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Integration of multi-view panoramic range data using global features

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Abstract

In this paper, we propose a robust and efficient method to integrate the multi-view panoramic range data using the global features acquired from panorama range data. In our approach, the planes with similar normal vectors are handled as one group, and multiple plane groups are extracted from the multi-view panoramic range data. Next, the transformation (rotation and translation) parameters between viewpoints are estimated by matching the plane groups in multiple viewpoints based on the global statistical features of each plane group. Since our method carries out the integration using the global features of panoramic range data, there is no necessity to consider the initial position, and it is robust to noise. Experimental results on real panoramic range data show the effectiveness of the proposed method.

1 Introduction

In past decades, many techniques for the integration of multi-view range data have been proposed, such as the methods based on data point correspondences and the methods based on motion invariant features. An example of a method based on data point correspondences is the iterative closest point (ICP) algorithm[1, 2, 3]. However, this method requires a suitable guess of the initial position, otherwise it may yield a local minimum solution.

On the other hand, when multi-views are integrated using the correspondences of features, such as curvature[4, 5], it may be difficult to stably extract the features from the range data containing noise. In recent years, due to the advent of the range finder, which can acquire three-dimensional data with a 360 degree field of view, panoramic range data is available for the modeling of a scene. In this paper, we propose a robust and efficient method to integrate the multi-view panoramic range data using the global features acquired from panorama range data. In our approach, the planes with similar normal vectors are handled as one group, and multiple plane groups are extracted from the multi-view panoramic range data. Next, the transformation (rotation and translation) parameters between viewpoints are estimated by matching the plane groups in multiple viewpoints based on the global statistical features of each plane group. Since our method carries out the integration using the global features of panoramic range data, there is no necessity to consider the initial position, and it is robust to noise. Experimental results on real panoramic range data show the effectiveness of the proposed method.

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2 Plane groups and global statistical features

In our approach, the transformation parameters between viewpoints are estimated by matching the plane groups in multiple viewpoints based on each plane group's global statistical features. Then, the plane groups and the global statistical features are extracted from multi-view panorama range data.

2.1 Extraction of plane groups

Unlike the three dimensional data obtained with general three dimensional measuring instrument, panorama range data contains large amounts of three dimensional information from all directions. In our approach the planes with similar normal vectors are handled as one group, and matching is performed.

Since points on the same plane have similar local normal vectors, the histogram space based on the normal vector is generated, and a plane group is extracted by detecting the peak value of the histogram space. A plane group is obtained as follows.

First, we fit plane equations to each local surface region of the panorama range data by the least-squares method using the following plane equation (1). A 7×7 window centered on an observation point is used as the local plane region.

$$Z = aX + bY + cZ + d \tag{1}$$

where a, b, c and d are parameters.

The coefficients of the local plane are estimated by minimizing, subject to the constraint $a^2+b^2+c^2+d^2 = 1$. The normal vector is obtained based on the parameters of the acquired plane, and the sign of the normal vector is decided such that it points outwards. The obtained normal vector is distributed in the spherical

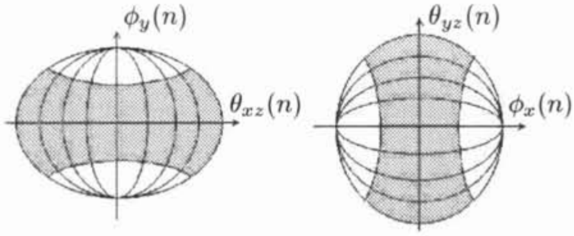
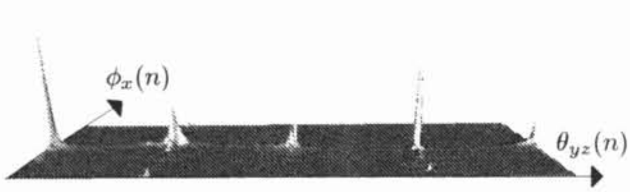


Figure 1: Normal vector voting space

(a) Histogram space$(\theta_{xz}(n)), \phi_y(n))$



(b) Histogram space$(\theta_{yz}(n)), \phi_x(n))$

Figure 2: Histogram space

surface. However, since it is difficult to handle spherical coordinate systems, in this research, as shown in Figure 1, the normal vector histogram which is voted in the spherical surface is developed in the rectangular coordinate space in two ring regions, and these are made to be the feature space of the normal vector. Moreover, in order to prevent the size occupied in the histogram space changing due to the distance and the angles from the range finder, even in a region of the same size, the histogram is obtained from the actual area of the plane which the observation point occupies. Figure 2 shows the histogram space of normal vectors.

Here, $\theta_{xz}(n)$ is the yaw angle of the vector in xz plane which is projected from the local surface normal n. $\phi_y(n)$ is the pitch angle in the y direction of n. Also, we multiply the histogram by $1/sin(y)$ or $1/sin(x)$ along the ϕ axis in the rectangular coordinate systems to preserve the homogeneity of the voting density of the histogram. In addition, the different plane group with the similar direction forms one distribution in the histogram space of Figure 2.

In order to extract the plane group from the acquired histogram space, a peak which exists on the space is detected, and a plane group can be obtained by extracting the distribution. Next multiple peaks are detected in order from the biggest peak value on the basis of the distribution of two histograms shown in Figure 2[7]. Each of these peak values becomes a plane group. In this research, ten plane groups are obtained from one viewpoint.

2.2 Global statistical features of plane group

The planes contained in one plane group are located at various places in the actual three-dimensional space. This distribution feature of the planes is regarded as a global feature of each plane group, and is used for calculating similarities between the area histograms of the plane groups.

In this research, for robustness, the global feature of each plane group is generated using the planes whose normal vectors are similar to that of the plane group. In our experiments, the global feature space was generated by using the planes which made the angle from the similar normal vectors of the observation plane group to 45 degrees for the observation plane group.

Moreover, when the global feature space is generated using the number of pixels which are visible from the position of a viewpoint, even if it is the region of the same size in the three dimensional space, the size occupied in the global feature space becomes heterogeneous under the influence of distance or the angle from the range finder.

In order to solve this, the histogram of the area of the planes in three dimensional space projected on the normal axis of the plane group, that is called area histogram, is used as the global feature of the plane group. In this case, the horizontal axis of the histogram shows the distance from a viewpoint, and the vertical axis shows area.

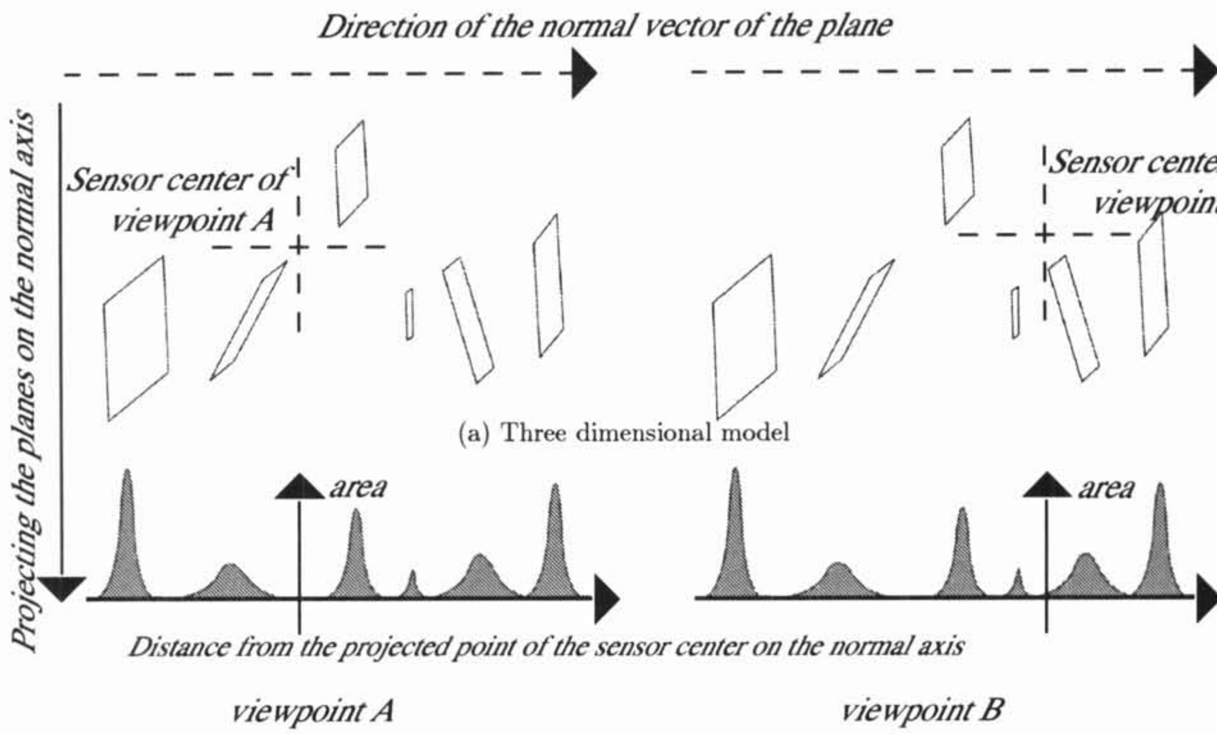
Figure 3 shows the example of three dimensional model (a) and the obtained the global feature space distribution (b). As shown in the example, when 6 planes exist on the three dimensional space, planes with a large area such as 1 and 6 take large values in the global feature space. And when there is an angle to the normal vector like planes 2 and 5, the global feature becomes a broad distribution.

3 Matching of plane groups

In this research, the plane groups obtained from the range data of different viewpoints are matched using the similarities of the area histograms of the plane groups. In addition, in this paper, in order to simplify explanation, the matching of two viewpoints is stated.

3.1 Similarities of global feature of plane group

If there are two corresponding plane groups in two viewpoints, their area histograms will be similar, except for a position shift along their normal axes. For each corresponding candidate of two plane groups in distinct viewpoints, their matching similarity is defined as the similarity of their area histograms, and is computed by shifting the area histograms of two plane groups and finding the minimum sum of the squared difference (SSD) of the two histograms. Then, the shift which maximizes the matching similarity of



(a) Three dimensional model

(b) Global feature space histogram

Figure 3: Example of global feature space

two histograms and the maximum matching similarity are obtained. In addition, the value is also calculated in case the histogram of only one side exists. In order to determine the same plane group between two viewpoints, these similarities are used as the amount of global statistics.

3.2 Matching of plane groups

The plane groups in two viewpoints are matched by finding the correspondences of the plane groups which satisfy the following conditions.

1. The angular relations of the plane groups in one viewpoint are preserved by the corresponding plane groups in another viewpoint.

2. The sum of the similarities of all the corresponding planes groups reaches the maximum value.

Then, the rotational parameters are estimated using the optimal correspondences of the plane groups obtained above.

4 Search of optimal correspondences of plane groups

In two viewpoints, although it is best to calculate the sum of the similarity to the combination of all plane groups in order to search for matching of the highest plane groups of the similarity, the efficiency of this method is poor. The efficient optimal solution is obtained by searching based on the following constraint condition.

1. The angular relations of the plane groups in one viewpoint are preserved by the corresponding plane groups in another viewpoint.

2. If the correspondence of three plane groups is obtained between two viewpoints, it is possible to obtain the rotation parameters[6].

In this chapter, the method of efficiently searching for the combination of the optimal plane groups and the method of estimation of parameters from the matching of plane group are stated.

4.1 Strategies for optimal correspondence searching

In order to decide the matching of multiple plane groups which has similar angle relations and the maximum similarity of their three dimensional area histograms in two different viewpoints, an exhaustive search method which searches for the optimal plane group matching from all the combinations of correspondences of the plane groups can be considered. However, this method is too expansive. For example, if there are 10 plane groups in each viewpoint, over 3.6 millions of combinations must be considered. In this research, the efficient search is carried out by the following method without searching for all the combinations.

1. In order to obtain the rotation parameter in three dimensional space, only the correspondences of three plane groups are required, because the rotation parameters can be estimated using the normal vectors in three directions. That is, if the correspondences of three plane groups in two viewpoints are selected as base groups for correspondence, the correspondences of the remaining plane groups will be determined by the rotation estimated from the correspondences of the base groups. Therefore, we need only to consider the combinations of three base groups and their correspondences in another viewpoints. For a given matching of three base groups, the sum of the similarities of both the three dimensional area histograms of the corresponding base groups and the remaining plane groups, which were determined by the correspondences of the base plane groups, are regarded as the evaluation criterion of the given matching of three base groups.

2. In order to stably obtain the rotation parameters using the correspondences of the three base plan groups, those base plane groups are desired to be perpendicular to each other as much as possible. Therefore, in this research, only the combinations of three plane groups in which the intersection angle of any two of them is not smaller the 60 degrees, are selected as base plane groups.

4.2 Search procedure

Based on the searching strategies described above, the search for the optimal matching of plane groups is carried out using the following algorithm. Let P_{i_1}, P_{j_1} and P_{k_1} be plane groups of viewpoint A, and P_{i_2}, P_{j_2} and P_{k_2} be plane groups of viewpoint B. Let the number of plane groups in viewpoint A be m, and the number of plane groups in viewpoint B be n. The optimal correspondence of the plane groups in viewpoints A and B can be found by the following procedure.

For $(i_1 = 0 \dots m-2)$
 For $(i_2 = 0 \dots n-2)$
  For $(j_1 = i_1+1 \dots m-1)$
   if $(P_{j_1} \neq P_{i_1} \& \angle P_{i_1}, P_{j_1} \geq 60^\circ)$ {
    For $(j_2 = i_2+1 \dots n-1) if (P_{j_2} \neq P_{i_2} \& \angle P_{i_2}, P_{j_2} \neq 60^\circ \& \angle P_{i_1}, P_{j_1} \approx \angle P_{i_2}, P_{j_2})$ {
     For $(k_1 = j_1+1 \dots m) if (P_{k_1} \neq P_{i_1}, P_{j_1} \angle P_{k_1}, P_{i_1} \geq 60^\circ \& \angle P_{k_1}, P_{j_1} \geq 60^\circ)$ {
      For $(k_2 = j_2+1 \dots n) if (P_{k_2} \neq P_{i_2}, P_{j_2} \& \angle P_{k_2}, P_{i_2} \geq 60^\circ \& \angle P_{k_2}, P_{j_2} \geq 60^\circ \& \angle P_{i_1} \&, P_{j_1} \approx \angle P_{i_2}, P_{j_2} \& \angle P_{i_1}, P_{k_1} \approx \angle P_{i_2}, P_{k_2} \& \angle P_{j_1}, P_{k_1} \approx \angle P_{j_2}, P_{k_2})$ {

Compute the sum of the similarities of the three dimensional area histograms of all the corresponding plane groups determined by the correspondence of $(P_{i_1}, P_{j_1}, P_{k_1})$ and $(P_{i_2}, P_{j_2}, P_{k_2})$, and keep the maximum one.
      }
     }
    }
   }

where $\angle P_i, P_j$ stands for the angle between planes P_i and P_j.

The sum of the similarities of the three dimensional area histograms of all the corresponding plane groups determined by correspondence of $(P_{i_1}, P_{j_1}, P_{k_1})$ and $(P_{i_2}, P_{j_2}, P_{k_2})$ are computed as follows.

Step0: Let $SUM = 0$.

Step1: A rotation matrix R is estimated using the normal vectors of the corresponding plane groups P_{i_1} and P_{i_2}, P_{j_1} and P_{j_2}, and P_{k_1} and P_{k_2}.

Step2: Multiply the normal vector of each plane group P_{l_1} of viewpoint A by the rotation matrix.

$$R\boldsymbol{n}_{l_1} = \boldsymbol{n}'_{l_1} \tag{2}$$

Step3: If there is a plane group P_{l_2} in viewpoint B whose the normal vector is similar to $\boldsymbol{n}'_{l_1}$, the matching similarity of the three dimensional area histograms of the plane groups P_{l_1} and P_{l_2} is added to the SUM. If there is no such plane group in viewpoint B, the similarity which is defined for no-correspondence is added to the SUM.

Step4: The inverse matrix R^{-1} is computed.

Step5: Multiply the normal vector of each planes group $\boldsymbol{n}_{l_2}$ in viewpoint B by the rotation matrix.

$$R^{-1}\boldsymbol{n}_{l_2} = \boldsymbol{n}'_{l_2} \tag{3}$$

Step6: If there is a plane group P_{l_1} whose the normal vector is similar to $\boldsymbol{n}'_{l_2}$, it is ignored because the matching similarity of the three dimensional area histograms of the plane groups P_{l_1} and P_{l_2} has been counted in Step2. If there is no such plane group in viewpoint A, the similarity which is defined for no-correspondence is added to the SUM.

Step7: The base plane groups $(\hat{P}_{i_1}, \hat{P}_{j_1}, \hat{P}_{k_1})$ and $(\hat{P}_{i_2}, \hat{P}_{j_2}, \hat{P}_{k_2})$ which gained the maximum SUM is regarded as the optimal base plane groups, and the correspondences of the plane groups determined by the optimal base plane groups are regarded as the optimal plane group matching. The transformation parameters are estimated by using the normal vectors of the corresponding plane groups and the shifts of their three dimensional area histograms.

4.3 Estimation of parameters

Although it is possible to estimate the rotation parameters using the correspondences of the optimal base plane groups $(\hat{P}_{i_1}, \hat{P}_{j_1}, \hat{P}_{k_1})$ and $(\hat{P}_{i_2}, \hat{P}_{j_2}, \hat{P}_{k_2})$, using all the correspondences of plane groups will improve the entire integration precision and stability of the estimation. The problem in that there may exist some wrong correspondences of plane groups which will bias the estimation as outliers. In our research, the outliers of correspondences of plane groups are excluded by the following procedures.

Step1: Estimate the rotation matrix R using the correspondences of the base plane groups, and compute the residual error of each corresponding plane group according to R as follows.

$$\epsilon_{l_1 l_2} = (R\boldsymbol{n}_{l_1} \cdot \boldsymbol{n}_{l_2} - 1)^2 \quad (4)$$

where $\boldsymbol{n}_{l_1}$ and $\boldsymbol{n}_{l_2}$ stand for the normal vectors of the corresponding plane groups of P_{l_1} and P_{l_2} in viewpoints A and B, respectively.

Step2: Compute the median of the residual errors of corresponding plane groups.

$$\epsilon_m = median \{\epsilon_{l_1 l_2} | for\ all\ corresponding\ P_{l_1}\ and\ P_{l_2}\} \quad (5)$$

Step3: Exclude the plane group correspondences whose residual error is greater than $2\epsilon_m$ and re-estimate the rotation matrix $\hat{R}$ using the remaining plane group correspondences.

As described in section 2.2, the shift of the area histograms of two corresponding plane groups is equivalent to the translation of the plane group along its normal vector. Therefore, after the rotation matrix is estimated, the translation T can be estimated using the shifts of the area histograms of the corresponding base plane groups as follows.

$$T = \begin{pmatrix} \boldsymbol{n}_{i_2}^\top \\ \boldsymbol{n}_{j_2}^\top \\ \boldsymbol{n}_{k_2}^\top \end{pmatrix}^{-1} \begin{pmatrix} d_{i_2} \\ d_{j_2} \\ d_{k_2} \end{pmatrix} \quad (6)$$

where d_{i_2}, d_{j_2} and d_{k_2} are the three dimensional shift distance of plane group p_{i_1}, p_{j_1} and p_{k_1} to their corresponding plane groups p_{i_2}, p_{j_2} and p_{k_2} along the normal vectors of the objective plane groups.

5 Experimental results

Experimental results on panoramic range data obtained by *SceneModeler* show the effectiveness of the proposed method. Experiments are carried out on panorama rage data obtained at three viewpoints in an hall with a size of $47m \times 30m \times 12m$. Figure 4(a) $\sim$(c) show the 360 degrees panoramic range data of each viewpoint A, B and C, respectively. The distance from the three-dimensional points to the range finder is shown in gray levels. Figure 4(d)$\sim$(f) show the cloud data of each viewpoint and the $X - Y$ axis. In the experiment, the transformation parameters between viewpoint A and B, as well as between A and C, were calculated. The range data of three viewpoints were integrated using the obtained transformation parameters. 10 plane groups were extracted for each viewpoint. The computation time is about 300 seconds using an SGI Octane. Figure 4(g) shows the integration results, which show that the proposed method is effective in integrating the panoramic range data of an indoor scene obtained from multiple viewpoints.

6 Conclusion and Future work

In this paper, we proposed a robust and efficient method to integrate the multi-view panoramic range data using the global features acquired from panorama range data. First, we generated the histogram space based on the normal vector for the panorama range data of each viewpoint. Then, we obtained the plane group with the similar direction based on the distribution of the histogram. Next, the histogram of the area of the planes in three-dimensional space projected on the normal axis of the obtained plane group, that is called area histogram, is used as the global feature of the plane group. In our approach, the planes with similar normal vectors are handled as one group, and multiple plane groups are extracted from the multi-view panoramic range data. Then, the transformation (rotation and translation) parameters between viewpoints are estimated by matching the plane groups in multiple viewpoints based on the global statistical features of each plane group. Since our method carries out the integration using the global features of panoramic range data, there is no necessity to consider the initial position, and it is robust to noise. Experimental results on panoramic range data obtained by SceneModeler show the effectiveness of the proposed method.

In future work, we plan to integrate the panorama range data with more precision using the method of adjusting each transformation parameter in order to reduce the whole positioning error, after panorama range data from all viewpoints is integrated using our method.

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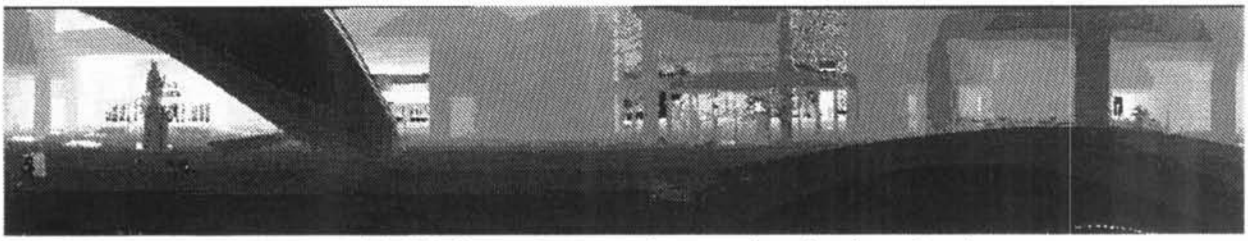
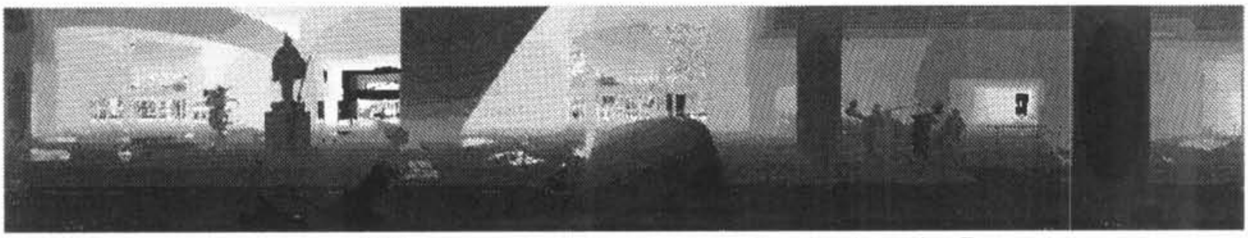
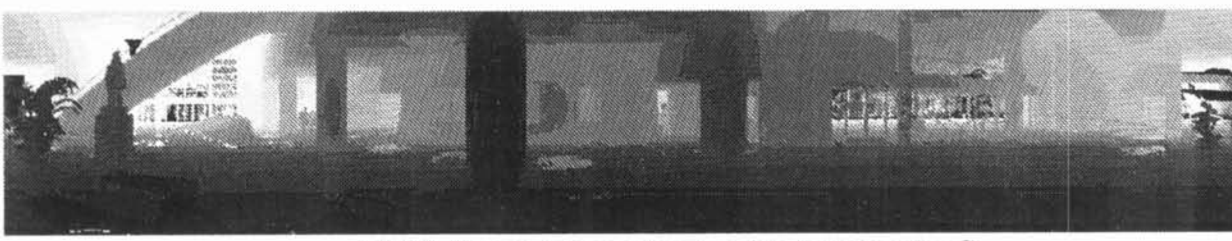
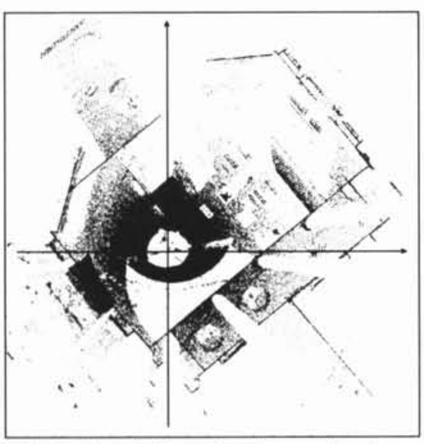
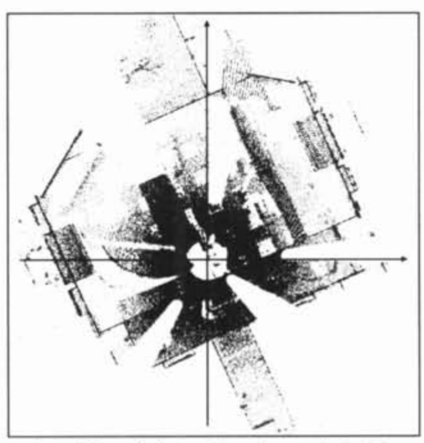

(a) 360 degrees panoramic range data in viewpoint A


(b) 360 degrees panoramic range data in viewpoint B


(c) 360 degrees panoramic range data in viewpoint C


(d) Cloud data in viewpoint A


(e) Cloud data in viewpoint B


(f) Cloud data in viewpoint C

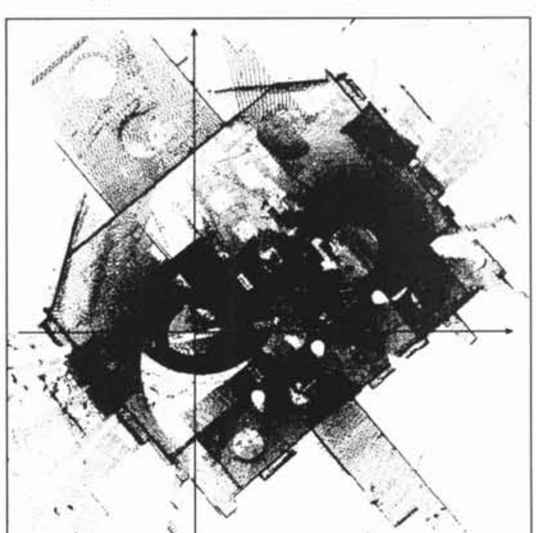

(g) Result of integration
(Using the coordinate system of viewpoint A)

Figure 4: Experimental Results