Research on Smart Indoor Energy-saving Technology Using a 3D LiDAR

Yu-Cheng Zhang, Ya-Wen Chang, and Jin-Siang Shaw

***Abstract*—In recent years, global warming has heightened energy conservation awareness. Taiwan's Ministry of Economic Affairs reports a record-high total electricity consumption in 2021 within the past decade, with lighting and air conditioning being the biggest energy consumers in commercial and office spaces. Employing YOLOv4 deep learning, we've developed a character recognition system for precise identification in experiments. Statistical data shows an average 228-minute electricity savings within 1800 minutes, reducing consumption by 12.7%. To create a privacy-conscious lighting energy-saving system, we've forsaken RGB cameras in favor of 3D LiDAR (Light Detection and Ranging) for point cloud image construction and processing under the Robot Operating System (ROS). Ultimately, individuals within the environment are selected from the point cloud and managed based on indoor lighting configurations.**

***Index Terms*—*Point Cloud Filtering*, *Rviz*, *3D Point Cloud*, *Automation*, *ROS*.**

I. INTRODUCTION

In the modern world, electricity has become an important demand for people's livelihood. According to the "2021 Electricity and Energy Supply and Demand Report" released by the Energy Bureau of Taiwan's Ministry of Economic Affairs last year, Taiwan's total electricity consumption in the past ten years has set a new record of 293 billion kilowatt-hours [1]. Lights and air conditioners are the top two consumers of electricity. Coupled with the outbreak of the Coronavirus Disease (COVID-19) in 2020, the virus has gradually spread around the world. From May 2021, the epidemic in Taiwan has heated up, and the "stay-at-home economy" has accelerated in various places, driving the revenue growth of the retail industry and delivery platforms. However, schools are turning to remote teaching, businesses are turning to work from home, and global warming and summer heat have combined to increase residential electricity consumption. Besides the development of semiconductors and electric vehicles, electricity demand is expected to grow by an average of 2.5% through 2027 [2]. Therefore, the domestic power was tight from April 2021, and Taiwan's power system was on the verge of collapse. These factors force a surge in electricity usage, which leads to power shortages. The 513 and 517 power outages continued [3]. If energy-saving policies are not corrected immediately, power shortages will become commonplace.

Since 1980, humans have created the first IoT devices. The IoT is ubiquitous today, combining sensors and cloud technology to collect and transmit data and apply it to factory equipment, automobiles, mobile devices, smart watches, etc. At the same time, urbanization has prompted reduced energy consumption without affecting the lives of users, so how to reduce the use of electrical appliances has a key role. Vishwakarma et al. control home devices through the Internet and Raspberry Pi, monitor the switch-off electrical world to actively promote smart cities, which can appliances, detect whether lights and fans are turned on and off, and add voice commands to control [4]. Although the Internet technology has made great progress, according to the report, information and communication technology (ICT) alone consumes 4.7% of the world's electricity, and it may rise to 10% in the future, so the effective transmission of information is also a very important topic [5].

But machine learning was developed after three waves of artificial intelligence in the 1950s. In 2006, a multi-layer neural network came out, resulting in deep learning. Recently, artificial intelligence combined with image recognition has become a trend, and face recognition is used in many applications. Islam et al. proposed Haar Cascades feature extraction. Labeling database images, through different black and white rectangular feature modules, using the Adaboost algorithm, and ROI detection to find faces. However, Haar will cause misjudgment due to the brightness of the light, and image shadows. Adding different lighting images to the building database can enhance accuracy. When faces are occluded more than 60%, they will not be recognized in low light [6]. Thus, Haar is more suitable for face recognition and can be used in smart home access control equipment and smartphone unlocking projects to ensure user security. Additionally, in the previous experiments, the laboratory has been used as the experimental field, and a 4800-image data set has been established with a 360-degree fisheye check installed, which contains negative samples of the environment to tell the model where to define the background of the environment. To increase the diversity, complexity, and generalization ability of the data, adding 6000 pieces of data from the open-source database which is called Open Images Dataset V6 + Extensions. Then divide them into the training set and validation set according to the ratio of 8:2, and use YOLOv4 for training. When IoU is set to 0.3, the accuracy is 98%.

Due to the use of surveillance to obtain recognized portraits in the smart office, there have privacy issues and limitations on cameras in some cases, this experiment uses the point cloud of 3D LiDAR instead. Point cloud technology provides depth and geometric information in 3D space and it is used in computer

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vision, autonomous driving, robotics, and medicine. Bhaskar Anand et al. obtained point cloud data at different oblique angles from various multi-channel optical radars, combined it with INS/GNSS data, and performed de-ground processing and obstacle segmentation to obtain the coordinate position of obstacles in real-time [7]. Jafargholi et al. determined the position of multiple targets using the peak value of the fuzzy function caused by the target in the region of interest obtained after LiDAR scanning. Using the good ability of the fuzzy function to radar waveform analysis, and then processing the noise in the environment through the empty function. It can accurately find out the small target next to the big target in a cluttered environment. To achieve fast and accurate PCL radar multi-target detection [8]. Zella et al. proposed a point cloud fast filter (Point-Cloud Fast Filter for People Detection, PFF-PED), using Velodyne VLP-16 (3D) to provide ten point cloud samples per second. Focusing on the human legs and torso in the samples, the data area is divided into different vertical parts. The proportion and size of the human body are defined concerning the principles of anthropometry, to matching two sets with each other. And the tracking trajectory is estimated when moving. This detection can be applied to people walking in corridors and other regions [9]. Held et al. used the data set of KITTI in the current largest autonomous driving scene for point cloud segmentation. Then through the visual appearance and motion to solve the category-independent segmentation problem in image space. Removing background before grabbing features. And compare the results of training by AVOD, PointPillars, PointRCNN, and SECOND. Finally, pedestrian detection achieves the highest accuracy of 78% in the Second++ algorithm [10].

In this study, excluding RGB images, only 3D optical radar is used to know the personnel configuration in the environment. then control the light by the results to achieve energy saving effect. Compared with image processing, processing point clouds are less developed by people. Furthermore, using LiDAR has no privacy concerns.

II. SYSTEM DESCRIPTION

The experimental equipment 3D LiDAR is used to obtain the environmental information of the energy-saving office.

A. Hardware Architecture

The hardware equipment used in this experiment is Yujin 3D LiDAR (Light Detection and Ranging, LiDAR), model YRL3-20, which has high precision, size small, and is easy to install. Its measurement distance is longer than the range of the image monitor. The maximum distance can reach 20m, the horizontal scanning angle is 270 degrees, which is enough to judge the position of personnel, and the frequency is 20 Hertz (Hz); the vertical angle is 90 degrees (-45 degrees to +45 degrees). If the vertical angle is set to 90 degrees, the frequency is 0.57 hertz. Generally, 3D LiDAR generates pulse waves with a wavelength of 905nm according to the frequency. This band belongs to infrared waves. Objects have no penetration in this band. Objects can reflect this to obtain the outline of the object. Since light travels at the speed of light, the time from beam emission to reception can be calculated, and the relative distance and position of objects can be converted. Compared with RGB images, LiDAR can detect day and night without being restricted by darkness or light. In order to scan the complete laboratory environment, the LiDAR was erected at a high position in the front left of the experimental site. As shown in Figure 1. Since its scanning vertical angle is ±45°, it can cover the required seating area below. After the erection is completed, the computer terminal uses the Ubuntu operating system to view the point cloud distribution. The point cloud in the laboratory environment in real-time, as shown in Figure 2.

B. System Structure

The LiDAR chooses the Robot Operating System (ROS) for point cloud processing. Then use C++ to write the relevant programs for point cloud processing in the ROS Melodic operating system of Ubuntu 18.04. First, rotated and translated the coordinate system of the real-time point cloud by PCL (Point Cloud Library). Removing the unnecessary point cloud of Walls and floors. And noise is removed through a series of filtering methods, such as pass-through filtering, RANdom SAmple Consensus filtering, etc., to obtain point clouds of people in each seat and aisle area. Then cooperate with laboratory lighting to divide point clouds. Finally simulate the configuration of light switches with environmental characters. To be able to operate on low-performance hardware, PCL will pass data through the Boost shared pointer during all operations, avoiding duplication of existing data and saving some computing time [uuu].

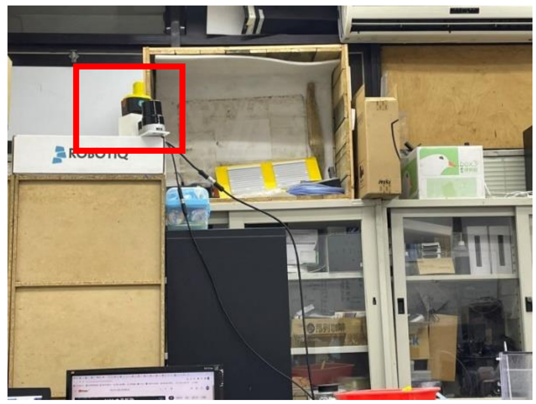

Fig. 1. Completed LiDAR.

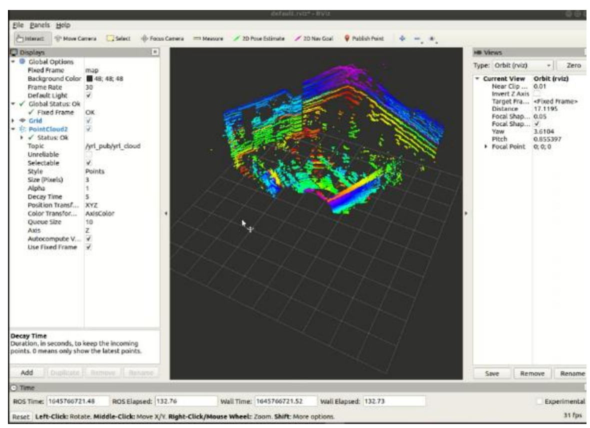

Fig. 2. Instant point cloud of the laboratory environment.

III. POINT CLOUD FILTERING METHOD

When creating 3D spatial point cloud data for 3D LiDAR, many unavoidable and unnecessary data will be generated due to insufficient equipment accuracy, inaccurate parameters, environmental factors, or user operations. The redundant points are called "noise", including outliers and holes. Because the laboratory environment is too complex, many interferences will be generated by scanning and must be removed by filtering. Including the noise or features such as ceilings and walls that will not be used when detecting people. It can be deleted to speed up the speed of subsequent system operations. The real-time point cloud obtained in Figure 2 was originally unordered. To perform rotation, filtering, and other processing on it, encoded the XYZ coordinate value and intensity (Intensity) for the unordered point cloud. Thus, point cloud information can be got by (x, y, z, I).

A. *Coordinate Rotation*

Due to the horizontal scanning angle of Yujin LiDAR being 270°, to scan from the doorway to the seating area, it is decided to rotate the LiDAR at some angles in the horizontal direction. To facilitate the subsequent processing of the point cloud, the z-axis is rotated by 1.66π through Affine3f, so that the point cloud and the coordinates coincide. And the resulting point cloud image of the rotation is shown in Figure 3, where the green (vertical) coordinate in the figure is the y-axis, the red (horizontal) one is the x-axis and the blue one is the z-axis.

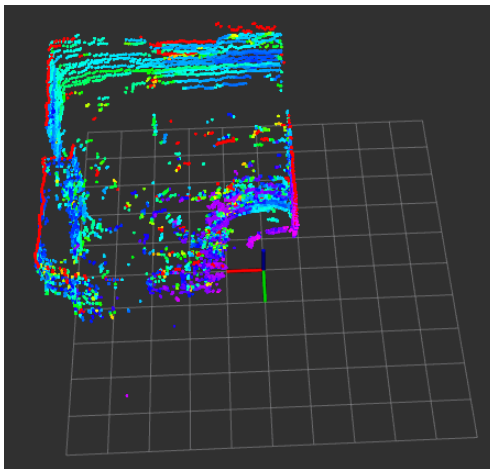

Fig. 3. The result after rotation by Affine3f.

B. *Remove Ceilings, Floors, and walls*

In Figures 1 to 3, to further clearly see some internal configurations to ensure whether it is the correct laboratory instant point cloud, the original point cloud has been processed to remove the ceiling. If the ceiling is not processed, it is shown in Figure 4.

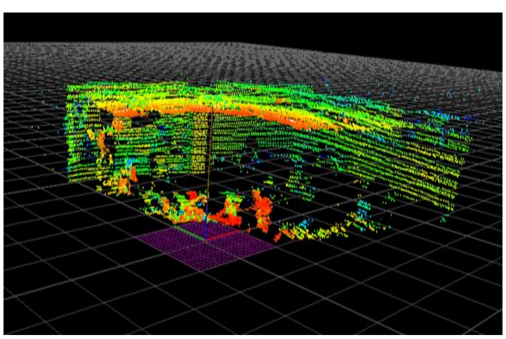

Fig. 4: Point cloud without ceiling removal.

Since the ceiling and the ground are both perpendicular to the z-axis, when the z-plane needs to be removed, only need to remove it. In this study, choosing a pass-through filter for filtering. It can choose to set up a removal area or a reserved area. By setting the z-axis value range, the point cloud of the entire dataset is searched. If the point cloud is determined to exceed the threshold, it will be deleted at a single point, and then the information that conforms to the value range will be left in sequence. The z-axis range is set to [0.3, 1.8] in meters, which removes the ceiling and floor features.

For filtering out walls, since all four sides will be perpendicular to the XY plane, filtering is performed using a pass-through filter in the same way as removing ceilings and floors. The front and rear walls of the laboratory are filtered by setting the y-axis value range to [-5.65, 0.9], and the result is shown in Figure 5; while the left and right walls are set to the x-axis coordinate interval [-0.7, 4.6], and finally the point cloud image filtered by the surrounding walls and the ground and ceiling is shown in Figure 6. It can be seen from the figure that the laboratory is divided into three rows of seats. Starting from the red x-axis, the first row of desks is almost parallel to the x-axis and two rows back to the y-axis. The grid is the second row, and the two grids back are the last row.

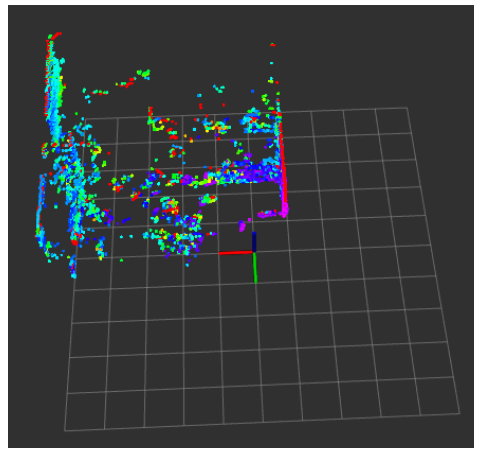

Fig. 5. Filter out the front and rear walls.

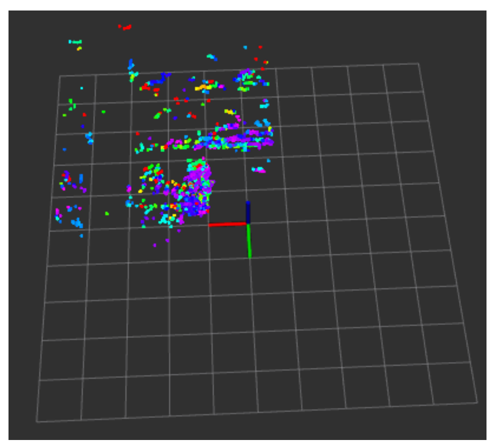

Fig. 6. Filter out left and right walls.

C. *Remove Plane*

There are many tables set up in the laboratory field, which can use the random sampling consensus (RANSAC) method to find out where the planes are in the data to split it. In this study, the SACMODEL_PLANE model in PCL is used for processing, and the distance threshold is set to 0.06 meters. After iteration, the inliers that are regarded as planes are removed, and the point cloud image of the removed plane is obtained, as shown in Figure 7. Compared with the number of point clouds in the table in Figure 6 dropped quite a bit.

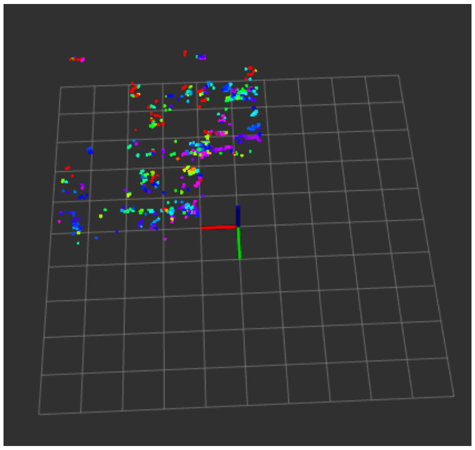

Fig.7. Remove the point cloud from the desktops.

D. *Remove Noise*

There are many sparse discrete points in the scanned point cloud. And different types of noise can be processed through different filtering, such as statistical outlier filtering, radius filtering, bilateral filtering, etc. In experiments, radius filtering is more suitable for this study to remove single-point noise. After RANSAC removes the plane and removes most of the outliers through radius filtering, the portrait can be seen more clearly, as shown in Figure 8.

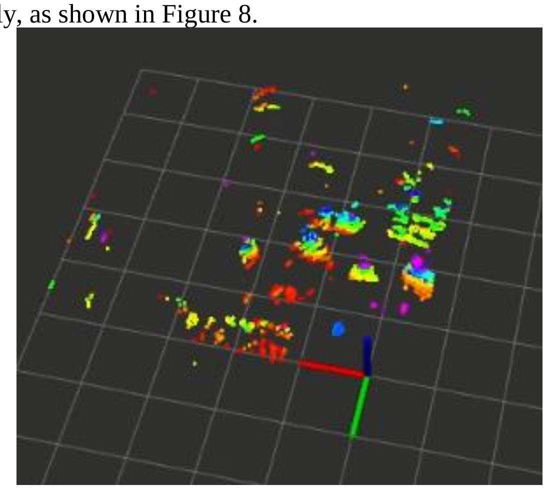

Fig. 8. The result of radius filtering to remove outliers.

E. *Voxelization*

Because the GPU performance of the hardware equipment used in the experiment is relatively insufficient, to speed up the speed without losing the characteristics of the point cloud, the point cloud is down-sampled its voxel, and the 3D voxel grid size is set as (0.01, 0.01, 0.01) to reduce the data volume of the point cloud.

F. *People Search*

Using the resulting graph after rotation and filtering, find the coordinates of the seating area through the pass-through filter and output it, as shown in Figure 9. It can be seen that the place enclosed by a circle is the seat with occupants, and the place without people is circled with a rectangle. In the seating area, you can see that in the front most people are still sitting on chairs.

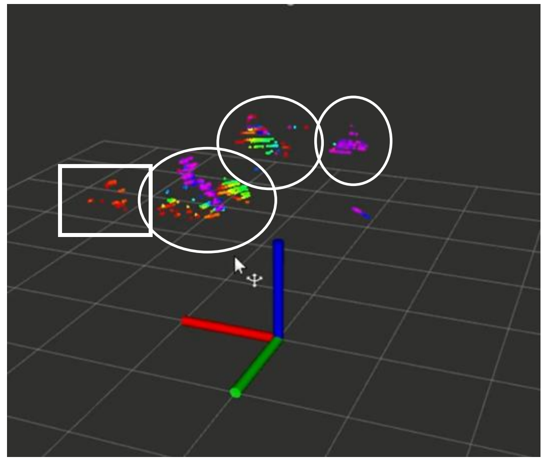

Fig .9. People search in seating area.

G. *Zoning Statistics*

In Figure 9 there still has some noise that needs to be filtered out. In addition, although the area selected by the square frame is not noise, it is only a chair in the seating area where no one sits. So, if want to remove these non-target objects where it must be processed by a filter. In this study, the seats in each area are processed separately. Due to the insufficient number of lines scanned by Yujin LiDAR and the low performance of computer hardware, the obtained point cloud information is less and uneven. And the intensity of the filter should not be too strong, otherwise It will cause the person information to be deleted together. As shown in Figure 10, the point cloud is the result of the overlapping output of four iterations. The point cloud which is selected in figure is the chair of the non-target object, so it needs to be filtered out by the radius filter.

First, use the radius filter to remove the outliers. And then calculate the number of point clouds near each point must be greater than the number caused by the area of the human body before output. Among them, the number of adjacent points of each point cloud is too small, so they are to be removed as non-target objects. After knowing how to determine whether there are no characters in the frame selection range, using the indoor lighting system to distinguish the characters. The lighting configuration is used to divide the laboratory into three areas. When there are people in the area, the program will be instructed to turn on the light source. The result obtained by the radius filter detection is used as the basis. If there is a target, the point cloud that was originally colored according to the intensity will be re-arranged as shown in Figure 11. If the middle area is regarded as a target, it will output yellow, otherwise, it will not output. The right block will output red as a character, and the leftmost corridor area will be purple. But in this picture, the corridor area has not yet been detected. There are many noise points, and the figure is to perform partition processing with Figure 10 and remove the chairs that are not the target objects.

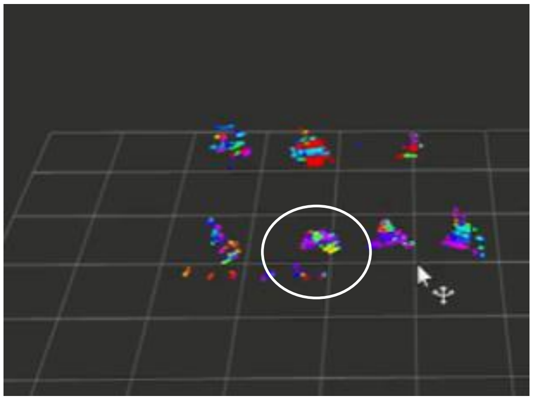

Fig. 10. Output point cloud of seating area.

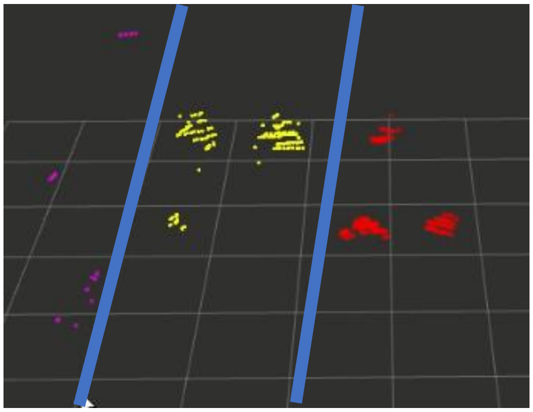

Fig. 11. Detect and partition the person in Figure 10.

The corridor area in the left half of Figure 11 is more complex than the seating area due to some sundries, and most of its blocks often have people passing by. The detection of dynamic people is more difficult for stationary people in the seating area, its results are shown in Figure 12 and Figure 13. These two point cloud images were created at similar times, the person in the corridor slowly moves towards the middle seating area. All three areas have people to be detected in Figure 12, so all the lights in the laboratory are turned on. And after a few seconds, Figure 13 is obtained, in which there is no one in the left corridor. So, the computer will instruct the lights to turn off.

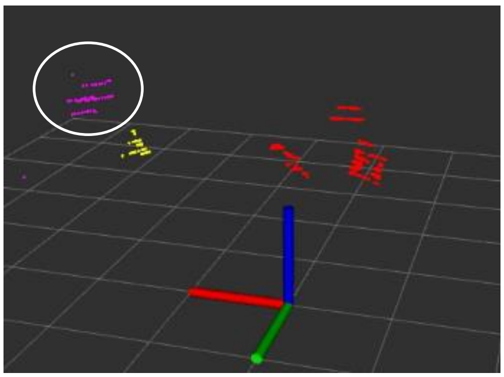

Fig. 12. Object detected in corridor area.

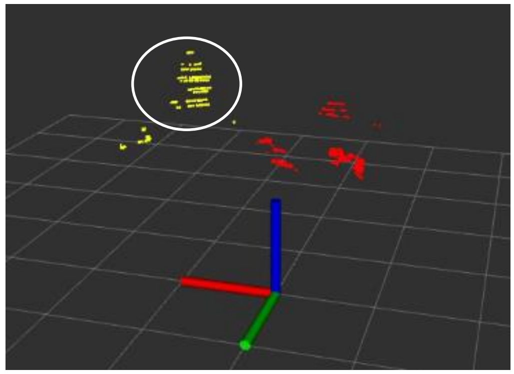

Fig. 13. People walking from the corridor area to the middle seating area.

IV. EXPERIMENTAL RESULT

This study uses 3D LiDAR to obtain a point cloud to search for people. And through various filtered results, and processed by partition in the seating area and corridor, so that the computer can know which lighting device needs to be automatically turned on or off. For example, the indoor personnel is configured as shown in Figure 14, persons are detected in all three areas.

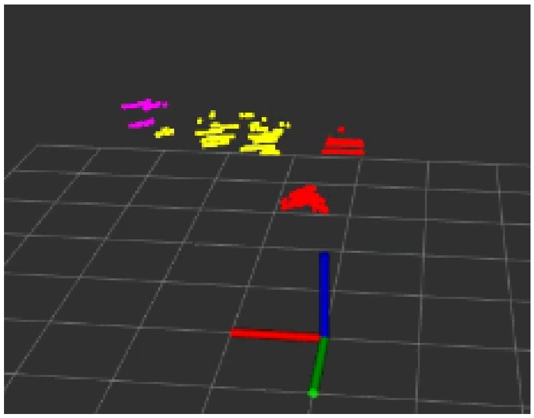

Fig. 14. Instant search of point clouds to find partition targets.

However, because there are many computers on the table in the third-row seating area to block the people behind, the people can only be scanned by the LiDAR when they stand up. So, the problem needs to be solved in the future.

V. CONCLUSION

This conclusions summarizes the findings and advantages of the study:

1. Only use the point cloud to detect personnel, which can avoid privacy issues.
2. Point cloud detection reduces the limit of the original light source in the environment.
3. Pass-through filtering can not only remove the surrounding walls and ceilings but also reduce the number of subsequent calculations.
4. The extra noise in the environment can be removed through statistical filtering and radius filtering.

Disadvantages that need to be improved in this study:

1. The low scanning frequency of Yujin 3D LiDAR results in insufficient point cloud information, also incomplete scanning of objects and environments.

2. The point cloud filter is used to find people in the environment. But there is no RGB image auxiliary detection, objects similar to the human body will be misjudged.

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