Research on Accurate Positioning of Indoor Objects Based on ROS and 3D Point Cloud

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Abstract. Due to the small environmental limitations of GPS satellite positioning and the complexity of the indoor environment, indoor object location technology has the opportunity to display its talents. Considering that the map constructed by ROS SLAM can only describe the two-dimensional information of the environment, the three-dimensional point cloud image can only describe the independent three-dimensional information of the object. This paper combines the indoor 2D map and the 3D point cloud image information of the object constructed by Gmapping algorithm and proposes a composite coordinate positioning system. The whole positioning experimental data has shown that the average measurement error of the position in the object room is only 4.2cm, and its positioning accuracy is 6.7% higher than that of the common ultrasonic and infrared positioning system[1], and the positioning accuracy of the positioning system based on Bluetooth angle measurement[2] is improved by 20% compared with ultra-wideband[3]. Positioning system increased by 72%. The object positioning error is small and the positioning is accurate.

1. Introduction
Due to the small environmental limitations of GPS satellite positioning and the complexity of the indoor environment, indoor object positioning technology has the opportunity to flex their muscles. The emergence and development of indoor small lidar and KINECT depth camera makes it easy to obtain high-definition RGB images of objects, indoor scene point clouds and three-dimensional feature point cloud image information, providing a technical means for achieving better positioning of objects.

The use of 3D point cloud image data to describe object features is simple and intuitive, and data acquisition is convenient. It mainly acquires equipment through three-dimensional scanning, records the three-dimensional coordinates, reflectivity and other information of a large number of highly dense points on the surface of the detected object, thereby describing the object features.

The ROS-based mobile platform [4] has developed rapidly in recent years due to its open source. Many well-known robot open source libraries, such as TF coordinate transformation, 3D point cloud processing driver, SLAM, etc. are all based on ROS development.

Therefore, based on the ROS-based mobile platform, this study is equipped with RPLIDAR A2 laser radar and KINECT depth camera, real-time construction of indoor map by SLAM algorithm, and 2D map and KINECT constructed by RPLIDAR A2 laser radar. The three-dimensional point cloud of the object performs composite coordinate positioning to achieve accurate positioning of the object.
2. Overall design of positioning system

2.1. Hardware and software platform construction

In order to complete the accurate positioning research of indoor objects, the RPLIDAR A2 laser radar and KINECT camera were placed on the basis of the ROS-based intelligent data acquisition mobile chassis independently developed by the laboratory. The RPLIDAR A2 Lidar is responsible for building the map[5], and the KINECT depth camera is responsible for acquiring the 3D point cloud of the object[6]. Its hardware system is structured as shown in Figure 1.

![Figure 1 Hardware system diagram](image1)

After building the hardware platform, you need the support of the software platform to complete the research. This study mainly uses the Linux-based Ubuntu16.04 system and the open source robot operating system ROS (Robot Operating System)[7].

2.2. Fusion algorithm implementation process

In this paper, the Gmapping algorithm is combined with SLAMTEC's ROS function package rplidar_ros for RPLIDAR laser radar to obtain indoor maps. Then, the KINCET depth camera is combined with the orb_slam package to obtain the 3D feature point cloud image of the object. Finally, the object is performed by the point cloud image and the indoor map. Composite coordinate positioning for precise positioning of indoor objects. The specific algorithm implementation flow chart is shown in Figure 2.

![Figure 2 Algorithm realization flow chart](image2)

3. Research on accurate positioning of complex coordinates

In order to complete this positioning research, the main research contents are: indoor map construction, 3D point cloud image acquisition, 3D coordinate information calculation and composite coordinate system positioning.
3.1. Gmapping algorithm selection and indoor map building
The key point of accurate positioning of indoor objects is to acquire the 3D coordinates of the object based on a certain coordinate system. Multi-indoor map construction is a key part of getting position of an object. Selecting the mapping algorithm is even more important.

The Gmapping algorithm is a particle filter algorithm based on RBPF [8]. It has made two important improvements in the RBPF algorithm: in order to reduce the particle number Gmapping algorithm, an improved proposed distribution is proposed. In order to reduce the number of resampling times, the Gmapping algorithm is proposed. Sex resampling [9].

Considering that the Gmapping algorithm requires a small amount of computation and high precision in constructing a small scene map, this study uses the Gmmaping algorithm to construct the map.

The experimental site of this study was a laboratory. In theory, the more the number of patterned laser particles, the more accurate the map is constructed. However, in actual operation, as the number of laser particles increases, the computer load rises sharply, and the pattern noise is more obvious. In the process of increasing the number of patterned laser particles P from 30 to 150, the generated two-dimensional map accuracy conforms to a normal-like distribution. Through test comparison. The composition particle is chosen to be 150.

After selecting the optimal number of particles, Gmapping's Linear Update and Angular Update parameters also have an effect on the composition. Finally, we selected the Angular Update parameter to be 0.2, and the map update works best when the Linear Update parameter is 0.2. The contrast effect is shown below. As shown in Figure 3.

![Figure 3](image)

(a) The influence of composition number on P  (b) Linear Update and Angular Update's influence

In the end, the number of laser particles was selected to be P=150, and both Linear Update and Angular Update were 0.2 for composition and subsequent experiments.

3.2. Calibration of two-dimensional coordinates
The calibration of two-dimensional coordinates is the basis for the establishment of a three-dimensional external coordinate system. An indoor 2D map that has been successfully built can be loaded in the virtual machine Rviz software. Take the bottom left corner of the constructed map as the origin of the two-dimensional coordinate system, and the indoor length and width are respectively the two-dimensional coordinate system x, y axis. First, you need to measure the length and width of the room, and then scale the Rviz software grid to obtain the unit grid length and width. The coordinates of any point can be calculated by equation (1), where point P is the point of real-time display of the mobile platform in Rviz.

\[ p(x_i, y_i) = \left( \frac{X}{nk} - n_i, \frac{Y}{nk} - n_i \right) \]  \hspace{1cm} (1)
The coordinate calibration of the indoor 2D map is completed here. As shown in Figure 4:

![Figure 4](image)

**Figure 4.** Two dimensional calibration of any point

3.3. 3D feature point cloud image acquisition

In this paper, the KINECT depth camera is used to obtain the point cloud image of the object to be located. In the Rviz simulation software on the PC side, the target point to be moved is selected, and the mobile chassis will move autonomously to avoid the obstacle to the target point. After observing the object to be located from the high-definition camera, we let the data acquisition chassis repeatedly move around the object to be positioned, and acquire the feature point cloud from different visions to obtain the three-dimensional point cloud image of the object. As shown in Figure 5.

![Figure 5](image)

**Figure 5.** High definition image and feature point cloud

In the above figure 5, the left image is the original image captured by the camera, and contains black and white images of red and green feature points. Comparing the two figures, after selecting the object to be positioned in the left picture, the data acquisition chassis is moved back and forth a plurality of times in the vicinity of the object to be positioned to ensure that enough feature points are collected. Finally, open Rviz in the local virtual machine to see the 3D point cloud image of the collected object. As shown in Figure 6, the blue box is a moving chassis driving track, and the red point cloud is a three-dimensional point cloud image of the collected object.

![Figure 6](image)

**Figure 6.** Object 3D point cloud
3.4. Precise positioning of composite coordinates

First, the construction of the four-dimensional positioning coordinate system is carried out. Firstly, the two-dimensional coordinates obtained by constructing the map are combined with the spatial information into a three-dimensional external coordinate system, and then the four-dimensional positioning coordinate system is constructed by classifying different indoors, I, II, III, etc. in combination with the external coordinate system.

After the four-dimensional coordinate system is constructed, in order to obtain the three-dimensional information of the object to be located, the process of obtaining the three-dimensional feature point cloud image of the object is filtered, clustered, and coordinate transformed.

Filtering Here we use a bilateral filter [10] to filter the point cloud. The advantage of the bilateral filter is that it can be edge preserved. It is a Gaussian filter function based on spatial distribution, so near the edge of the point cloud, pixels farther away will not affect the pixel value on the edge too much [11]. According to the working principle of KINECT vision sensor, the point cloud data coordinates obtained in this paper are obtained with respect to the KINECT vision sensor. The camera coordinate system of KINECT is different from the external coordinate system we define. Therefore, we have established the following coordinate transformation matrix based on the parameter optimization method of feature point cloud [12].

\[
T_i = \begin{pmatrix}
R_i & \mathbf{i}_i \\
0 & 0 & 0 & 1
\end{pmatrix}
\]

The rotation is represented by a 3 by 3 matrix, indicating that the translation is a three-dimensional vector. We select the M points with the known coordinates of the group, sit and mark them, and then measure the coordinates Q of these points. According to the transformation relationship, we can calculate the coordinates of them. Finally, the transformation matrix is calculated as:

\[
\arg \min_{T_i} \sum_{k=1}^{M} E(P_k, T_kQ_k)
\]

In order to calculate the distance error between two points, a function E is constructed. In practice, the square of the three-dimensional Euclidean distance is obtained.

\[
E(P, Q) = (P_x - Q_x)^2 + (P_y - Q_y)^2 + (P_z - Q_z)^2
\]

Where P denotes P corresponding to the three-dimensional coordinates of KINECT, Ti is a coordinate transformation matrix, and the summation process is equivalent to merging all the calculated point cloud coordinates, the coordinate values of which are based on the external coordinate system we define.

The key point of the above coordinate transformation calibration process is to have an accurate coordinate value P. Here, the point cloud data based on the three-dimensional coordinate values of the KINECT is obtained by reading the three-dimensional data of each pixel.

In addition to the point cloud information of the object to be located, the Pi has a lot of information about the undesired points. Since the objects to be located are only clustered within a certain range, we need to remove the information that does not need points [13]. In this paper, the image collected by the high-definition camera is compared with the 3D point cloud information, considering the dense point relationship of the object to be detected, and the point cloud data is separated by the point cloud data generated by the surface of each object. Therefore, we can calculate the distance between adjacent points, and cluster the point clouds by the magnitude of the distance, so as to obtain the point cloud P of only the object to be tested. These point cloud information is ultimately used for position coordinate calculation of the object to be located. Considering that the point cloud obtained in this paper is uniformly sampled on the surface of the object, the point cloud data is based on the three-dimensional coordinates of KINECT as follows:

\[
\text{Centroid} = \frac{1}{N} \sum_{i=1}^{N} (x_i, y_i, z_i)
\]
Based on the optimization theory, in order to reduce the calculation error, the number of feature points needs to be sufficient. Location selection should be representative. The coordinates of the object based on the external coordinate system are obtained by passing the three-dimensional coordinates based on KINECT through the affine matrix through equation (6).

$$P = \sum_{i=1}^{N} T_i * PC_i \quad (6)$$

Combined with the first dimensional coordinates, the four-dimensional coordinate data of the object is obtained to achieve the effect of precise positioning.

4. Experimental result

Here, the effect diagrams of two typical experiments are intercepted. The results of multi-chamber and multi-object precise positioning experiments are as follows. The average position measurement error of the two objects is only 4.2 cm. As shown in Figure 7.

![Figure 7. Location experiment result diagram](image)

(a) Four-dimensional coordinate calibration of the room I

(b) Four-dimensional coordinate calibration of the room II

After that, three other indoor object positioning systems were tested: ultra-wideband positioning system, ultrasonic and air-line positioning system, and positioning system based on Bluetooth angle measurement to locate large object bottles and small object dolls in the same indoor environment. Compared with the other three common indoor positioning methods, the accuracy is higher and the effect is better. The positioning results are compared as shown in Table 1 below.
### Table 1. Comparison of positioning results

| Method                                      | Large object | Precision (cm) | Small object | Precision (cm) |
|---------------------------------------------|--------------|----------------|--------------|----------------|
| Ultra-wideband positioning system          | bottle       | 12             | doll         | 18             |
| Ultrasonic and infrared positioning system | bottle       | 4.7            | doll         | 4.3            |
| Positioning system based on Bluetooth angle measurement | bottle       | 5              | doll         | 5.5            |
| Positioning system based on ROS and 3D point cloud | bottle       | 4.3            | doll         | 4.1            |

From the experimental results, the positioning system proposed in this paper can locate the indoor objects more accurately, especially in the positioning accuracy of the more difficult small objects.

### 5. conclusion

In this paper, a RG-based SLAM algorithm and a three-dimensional feature point cloud object precise positioning system are proposed. The ROS SLAM can only describe two-dimensional information, and the three-dimensional point cloud can only describe the independent three-dimensional information of objects. Through the experimental results, the positioning accuracy is 6.7% higher than that of the common ultrasonic and infrared positioning system, 20% higher than the positioning accuracy based on Bluetooth angle measurement, 72% higher than the ultra-wideband positioning system, and accurate for indoor objects. The positioning effect is remarkable.

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