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Real-time Contextual Data-Updated 3-D Radiation Image Reconstruction for Large-Area Hybrid Gamma Imager

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1. Introduction

When decommissioning nuclear facilities or decontaminating areas where nuclear accidents happened, numerous isotopes emitting gamma rays with various energies are involved. To identify and localize the released isotopes, a broad energy range and high imaging efficiency gamma-ray imager is needed.

The recently developed large-area hybrid gamma imager (LAHGI) achieved the requirements of broad energy range and high imaging sensitivity by using two large-area scintillation detectors and a hybrid imaging method involving Compton and coded-aperture imaging [1].

In the LAHGI system, the radiation image is registered on the RGB image by simply overlaying the radiation image on the RGB image. The main limitation of this simple approach, however, is that the parallax between the RGB image and the radiation image degrades the accuracy of the estimated position of the radiation source. In addition, the reconstructed image can be obtained only when the imager is stationary or motionless.

These limitations can be overcome by using the approach of scene data fusion which combines the contextual scene data and the emission data from the radiation imager and ensures accurate registration of the radiation image on the RGB image [2].

In the present study, we developed and tested a real-time contextual data-updated 3-D radiation image reconstruction algorithm based on the simultaneous localization and mapping (SLAM) algorithm for the LAHGI system.

2. Materials and methods

2.1. System configurations

The LAHGI consists of a front and a rear detector, a coded aperture mask, and contextual sensors. The LAHGI was designed for high imaging sensitivity, so the NaI(Tl) crystal which can be grown to a large size with relatively competitive cost [3] was chosen. Each of the scintillators is a monolithic NaI(Tl) crystal with arrays of 2-inch square-type photomultiplier tubes optically coupled to the scintillators. The coded aperture mask was designed as a 2 × 2 mosaic pattern of rank 19 modified uniformly redundant array (MURA) tungsten mask [4]. Two cameras were used to acquire contextual data: a tracking camera (Realsense T265 Intel, CA, USA) and an RGB-D camera (D455, Intel, CA, USA). The tracking camera provides real-time odometry of the system with two fish-eyed cameras, inertial momentum unit sensor, and a built-in visual processing unit. The RGB-D camera provide the RGB images and the depth images, which were used to map the surrounding environment with point clouds.

In the present study, a C++ based program was developed using the Open3d library [5] to process the point cloud data to achieve real-time registration of the radiation image and the RGB image.

2.2. Real-time contextual data-updated radiation image reconstruction

The contextual data is the surrounding geometry information and the position of the system acquired by the SLAM algorithm. The SLAM algorithm maps the surrounding environment and tracks the position of the system using the depth and tracking cameras. The iterative closest point (ICP) algorithm calculates odometry as a transformation matrix between the neighboring frames of point clouds from the depth camera. The tracking camera provides the initial odometry value of the ICP algorithm which makes calculation accurate and fast. After calculating the transformation matrix between the frames of point clouds, each frame is transformed and combined as a whole map and provides the current position of the system.

In the real-time contextual data-updated radiation image reconstruction algorithm, each frame of the radiation image and each frame of the point cloud are updated by the position of the system at a given time. Each frame of the radiation image is a far-field hybrid image assuming the sources are placed in a far-field range. The far-field range is the distance of the source that cannot be physically determined since the gamma rays from a remote source is almost parallel at the location of the imaging system. Because the far-field imaging only needs to calculate the directional information, the calculation is very fast.

The simple back-projected far-field radiation image is generated every one second. The positions of far-field radiation images align with a transformation matrix calculated by the SLAM algorithm in real-time.

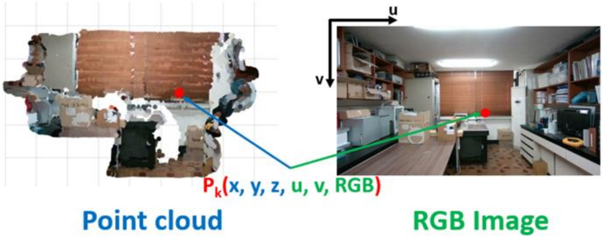

Fig. 1. A point that corresponds to the point cloud and the RGB image.

The cumulated radiation images are projected on a current 3-D point cloud (x, y, z) and resampled on a corresponding two-dimensional plane (u, v) of the RGB image (Fig. 1). The radiation image was normalized and registered in a jet color scale on the RGB image using the alpha blending method (scale of 0 – 0.5) for enhanced visibility.

Although the contextual data updated radiation image projected on the RGB image provides a geometrically calibrated radiation image, the field of view (FOV) is limited in the FOV of the RGB image. The additional 3-D radiation image reconstruction algorithm has no limit of FOV by reconstructing radiation images on the 3-D mapped surrounding environment. Every contextual data updated far-field hybrid radiation image is overlayed on the down-sampled map from the SLAM algorithm. The radiation image space point cloud is down-sampled with larger voxel size to reduce the calculation time of overlaying radiation images.

3. Results and discussion

To test the imaging algorithm, a ^{137}Cs point source of 86 µCi was placed on a desk located at 5 m from the LAHGI system. The imaging system was slowly moved toward the source and then turned around at 3 m from the source to get a 3-D map of the room. The total imaging time was 90 seconds. The images were displaced in real-time in the imaging system with an in-house GUI program developed for this purpose.

22 seconds **63 seconds**

Fig. 2. Real-time contextual data updated radiation images projected on RGB images of the ^{137}Cs source at 22 and 63 seconds.

Figure 2 shows the real-time contextual data-updated radiation images at 22 seconds and 63 seconds, which shows that the source location is accurately registered on the RGB image despite the fact that the imaging system moves continuously in the experiment.

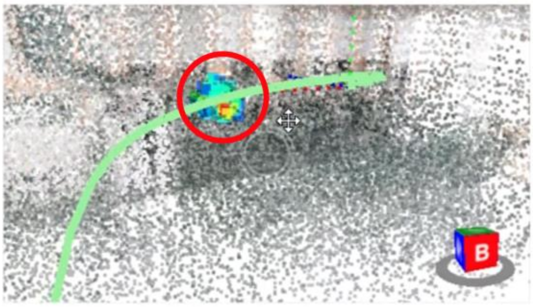

Fig. 3. 3-D radiation image. The green line is the moving path of the imaging system. The radiation source image is reconstructed in the red circle.

Figure 3 shows the 3-D radiation image which was reconstructed as a jet color scaled point cloud. The position of the source in a 3-D point cloud was estimated by fusing the surrounding point cloud map and the 3-D radiation images.

4. Conclusion

An algorithm for real-time contextual data-updated 3-D radiation image reconstruction for the LAHGI system. By using a wide detection energy range and a high-efficient hybrid radiation imager with the tracking and RGB-D cameras, it was shown that the fused image accurately provides the location of the source in real-time in both the RGB image and the 3-D map. The image reconstruction was based on simple back-projection in which the intensity of the source cannot be determined. Therefore, the maximum likelihood expectation-maximization algorithm will be developed to calculate the quantitative information of the radiation source.

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