MOTION DETECTION AND TRACKING IN CONSTRUCTION SPACE USING TEMPORAL POINT CLOUDS

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KEY WORDS: Point Cloud, Object Recognition, Object tracking, Object classification, Construction vehicle

ABSTRACT: Conventional ICT construction vehicles have been developed to improve productivity. However, the conventional ICT construction vehicles have several technical issues in cooperated operations with workers. Therefore, we focus on a methodology to keep the safety in cooperated operations with workers and construction vehicles at a construction site. Our proposed methodology is based on 3D sensing from a construction. In 3D sensing, temporal point clouds are acquired for moving object tracking. Moreover, we develop an exterior-typed 3D measurement unit with low-price RTK-GNSS and LiDAR to provide lower-price ICT construction vehicles. In this research, we experimented excavation works using a backhoe at a simulated construction space. Through the experiment, we confirmed that our methodology can detect and track the bucket and workers using temporal point clouds acquired from a backhoe in drilling works.

1. INTRODUCTION

Recently, construction fields hold technical issues, such as improvement of project productivity, reduction of accidents, and shortage of engineers. Thus, various actions and projects are underway to develop and introduce advanced construction vehicles equipped with ICT technology and building information modeling (BIM). In large-scale construction spaces, experiments on construction using remotely operated unmanned construction vehicles are conducted to improve productivity and safety with the BIM/CIM framework. The remotely operated unmanned construction improves an operation environment with joystick type remote control and monitors, to cover wide viewing angles to replace onsite backhoe operation (Kajita et al. 2017). Taisei Corporation has experimented camera systems at Unzen Fugen-dake (Kondo et al. 2011). Onboard cameras mounted on the driver's seat of a construction machine are used to share an operator's perspective with a mobile remote control room. The system support operators can quickly evacuate to a safe location in case of an emergency such as mudslides. Kajima Corporation also has conducted experiments on construction vehicles with ICT technology at unmanned construction sites since 2005. Full-scale unmanned construction was implemented in 2018 at dam construction sites. Although construction vehicles are not controlled remotely instructions from the control room are sent to multiple construction vehicles to perform automated construction (KAJIMA CORPORATION, 2020).

Although various conventional ICT construction vehicles have been developed, several technical issues are remained in working together with workers. In small construction sites in urban areas, construction vehicles need various kinds of assistance from workers to perform detailed tasks such as excavation and drilling works, as shown in Figure 1. Therefore, we focus on methodologies with 3D scanning to keep safety in cooperative works with workers and construction vehicles at construction sites. Our proposed methodology is based on 3D sensing of construction sites. In 3D sensing, temporal point clouds are acquired to trace workers and moving objects. We also proposed a methodology to detect and track moving objects to estimate collision risks among vehicles and workers.

Moreover, we develop an exterior-typed 3D measurement unit with low-price RTK-GNSS and LiDAR to provide lower-price ICT construction vehicles. In this research, we experimented with excavation works using a backhoe at a simulated construction space. Two LiDARs were installed at the front of the backhoe to acquire horizontal and vertical scanning data simultaneously. A moving bucket and workers were detected as moving objects from two temporal scanning data with point cloud segmentation and clustering. Moreover, relative distances were measured among the backhoe, the bucket, and workers with object recognition. Through the experiment, we confirm that our methodology can detect and track the bucket and workers using temporal point clouds acquired from a backhoe in drilling works.

Figure 1. Cooperative works with workers and construction vehicle

2. METHODOLOGY

In our methodology, we use two LiDARs installed at the front of the backhoe to acquire horizontal and vertical scanning data simultaneously. The horizontal scanning is used to reconstruct a wide construction space around the backhoe. The vertical scanning is used to reconstruct bucket actions and closed construction space in front of the backhoe.

The proposed methodology is shown in Figure 2. First, range images are generated from the point clouds acquired by LiDAR mounted on a construction vehicle. In this processing, depth and intensity images are generated as range images. The depth images use distances estimated from a LiDAR to measured objects.

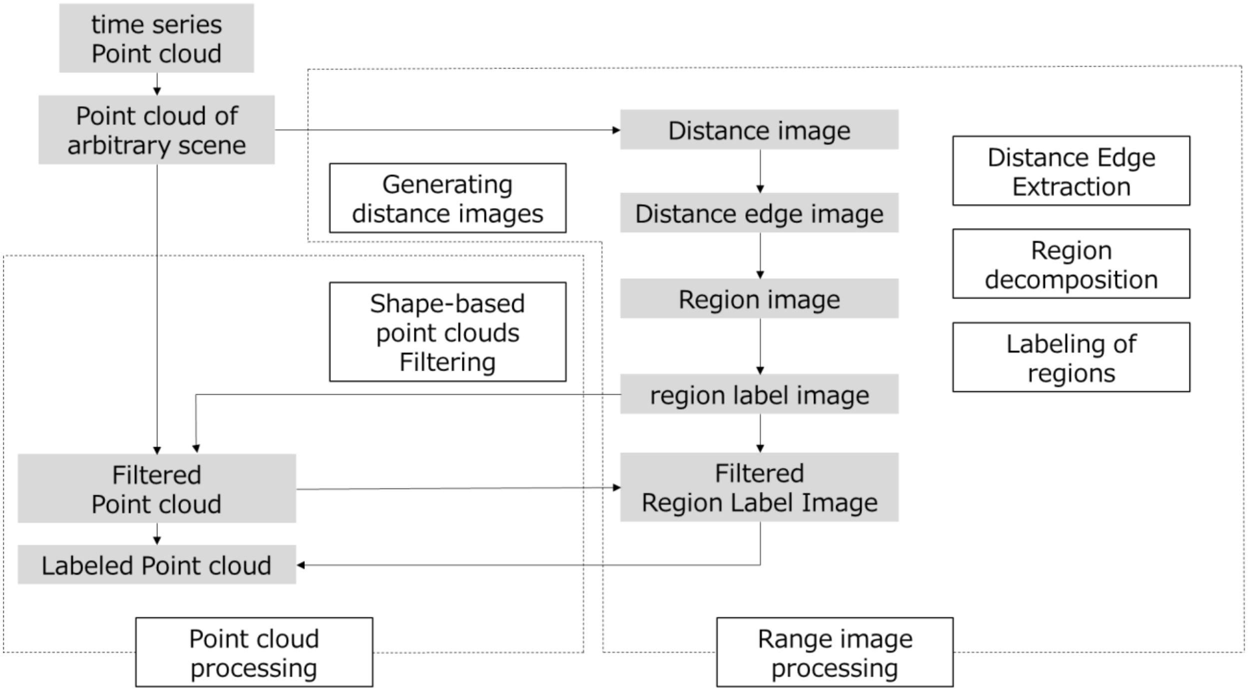

Figure 2. Proposed methodology

Next, distance edge-images are generated as feature boundaries with threshold values, such as ground height, ranges of a construction site, minimum distance value between workers, to generate region segments. Then, the region segments are generated from distance edge images to extract objects from point clouds. In the point cloud processing, the generated region label images are used as input data, and the point clouds corresponding to each region are filtered based on the shape-based point cloud filtering to generate labeled point clouds. The shape-based point cloud filtering consists of ground surface filtering and moving object filtering, and voxel-based segmentation The ground surface filtering uses a height parameter. The moving object filtering uses parameters on the height and width of objects. The voxel-based segmentation uses several thresholds, such as the minimum number of point clouds for spike noise removal and point cloud clustering. An example of worker extraction in a scene (Figure 3) shows that point clouds higher than the ground surface can be clustered and the voxel segmentation process can be properly cluster moving objects.

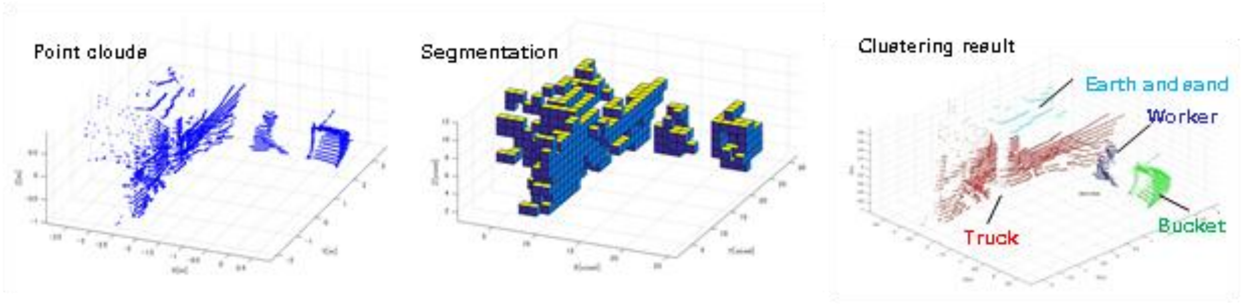

Figure 3. Results after segmentation and clustering of point clouds

Moreover, object tracking is applied to segments extracted from temporal point clouds with the continuity of object motion. In the object tracking, SLAM is applied to stabilize the tracking results of a moving object (Figure 4), because the horizontal rotation and translation of point clouds caused by the rotation and translation of the construction vehicle. However, the effect of the translational movement correction is small for the caterpillar movement of a backhoe in a construction space. Therefore, in this study, only the horizontal rotation correction is applied. Since the motion extraction results are processed independently from the neighboring time-series scenes, the continuity of the time-series is reconstructed in the motion tracking. Since the moving speed in the construction space is slow and the horizontal rotation correction reproduces the time series point cloud without the turning of the construction machine, the search range of the motion object tracking should be set to the range where the motion object may move during one scan, with the position of the motion object (worker) in the previous scene as the center position.

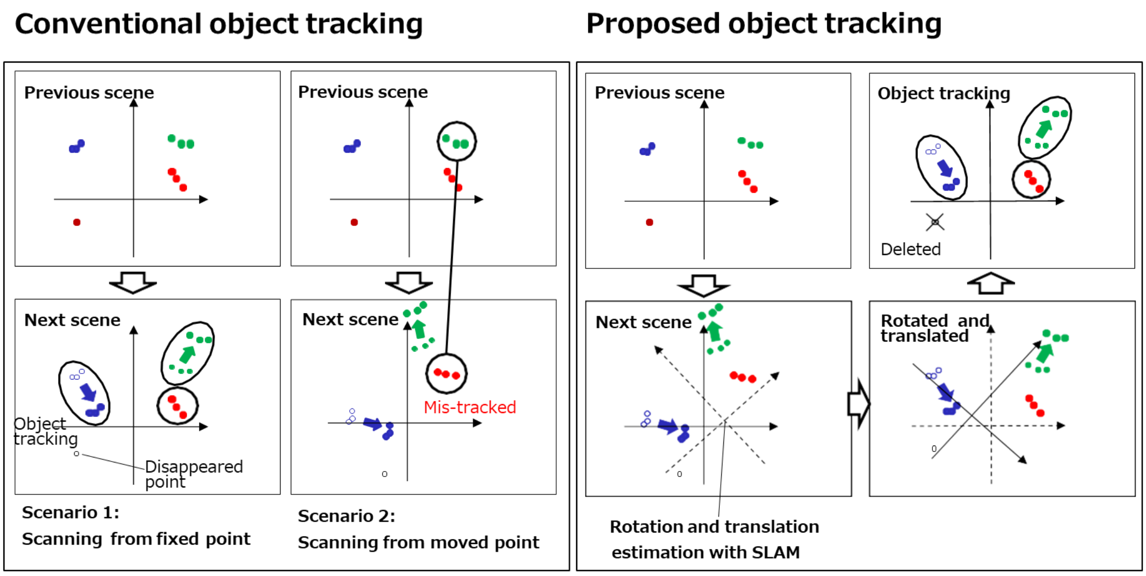

Figure 4. Moving object tracking and filtering

In the previous study (Nakagawa et al. 2017), the results of horizontal scanning were used to detect and track moving objects. In this study, we proposed a vertical scanning to obtain the details of object information in front of the construction vehicle. By scanning the vertical section, we can accurately measure the movement of the bucket and the closed work spaces, which is difficult to obtain by horizontal scanning.

3. EXPERIMENTS

We prepared a simulated construction environment (Figure 5) with a construction vehicle (backhoe) and workers to represent construction works, such as excavation, piping, and backfilling. The construction process was measured using 3D scanners. In this experiment, we selected multi-layered LiDAR for autonomous robots and automatic driving to acquire temporal point clouds automatic driving. We installed two scanners at the front of the backhoe for horizontal and vertical scanning, as shown in Figure 6. The horizontal scanner (VLP-32C, Velodyne) is installed at a height of 1.0 m above from the ground to acquire point clouds of a wide construction environment. The vertical scanner (VLP-16, Velodyne) was installed at a height of 1.2 m above from the ground to acquire point clouds of bucket motions and closed workers. Each LiDAR was connected to stick computers (BLKSTK2MV64CC, Intel) to record point clouds. Moreover, RTK-GNSS positioning antenna and receiver (C94-M8P, u-blox) were mounted on the rooftop of the backhoe to acquire reference position data. The front camera (HDR-AS300, SONY) and omni-directional camera (THETA Z1, RICOH) were also mounted on the rooftop of the backhoe to acquire reference data.

Figure 5. Simulated construction space

LiDAR(VLP-16,Velodyne)	
Distance measurement accuracy	3 cm
Angle resolution(Horizontal axis)	0.25 deg
Angle resolution(Vertical axis)	2 deg
Measurement range(Horizontal axis)	360 deg
Measurement range(Vertical axis)	±15 deg
Sampling rate	10 Hz

LiDAR(VLP-32C,Velodyne)	
Distance measurement accuracy	3 cm
Angle resolution(Horizontal axis)	0.25 deg
Angle resolution(Vertical axis)	0.33 deg (non-linear distribution)
Measurement range(Horizontal axis)	360 deg
Measurement range(Vertical axis)	40 deg (-25 deg to +15 deg)
Sampling rate	10 Hz

Figure 6. Measurement system

4. RESULTS

The processing results in a scene are shown in Figure 7. We generated range images, such as laser intensity image, distance image, distance edge image, region segment image, region label image, and filtered region label image. The labeled images show that the bucket of the backhoe was extracted from point clouds.

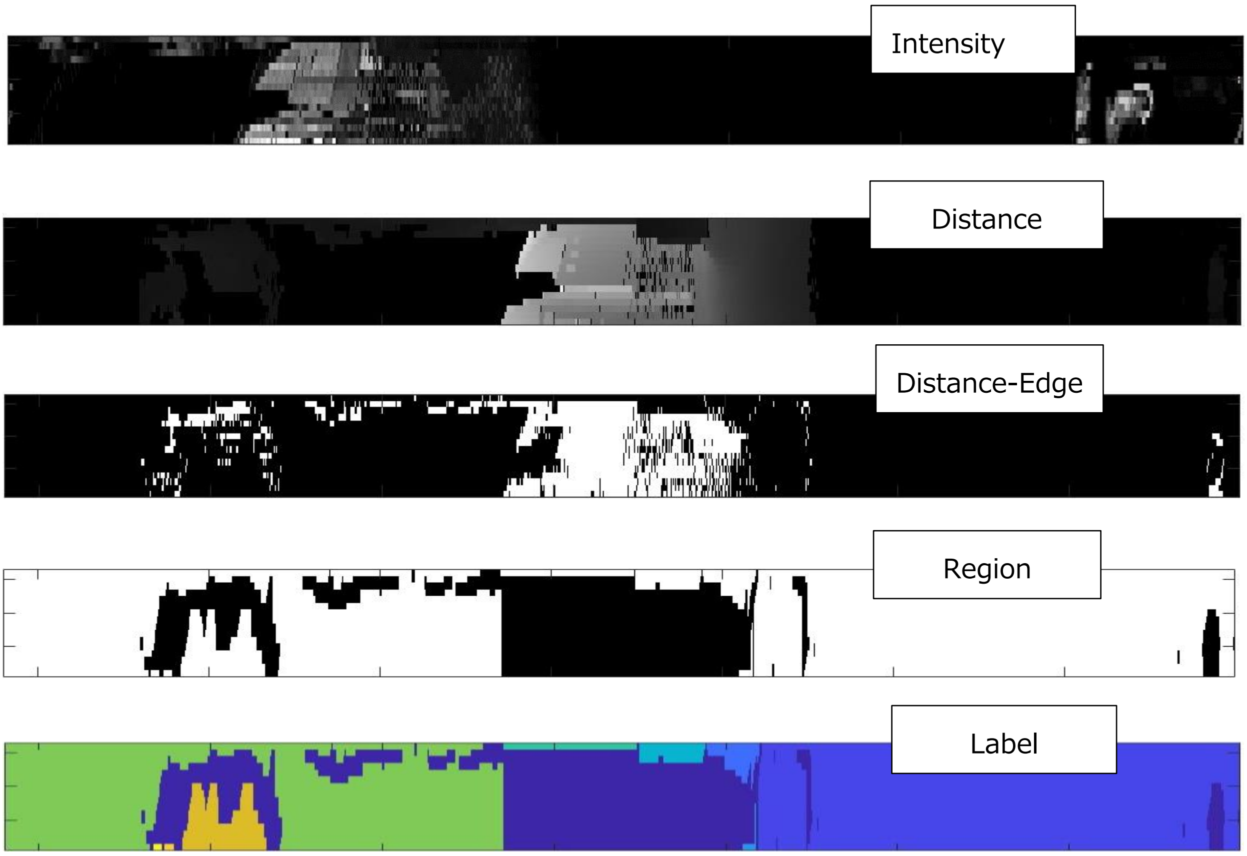

Figure 7. Range images (laser intensity image, distance image, distance edge image, region segment image, and, region label image)

5. CONCLUSION

In this study, we performed horizontal and vertical scanning of the construction space, and used the vertical scanning results to detect moving objects. We confirmed that our methodology can detect the motion from the vertical scanning data. One of the future works is the integration of the horizontal and vertical scanning results to improve the performance of object recognition and tracking.

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