Journal of Engineering and Applied Sciences 12 (7): 1902-1909, 2017
ISSN: 1816-949X

Evaluation of a Proposed Blunder Detection Method in ICP Algorithm for Fine Registration of Point Cloud Data

[1]M. Ranjbar and [2]M. Saadatseresht
[1]Department of Civil Engineering, College of Engineering, University of Zabol, Zabol, Iran
[2]Department of Geomatic Engineering, College of Engineering, University of Tehran, Tehran, Iran

Abstract: Laser scanners directly measure 3D coordinates of huge amounts of points in a short time period, so that it has a well-known solution in 3D object modeling. The abundant data of laser scanner can be efficiently utilized to model the scene, however in many cases; the object has to be scanned from different viewpoints due to accuracy occlusion field of view and range limitations. Because each scan has its own local coordinate system, all the different point clouds must be transformed into a common coordinate system. This procedure is usually referred to 'registration'. There are many methods for registration problem including Target based, Image based and surface based registration methods. Surface based registration techniques give the highest registration accuracy and automation. This dissertation addresses refinement issue of surface based registration by use of an accurate and fast ICP algorithm. In the ICP algorithm, every point in one surface should be matched to a point on the other surface so that the matched surfaces have minimum deflection error. In our research, we compared both distant and normal vector thersholding and proposed a combined method in 3D surface matching. Analysis and experimental results demonstrated the proposed combined method gives better registration accuracy than the other standard approaches. Also in the research, different factors in accuracy and efficiency of registration algorithm are tested such as mathematical criterion function, using respectively Singular Value Decomposition (SVD) or eigen system computation based on the standard (R, T) representation and the eigen system analysis of matrices derived from quaternion forms of the transform, simple/complex surface geometry, initial values, surface overlapping and data conditions (ideal or noisy). The examinations demonstrate that accuracy of registration is not significantly different for the both mathematical computation methods of SVD and quaternion. It also shows that efficiency of registeration diminish for tough breaking surfaces and by low approximation of initial values. Registration has higher accuracy for more overlapping surfaces and lower level of noise in data. Therefore determination of initial overlap area especially for noisy data is so important.

Key words: Registration, thersholding, normal vector, point cloud, laser scanning, SVD, quaternion

INTRODUCTION

Today, one of the most important goals in photogrammetry and computer vision is preparation the 3D data from the surface of objects and 3D object modeling that its various applications including the reverse engineering (Peng *et al*., 2001; 2002) quality control of industrial plants (Boverie *et al*., 2003) robot guidance, preparing CAD models of objects, cultural heritage and historic buildings, reconstruction of human face for animation applications (Nahmias *et al*., 2005) has been caused extensive research in this field.

In this regard, techniques and different methods for extracting and preparation the 3D data from the surface of objects are presented (Bradshaw, 1999; Dipanda *et al*., 2003; Remondino and Hakim, 2006; Remondino *et al*., 2005). Laser scanners directly measure 3D coordinates of huge amounts of points in a short time period so that it has a well-known solution in 3D object modeling (Gruen and Akca, 2004; Akca, 2007).

In many cases, the object has to be scanned from different viewpoints due to accuracy, occlusion, field of view and range limitations. Because each scan has its own local coordinate system, all the different point clouds must be transformed into a common coordinate system. This procedure is usually referred to registration (Akca, 2007).

For this purpose, now a days most terrestrial laser scanners in the process of a ground operation after installing some target and measure their exact coordinates at each station using a sign on the target and scan it with high-resolution, obtained point clouds from different stations are joint together.

Corresponding Author: M. Ranjbar, Department of Civil Engineering, College of Engineering, University of Zabol, Zabol, Iran

This method aside from being time consuming and requires a ground operation, causes manipulate the object and the surrounding environment for installing the target. also the accuracy of this method depends on the user control, the number, distribution, stability, orientation and targets distance of each station (Sternberg *et al*., 2004).

In contrast, methods based on surface matching are discussed that without the use of target and almost automatic register the surfaces. Although, in these methods directly are used massive and with errors point clouds, however, based on recent research tests, these methods have achieved of higher speed, accuracy and reliability than target based registration methods (Gruen and Akca, 2004).

The goal of this research is surface based registration by use of an accurate and fast Iterative Closest Point (ICP) algorithm (Chen and Medioni, 1992). Since, one of the most important steps of registration is find the pair of corresponding points, must be ensured the accuracy of the selected pair of corresponding points.

So pair of points must be removed after ensuring that they do not reliability. In this study, we compared both distance and normal angles thersholding in constant and variable mode, we examine the features of each of the methods and according to good standards of each of these methods to exclude wrong pair of corresponding points, proposed a combined method that is having both the features of methods. On this basis, the registration algorithm implement according to the above defined thersholding method and the shape of surfaces was investigated as a factor in efficiency and accuracy of the registration.

MATERIALS AND METHODS

Overall work process steps are as follows:

- Data modeling by triangulation and determine common areas. To find common areas we use a nearest neighbor algorithm with a almost small threshold. We in this here in regard to resolution of the point cloud and approximate amount of cover between point clouds we experimentally determined the threshold
- Determine convex surface surrounding points for primary registration and calculation initial rotation and transfer parameters and acts it on the point cloud that we want register it
- Matching between points from the nearest neighbor algorithm kd-tree
- Reject the wrong pair of corresponding points
- Using quaternion algorithms to calculate the transformation parameters
- Calculation error of registration e that is defined as RMS distance between corresponding points
- Define an error metric for algorithm stop
- Repeat the steps with a new set of obtained points and optimizing the parameters

Here, we have used six methods of thresholding on the corresponding points including:

- Using a constant thresholding on the distance between corresponding points
- Obtain the normal angle of each point and using a constant thresholding on the surface normals
- Combined use of both constant thresholding on the distance and surface normals
- Get variable of corresponding points distance based on the amount of standard deviation: by use of the test known as three sigma (3σ), the distance between corresponding points that do not apply in relation $d < \bar{d} + 3\sigma$ identified in set of corresponding points and was removed as the corresponding error from set of corresponding points and the remaining corresponding were used to calculate the transformation parameters that the amount σ is optimal in each iteration
- Thresholding on the surface normals as variable: in this case was used as a variable distance from the three sigma test (3σ) and if the angle between the surface normals does not apply in range of $\bar{\theta} - 3\sigma < d < \bar{\theta} + 3\sigma$ is known as the corresponding error
- Combination use of both methods of variable thresholding on the distance and surface normals: points are selected as corresponding points that apply to both distance and angle between the normals conditions

By using the obtained corresponding and with the computational quaternion algorithm are obtained the registration parameters.

Determine the registration mathematical model: In simple terms, registration is R roatation and T transfer from one surface X to another surface Y which causes two surfaces to be connected with an optimum connection. Usually transformation equation is defined as follows:

$$Y = RX + T \tag{1}$$

where, X and Y are given and the purpose of registration is determine the T and R. So that connect two surfaces whit high precision. Surfaces contain N corresponding points and only some of them be used to process of registration. Outliers due to inaccurate measurements and hidden areas may be Strongly Cause of the loss of quality registration that should be removed they. Corresponding X and Y points can be described in subsets $\{x_1, x_2, ..., x_n\}$, $\{y_1, y_2, ..., y_n\}$. Using this corresponding points Eq. 1 can be written as follows:

$$y_i = Rx_i + T \tag{2}$$

If the data are complete, then T and R can be calculated from Eq. 2. Practically never will not find the same rotation and transmission for any point and this is the result of factors such as irregular sampling and noise. Therefore it is necessary to consider an error for every point (Chen and Medioni, 1992).

$$e_i = y_i - Rx_i - T \tag{3}$$

And to minimize sum square errors we use Eq. 4 for determine T and R:

$$\sum{}^2 = \sum_{i=1}^{N} \left\| y_i - Rx_i - T \right\|^2 \tag{4}$$

Registration algorithm, is the process that are used for determine R and T. For this purpose, some pre-processing is required. It is necessary that set of corresponding points $\{x_1, x_2, ..., x_N\}$ and $\{y_1, y_2, ..., y_N\}$ shifted to center of gravity the data. In the first are calculated center of corresponding X,Y points as:

$$\mu_x = 1/N\sum_{i=1}^{N} x_i \text{ and } \mu_y = 1/N\sum_{i=1}^{N} x_i$$

Original data sets are shifted to the center of gravity as $y'_i = y_i - \mu_y$ and $x'_i = y_i - \mu_y$. Then, the registration matrix is calculated by use of this transferred data set. Note that the T transformation is a function of R which is calculated with $T = \mu_y - R\mu_x$. Equation 4 can be written as follows:

$$\sum{}^2 = \sum_{i=1}^{N} \left\| y'_i - \hat{R}x'_i \right\|^2 = \sum_{i=1}^{N} (y_i^{'T} y'_i + x_i^{'T} x'_i - 2y_i^{'T} \hat{R} x'_i) \tag{5}$$

This equation is a minimum when the last term is the maximum and this is equivalent to maximum $\mathrm{Trace}(\hat{R}, H)$ which the correlation matrix H is defined as follows:

$$H = \sum_{i=1}^{N} x'_i y_i^{'T} \tag{6}$$

Several methods is proposed to minimise Eq. 4. That can be noted quaternion rotations (Johnson and Kang, 1997), Eigenvalue decomposition (Peng *et al.*, 2001) orthogonal matrices (Godin and Boulanger, 1995) and dual quaternion (Johnson and Kang, 1997). Quaternion and svd methods has been considered in most research. The reason for this is that these methods do not need repeat consequently will cost less computational.

RESULTS AND DISCUSSION

Performed tests: In this study with examination of tests and results evaluate the quality and quantity of algorithm. Algorithms are implemented in mathlab Software environment. We have the stop condition of implemented algorithm coordinate change in each step than the previous step, maximum number of repeats and relative error of registration process. If we assume the d is corresponding point to the first set and m is corresponding point to the second set error is calculated by the following equation:

$$\text{Error} = \sqrt{\sum_{i=1}^{N} ((d_{x_i} - m_{x_i})^2 + (d_{y_i} - m_{y_i})^2 + (d_{z_i} - m_{z_i})^2)} \tag{7}$$

Also relative changes of error is calculated as follows:

$$\text{rel}_{\text{error}_{\text{change}}} = \left[\frac{\text{error}_{\text{old}} - \text{error}}{\text{error}_{\text{old}}} \right] \tag{8}$$

And coordinate changes of the destination set $\{m_i\}$ is obtained as the following equation:

$$\text{Coord} - \text{Change} = \sqrt{\sum_{i=1}^{N} ((m_{x_{i_{old}}} - m_{x_i})^2 + (m_{y_{i_{old}}} - m_{y_i})^2 + (m_{z_{i_{old}}} - m_{z_i})^2)} \tag{9}$$

If any of the above conditions applies the algorithm stops and otherwise we use maximum number of repeate condition. Finally, the final parameters are defined.

Review of thresholding method: In this test by use of the SVD algorithm the obtained corresponding points were examined by a constant thresholding on the distance between corresponding points, constant thresholding on the surface normals, the combined use of both constant thresholding on the distance and surface normals, get variable corresponding points distance based on amount of standard deviation, variable thresholding on the surface normals and the combined use of both variable thresholding on the distance and surface normals and algorithm is implemented with each of the thresholding methods.

Table 1: Results of thresholding methods in low rotation and transfer mode

Thresholding methods	Repeat	Error(m)	Relative error	Coordinate changes	No. of corresponding points in the final repeat (%)	Stop condition
Constant distance	7	7.70E-15	0.66	1.23E-12	100.00	Establishing the coordinate change condition
Constant Angle	7	6.51E-15	0.70	1.33E-12	78.60	Establishing the coordinate change condition
Constant combination	7	1.16E-14	0.68	1.99E-12	78.60	Establishing the coordinate change condition
Variable distance	7	1.34E-14	0.20	1.32E-12	98.40	Establishing the coordinate change condition
Variable angle	7	1.15E-14	0.49	1.40E-12	100.00	Establishing the coordinate change condition
Variable combination	7	1.34E-14	0.20	1.32E-12	98.40	Establishing the coordinate change condition

Table 2: Results of thresholding methods in high rotation and transfer mode

Thresholding methods	Repeat	Error(m)	Relative error	Coordinate changes	No. of corresponding points in the final repeat (%)	Stop condition
Constant distance	124	0.201995	-9.6E-16	8.00E-13	42.20	Establishing the coordinate change condition
Constant Angle	12	2.09E-14	0.38	1.59E-12	78.60	Establishing the coordinate change condition
Constant combination	100	0.196917	0.00	9.28E-13	40.30	Establishing the coordinate change condition
Variable distance	12	1.52E-14	0.76	3.98E-12	98.90	Establishing the coordinate change condition
Variable angle	12	8.57E-15	0.59	1.08E-12	100.00	Establishing the coordinate change condition
Variable combination	12	2.07E-14	0.62	3.07E-12	98.60	Establishing the coordinate change condition

We performed test for simulation data of aircraft fuselage with 37,500 points. For this purpose first We took point cloud of fuselage as reference point cloud. Then rotation and transfer this point cloud to desired amount and we selected as secondary surface that should be register to the first point cloud. Test was done in low rotation and transfer ($\omega = \phi = \kappa = 1$, $t_x = t_y = t_z = 1$) and relatively high rotation and transfer ($\omega = \phi = \kappa = 10$, $t_x = t_y = t_z = 10$) that can be seen in Fig. 1.

We noticed with view Table 1 when surfaces have little difference together ($\omega = \phi = \kappa = 1$, $t_x = t_y = t_z = 1$) can not be seen dramatic differences between the thresholding methods. Considering that combined method with more sensitive select the corresponding points and must be both conditions of normal distance and angle, our confidence level to being the corresponding in combination mode is over other methods. Results of relatively high rotation and transfer ($\omega = \phi = \kappa = 10$, $t_x = t_y = t_z = 10$) can be seen in Table 2.

As we see in Table 2 when two surfaces have a large difference, constant distance thresholding method have not been successful in identifying corresponding and accuracy of registration is greatly reduced and causes in the constant combined mode also the performance of algorithm is reduced and require higher computing time. But in variable mode in all three angle, distance and combined modes algorithm works well. What we notice here is that constant threshold value determining is an important factor for algorithm performance.

Review of computational algorithm: As we have seen, algorithm performance in surfaces with low difference is high and in high differences do not reach the desired accuracy (desired accuracy in our experiments is 10^{-6} m). So here for review and evaluation of both SVD and quaternion methods is used only two surfaces with low rotation and transfer difference with the variable

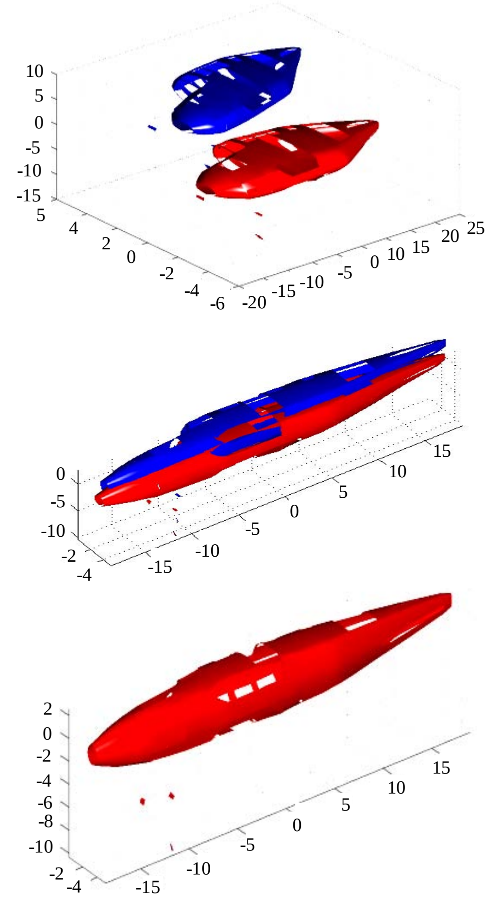

Fig. 1: Simulated aircraft fuselage view: left image: reference surface, middle image: low rotation and transfer mode, right image: high rotation and transfer mode

Table 3: Results of variable distance and angle combined thresholding in low rotation and transfer mode with quaternion method

Repeats	Error (m)	Relative error	Coordinate changes	No. of used corresponding points (%)
1	0.15040600	0.27	9.073500	97.80
2	0.06769810	0.55	4.511000	98.10
3	0.02646460	0.61	2.079620	99.10
4	0.00551304	0.79	0.731710	99.10
5	2.55E-05	1.00	0.112556	99.30
6	2.08E-14	1.00	4.15E-05	100.00
7	4.58E-15	7.80E-01	1.28E-12	99.10

Algorithm stop condition; Minimum reached: coordinate change 1.28003e-012<1e-006; used time to execute the algorithm; 2.012361 sec

combined thresholding method. We have observed results of the SVD method in variable combined thresholding mod in Table 1. Results of the quaternion method in variable combined thresholding mode can be seen in Table 3. We notice with comparison Table 1 and 3 that there is not much difference in the use of SVD and quaternion method.

Review of algorithm in noisy surfaces: In this test algorithm was evaluated using SVD function and i variable combined thresholding method on the noisy surfaces that had a degree of difference. Algorithms carried out in three levels of normal noise ($\sigma = 0.01$, 0.1, 0.5) that can be seen in Fig. 2-4.

As is clear in Fig. 2-4 algorithm do not performance for noise surfaces and not convergence to the answer. Any amount of noise is more highly accurate time of registration is reduced. Therefore, it is necessary before register the surfaces remove the surfaces noise through filtering.

Review of surfaces shape: Surfaces shape plays an important role in the precision of registration. For this purpose was used three types of data with different properties that can be seen in Fig. 5. We test on this three surfaces in the case differed three degrees together. Algorithm execute with quaternion and variable combined thresholding method. Results of each of the surfaces can be seen in Fig. 6-8.

As is known in Fig. 6 algorithm have not been successful for surfaces with severe fractures and is not converging to the desired response (10^{-6}). As can be seen in the figures We have trouble in fractures and edges.

As is clear in Fig. 7 algorithm have not been successful for smooth surfaces and is not converging to the desired response. This could be due to the algorithms in smooth surfaces due to proximity of normal angles to one another and finally is choosing the wrong pair of corresponding points. also in smoothing areas usually is selected a few points as the corresponding point which causes low accuracy of registration. We notice with seeing Fig. 8 the algorithm well acted on the surfaces with Suitable topography and is converging to answer with a suitable number of repeats.

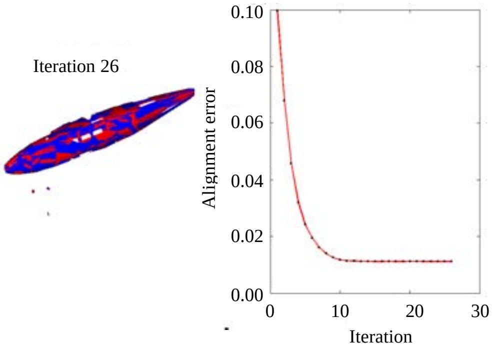

Fig. 2: Accuracy and convergence of surfaces with noise level $\sigma = 0.01$

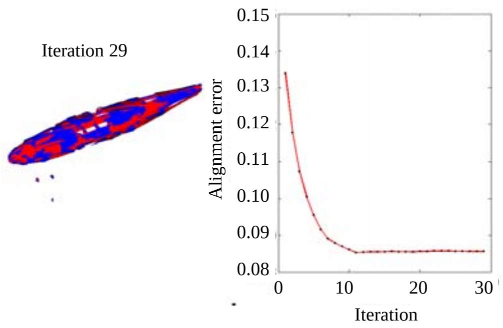

Fig. 3: Accuracy and convergence of surfaces with noise level $\sigma = 0.1$

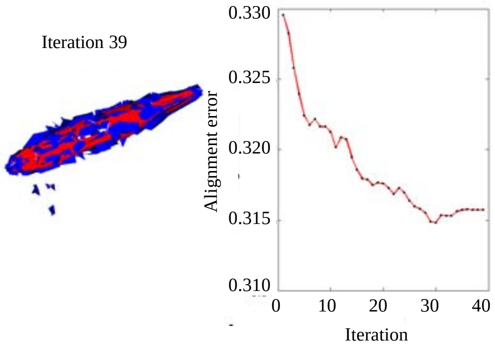

Fig. 4: Accuracy and convergence of surfaces with noise level $\sigma = 0.5$

Quality assessment of algorithm: To quality assessment of the registration algorithm was used the real point cloud, output of program in the Matlab Software. Results from the registration of point clouds can be a seen in Fig. 9-11.

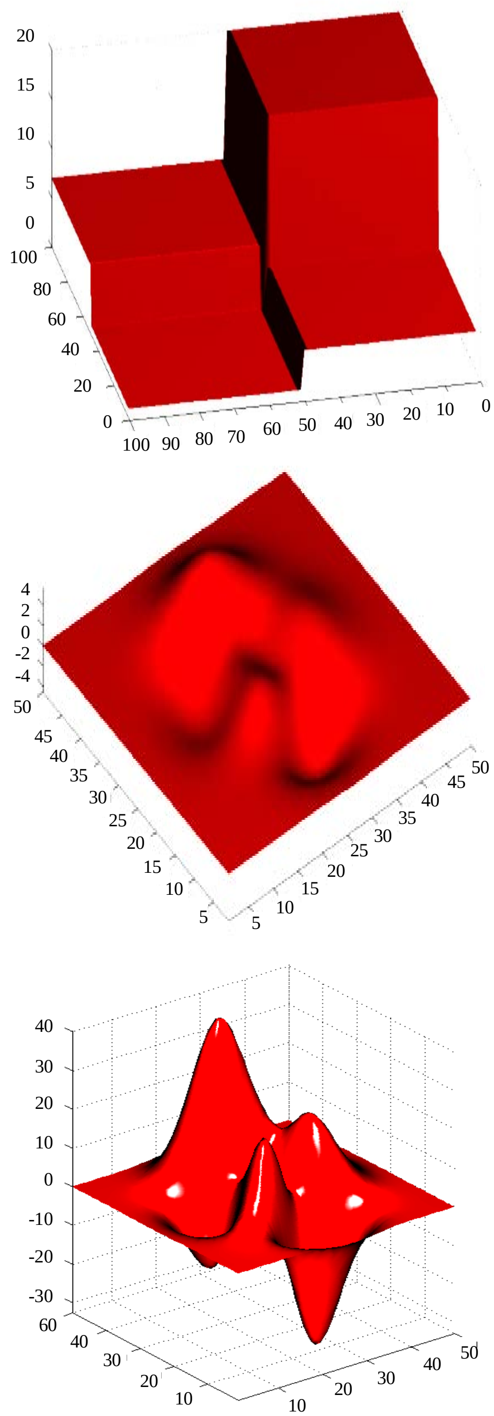

Fig. 5: Display various surfaces to check the convergence of the algorithm. Left image: flat surface with severe fractures. Middle image: the relatively smooth surface. Right image: rough surface

All registered point clouds demonstrate the good quality and accuracy of the proposed algorithm.

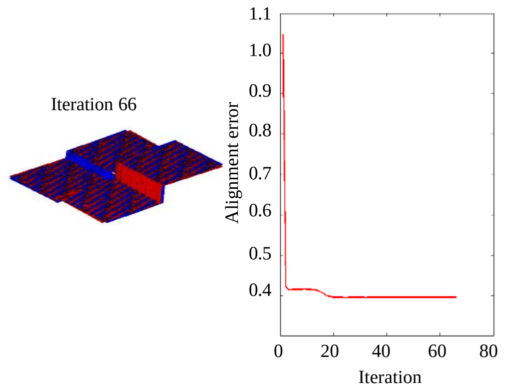

Fig. 6: Convergence of smooth surfaces with severe fractures

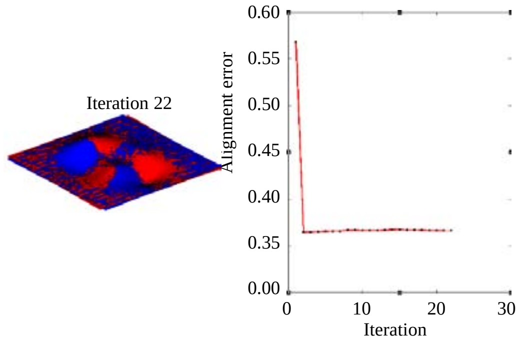

Fig. 7: Convergence of smooth surfaces without blunder

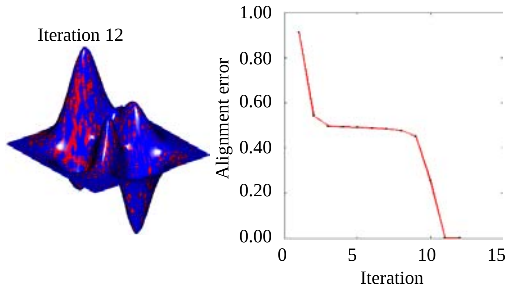

Fig. 8: Convergence of rough surfaces without a blunder

Fig. 9: Registeration of rooster statue. right Image: color image of statue. Middle image: two views of the statue before registeration. Left Image: 3D model of the statue after registeration

Fig. 10: Registeration of achaemenid soldier statue. Right image: color image of statue. middle image: two views of the statue before registeration. left Image: 3D model of the statue after registeration

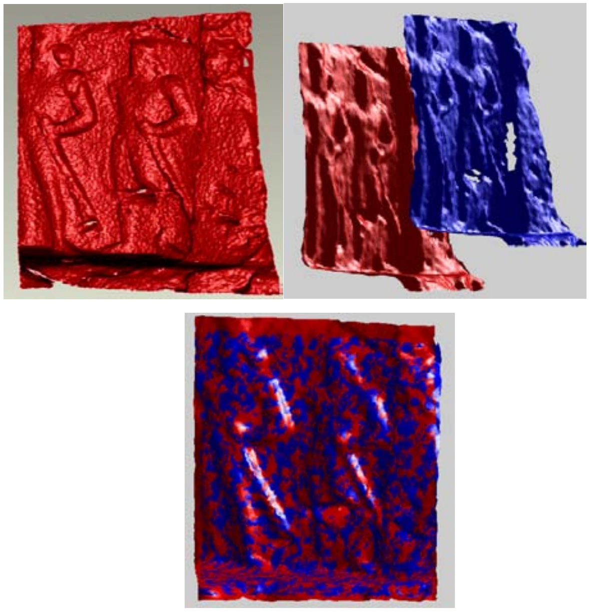

Fig. 11: Registeration of achaemenid inscription. Right image: two surfaces before registeration. Middle image: View the inscription in geomagic studio software after get the parameters. Left image: 3D model of the inscription after registeration

CONCLUSION

Since, one of the most important steps of registeration is finding the pair of corresponding points, must be ensure of the correctness of the selected pair of corresponding points. Therefore pair of points that do not ensure to they must be removed. In this study by comparison of variable distance thresholding and normal angle thresholding methods We found that each of these two methodes is a particular feature and each alone has a good criterion for rejecting the wrong pair of corresponding points.

Also tests in combined thresholding mode and was observed that the accuracy and speed of registeration increased to an acceptable level. Thus by using the combined thresholding method can be achieved to accurate, efficient and reliable registeration system in different conditions. With review the performance of algorithm with regard to surfaces shape we found that the algorithm acts unsuccessful for surfaces with severe fractures, especially at the edges. Also algorithm for smooth surfaces is not converging to answer and is reached to a local minimum point. Algorithm is well acted For severe roughness surfaces. But for the complex and uneven surfaces that have wrong points, the ability to identify these points is a little reduced.

REFERENCES

Akca, D. 2007. Matching of 3D surfaces and their intensities. ISPRS. J. Photogramm. Remote Sens. 62: 112-121.

Boverie, S. M. Devy and F. Lerasle, 2003. Comparison of structured light and stereovision sensors for new airbag generations. Control Eng. Pract. 11: 1413-1421.

Bradshaw, G. 1999. Non-Contact Surface Geometry. BA Thesis, Trinity College Dublin, Dublin, Irland.

Chen, Y. and G.G. Medioni, 1992. Object modeling by registration of multiple range images. Image Vision Comput. 10: 145-155.

Dipanda, A. S. Woo and F. Marzani, 2003. 3-D shape reconstruction in an active stereo vision system using genetic algorithms measuremen techniques. J. Pattern Recognit. 36: 2143-2159.

Godin, G. and P. Boulanger, 1995. Range image registration through viewpoint invariant computation of curvature. Proceedings of the ISPRS International Workshop on Pixel to Sequences, March 22-24, 1995, ISPRS, Zurich, Switzerland, pp: 170-175.

Gruen, A. and D. Akca, 2004. Least squares 3D surface matching. Proceedings of the ISPRS Workshop on Panoramic Photogrammetry, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences Vol. 34, February 19-22, 2004, ISPRS, Dresden, Germany, pp: 1-8.

Johnson, A. and S. Kang, 1997. Registration and integration of textured 3-D data. Proceedings of the IEEE International Conference on Recent Advances in 3-D Digital Imaging and Modeling, May 12-15, 1997, IEEE, Ottawa, Canada, ISBN:9780818679438, pp: 234-241.

Nahmias, J.D. A. Steed and B. Buxton, 2005. Evaluation of modern dynamic programming algorithms for real-time active stereo systems. Proceedings of the 13th International Conference on Central Europe on Computer Graphics, Visualization and Computer Vision 2005, January 31-February 4, 2005, University of West Bohemia, Pilsen, Czech Republic, ISBN:80-903100-9-5, pp: 113-116.

Peng, X. C. Liu, Z. Zhang and P. Gu, 2001. Reverse engineering with 3-D imaging and modeling. Master Thesis, University of Calgary, Calgary, Alberta.

Peng, X. Z. Zhang and H.J. Tiziani, 2002. 3-D imaging and modeling-Part I: Acquisition and registration. Opt. Intl. J. Light Electron Opt. 113: 448-452.

Remondino, F. and E. Hakim, 2006. Image based 3D modeling: A review. Photogramm. Rec. 21: 269-291.

Remondino, F. A. Guarnieri and A. Vettore, 2005. 3D modeling of close range objects: Photogrammetry or laser scanning. Proceedings of the SPIE Conference on Electronic Imaging Science and Technology, January 18-20, 2005, SPIE, San Jose, California, pp: 216-225.

Sternberg, H. T. Kersten, I. Jahn and R. Kinzel, 2004. Terrestrial 3D laser scanning: Data acquisition and object modeling for industrial as-built documentation and ar-chitectural applications. Intl. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. 35: 942-947.