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LADAR data generation fused with virtual targets and visualization for small drone detection system

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ABSTRACT

For detection of a small target using electro-optical systems, multi-band 2D image sensors are used such as visible, NIR, MWIR, and LWIR. However, 2D imaging systems are not capable to detect a very small target and they are also not capable of calculating target 3D position coordinates to develop the strategic counter method. 3D sensors (e.g. Lidar, RGBD and stereo camera) are utilized to control unmanned vehicles for detecting threats and response for specific situations. Conventional Lidar systems are unable to detect small drone threat at distances higher than their maximum detecting range of 100 $\sim$ 120 meters. To overcome this limitation, laser radar (LADAR) systems are being developed, which allow the detection at distances up to 2 kilometers. In the development of LADAR, it is difficult to acquire datasets that contain cases of long distant targets. In this study, a fusion data generation with virtual targets technique based on minimum real LADAR initial map dataset is proposed, and precise small target detection method using voxel-based clustering and classification are studied. We present the process of data fusion generation and the experimental results for a small target detection. The presented approach also includes effective visualization of high-resolution 3D data and the results of small target detection in real time. This study is expected to contribute to the optimization of a drone threat detection system for various environments and characteristics.

Keywords: Laser Radar, target detection, classification, data fusion, visualization

1. INTRODUCTION

The development of drone and unmanned aerial vehicles has become common for high-tech companies. New products have been developed for making countermeasure and defense reactions against threats. There are several technologies used for threat detection such as Silent Strike (Boeing, US), Counter UAV system (Airbus, UK) which uses infrared camera and position sensors, or Anti-UAV defense system (AUDS, UK) which uses electro-optical infrared (EO/IR) sensors in combination with radar sensors. Different methods are employed as reactions after detecting threats such as direct collision, interception using Drone killer (UCON, KR), radio frequency disturbance of target control system, use of high power laser beam irradiation methods. The most reliable and fast reaction is the laser beam irradiation method, which requires continuous and accurate target 3D coordinate tracking performance. We have decades of experiences with development and operation of multi 2D imaging sensor systems for target detection and tracking providing functionalities such as forward-looking

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infrared (FLIR), EO/IR and target acquisition and designation sight (TADS*).[1] However, such systems are showing problems and limitations with detection and tracking of small targets which are approaching from far away. 3D sensors can solve these problems, but a representative 3D sensor such as LiDAR cannot be used to detect small targets due to its low resolution and detectable range. They also do not meet the requirements for a small drone detection system.[2–4] To overcome these problems, we are developing the laser radar (LADAR) system using Galvano mirror scanners and motorized pan-tilt gimbals.[5] Such system has high-resolution and detectable range over several kilometers and is appropriate for small object detection. One of the difficulties in developing LADAR is a target detection algorithm based on 3D point data for obtaining precise coordinates of the target center. To develop an optimized target detection algorithm for various types of drones, many different drones should be taken into account in experimental setup for acquiring a test dataset at different ranges, which is very time consuming and impractical. In this study, we consider the characteristics of the data detected by the real LADAR sensor and generate test datasets by fusing various types of virtual drone threat target data with the actual LADAR data. Using generated datasets, a 3D clustering based on voxel point cloud and a classification methods can be optimized.[6–8] At the experimental result, virtual drone fusion process with real LADAR data and its visualization results are described.[9] This study is expected to contribute to the improvements of the detecting and tracking accuracies considering various characteristics and conditions (e.g. size of targets, distances, noises, trajectory behaviors, background) for state-of-the-art LADAR system to detect threats of small drones.

2. CONVENTIONAL SYSTEMS

Following development of drone technologies, countermeasures are also developed. Different types of sensors are applied to design each countermeasures for drone detector as shown in Table 1. Major sensors are EO/IR cameras for getting final decision where drones are detected. After finding drones, there are several countermeasures to process and attack the drones such as RF jammer, laser burnner, and direct collision. LADAR uses high power laser scanner for detecting sensor and coordinate designation for countermeasures.

Table 1. Countermeasures and detector sensors for drone detection

Items	**Developer**	**Detection sensor**	**Countermeasures**
Counter UAV system[10]	Airbus (UK)	EO/IR camera	RF jammer
Anti-UAV Defense system[11]	AUDS (UK)	Radar, EO/IR camera	RF jammer
Silent Strike[12]	Boeing (US)	IR camera	Laser Burnner
Drone Killer[13]	UCON (KR)	IR camera	Collision
LADAR	ADD,HSC (KR)	High power laser scanner	Coordinate designation

2.1 2D imaging system (EO/IR)

Most conventional systems use EO/IR camera sensors to detect position of drones. Figure 1 shows the results of a small drone detection experiment using EO/IR camera under various background conditions. In case shown in Figure 1 (a) and (b), the drones can be detected because they are simple background conditions. However, if the background is complex, for instance composed of tree branches as shown in Figure 1 (c), or saturation occurs in the image as shown in Figure 1 (d), drone detection is disabled.[14] When detecting a target such as a drone with a 2D image sensors, it is difficult to confirm the exact coordinate position of the detected drones in the scene.

2.2 3D sensors (Lidar)

In recent years, Lidar sensors are extensively used to avoid pedestrians and obstacles in autonomous vehicle technology since EO/IR has limitations in object detection accuracy under various backgrounds.[15] Also, 3D detection sensors based on laser range finder were developed.[16,17] Figure 2 (a) shows an experimental space to

*Target Acquisition and Designation Sights

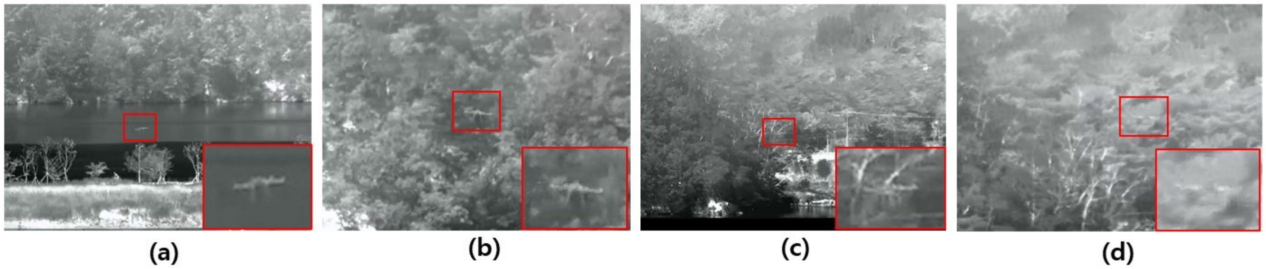

Figure 1. Drone detection using EO/IR imaging system at different background condition, (a) Plane background (successful), (b) Simple background (successful), (c) complex background (fail), (d) saturation (fail)

detect 60 $\times$ 30 cm small drone flying at a distance of 50 m from the sensor and flying at an altitude of 30 m. Figure 2 (b) shows point data of the space detected by the Lidar sensor and the detection results for the drone target in magnification data was confirmed as 3 points as shown in Figure 2 (c). The Lidar sensor is not sufficient to detect small 60 $\times$ 30 cm drones approaching from the distant airspace, because the angle resolution are very sparse to the level of EL: 2°, AZ: 0.1° $\sim$ 0.4°.

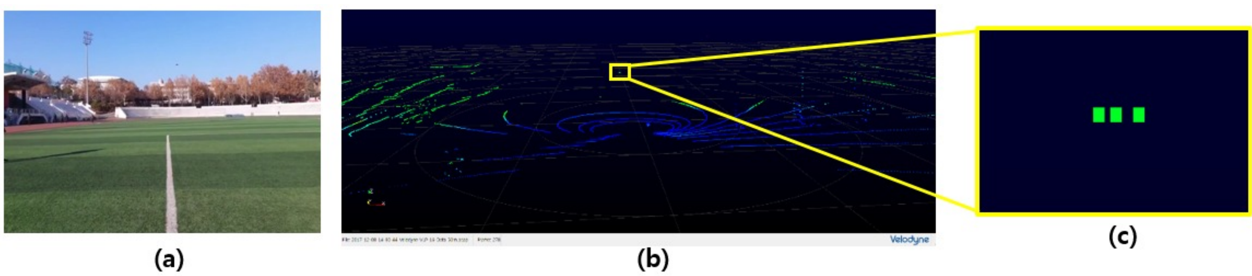

Figure 2. Target detection using 3D Lidar sensor system, (a) Drone detection environment (Range = 50 m) , (b) Result of Lidar scanning and drone detection, (c) 3 points detection for small drone which is 50 m away

3. DEVELOPED SYSTEM (LADAR)

LADAR means a radar system based on a laser sensor. Conventional Lidar sensors have the advantage of 360° azimuth directional scanning, but it is difficult to detect small objects at far distance because of sparse resolution of EL: 2° and AZ: 0.1° $\sim$ 0.4°. A high-performance Lidar model, HDL-64E was developed as high resolution using integrated 64 array of lasers. The target detection distance of high-performance Lidar is up to 120 m, and the angular resolution is about 0.4° for EL and 0.09° for AZ. According to the angle resolution (EL_{angle}), the horizontal and vertical resolution of the actual laser detection scan lines can be simply calculated according to the *Range* of the target using the tangent function, and the equation is as shown in (1) and (2). On the other hand, for LADAR, the angular resolution is very dense with EL: 0.0323° and AZ: 0.0041°, also the detectable distance is more than 2,000 m. However, the detection FOV of LADAR is not wide and measures 0.65° $\times$ 0.65°. In order to compensate this disadvantage, the laser detection module is rotated using the pan tilt servo drive module. Figure 3 (a) shows the overall operating concept of LADAR, and Figures 3 (b) and (c) show the experimental environment and the detected example data respectively. In Figure 3 (c), the red area means background dataset of real LADAR sensor dataset in the area under its FOV.

For comparing resolution of Lidar and LADAR, the first column of Table 2 shows the angular resolution of the scan lines by EL / AZ direction for each model of Lidars and a LADAR. Lidar and LADAR sensors have beam divergence angle characteristics and the angle changes design parameter of scan lines in different distances. The intervals between the scan lines according to distance divergence can be easily calculated by Equations (1) and (2), and the size of the detectable target can be predicted using this result.

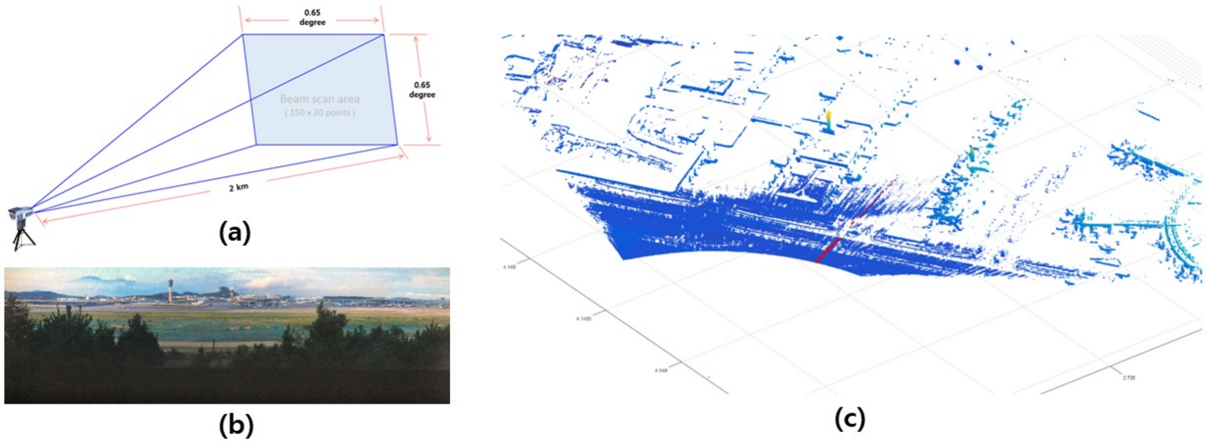

Figure 3. LADAR concept and the example dataset of the ICN airport

$$Horizontal\_resolution = \tan(EL_{angle} \times \frac{PI}{180}) \times Range\,, \tag{1}$$

$$Vertical\_resolution = \tan(AZ_{angle} \times \frac{PI}{180}) \times Range\,, \tag{2}$$

Table 2. Comparison of Lidar and LADAR resolutions of scan lines at different ranges (Unit:m)

Models(EL/AZ angle)	**Resolutions (horizontal/vertical)**			
	Range = 100 m	Range = 500 m	Range = 1000 m	Range = 2000 m
Lidar HDL-16 (2.0°/0.10°)	3.4921/0.1745	17.4604/0.8727	34.9208/1.7453	69.8415/3.4907
Lidar HDL-64 (0.4°/0.09°)	0.6981/0.1571	3.4907/0.7854	6.9814/1.5708	13.9629/3.1416
LADAR (0.0323°/0.0041°)	0.0564/0.0072	0.2822/0.0360	0.5645/0.0720	1.1289/0.1439

For horizontal and vertical scanning, LADAR has compact mirrors which can drive in each directions. When laser beams are irradiating to a long distance and detecting distance points, the generated laser beam divergence is suppressed using a telescope. Since scanning FOV of LADAR is levels of 0.65° × 0.65°, for wide field of view, the laser module is installed on the servo driving module so that the installation angle of the laser scanning modules including micro mirrors can be adjusted in real time. The operating range of the servo module is AZ: 360°, EL: 60°. The operating range of the module is AZ: 360°, EL: 60°. For the coarse angle detection, the approximate angle of a target approach is obtained through an integrated radar sensor, and the servo driving module moves to the angle position detected by the radar to adjust the angle of the entire laser scan module. After the coarse detection, the laser scan module starts scanning the directed area. Figure 4 (a) shows an example of detection of a small target scanned at 100 m and detection point data of about 392 points can be obtained. Figure 4 (b) and (c) show the example results when the range is 500 m and 2000 m, respectively. Approximately 72 points and 36 points are detected. The resolution was 12.3 times higher in the EL direction and 21.8 times higher in the AZ direction than the conventional high performance Lidar. By developing and implementing small target detection software using point data at these resolution levels, small targets can be observed/detected without distortion or problems. The development of the detection SW algorithm is very important, and for high accuracy, it is essential to acquire various LADAR experimental datasets. However, it is difficult to carry out various experiments for target detection in the design process of the LADAR system because the design of laser source module, the reflection/refraction optics, the telescope, and the servo driving module and their alignment takes long terms. In addition, frequent testing of LADAR sensors with high output

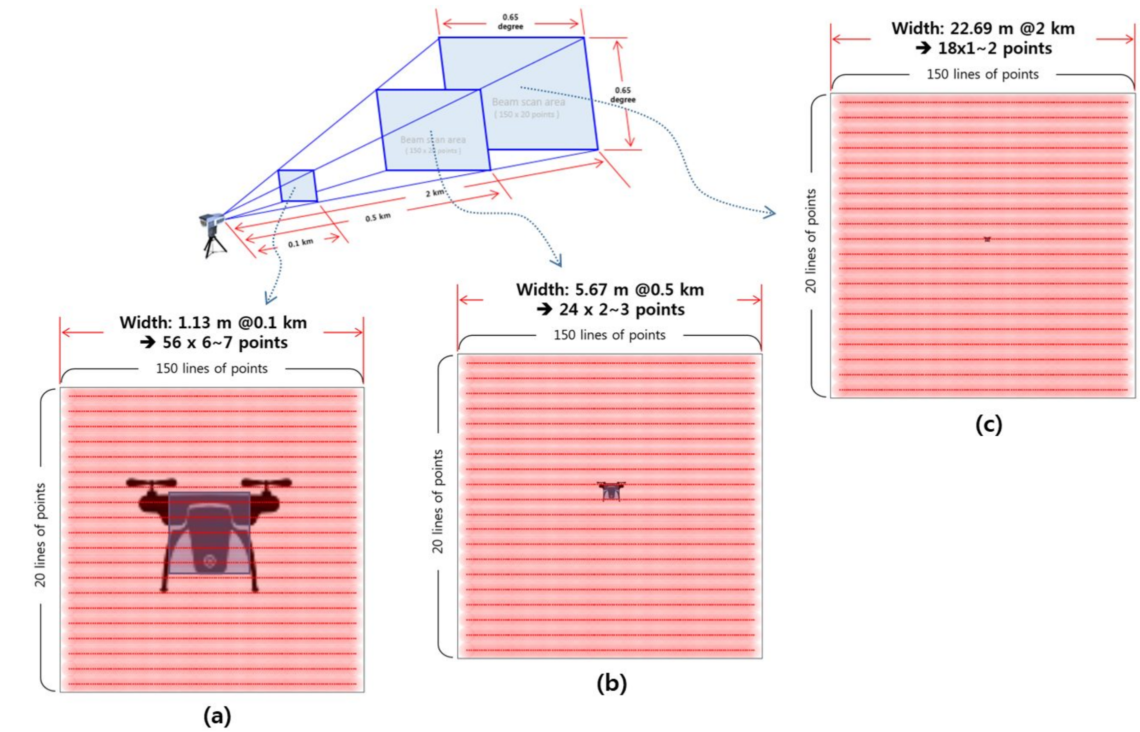

Figure 4. Calculation for equivalent target projection points

lasers can cause safety problems. Therefore, it is necessary to analyze the laser beam, the target shape, the target trajectory, and the noise characteristics. To do this we performed experiment using the simulation data similar to the actual target data.

3.1 Estimation of target and LADAR beam

Figure 5 (a) is a schematic drawing of the characteristics of the intersection and the laser beam considering the resolution of the horizontal scan line and the divergence angle of the laser beam derived from the calculation process. The divergence angle of the laser beam is 0.035523° and the intersection for 0.65° FOV can be calculated as 0.003182°.

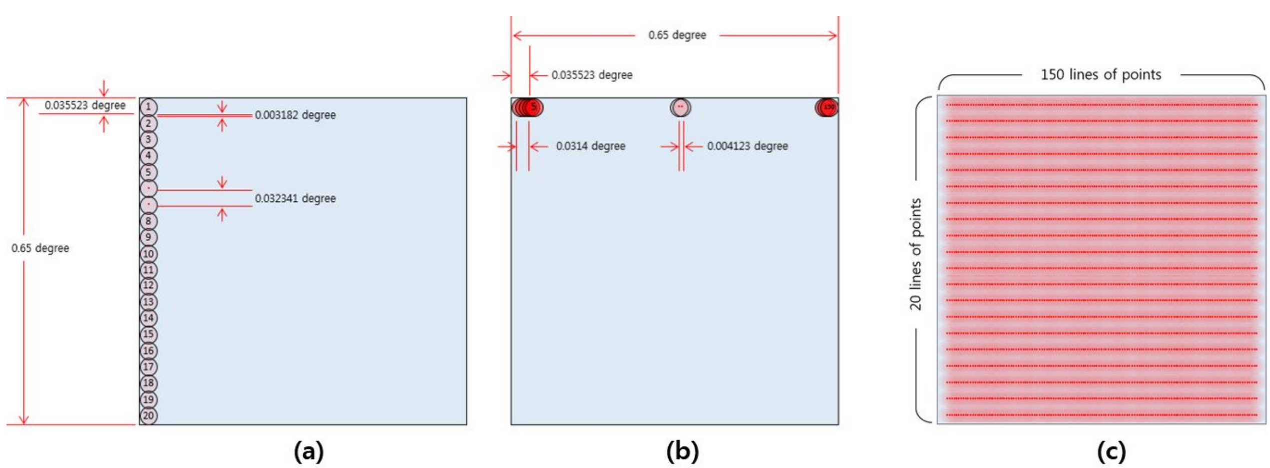

Figure 5. Characteristics analysis of LADAR laser beam

Figure 5 (b) shows an intersection that considers the resolution and beam divergence of the vertical scan line. Its value is 0.004123°. Figure 5 (c) shows the characteristics of the entire laser scan considering the horizontal and vertical scan directions. Figure 6 shows the shape of a small drone to be simulated for a target, and the dense area means that it is close to detectable space by a laser sensor. The simulation space is approximately 30 × 30 cm among the total drone size of 60 × 30 cm. The target data for the experiment can be designed by analyzing the scan characteristics and targets of the laser beam.

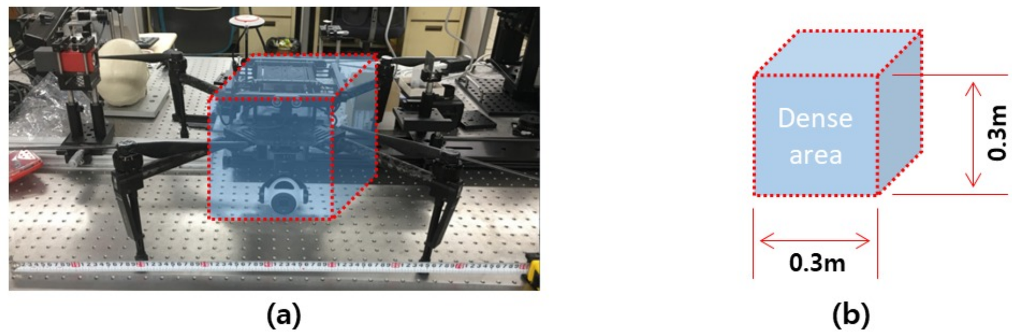

Figure 6. Detectable area estimation of purpose drone target, (a) small drone feature, (b) dense area

3.2 Virtual target and noise generation

Figure 7 shows the result of generating the target considering the characteristics of the target and the laser beam analyzed above. Figure 7 (a) shows the shape of the target that can be detected at a distance of about 880 m. Figure 7 (b) shows the shape of the target that can be detected at about 970 m. Figure 7 (c) shows the shape of the target that can be detected at about 1500 m. The number of points that can be detected as the target component and how many lines are detected are fitted in relation to the range. Over 700 m, the target can be represented by one or two lines depend on its position. In addition, the noise that can randomly overlap the target and the position and trajectory of noise are designed differently from the target. Noise has sparse characteristics rather than a target, and it can be seen that it is distributed in a random position rather than detected in one or two lines as in the target.

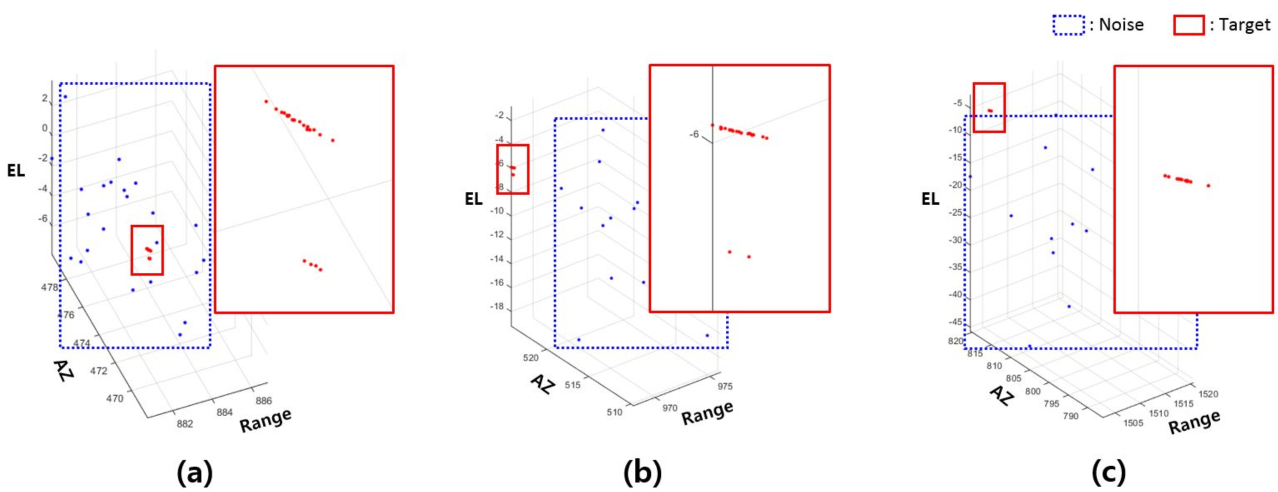

Figure 7. Shape of targets and noises at different ranges, (a) range = 880 m, (b) range = 970 m, (c) range = 1500 m

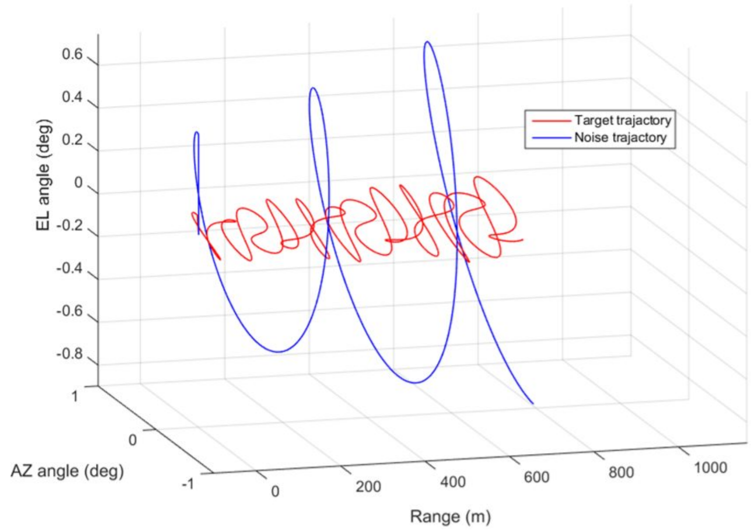

Figure 8. Trajectories for virtual target and noise

3.3 Design of trajectories

Trajectories of small drones can be generated in a wide variety of ways, including straight, curved, and random directions. And noises can also be generated in different ways, not in the same trajectory as the target. In order to develop the detection algorithm considering various target movement, trajectories are designed as shown in Figure 8. The trajectory of the red line corresponds to a small target, which is very fast and has dynamic continuous motion. The trajectory of the blue line corresponds to the noise component, and it moves slowly like a cloud, and it is designed to consider occasional overlapping with the target.

3.4 LADAR data fusion with virtual targets

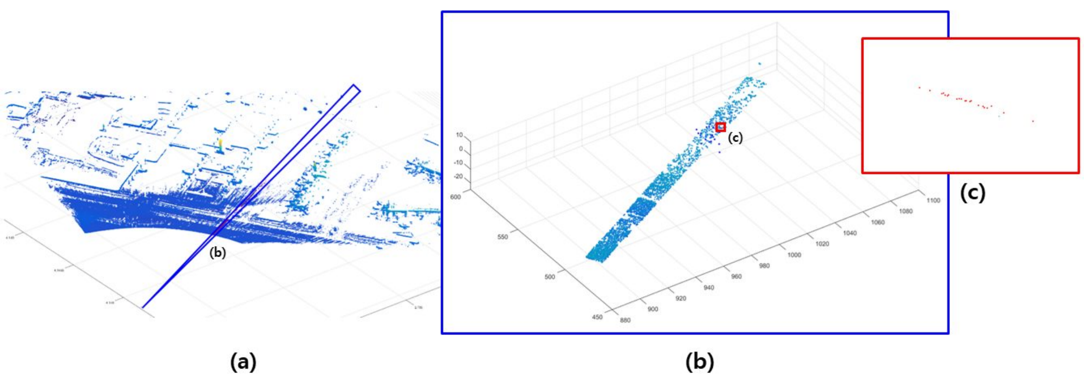

Figure 9. Fusion dataset, (a) background and cropped data area, (b) fused dataset with target and noise, (c) magnification target feature

Figure 9 (a) shows the result of detection of actual existing background data (an airport in South Korea) using the existing low-performance LADAR sensor. Figure 9 (b) shows the fused data of background data and noise including virtual objects, which are cut into FOV range where the actual LADAR is obtainable, and Figure 9 (c) is point data of the enlarged target. The types of noise generated different point distributions and fake targets moving in different directions and flickering noise generated throughout the entire scan area. At the time of updating each frame point, the position of the background point periodically changes in order to simulate the background detection point change phenomenon like a real situation.

4. VISUALIZATION FOR SMALL DRONE DETECTION

The target detection system is designed using fused target, background, and noise data. Figure 10 shows a result of visualization for fused dataset. The detection of the target uses the voxel method to remove the background component, the clustering method of the radial range search method to detect the candidate target, and the noise canceling method to determine the final target. Figure 11 (a) shows the merged data of the generated target and noise, and the blue box means the base position of the generated target (Ground Truth). Figure 11 (b) shows the result of the detection algorithm using the generated data set, which means that the position of the red box is detected. In Figure 11 (b), the red box indicates the location of the target, which is the result of the detection algorithm using the generated dataset, since most red boxes overlap the blue box, It means that the detection performance is high. Target detection information of each frame was correctly indicated, but an error was detected where the target generated on two lines in several frames was detected as one line.

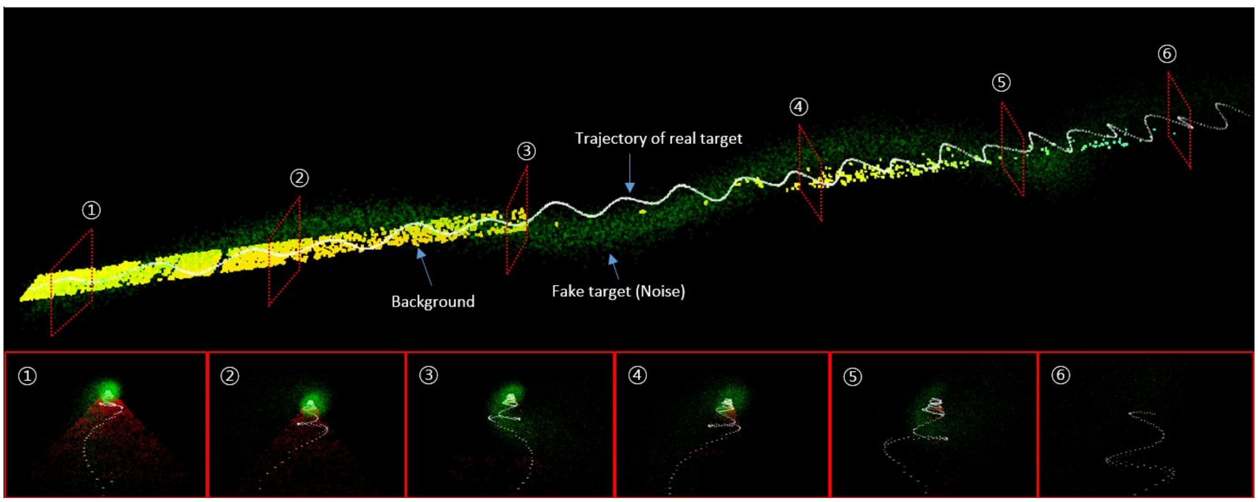

Figure 10. Visualization of fused dataset, ① ∼ ⑥ are orthogonal images at different range positions

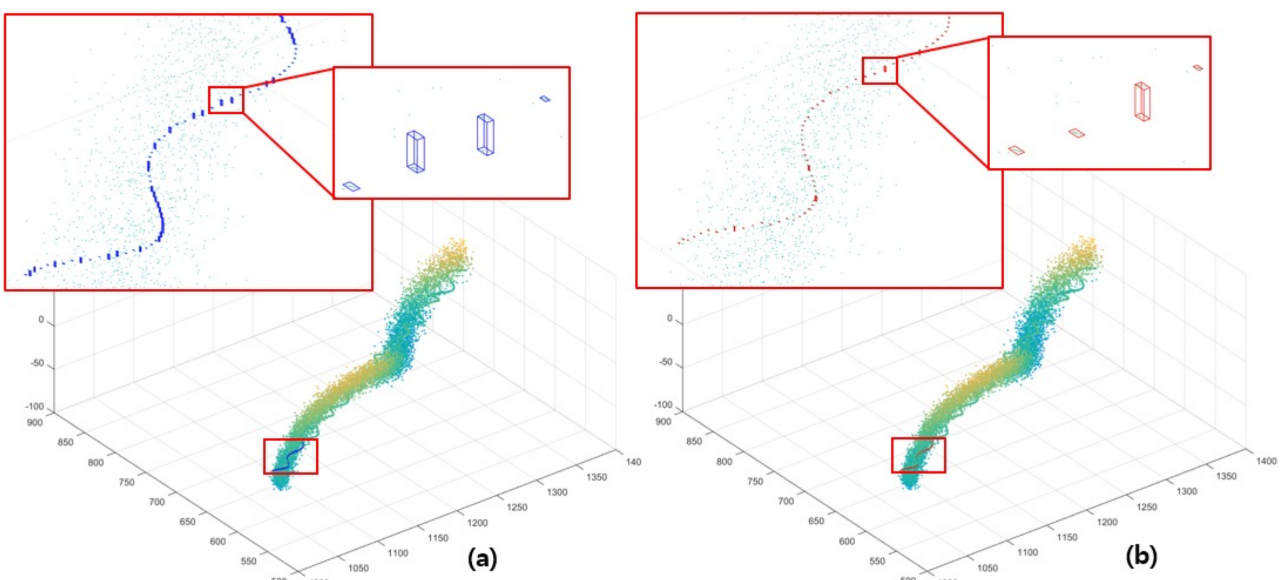

Figure 11. Small drone detection result, (a) Ground True, (b) Small target detection result

5. CONCLUSION

2D image sensors such as conventional EO/IR have a problem of low accuracy case of small target detection under various image conditions and advanced 3D Lidar sensors have problems of low resolution to detect small targets at far distances. Advanced LADAR is developed as a countermeasure system to overcome the problems. During the development of a new LADAR system hardware module, a simulation for developing a small target detection algorithm is required. To do this, characterization of the data that can be obtained in the actual LADAR should be preceded. In this study, we analyzed scan resolution and beam angle of LADAR. Based on this, predictions of target, noise, and background change were fused and simulated closely to the actual situation. The detection algorithm is designed using fused data and the detection results of small drones are visualized in a integrated environment. Since the target simulation technique that can be simulated with various conditions can replace the outdoor detection experiment using actual targets, it is expected to improve and optimize the developed detection algorithm of LADAR system.

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REFERENCES

[1] Kim, B. H., Kim, M. Y., and Chae, Y. S., "Background registration-based adaptive noise filtering of lwir/mwir imaging sensors for uav applications," *Sensors* **18**(1), 60 (2017).

[2] Wang, Z., *Laser-based detection and tracking of dynamic objects*, PhD thesis, University of Oxford (2014).

[3] Dewan, A., Caselitz, T., Tipaldi, G. D., and Burgard, W., "Motion-based detection and tracking in 3d lidar scans," in [*Robotics and Automation (ICRA), 2016 IEEE International Conference on*], 4508–4513, IEEE (2016).

[4] Navarro-Serment, L. E., Mertz, C., and Hebert, M., "Pedestrian detection and tracking using three-dimensional ladar data," *The International Journal of Robotics Research* **29**(12), 1516–1528 (2010).

[5] Bohak, C., Kim, B. H., and Kim, M. Y., "Web-based real-time ladar data visualization with multi-user collaboration support," *Augmented Reality, Virtual Reality, and Computer Graphics. AVR* **10850**, 214–224 (2018).

[6] Bogoslavskyi, I. and Stachniss, C., "Fast range image-based segmentation of sparse 3d laser scans for online operation," in [*Intelligent Robots and Systems (IROS), 2016 IEEE/RSJ International Conference on*], 163–169, IEEE (2016).

[7] Klasing, K., Wollherr, D., and Buss, M., "A clustering method for efficient segmentation of 3d laser data," in [*Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on*], 4043–4048, IEEE (2008).

[8] Rabbani, T., Van Den Heuvel, F., and Vosselmann, G., "Segmentation of point clouds using smoothness constraint," *International archives of photogrammetry, remote sensing and spatial information sciences* **36**(5), 248–253 (2006).

[9] Lavrič, P., Bohak, C., and Marolt, M., "Collaborative view-aligned annotations in web-based 3d medical data visualization," in [*Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2017 40th International Convention on*], 259–263, IEEE (2017).

[10] Belz, L., "Sensor Data Fusion offers countermeasures against small drones." Airbus website, 16 September 2015 "http://company.airbus.com/news-media/press-releases/Airbus-Group/Financial_Communication/2015/09/20150916_airbus_defence_and_space_counter_uav.html. (Accessed: 15 July 2018).

[11] Systems, B. S., "AUDS Anti-UAV Defence System." Blighter website, 4 September 2017 "http://www.blighter.com/products/auds-anti-uav-defence-system.html. (Accessed: 4 July 2018).

[12] Boeing, "Compact Laser Weapons System tracks and disables UAVs." Boeing website, 27 August 2015 "https://www.boeing.com/features/2015/08/bds-compact-laser-08-15.page. (Accessed: 15 July 2018).

[13] UCON, "Miniature UAV Strike System, DRONE KILLER." FOOSUNG UCON system Co., 27 August 2015 "http://www.uconsystem.com/eng/products/military/military_drone.asp. (Accessed: 1 August 2018).

[14] Kim, B. H. and Kim, M. Y., "Anti-saturation and contrast enhancement technique using interlaced histogram equalization (ihe) for improving target detection performance of eo/ir images," Control, Automation and Systems (ICCAS), IEEE (2017).

[15] Morris, D. D., Colonna, B., and Haley, P., "Ladar-based mover detection from moving vehicles," *arXiv preprint arXiv:1709.08515* (2017).

[16] Laurenzis, M., Hengy, S., Hommes, A., Kloeppel, F., Shoykhetbrod, A., Geibig, T., Johannes, W., Naz, P., and Christnacher, F., "Multi-sensor field trials for detection and tracking of multiple small unmanned aerial vehicles flying at low altitude," in [*Signal Processing, Sensor/Information Fusion, and Target Recognition XXVI*], **10200**, 102001A, International Society for Optics and Photonics (2017).

[17] Khan, D., Shirazi, M. A., and Kim, M. Y., "Single shot laser speckle based 3d acquisition system for medical applications," *Optics and Lasers in Engineering* **105**, 43–53 (2018).