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Indoor Map Display Method Using Mixed Reality

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Abstract

We have developed a remote control robot for searching for victims inside buildings during disasters. We used the approach of searching inside buildings by displaying a map. Concerning displays, several studies have been done on constructing 3D indoor maps from laser scan data acquired by a laser scanner. However, it is difficult to construct 3D maps in a vast or complicated space. Conventionally, these systems display only part of the indoor architecture that the robot was able to acquire.

We describe here a method to display an entire indoor architecture using mixed reality. This method can display vast or complicated space using an image. Furthermore, we developed a method of synthesizing a display of a 3D map on an image by using a translation technique that recognizes the borders of a 3D map and an image. Our method allows the system to represent the entire indoor architecture seamlessly.

1. Introduction

In times of disaster, it is advisable to search for victims inside buildings by using a remote control robot equipped with a camera. For the rescue team, the indoor architecture acquired by the robot is helpful to them in rescuing victims. The conventional methods of representing indoor architecture are constructing a map, and using images as a map.

As a map construction method, several researchers have developed methods of matching and combining laser scan data acquired at separate locations [1,2,3,4]. A 3D map is translated from a constructed map simply by adding height. The feature of this 3D map view is that there are no restrictions on the view location or direction. It allows a walkthrough in virtual space. However, despite the effective space representation, it is difficult to make a map of a wall in the distance or in a complicated space.

On the contrary, several studies have been done to develop a method of representing indoor architecture using images as a map [5]. Image based rendering (IBR) is a method to display an image of an indoor scene according to a view location in virtual space. One of the notable features of IBR is the ability to represent complicated and distant spaces. On the other hand, view location and direction in virtual space are restricted by the acquired locations of images.

Further, it is impossible to display 3D maps and IBR images as seamless space; however, the indoor structure of the whole space can be displayed by choosing a 3D map or using IBR based on the acquired data. Because it relates to this problem, research on mixed reality (MR) to superimpose computer graphics (CG) objects onto an image of a scene has been done [6,7,8]. On the contrary, not much research has been done on synthesizing CG as space to a scene image.

To address this problem, we developed a method to synthesize images of a 3D map in order to represent indoor architecture seamlessly. Paying attention to the border of a 3D map and an image map, we developed a system to extract a border shape model as a "Gate" from a 3D map. In addition, the position on the image-plane of the Gate is a map that is based on the location and the direction of the image that is taken. By attaching the Gate model in a 3D map and the Gate position on an image, a seamless display of indoor architecture was enabled.

2. Indoor map display system

The configuration of the indoor map display system is depicted in Figure 1. The system is composed of a remote control robot and a computer connected via Wi-Fi. A rescue team watching the images obtained by the robot on the computer controls the robot during its search. The system constructs a 3D map or an image map, by laser scan data acquired by the robot. In addition, the system constructs linkage data as a “gate” between a 3D map and an image map. The constructed map is displayed on the computer. The representation of indoor architecture is seamless using the image synthesis method of a 3D map on an image map.

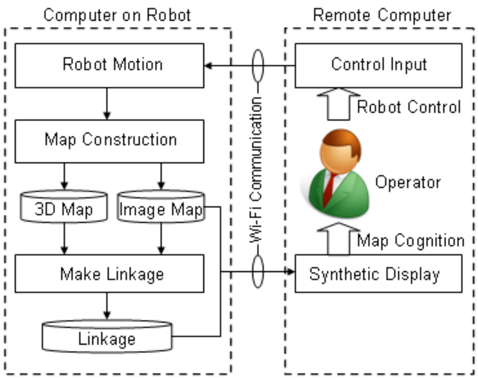

Figure 1. Indoor map display system configuration.

2.1. Map construction

First, we describe how the map is constructed using the sensing data. The configuration of the sensors on the robot is shown in Figure 2. A laser range scanner is installed horizontally, and a camera is installed with the optical axis positioned in the direction of the robot. A pan unit is installed for turning camera to take texture. The robot moves about 1 meter with each control order, and it stops to acquire laser scan data and an image. The laser scan data lines for walls are straight because the scan data show the distance from the robot to the surrounding walls. As illustrated in Figure 3, the system detects straight lines using Hough transform and gives height to the shape of the wall and constructs a local 3D map. To construct a 3D map of the whole space, sequential local 3D maps are combined according to the distance the robot has moved as acquired by an odometer. Further, a texture image taken by the camera is put on the wall of the 3D map.

Here, we describe the approach used to determine the 3D model construction. The features of the laser scan data allow the system to distinguish whether or not 3D map construction is possible.

If the distance from the robot to the wall exceeds the range limitations of the laser scanner, the wall cannot be extracted from laser range data. Likewise, the laser scan data lines become disordered in a complicated space, and consequently, the wall cannot be extracted. The system can construct a 3D map where the wall can be extracted on both sides of the robot.

On the contrary, in the area where the 3D map cannot be constructed, the robot takes sequential images with records of the location and direction of these images using calculations from odometer data (Figure 4).

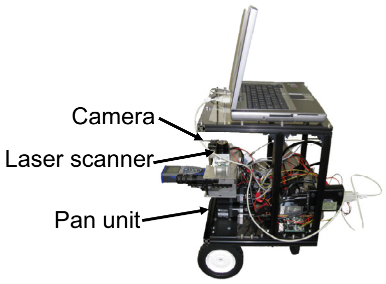

Figure 2. Robot configuration.

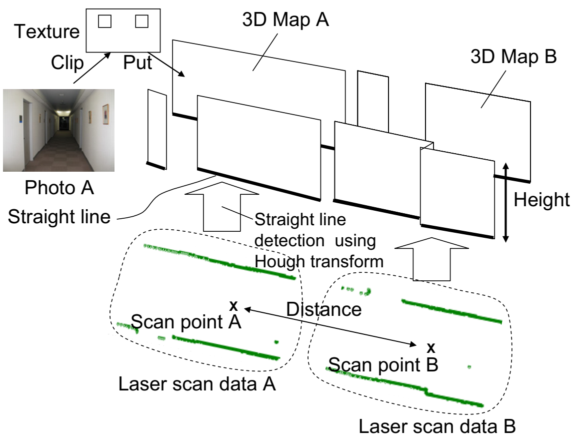

Figure 3. 3D map construction.

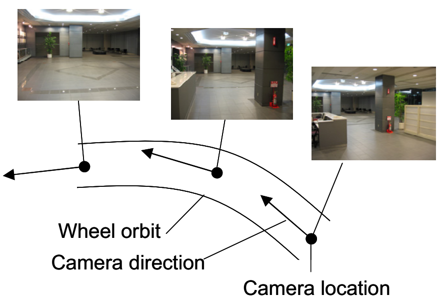

Figure 4. Image map construction.

2.2. Linkage of 3D map and image map

This section describes the construction of linkage data between a 3D map and an image map. We call the linkage data a "Gate" that connects the 3D and image maps.

First, The method to extract the Gate from laser scan data is shown in Figure 5. At point A in the figure, a wall is detected in the robot's surroundings. Next, at point B, another wall has already been detected in front of the robot. At point C, the robot turns to the left and passes the space between the detected walls, where there is no wall on the left side of the robot. We found from the result that the space the robot passed is a boundary between possible and impossible areas for 3D map construction, and the ends of the wall beside the space are considered to be the edges of the Gate.

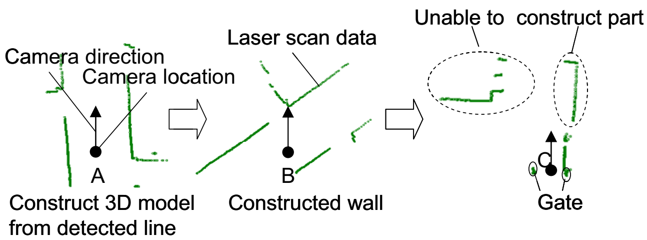

Figure 5. Link gate detection.

The method used to map the vector of the Gate on an image is illustrated in Figure 6. The system expresses the laser scan data in circular polar coordinates, and its polar axis agrees with the optical axis in the horizontal plane. In the figure, θa and θb are azimuth angles that show the edge of the Gate, and these are obtained from the laser scan data. Distance ra and rb from the robot to the edges of the Gate are also observed by laser scan data. Angle θr, which is the intersection of the ceiling and wall a, and angle θf, the intersection of the floor and wall a, are shown in an elevational view. Assuming that height hr of the ceiling, height hc of the camera, and focal length f of the camera are known, θr and θf can be calculated from hr, hc, and ha according to formulas (1,2). Figure 7 shows the four corners of the "gate" and the plane-coordinate axes on an image. The coordinates in the four corners of the Gate are calculated from θa, θb, θr, and θf. The x-coordinate value of the four corners can be obtained by formulas (3) and (4). The y-coordinate value of the four corners can be obtained by Formula (5). ra in Formula (1) or (2) can be changed to rb by selecting it. Also, ya and θa in Formula (5) can be changed to yb, and θb by selecting them.

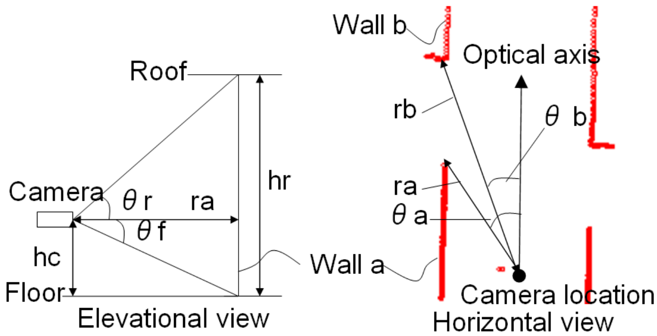

Figure 6. Mapping vector of gate.

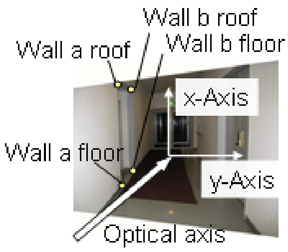

Figure 7. Image plane.

$$\theta r = \arctan((hr - hc) / ra) \quad (1)$$
$$\theta f = \arctan(hc / ra) \quad (2)$$
$$xr = f \tan \theta r \quad (3)$$
$$xf = f \tan \theta f \quad (4)$$
$$ya = f \tan \theta a \quad (5)$$

2.3. Synthesized display method

This section presents a synthesized method of displaying a 3D map on an image in order to represent indoor architecture seamlessly. This method has two cases. One involves switching from the 3D map display method to the scene image display method, and the other is the reverse.

The synthesized display method for switching from the scene image display method to the 3D map display method is shown in Figure 8. Sequential images are taken while the robot is moving, as shown in Figure 4. In Figure 8. The left image shows the vector of the Gate. The system selects the 3D map data connected with the position of the vector of the Gate from the view location and view direction of the image. The system adjusts the position and the azimuth of the 3D map data, as the length of the right and left vectors of the Gate in the image agree with the 3D map. The system then superimposes a 3D map on the image.

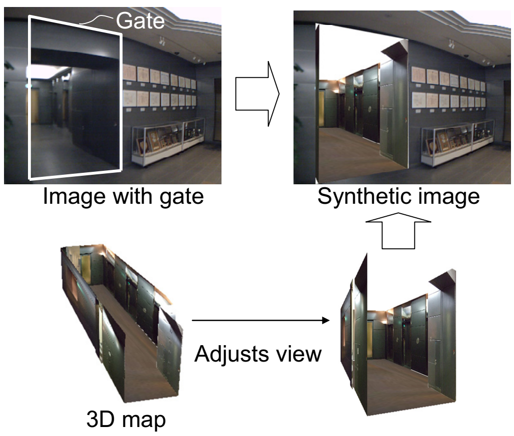

Figure 8. Synthesized 3D map in image map.

Figure 9 shows the synthesized display method for switching the 3D map display method to the scene image display method. The system clips the image from the scene image according to the vector of the Gate. The system then maps the image clip to the Gate in the 3D map, since the space inside the gate is not expressed as a 3D map. This method allows the expression of complex shapes and vast spaces.

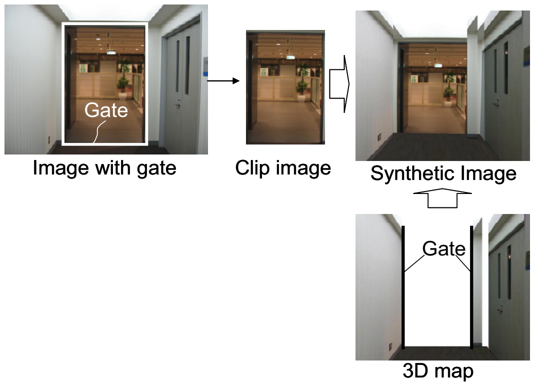

Figure 9. Synthesized image map in 3D map.

We developed software that superimposes an image layer on a 3D map layer in order to embody the synthetic display method. The system displays non-displayed parts in the image layer based on the transparency color, and superimposes it on the 3D map layer. (Figure 10).

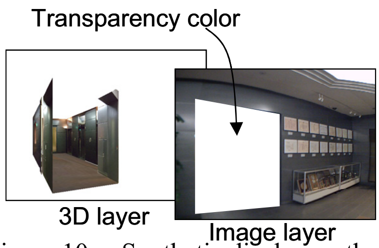

Figure 10. Synthetic display method.

There are advantages and disadvantages to both types of display methods. The 3D map display method is restricted within the construction range; however, it can change the view location and direction. In contrast, the image map display method has a restriction in the view location, but nevertheless, it can express any space. Our method of synthesized display complements both display methods, and consequently represents indoor architecture seamlessly.

3. Experimental Results

We carried out experimental evaluations of the effect of expressing indoor architecture using our method. We constructed a map of a floor of a building including corridors, rooms, and a lobby as the architecture to represent. The result appears in Figure 11. A 3D map of the corridors surrounded by walls was constructed, and a wide lobby was expressed in the image map. A room connected to a corridor was also expressed in the image map. The dotted line is the path of the robot during the image map construction. We input 3D data, images and location data where images were taken to the software. The software generated the synthetic images.

The display results of the indoor structure using the synthetic display method are shown below. Figure 12 shows the results of switching from the 3D map display method to the scene image display method. The left images in Figure 12 are examples of displaying the inside of a room by using an image, and displaying the outside of a room by using a 3D model. The images at the right of the figure are examples of displaying a lobby by using an image, and displaying the corridor connected to the lobby using a 3D model.

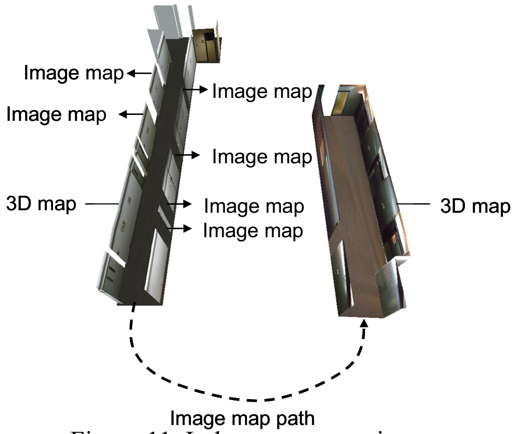

Figure 11. Indoor map overview.

Figure 12. Sequence display 3D map and image map.

It was found from the results that the clip part of the image is transformed according to the movement of the 3D map view position. Consequently, it is possible to achieve a seamless walkthrough from the 3D map to the image map.

On the other hand, Figure 13 shows the display result of switching from the scene image display method to the 3D map display method. The clip area precisely covered the undisplayable area with a 3D map. As a result, a seamless walkthrough from the image map to the 3D map is possible.


Figure 13. Sequence display image map and 3D map.

The notable feature of our method is the ability to display the entire area of the indoor architecture seamlessly. Our method makes it possible to display complicated or vast space using images even though 3D map construction of such space is thought to be difficult. Furthermore, by displaying the 3D map display view location and the scene image display view location in seamless way, the system can express the topological relations of the complete indoor architecture.

With regard to the effect of expressing indoor architecture, we carried out comparative experiments of our method and an image display method. Specifically, we observed operating time needed to count rooms and find a specific room. In the image display method, the system displays images in the order they are received. The operator can only select the previous image or the next image to display. With our method, the operator can change the forward viewpoint, turn right, and turn left in the 3D map. Our method provides an operation to display the previous image or the next image in an area without a 3D map. It clearly shows that our method is effective for gaining an understanding of an indoor structure and for searching for a victim indoors. By displaying a 3D map with structure and a real image map seamlessly, the users were able to recognize it as one space.

4. Conclusion

We developed a remote control robot for searching for victims inside buildings in times of disaster. In this paper, we described a method to synthesize a 3D map with an image of vast space in order to represent indoor architecture seamlessly. The method reduced the restricted area of the view position that is a problem with IBR through synthesis with the 3D map. Moreover, the method made it possible to express a complicated area where 3D map construction is difficult. This method enables a remote control robot to express indoor architecture to an outside location in order to facilitate rescue.

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