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Projection Mapping by Mobile Projector Robot

Misaki Kasetani[1], Tomonobu Noguchi[1], Hirotake Yamazoe[2] and Joo-Ho Lee[2]

[1]Graduate school of Science and Engineering, Ritsumeikan University, Kusatsu, 525-0058, Japan
(Tel : +81-77-561-5931; E-mail: {is0060er,is0082rs}@ed.ritsumei.ac.jp)
[2]College of Information Science and Engineering, Ritsumeikan University, Kusatsu, 525-0058, Japan
(Tel : +81-77-561-5931; E-mail: yamazoe@fc.ritsumei.ac.jp,leejooho@ieee.org)

Abstract - In this paper, we propose a method to achieve projection mapping by mobile projector robot. Projection mapping technology become popular and is used in various situations. However, since most of the current projection mappings are based on pre-calibrated fixed projectors, projectable areas become small fixed regions. We have been researching Ubiquitous Display (UD) that is a mobile-projection robot and aims to support the users by projecting various information. In this paper, we propose projection mapping technology by the mobile projector robot. UD has sensors for self-localization, but their accuracy are not enough for achieving projection mapping. Thus, in our method, we first models projection target beforehand. Then, UD moves to the front of the target and obtains point cloud observations of the scene. After that, the pose and position of the model is estimated. By using the estimated pose and position, we can realize the accurate projection mapping based on the mobile projector. Preliminary experiment shows the effectiveness of the proposed method.

Keywords - Projection Robot, Ubiquitous Display, projection mapping, 3-D modeling, 3-D object detection, 3-D object recognition, point-cloud, pose estimation

1. Introduction

In recent years, projection mapping is attracting attentions as new visual expression approach. Projection mapping is used in various situations such as events, stages and concerts. In the past few years, projection mapping on outdoor buildings such as Tokyo Station and Osaka Castle were performed [1].

The conventional projection mapping methods are based on fixed projectors and requires calibration procedures in advance to fit projection images to the target objects. Since such calibration procedures are required beforehand, projection targets become fixed and limited regions.

Therefore, in this paper, we propose a new projection mapping scheme by using mobile projector robot. We have been researching Ubiquitous Display (UD) that is a mobile-projection robot and aims to support the users by projecting various information [2][3]. We aim to realize projection mapping in various places by using UD.

Ubiquitous Display (UD) is a mobile projection robot system with visual information. UD consisteds of a mobile platform, a projector with pan-tilt mechanism and sensors such as laser range finders and RGB-D camera shown in Fig. 1. This structure enables UD to project visual information onto a plane in human's field of view. Because of this feature, comfortable and easily comprehensible information presentation for humans can be achieved.

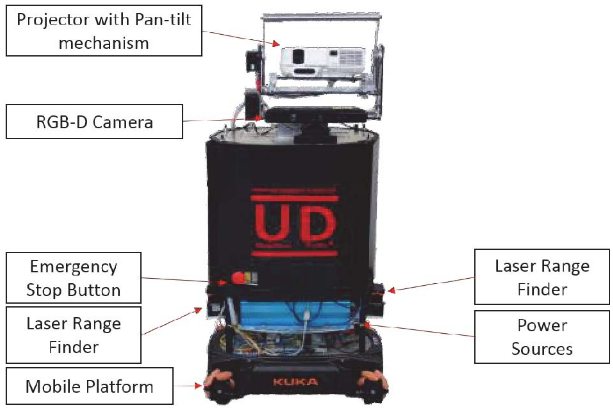

Fig. 1 Ubiquitous Display

In this paper, we aim to realize projection mapping by UD, however, a problem of self-localization accupracy are userd for self-localization of mobile robots. One of the method is based on odometry. However, since odometry-based methods cause cumulative errors, and their accuracy are not enough for the projection mapping [4]. Another method is based on Simultaneous Localization and Mapping (SLAM) [5][6]. The accuracy of SLAM are higher than odometry-based method, however, its accuracy still not be enough for projection mapping. Therefore, in the proposed method, we estimate position and pose of the target in the scene based on iterative closet point (ICP) algorithm to remove errors of self-localization.

2. Projection Mapping by UD

In this section, we describe about the proposed method of projection mapping by UD. First, we explain the preconditions for designing the proposed method of projection mapping by UD.

2.1 PreConditions for the Proposed Method

Following items are preconditions for the proposed method. There are four preconditions, one is about environment settings and other three are about knowledge given in advance.

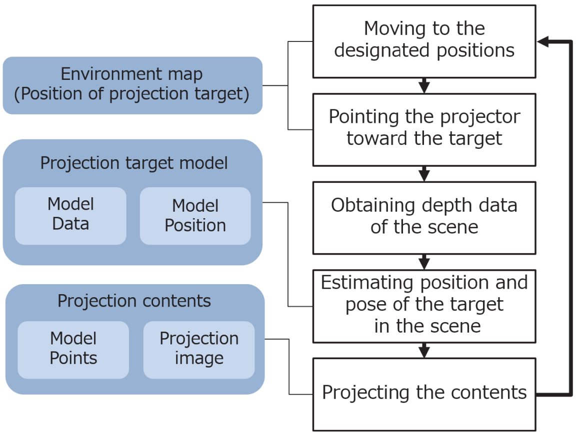

Fig. 2 propose method

1. No environmental fixed sensors are placed in the environment.
2. The positions and poses of the projection targets are known
3. The 3D model data of the The 3D model data of the projection targets are obtained in advance
4. The projection positions on the projection targets and contents are pre-determined

Based on these preconditions, we designed the proposed method. Figure 2 show the flow chart of the proposed method.

A. Precondition 1

We consider that UD moves in wide area. First, UD moves to the place of the projection target. After that UD moves to the place of another projection target. Installations of sensors to wide areas take huge cost and are burdensome tasks. Thus, the preconditions 1 is required for increasing availability of the projection mapping.

B. Precondition 2

We assume that UD has environment map that is built in advance and knows the position of the projection target as shown in Fig. 2. Referring to the environmental map, UD can move to the front of the projection target. Then, UD rotate the projector toward the position of the projection target. For the projection mapping, we need to decide projection target and prepare the contents of the projection in advance. Thus, we consider the precondition 2 is natural condition.

C. Precondition 3

As mentioned in Section 1, only self-localization is insufficient accuracy even if we can use accurate sensors of the robot and the accurate environment map. Therefore, we consider to compensate such errors by estimating the positions and poses of the projection target in the scene. To do this, we need to obtain the 3D models of the projection targets in advance. Thus, we set the precondition 3.

D. Precondition 4

When estimated position and pose of the projection target, using Model Position, align with approximate position the obtained data and Model Data in advance. It is possible shorten the time it takes alignment, and the accuracy is increased. In addition, In order to project at any position of the projection target to determine the four points of the range projected from the modeled data. This corresponds to the Model Points of Fig. 2. When attitude convert this Model Points to the projector coordinate system, projection position is obtained. From these factors, we have set the conditions 4.

E. Process flow

For summarizing the discussions of the preconditions, we explain the process flow shown in Fig. 2. As described above, the environment map, the projection target model, and the projection contents are obtained/estimated in advance. First, based on the environment map and using the odometry sensors of UD, UD moves to the designated positions of the projection target model, UD can estimate the positions and poses of the target in the observed depth data. Finally, UD can project the contents accurately.

In the next subsections, we will describe the details of each process.

2.2 Definition of the Coordinate System

Fig. 3 shows coordinate systems used in this paper. The projector of UD is on the pan-tilt mechanism. When UD projects, several transformations are required. Thus, we set respective coordinate systems for each moving part of the UD: pan, tilt, Kinect (RGB-D camera) and projector. In contrast, the 3D model data of the projection target has own local coordinate system. We call it the model coordinate system. The origin of the model coordinate system is the centroid of the 3D model data. Here, note that the Kinect on UD rotates in conjunction with pan-move of the projector. The relative relationship between the projector and the Kinect is calibrated in advance. The proposed projection mapping can be realized model coordinate system, the projector coordinate system, the RGB camera coordinate system Kinect, the projection plane coordinate system and world coordinate system.

2.3 Modeling of Projection Targets

First, we describe about the modeling of the projection targets. To obtain the 3D data of the projection targets, we use Kinect Fusion [7]. We move a Kinect around the projection target. By using the observation sequences, we can create the three-dimensional model of the target. This 3-D model define as “Model Data”, and the Model Data has own local coordinate system. This coordinate system is defined as “ Model Coordinate System ”.

After that, we pick 4 point up from Model Data for setting the projection area on the target. These points are

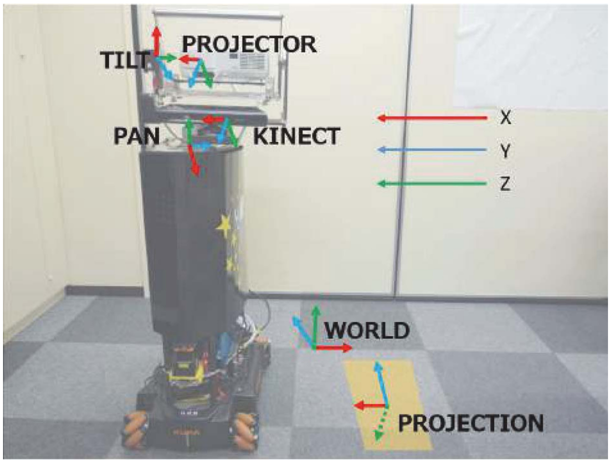

Fig. 3 Coordinate System of Ubiquitous Display

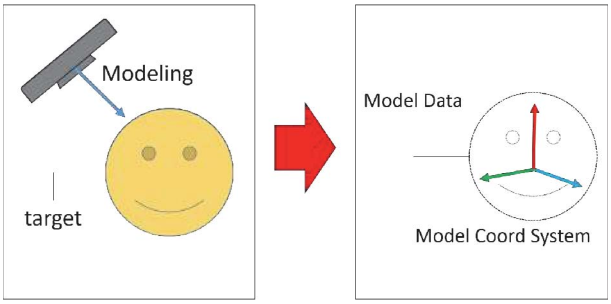

Fig. 4 Image of Model Data

defined as "Model Points". The Model Points decide the area of the projection on the target. When Model Points convert to the projector coordinate system, we can get homography from projector image points and converted Model Points. The relations of Model Data and Model coordinate system are shown in Fig. 4.

2.4 Moving to the designated positions

First, UD moves to the position of the target. An example scene before UD moves to the position of the target is shown in Fig. 5. In this scene, the projection target is 2 meters ahead and 1 meter right from UD. Although it is possible to project from any positions, in this paper, we do not consider the standing position of the person, and the position of UD are 1 meter away from the projection target.

2.5 Pointing the projector toward the target

As mentioned in the previous subsection, UD recognizes the position of the projection target. The initial projection position is the center point of possible projection range from the projector. In this paper, the initial position of the projection is the same with the center position of the target that is viewed from the position of UD. Therefore, if UD recognizes the position of the target, the pose (rotation angle) of the projector can be calculated by using inverse kinematics. Further, Kinect moves in conjunction with the pan of the projector. Therefore, UD is possible to get the 3-D depth data of the scene including the target. The 3-D data is viewed from the projector of

Fig. 5 UD's initial position

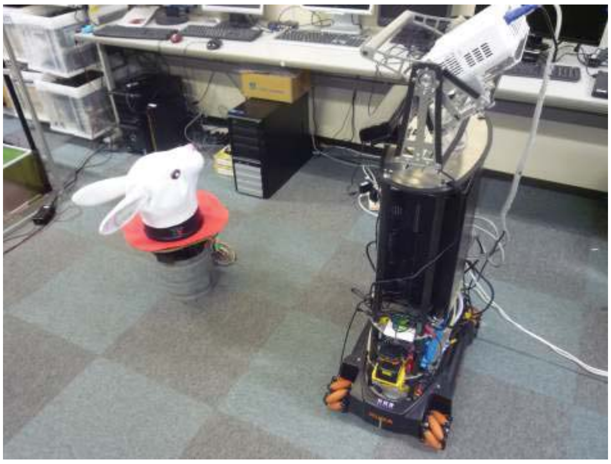

Fig. 6 UD moved and rotated projector

UD. Fig. 6 shows an example scene when UD moved and rotated the projector toward the target.

2.6 Estimating position and pose of the target in the scene

To estimate the position and pose of the target, UD obtains 3-D point-cloud data of the target by RGB-D camera (Kinect). By aligning the 3-D point-cloud and the Model Data, we can obtain the positions and poses of the target from the Kinect on UD. First, we describe the initial alignment.

A. Initial alignment

Registration without giving an initial position takes much time, and the accuracy of the registration is decreased. In contrast, if the close initial position and pose are given, the registration accuracy become higher. Therefore, first, UD moves to the projection position, and obtains the projection target from three-dimensional point cloud in the Kinect on UD. Then, we estimate the position and pose of the model data from the three-dimensional point cloud and save them as the initial position and pose. In the projection phase, by using the initial position and pose for initial alignment, registration speed and accuracy are increased. We use Point Cloud Library

(PCL) to process of 3-D point cloud data [8]. PCL is an open source library that includes various 3D point cloud data processing algorithms.

B. Estimating position and pose of the target

After the initial alignment, we estimate position and pose of the target by using the ICP algorithm. Initial alignment is movement of the model to the position of the target. Thus, the results of ICP should be the conversion to Kinect coordinate system on UD from the Model coordinate system. This conversion can be expressed as follows:

$$X_k = M_{km} X_m + X_{m'} \tag{1}$$

Note that, X_k is 3-D positions of the Kinect coordinate system. M_{km} the conversion matrix obtained by ICP. X_m is the 3-D positions of the Model Points. $X_{m'}$ is amount of movement of the initial alignment of Model Data. Thus, we can convert the Kinect coordinate system to the projector coordinate system as follows:

$$X_{k'} = X_k + \begin{pmatrix} 0.05 \\ 0 \\ 0 \end{pmatrix} \tag{2}$$

$$X_p = A_p M_{pk} X_{k'} \tag{3}$$

Note that, $X_{k'}$ is shift value from Kinect RGB coordinate system to depth coordinate system. Because the distance between the depth camera and RGB camera of Kinect is 5cm in the x-direction. X_p is 3-D positions in the projector coordinate system. A_p is intrinsic parameters of the projector. M_{pk} is conversion matrix from Kinect coordinate system to the projector coordinate system.

It is possible to determine the homography from the Model Points and the projector image points. Thereby, UD can generate projection images corresponding to the target model.

3. Experiment

To show the effectiveness of the method, we perform the following experiment..Projection target is the position of 1m in x direction and in z-direction from UD ’ s initial position. In the experiment, we use only odometry of UD for self localization, and moves to the front of the projection target. Then, the position and pose of the target are estimated and UD projects to the projection target based on the estimated position and pose. The projection target is a head of the rabbit. Model Data show in Fig. 7. Projected content is shown in Fig. 8. In addition, the optimal projection image in this experiment is shown in Fig. 9.

The results of alignment of the projection target in the obtained scene and the Model Data is shown in Fig. 10. The projection of the previous alignment is shown in Fig. 11, and the projection after the modification of the projection position is shown in Fig. 12. Comparing the projection results of before and after alignment, although slightly shifted from the ideal position, the projection position has been modified by our method. From

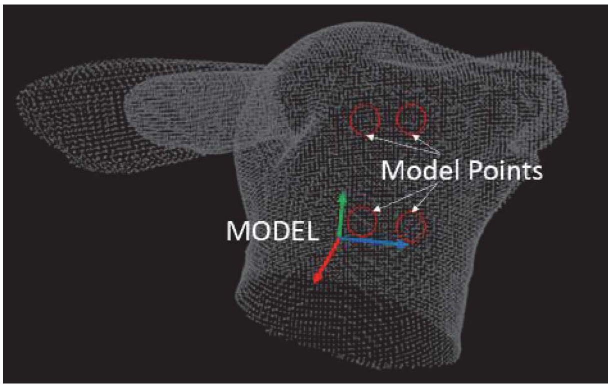

Fig. 7 Model Data

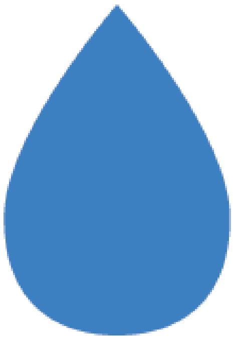

Fig. 8 projection image

Fig. 9 optimal projection

these result, the proposed method can compensate the errors due to odometry and realize accurate projection position. However, as can be seen in Fig. 12, there are some errors in the alignment phase. We are now investigating to solve such errors.

4. Discussions

From the experimental results, our method can compensate the displacement errors of the projection position and achieve the accurate projection. However, although the projection accuracy is increased, small errors remain. The following are possible reasons for the error: Errors in registration of the model data and the projection target in the scene Errors of calibration between the Kinect and the projector. By solving these problems, we will improve the accuracy in the future. Furthermore the problems of

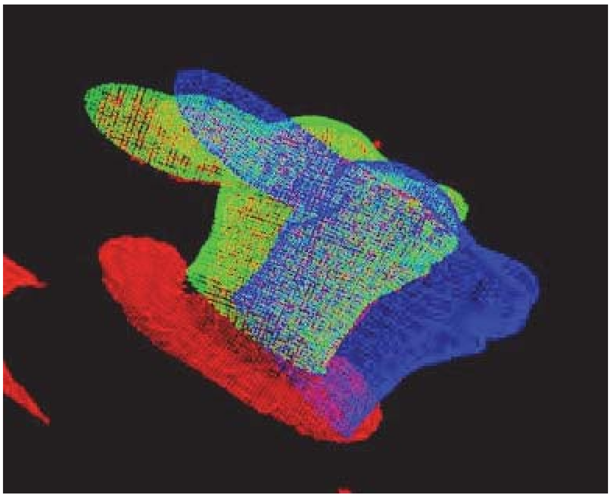

Fig. 10 estimated of position and pose(Blue point cloud is Model Data. Red point cloud is the obtained scene data. Green point cloud is aligned Model Data.)

Fig. 11 projection before alignment

Fig. 12 projection after alignment

the proposed method is processing time, since it takes 1-2 seconds for the alignment. Speeding up is necessary for actual applications.

This research realize projection mapping to various products signboards in large public facilities. It is expected to contribute as an effective advertising in the future.

5. Conclusion

In this paper, we propose a method to achieve projection mapping by mobile projector robot. Ubiquitous Display (UD) that we have developed, it was used in the proposed method. The proposed method is possible to project to the optimal projection position with compensating errors of self-localization by UD. In the experiment, UD moves to the projection position and projects the contents. The results show that our method can compensate the errors of self-localization and accurate projection can be realized. However, the accuracy of the projection is not enough in the current implementation. Thus, future works are improvement of the projection accuracy and alignment accuracy.

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