposed tangent continuity algorithm and save the file with data (dat.) format ('file name.dat.'). The file of the first case study has been contained in the total number of points (900820) in the beginning, while in the second case study's file the total number of points was (1133648) after complete the 3D scanning process.
Wherever Figure 6 shows the resulted shape of the first case study after completing the 3D scanning process, while Figure 7 illustrates the 3D scanning process for the second case study, which was associated with imperfect and noised scanning data points or loosed data, so, the aim of proposed

simplification algorithms is to detect and ignore the noise data 'points' which appear in Figures 6 and 7 as scatter points.

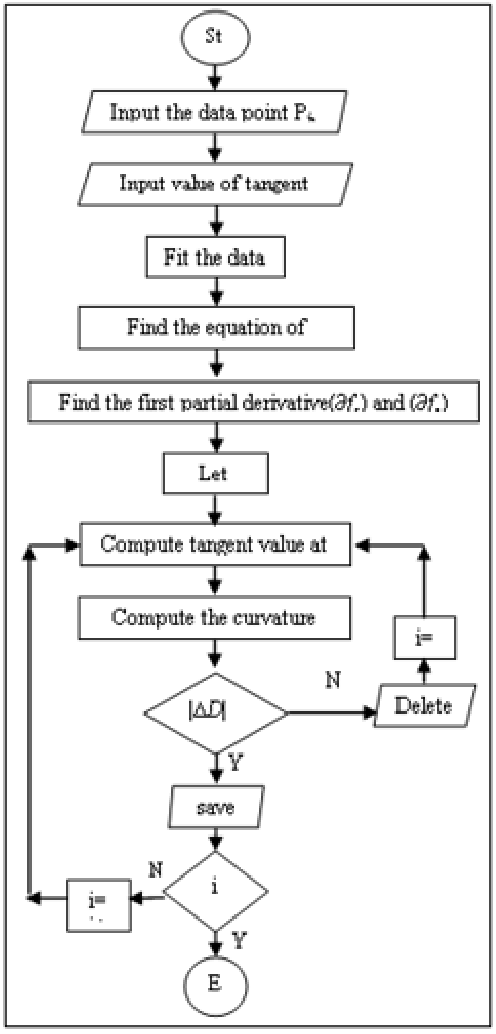

Figure 3: Flow chart of Tangent Pre-Processing algorithm

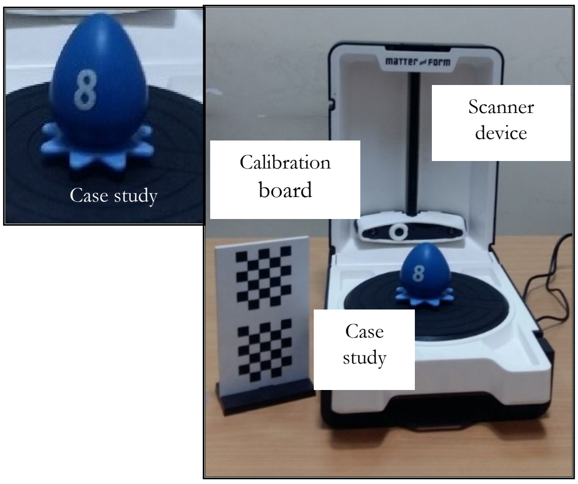

Figure 4: The First Case Study

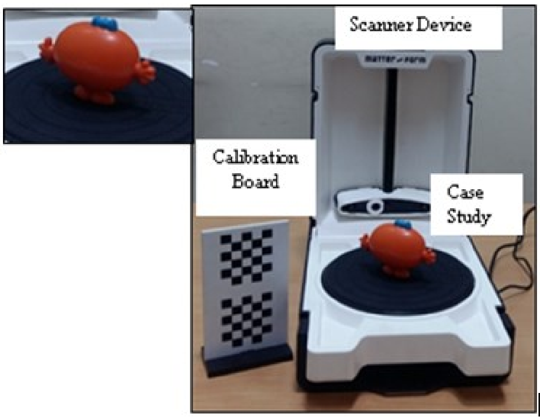

Figure 5: The Second Case Study

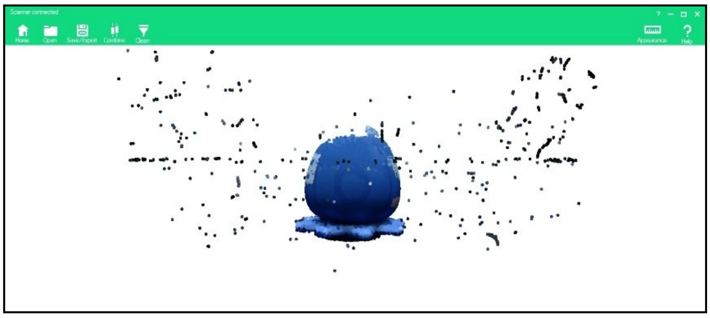

Figure 6: Noise Points in First Case Study

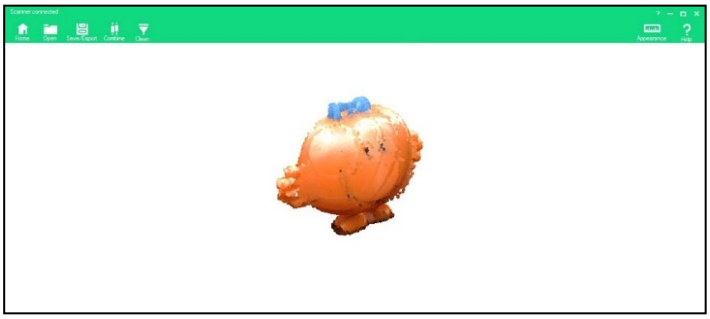

Figure 7: Noise Points in Second Case Study

5. Results and Discussion

As a result of applying the adopted tangent continuity algorithm with x-axis for point clouds simplification, the file of the first case study become include (507826) as the total points, for single processing attempt and the percent of deleted points as noisy points was (43.63%), which was neglected as unnecessary points, while the file of the second case study was included (770776) and the percent of deleted points was (32.01%), as a result to execute the adopted algorithm for single attempt. These results for the proposed two case studies showed that the adopted tangent continuity algorithm for the x-axis was very effective for the data points simplification through detecting and removing the noisy points as unnecessary points. Figures 8 and 9 show the final resulted point clouds for the first and second case study respectively. The surface reconstruction process was done using the facilities of MeshLab software for the first and second proposed case studies, respectively as shown in Figures 10 and 11.

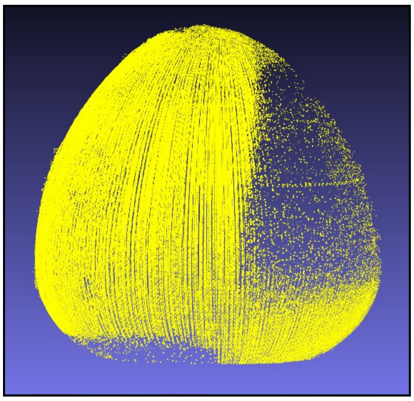

Figure 8: Resulted point cloud of the first case study

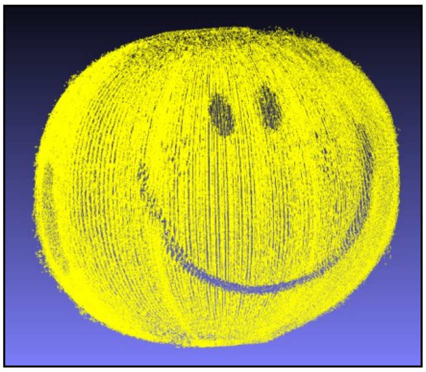

Figure 9: Result point cloud of the second case study

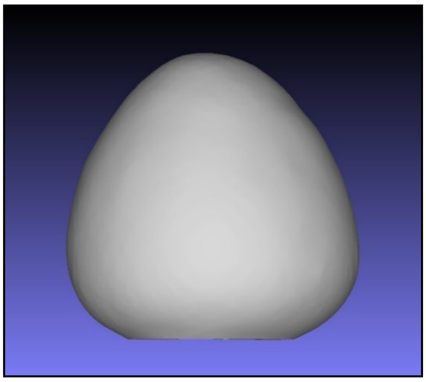

Figure 10: Resulted Surface Model for The First Case Study

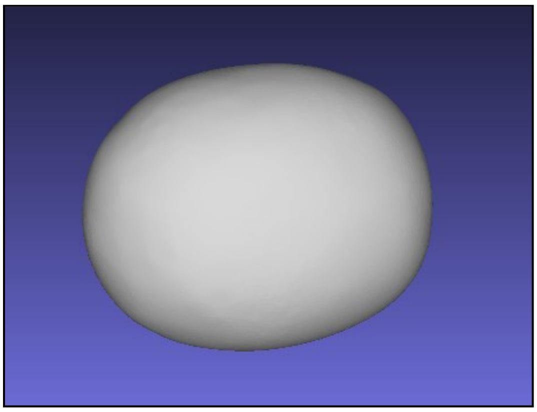

Figure 11: Resulted Surface Model for The Second Case Study

The resulted point clouds from the application of the proposed tangent continuity algorithm of the chosen case studies were fitted using the surface fitting process in MATLAB software to generate a mathematical representation for the studied case studies.
And the result of this fitting process has listed as equation as follow:
First case study:
The equation is a linear polynomial with degree three in x and y direction:

$$F(x,y)= p_{00} + p_{10}*x + p_{01}*y + p_{20}*x^2 + p_{11}*x*y + p_{02}*y^2 + p_{30}*x^3 + p_{21}*x^2*y+ p_{12}*x*y^2 + p_{03}*y^3 \quad (6)$$

And the Coefficients of the polynomial were inserted in Table 1 according to tangent continuity with the x-axis algorithm.

Table 1: Coefficients of Polynomial of the First Case Study according to tangent continuity with x-axis.

Coefficient	p_{00}	p_{10}	p_{01}	p_{20}	p_{11}	p_{02}	p_{30}	p_{21}	p_{12}	p_{03}
Value	6.403	-3.557	0.2931	0.03756	-0.01133	0.04866	0.005375	-0.000481	0.005792	-0.000587

Second case study:
The equation is a linear polynomial with degree three in x and y direction, which similar to equation (6). And the polynomial coefficients were listed in Table 2, according to tangent continuity with the x-axis.

Table 2. Coefficients of Polynomial of the Second Case Study according to tangent continuity with x-axis.

Coefficient	p_{00}	p_{10}	p_{01}	p_{20}	p_{11}	p_{02}	p_{30}	p_{21}	p_{12}	p_{03}
Value	-12.12	0.5777	1.633	-0.03321	-0.02776	0.0003475	-0.04435	0.0002892	0.0001854	0.0007664

6. Conclusion

The 3D scanning process by a modern 3D laser scanner devices used for the digitization of the 3D objects as a reverse engineering application. There is some imperfect information, which associated with the digitization process, such as noisy points and the huge number of points in the point could of the scanned objects. So, it's necessary to simplify and preprocessing the row point clouds with the number of approaches and algorithms to treat these problems. In the present paper, a data simplification algorithm has been proposed to extract the necessary points from the huge point clouds to generate the geometrical representation of the scanned objects and delete the noisy points, the proposed algorithm based on the instantaneous estimation of tangent value for each point in the point cloud set. The application results of the proposed tangent continuity algorithm and the result of the surface fitting process proved the proficiency of the present algorithm to simplify and preprocessing the point clouds for any selected case study. Where the total number of the scanned points for the first proposed case study was (900820), which become (507826) after application the adopted tangent continuity with x-axis algorithm, and the percent of deleted points was (43.63%), from the total number of the data points, while for the second case study the scanned file was contained (1133648) as total points, then this points becomes (770776) after application the adopted tangent continuity algorithm and the percent of deleted points was (32.01%).

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