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POINT CORRESPONDENCECORRECTION BASED ON SURFACECURVATURE FEATURES

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Abstrak

Model komputer object *3D* dari suatu nyata telah banyak digunakan di berbagai macam aplikasi seperti motion capture, visi computer dan komputer grafik. Untuk membangun model komputer *3D* tersebut, data point cloud multiview objek nyata dari beberapa sudut pandang yang diperoleh dari scanner *3D* harus diregistrasi untuk diletakan pada sistem koordinat acuan yang sama. Salah satu langkah yang penting didalam registrasi adalah korespondensi Salah korespondensi akan mempengaruhi kualitas registrasi. Pada paper ini diusulkan teknik baru perbaikan korespondensi sehingga kualitas registrasi dapat ditingkatkan. Perbaikan korespondensi dimulai dengan mencari kandidat pasangan titik pada dua point cloud menggunakan konstrain rigid dua titik referensi dan dilanjutkan dengan perbaikan korespondensi dengan menggunakan fitur kurfatur permukaan. Teknik tersebut diaplikasikan pada tiga algorithma registrasi yaitu *ICP*, *ICP-AIF* dan *ICP-SCF* dan hasilnya dibandingkan dengan algorithma registrasi tanpa perbaikan korespondensi. Hasil percobaan menunjukan bahwa algorithma registrasi dengan perbaikan korespondensi 63% lebih cepat, 23% lebih akurat dan 530% lebih banyak menemukan korespondensi yang tepat dibanding dengan registrasi algorithma tanpa perbaikan korespondensi.

Kata kunci: Regsitrasi, *Point Cloud*, *Surface Curvature Feature*, Korespondensi.

Abstract

3D computer model of a real object has been widely used in various applications such as motion capture, computer vision and computer graphics. To build a 3D computer model, multiview data point cloud of real object from different view point that obtained from a 3D scanner must be registered to placing the multiview data point cloud into a common coordinate system. Correspondence to find pair point matching is an important step in registration. False correspondence will affected to the registration quality.A novel technique of point correspondence correction between two point clouds is presented in this paper. The correspondence technique is started by selecting pair point matching candidate base on two reference point constraint then followed by correspondence correction using surface curvature feature. We tested the technique by applying thecorrespondence correction technique into three registration algorithm registration which is ICP, ICP-AIF and ICP-SCF then compare it with the original registration algorithm The result shows that registration algorithm using correspondence correction 63% faster, 23% more accurate and to find 530% more correct pair matching point than the original registration algorithm.

Key words: Registration, Point Cloud, Surface Curvature Feature, Correspondence.

INTRODUCTION

Constructing a *3D* computer model of a real object from *3D* surface measurement data has various applications in computer graphics, virtual reality, computer vision and reverse engineering. To build a *3D* model it is necessary to have the *3D* information of the object surface which is collected by scanning device such as Laser scanner. However, most scanning device can only acquire partial information on the object surface at one viewpoint. In order to obtain a complete model, multiple acquisition from different pose must be performed. Then the derived local point cloud must be transformed into a common coordinate system. This procedure is usually referred to as registration.

Registration is performed within two stage, correspondence to find pair compatible point and follow by estimation of the transformation motion. Correspondence is difficult task. False to find correspondence will be affected to the registration quality. So exactly find point correspondence and effectively reject false matching pairs are important for increase registration accuracy.

Iterativeclosestpointalgorithm(*ICP*)[1] is a common algorithm registration that widely used by researchers. *ICP* and its invariant [2][3][4][5] establish correspondence by finding the closest point base on the metric distance techniques to find closest compatible point. This techniques can lead the registration algorithm converge to a local minima because the closest points is not exactly represent compatible point on the original surface.

Some researches improve correspondence point using features such as color[6], curvature[7], spin image[8]that have extracted from a set of point interest previously selected in both point cloud to find the compatible points. Two points arecompatible if the valueof theassociatedfeaturesliesbelow athreshold.

To find correct correspondence Liu [9] propose three constraint. These can remove false point pair moderately but effective is only the overlapped surface is closest enough.

This paper propose a correspondence correction technique to increase the number of correct compatible point. To find correct compatible point first we select candidate correspondence point using two reference point constraint then correspondence correction using surface curvature feature is performed. Our technique is successful to increase the number of correct compatible point during correspondence stage.

RIGID OBJECT MOTION

A rigid-body can be regarded as a set of *N* points remains constant under an arbitrary motion undergone by the set. Given two sets of point $P = \{\vec{p}_1, \vec{p}_2, .., \vec{p}_N\}$and $P' = \{\vec{p}'_1, \vec{p}'_2, .., \vec{p}'_{N'}\}$ that derived from *3D* scanner device from different view.

Distance any point on rigid object is constant

$$\left|\vec{p}_i - \vec{p}_j\right| = constant \quad (1)$$

where $\vec{p}_i$ and $\vec{p}_j$ are any point at *P*.

Rigid objects motion have six degree of freedom. Three coordinates are needed to locate the bodys's center of mass and three is to describe its orientation. [10]. The relation set point *P* and *P'* as follow:

$$P' = PR + T \quad (2)$$

where *R* is the orientation matrix and *T* is the translation vector.

Using set of two correspond point $\{\vec{p}_i, \vec{y}_i\}$ which $\vec{p}_i \in P, \vec{y}'_i \in P'$, the motion of set point *P* to *P'* can be estimated by minimizing the distance of correspondence point using the least square distance metrics.

$$\min_{\mathrm{R},\vec{t}} \sum_{i=1}^{N} \left\| (R\vec{p}_i + \vec{t}) - \vec{y}_i \right\| \quad (3)$$

Arun et all using *SVD* to calculated the rigid motion *R* and *T'*[11]

Distance of Two Vector

Given two vector $\vec{x}$ and $\vec{y}$ which $\vec{x} = (x_1, x_2, .., x_k\}$ and $\vec{y} = (y_1, y_2, .., y_k)$. The distance between vector $\vec{x}$ and vector $\vec{y}$ denoted:

$$d(x, y) = ((x_1 - y_1)^2 + .. + (x_1 - y_1)^2)^{0.5} \quad (4)$$

Which *d* is distance operator. In this paper *d* will be use as represent the distance of two vector.

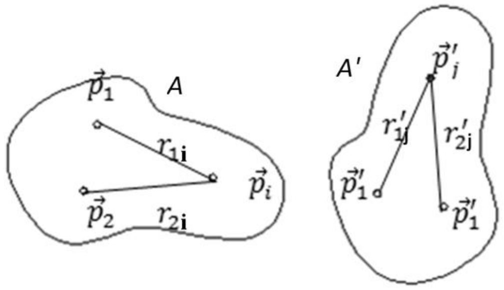

Figure1. Object *A*is Transformed into *A*' Using Rigid Motion, $\vec{p}_1$ and $\vec{p}_2$ is Two Reference Point, $\vec{p}'_1, \vec{p}'_2$ is The Conjugate of $\vec{p}_1$ And $\vec{p}_2$.

Liu's Point Constraint

To increase the number of correct correspondence Liu propose three constrain to find point matching.Let $(\vec{p}_1, \vec{p}'_1)$ and $(\vec{p}_2, \vec{p}'_2)$ are two pair point. Point pair constraint as follows [9] are:

1) Orientation constraint

$$(\vec{p}'_2 - \vec{p}'_1).(\vec{p}_2 - \vec{p}_1) \geq 0 \quad (5)$$

2) Rigidity constraint

$$\|\vec{p}'_2 - \vec{p}'_1\| \leq 2(l_1 + \|\vec{p}_2 - \vec{p}_1\|) \quad (6)$$

3) Matching error constraint.

$$\|\vec{p}'_2 - \vec{p}_2\| \leq l_1 + \|\vec{p}_2 - \vec{p}_1\| \quad (7)$$

With$l_1 = \|\vec{p}'_1 - \vec{p}_1\|$

This three constraint canremove moderate of false pair point matching.

Rigid Constraint Using Two Reference Point

This section will investigate rigid constraint using two reference point for predict the correct position of pair point matching. The Liu's rigidity constraint using one point as reference point is effective when the overlapped surface is closest enough. Our correspondence technique correction fix false correspondence precisely by predict the correct position of the pair point matching using two reference point as rigidity constraint.

Figure1 shows a rigid object A is transformed into A' using rigid transformation. If two point set $P = \{\vec{p}_i\}, i = 1..N$ and $tP' = \{\vec{p}'_j\}$, $j = 1..N'$ are the point cloud that obtained using 3D scanner device of the object *A* and its transformed *A'* respectively. Based on rigid constraint using two reference point, pair matching points $\{\vec{p}_i, \vec{p}'_j\}$,$\vec{p}_i \in P, \vec{p}'_j \in P'$ can be stated as correct pair correspond point if satisfy the constraint:

$$d(\vec{p}_i, \vec{p}_1) - d(\vec{p}'_j, \vec{p}'_1) = 0 \quad (8)$$

and

$$d(\vec{p}_i, \vec{p}_2) - d(\vec{p}'_j, \vec{p}'_2) = 0 \quad (9)$$

Where $\{\vec{p}_1, \vec{p}_2\}$ and $\{\vec{p}'_1, \vec{p}'_2\}$ are the reference point and its conjugate respectively. Base on rigid constraint using two reference point,a pair correspondence point $\{\vec{p}_i, \vec{p}'_{c(i)}\}$ which $\vec{p}_i \in P, \vec{p}'_{c(i)} \in P'$ can be computed based on *c(i)* as follow:

$$c(i) = \arg\min_j \left(\sum_{i=1}^{N} \sum_{j=1}^{N} \left((r_{1i} - r'_{1j})^2 + (r_{2i} - r'_{2j})^2 \right)^{0.5} \right) \quad (10)$$

where

$r_{1j} = d(\vec{p}_1, \vec{p}_j)$,
$r_{1j} = d(\vec{p}_1, \vec{p}_j)$,
$r'_{1i} = d(\vec{p}'_1, \vec{p}'_j)$,
and
$r'_{2i} = d(\vec{p}'_2, \vec{p}'_j)$

SURFACE CURVATURE FEATURE

Surface curvatureis definedasthe curvature ofacurveon thesurfacepassing through a point. On a rigid object, surface curvature is an important feature because of its invariance with respect to the rigid transformation[12]. Base of this idea we establish surface curvature feature of point to predict surface geometry of a point.

Suppose *S* is a local surface which centered at point $\vec{p}$ and the normal vector of surface *S* pointing to positive *Z* axis. *If*$\vec{p}$ is located at origin and $\vec{q}$ is a point that lie on the local surface *S*. Figure 2shows, in cylindrical coordinates system$\vec{q}$ isrepresented as graph function$z = f(r, \theta)$which *r is* the radius of the point to the central point and θ is the angle between the reference direction on the chosen plane and the line from the originto the projection of $\vec{q}$ on the plane. If *r* is set to α, it will be obtained a closed curve *c* on local surface *S* withinα. Sampling those *z* coordinate of the closed curve*c*at $\theta = \theta_1, \theta_2, ..., \theta_k$one lap will obtain the relation between the angle and the *z* coordinates of the closed curve on local surface *S* at radius α.

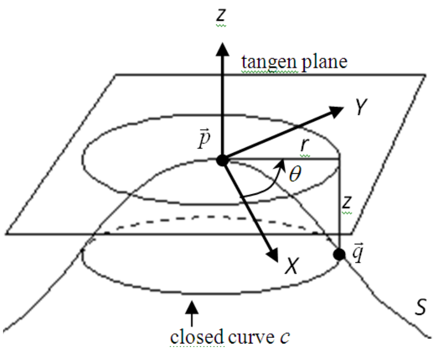

Figure 2. The relation between angle and z coordinate of closest curve *c*, with which surface curvature feature can be constructed.

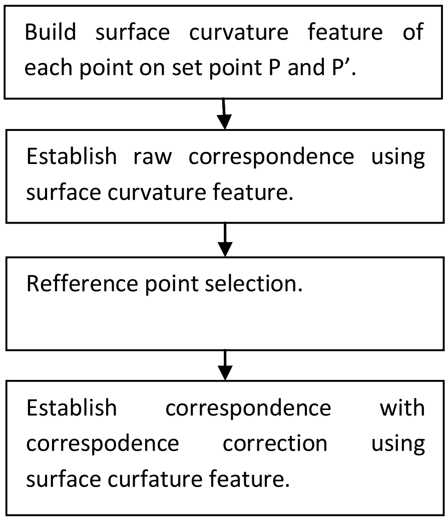

Figure 3. Proposed Technique to Establish Correspondence Correction Using Surface Curvature Feature.

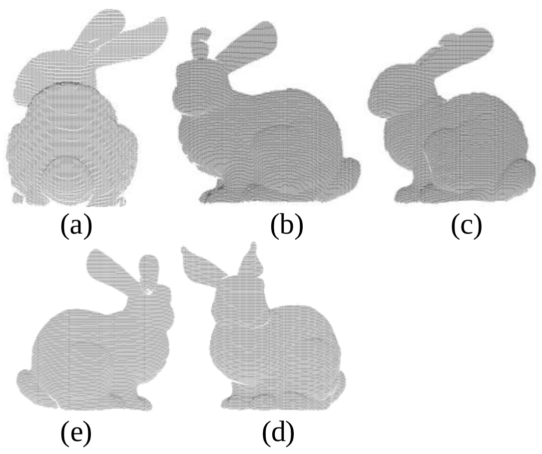

Figure 4. Pose of each view of the bunny object (a) 0°, (b)45 °, (c)90 °, (d) 270 °, and (e) 315 °.

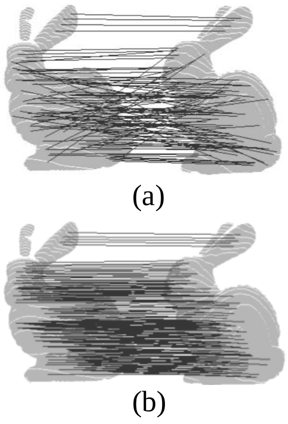

Figure 5. Correspondence Comparison Result. (A) Without Correspondence Correction and (B) Using Correspondence Correction.

This relationship is defined as the surface curvature feature of the point $\vec{p}$ which denoted by:

$$SCF(\vec{p}) = (z_1, z_2, .., z_k). \quad (11)$$

CORRESPONDENCE CORRECTION USING SURFACE CURVATURE FEATURE

In this paper we propose new correspondence correction technique based on curvature correction as shown on Figure 3. The proposed correspondence correction technique is started by build surface curvature feature in all point. This feature is used to predict the geometry of the surface at a point. Based on these surface curvature feature a raw correspondence is established to find pair point matching withrespect to the similarity of the surface geometry.Within the pair point that obtained from raw correspondence we select two point as point reference to establish point constraint using two point reference. After the reference point is found correspondence correction can be establish by considering surface geometry using surface curvature feature.

Raw Correspondence Using Surface Curvature Feature

Given two point set $P = \{\vec{p}_1, \vec{p}_2, .., \vec{p}_N\}$and $P' = \{\vec{p}'_1, \vec{p}'_2, .., \vec{p}'_{N'}\}$. If $\vec{p}_i$ is the ith of the whole data point set P and $\vec{p}'_j$ is the jth data point of the whole data point set P. Let $SCF(\vec{p_i}) = (z_{i1}, z_{i2}, .., z_{ik})$and $SCF(\vec{p}'_j) =$

$(z'_{j1}, z'_{j2}, .., z'_{jk})$ are surface curvature feature related to the point $\vec{p}_i$and point $\vec{p}'_j$ respectively.

The point matching strategy is finding the closest point with respect of the surface curvature feature distance. Raw correspondence $\{\vec{p}_i, \vec{p}'_{c_r(i)}\}$ between two point sets P and P' is computed based on $cr(i)$ is follow:

$$c_r(i) = \underset{j\in\{1..N'\}}{\arg\min}\left(\sum_{i=1}^{N} d(SCF(\vec{p}_i), SCF(\vec{p}'_j))\right) \quad (12)$$

The pair point matching $\{\vec{p}_i, \vec{p}'_{c_r(i)}\}$ that obtained from this correspondence is contain closest pair point with respect to the surface curvature feature.

Reference Point Selection

Our correspondence correction technique employ two reference point constraint to predict correct position of the pair point matching. Two references point $\{\vec{p}_1, \vec{p}_2\}$ and its conjugate $\{\vec{p}'_1, \vec{p}'_2\}$ is selected from pairpoint$\{\vec{p}'_1, \vec{p}'_2\}$ thatobtained from raw correspondence using surface curvature feature. We select the reference point and its conjugate within three criteria to guarantee that the reference point and it's conjugate point is represent the same point onreal surface. Our three criteria to find the reference point are:

1) The distance of the two references point $\{\vec{p}_1, \vec{p}_2\}$ is long enough above the minimum allowable distance limit d_{min}

$$d(\vec{p}_1, \vec{p}_2) \geq d_{min} \quad (13)$$

2) The differences between distances of the references point $\{\vec{p}_1, \vec{p}_2\}$ and the distance its conjugate points $\overrightarrow{\{p'_1}, \vec{p}'_2\}$ is small under maximum allowable tolerance limit $\mathcal{E}r$.

$$|d(\vec{p}_1, \vec{p}_2) - d(\vec{p}'_1, \vec{p}'_2)| \leq \mathcal{E}r \quad (14)$$

3) The surface geometry of the references point must identical with its conjugate point which is the distance between two surface curvature vector under maximal allowable tolerance limit $\mathcal{E}c$

$$(d(SCF(\vec{p}_1) - SCF(\vec{p}'_1))^2 + d(SCF(\vec{p}_2) - SCF(\vec{p}'_2))^2)^{0.5} \leq \mathcal{E}c \quad (15)$$

By filtering raw pair matching point using these criteria we will have M pair candidate of reference point $\{\vec{y}_{1i}, \vec{y}_{2i}\}$ which $\vec{y}_{1i}, \vec{y}_{2i} \in \{\vec{p}_i\}$and its conjugate$\{\vec{y}'_{1i}, \vec{y}'_{2i}\}$ which $\vec{y}'_{1i}, \vec{y}'_{2i} \in \vec{p}'_{c_r(i)}$. The pair reference point is selected from .Where $\hat{\imath}$ is the index of the selected reference point,

$$\hat{\imath} = \arg\max_j count\left(\sum_j^N \sum_i^N \left(((r_{ij})^2 + (r'_{ij})^2\right)^{0.5} <= dt\right) \quad (16)$$

reference point candidate by finding the maximum number pair point matching$\{\vec{p}_i, \vec{p}'_{c_r(i)}\}$which has the distance with the reference point candidate under d_t.

$$r_{ij} = d(\vec{p}_i, \vec{p}_{1j}) - d(\vec{p}_i, \vec{p}_{2j}) \quad (17)$$

and

$$r'_{ij} = d(\vec{p}'_{c_r(i)}, \vec{y}'_{1j}) d(\vec{p}'_{c_r(i)}, \vec{y}'_{2j}) \quad (18)$$

Then the selected reference point and its conjugate are

$\{\vec{p}_1, \vec{p}_2\} = \{\vec{y}_{1\hat{\imath}}, \vec{y}_{2\hat{\imath}}\}$

and

$\{\vec{p}'_1, \vec{p}'_2\}$=$\{\vec{y}'_{1\hat{\imath}}\vec{y}'_{2\hat{\imath}}\}$

Correspondence Correction Using Surface Curvature Feature.

Our correspondence correction technique need reference points and its conjugate exactly closest to a same point in real surface. But due to self similarity, noise introduced by scanner and nonuniform sampling of point cloud we must correct the correspondentionby considering the surface geometry at the point and Equation (10) can be modified as.

$$c(i) = \arg\min_j\left(\sum_{i=1}^N \sum_{j=1}^N \left((r_{1i} - r'_{1j})^2 + (r_{2i} - r'_{2j})^2 + w \times k_{ij}^2\right)^{0.5}\right) \quad (19)$$

where $k_{ij} = d(SCF(\vec{p}_i), SCF(\vec{p}'_j))$ is the distance between surface curvature feature of point $\vec{p}_i$ and surface curvature feature of point $\vec{p}'_j$, w is weight to show the surface geometry contribution to find the pair matching point.

RESULT AND DISCUSSION

In this section, we evaluate the performance of proposed correspondence correction technique. We test the proposed technique to the bunny object. The bunny object isobtainedfromdatarepository of Stanford University that is consisting five different views. The amount of points of each view is shown in Table 1 while each view pose is shown on Figure4 We apply our correspondence correction to three registration algorithm which is Iterative Closest Point algorithm (*ICP*)[1],Iterative Closest Point with angular invariant feature algorithm (*ICP-AIF*)[7] and Closest Point with Surface Curvature Feature(*ICP-SCF*) and comparewith original registration algorithm. As we know the real conjugate points between point clouds.

Therefore, we measure *RMS* distance error between two ground truth point sets. All registration result is plotted as graphic *RMS* registration error (ground truth) as a function of iteration number.During the registration process there are many false correspondence that introduce by registration algorithm technique as shown on Figure 5(a). By implementing our correspondence correction technique, false correspondence can be fixed as shown on Figure 5(b).

The comparison of registration result between original registration algorithm and registration algorithm is shown on Figure 6.

We test the registration algorithm to the view-1 and view 2 of bunny objects. Figure 6.a. shows that the original *ICP* registration algorithm fail to toconvergent however *ICP* registration using correspondence correction can achieve convergence at 10 iteration with 5 mm *RMS* error registration with out any initial transformation. By applying correspondence correction to *ICP-AIF* and *ICP-SCF* convergence iteration is reduced from 73 and 28 into 21 and 13, the registration error is decrease from 0.61 mm and 0.33mm without correspondence correction into 0.30 mm and 0.27 with correspondence correction. The correspondence result is increase also from 143 and1510 with out correspondence correction become 3496 and 5261 using correspondence correction.

Table 2 shows the registration result of all view of bunny objects. We compare the iteration convergence, *RMS* error registration and correspondence result between original registration algorithm and registration algorithm using correspondence correction. Our correspondence correction can reduce the iteration convergence from average 60.8 without correspondence correction into average 22.5 using correspondence correction.

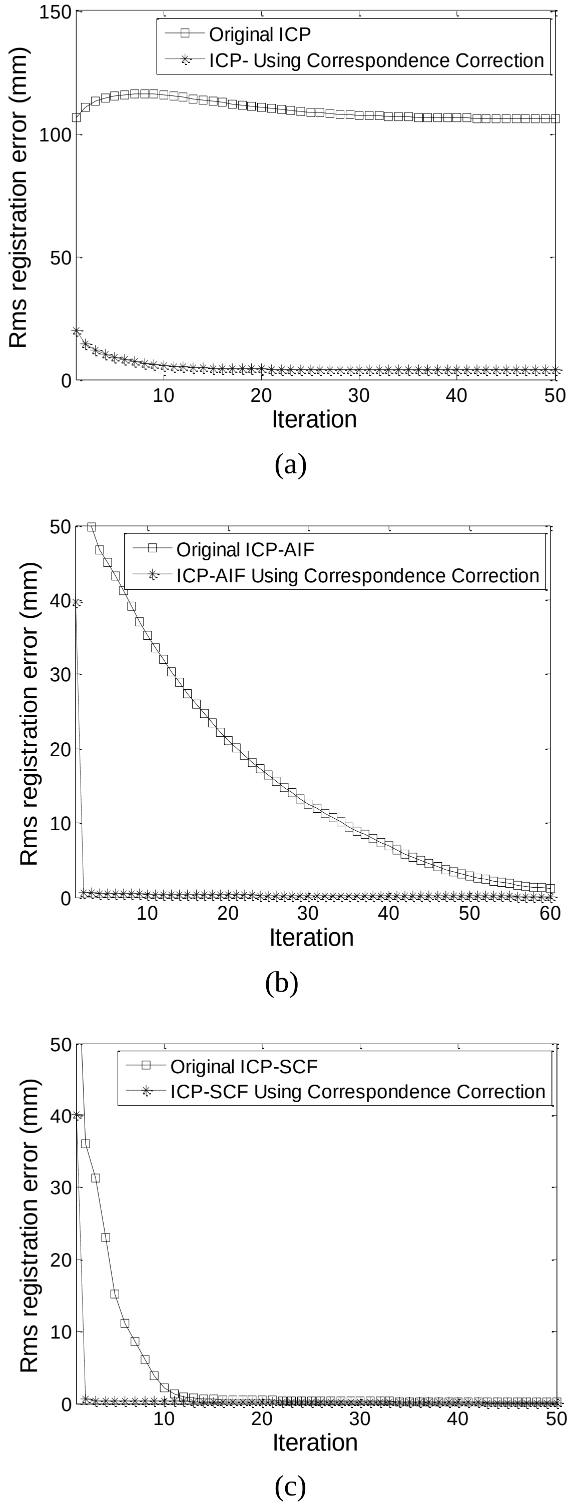

Figure 6. The *RMS* Error Registration of The View-1 and View-2 of Bunny Object Result Comparison Using Correspondence Correction and With Out Correspondention Correction to The View-1 and View-2 of Bunny Object. (a) *ICP*, (b) *ICP-AIF*,and (C) *ICP-SCF*.

Table 1. The Number of Point Each View of Bunny Object.

	Amount of point	*Pose (degree)*
View-1	40256	0
View-2	40097	45
View-3	30379	90
View-4	31701	270
View-5	35336	315

The registration error is also decrease average 0.5 mm without correspondence correction into average 0.35 mm with correspondence correction. The correspondence result is increase from average 422.9 with correspondence correction into average 2661 without correspondence correction. It shows that registration using correspondence correction 63% faster , 30% more accurate and 530% more correspondence result than original registration algorithm.

We have not included the *ICP* registration comparison result into Table 2 because the original *ICP* registration fail in all registration test but as shown in figure 5 *ICP* can achieve convergence using our correspondence correction.

Figure 7 shows the result of registration all views of bunny object using correspondence correction. Each view is transformed relatively to View-1 as the result of registration process.

CONCLUSION

This research proposes a correspondence correction for point cloud registration base on surface curvature features. The surface curvature feature estimate correct position by compare the surface geometry of at a point.

In experiment we compare three original registration algorithm *ICP*, *ICP-AIF* and *ICP-SCF* with *ICP*, *ICP-AIF* and *ICP-SCF* using correspondence correction. The result shows that registration algorithm using correspondence correction 63% faster, 23% more accurate and 530% more correspondence result than the original registration algorithm.

For further works the proposed correspondence correction technique can be used for multi rigid object segmentation and registration. Segmentation is separate an object into its part while the registration is construct an object from its components. Segmentation and registration of multi rigid objects is useful in various applications such as reverse engineering, computer vision and computer graphics.

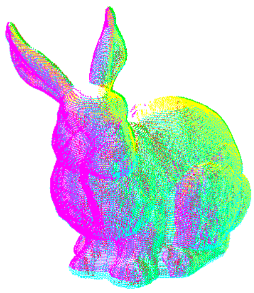

Figure 7. The Registration Result of All Views of The Bunny Object Whicheach View is Transformed Relativelyto View-1.

Table 2. Registration Comparison Result.

Registration Algorithm	Registration	Iteration Convergence		*RMS*Error Registration(mm)		Correspondence Result	
		Original Algorithm	Using Correspondence Correction	Original Algorithm	Using Correspondence Correction	Original Algorithm	Using Correspondence Correction
	view 1-view 2	73	21	0.61	0.30	143	3486
ICP-AIF	view 2 view 3	87	34	1.22	0.46	46	955
	view1 view 5	-	20	-	0.61	-	2991
	view 5-view 4	83	15	0.43	0.38	49	2448
	view 1-view 2	28	13	0.33	0.27	1510	5261
ICP-SCF	view 2 view 3	66	41	0.35	0.29	153	665
	view1 view 5	48	17	0.26	0.27	447	3490
	view 5-view 4	37	19	0.35	0.29	608	1992
Average		60.28	22.5	0.50	0.35	422.28	2661.00

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