A Study on Vehicle Inspection by a Surveillance Robot Equipped with Laser Range Sensors

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Abstract

The security mission in the parking lot is one of an important task for safeguard area and protection for threats, e.g. car stealing, car break in, etc. Most of them at those parking lots at airport, business central, head government office, shopping mall, stadium, university have been operated the inspection mission. By setting vision surveillance station was useful applied within a parking lot for monitoring the parking state and detected the parked vehicle in car slot, and the manual inspection is also operated to check the parked vehicles in each car slot.

The manual inspection had been widely performed for inspecting a target vehicle by manual patrolling on several time operations. The various inspection missions are including to inspect parked vehicle in prohibit area, outer a car slot, checking a parked vehicle in long term, searching the dangerous item, explode item, or contraband item at vehicle undercarriage. This kind of manual inspection was implemented to work in any parking place for safeguard area. Therefore, the human mission have some limitation such as take a long time for covering any a parking lot, hard to operate in narrow area, limitation by human eye, operate in dangerous situation so these can be replaced by some type of automation.

In this research work, three applications of vehicle inspection in parking lot are proposed. First, for creating parking lot information, the information of parking lot state is occupancy or vacancy state and locates the parked vehicle which is parked for long term in parking lot by a task of occupancy state recognition. Second, for protection from threats, the information of inside vehicle is need to realize the state of inside vehicle by detection through car windows from the task of inside vehicle inspection. Third, information of vehicle undercarriage is required to inspect the anomalous object appearing underside of vehicle by a task of under vehicle inspection.

In this study, we introduce a mobile robotic system on application of inspection tasks from an automated function on mobile robot platform to work in a parking lot. The robot operation on multiple time operations (t_1, t_2,…,t_n) of data scanners in parking lot, is to acquire the information of vehicle configuration by equipped with laser range finder (LRF) sensor.

The data from scans relate to robot position estimation while robot operations in same place so the data is difference position in world coordinate. We proposed the approach of data alignment is applied to compute the data between previous inspection and current inspection until data convergence between them. And then the data

comparison technique is performed to find the potential change between them.

The key common of three tasks of vehicle inspection can be summarized as follows:

- Several time operation (t_1, t_2,…,t_n) for data detection by robotic system
- Data alignment for matching data between t_i and t_{i+1}
- Data comparison for detecting difference point data between t_i and t_{i+1}

Above of tasks, we mainly interested the mobile robot security in parking lot for protection and safeguard area by several time operations. The robot can operate nearby target inspection to obtain clearly information on target vehicle. And the robot can work under dangerous situation with the explode object that replace the manual inspection task to safe human life.

The contributions of this work can be summarized as follows:

- A parking lot management system by a mobile robot is proposed
- An application of inside vehicle inspection is newly proposed
- Detection anomalous object underside of a vehicle is proposed
- Extend to the application field of mobile robot

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Chapter 1

Introduction

1.1 Background and Motivation

Security task for safeguard in parking place had been played an important role to guard against threats such car break-in, car stealing, and worst case of car bomb. To prevent vehicles from threat, the inspection task has led to be an increased interest to develop technologies for safeguard bases or automated robotics that assists the human mission for security tasks in parking place such as those at airport, business central, stadium, government office, university and so on. The missions of security and safeguard in parking lots are required for protection from threats.

Basically human surveillance had been operated to patrol in parking lots for inspecting vehicles in each parking slot by several time operations as the manual inspection mission. A simple inspection task was examined for checking whether a pose of vehicle which it parked inside a parking lot or it parked outside at prohibit area such as a vehicle is parked at the corner of path way that risk to accident. To inspect in several time operation, the inspector was performed for checking state of vehicle in each parking slot as long term parked without action or movement that tend to use in criminality, as well as it risk to car break-ins. In case of own car is placing valuable object inside vehicle (e.g. laptop PCs, wallet, pocket bag, etc.) there is one risk of car break-in or steal a car. Moreover, the task of inspection for protection from threats is one of important mission to require any parking place for safeguard area. Many techniques were applied to examine vehicle parked in the parking lot, for example, to check underside of the vehicle to find an anomalous item by using a mirror hand held, as well as checking a contraband item, dangerous or explode item at target inspection with k-9 team operation. Most of them were increasing performance of security and safeguard in parking lots.

However, above of these tasks by manual inspection have somewhat limitation to take a long term for patrolling any parking lots, there is difficult to inspect inside a vehicle through car window with dark tinted from manual observation, and there is hard work to detect at narrow area underside of vehicle for covering hidden area. These kinds of manual inspection have been performed in any parking lots to prevent from the threat, so some types of automated inspection are required.

Vision surveillance is one technique that widely used to operate for monitoring vehicles in the parking lot from base stationary. A simple function was performed to inspect a parking lot state as occupancy or empty lots and also finding an empty lot location. This technique was provided vehicle information (e.g. color, shape, etc.) from image capture. Nevertheless, vision techniques have limitations on the susceptible to illumination changes such as on sunlight, cloudy, dark night, or the light reflection on car windshields, which are affected to obtain the vehicle information, otherwise many base stationary are needed to cover in a large parking lot and also special processor is required. Therefore, author wants to find out for obtaining the vehicle information in explicitly and certainly so the mobile robot technology is employed for the operation.

For automation surveillance in parking lots, a mobile robot is favorite used to operate for inspecting any vehicles in parking lots. This technological system is one of key to develop various applications of vehicle inspection that assists the human inspection and to operate in dangerous situation for the safety of human life. The mobile robot can perform to patrol surrounding in parking lots in several time operation for covering the occlude area, as well as it can move to nearby target inspection and continues operation for repeatedly inspection task. The tasks of inspection on robotics platform have various feature functional to employ in parking lots such as creating a car parked map, checking parking lot information from pose of vehicle which is parked in parking slot, license plate number recognition of each parking slot, and so on. Moreover, to develop a compact robotics is operating at narrow area which is preform to inspect underside of the vehicle for detecting at vehicle undercarriage. Above these applications, author wants to develop the application of inspection task by using a mobile robot platform for operating the vehicle inspection in parking lots.

The motivation of this research is to develop a robotics platform for operating in parking lots, to create a new application of inspection task on robotics technology and replace manual inspection task by the automated inspection system for increasing the performance of inspection task, security task and safeguard in parking lots.

1.2 Related work

In presents, application of vehicle inspection were developed various technique to examine the vehicle in parking lots. The vision technique is useful for detecting in the parking lot state, and monitoring in wider area. Many researches utilized vision surveillance [1-3] at the car parked to retrieve the information regarding to each parking slot whether there is the occupancy state or the empty lot state and also observing the vehicle overall parking lot for safety and safeguard area. Nonetheless, the vision system has limitation due to the lighting condition and relatively high cost for covering survey in the wider parking lots.

By surveillance robot, the mobile robot system was developed various applications in widely used to operate for patrolling in parking area with the automated inspection function. Many functions are developed on mobile robot for automatically vehicle detection in parking lot with the sensor devices which are required to obtain vehicle configuration such as vision sensor and laser range finder (LRF) sensor. With these sensors, mobile robots detect and create vehicle configurations. The LRF sensor is used for data measurement to obtain the distance in data scanner range that provides both position and orientation. Readings from LRF sensors are very accurate up to a maximum distance of 10 meters, give or take 30 mm. Such sensors also have high scanning rates and their readings are independent of lighting conditions. By installed on mobile robot platform, the LRF sensor device can be able to obtain the vehicle data in range scanner for creating configuration of the parked vehicle in parking lot.

Many researchers were developed mobile robotics system to perform the tasks in parking lot. The techniques were implemented on mobile robotics platform to patrol and inspect vehicle parked in parking lot, for detecting the empty slot [4], creating car parked map [5] while robot operation.

Zhen *et al.* [6] presented the robot is to identify the bumper locations of vehicles in the parking area by 2D laser scanner and then precisely position the license plate recognition with camera relative to the bumper for autonomous mobile parking security. Moreover, a compact robot Spector [7], omni-direction wheel ODIS [8], Safebot [9] were developed for robot motion underside of vehicle to inspect at vehicle undercarriage and monitoring under vehicle state for protection from threats as contraband object or dangerous object or explode object that risk to harmful human life.

1.3 Objective

The purpose of this study is to develop a mobile robot able to patrol and inspect parked vehicle in each parking lot (Fig. 1.1). Basically, author wants to develop a mobile robot platform which performs the task of inspection for detecting the vehicle in parking lots. The inspection tasks are including detection a parking lot state to recognize vehicles in each parking lot, checking the interior vehicle and underside of the vehicle for finding a potential changes from data inspections.

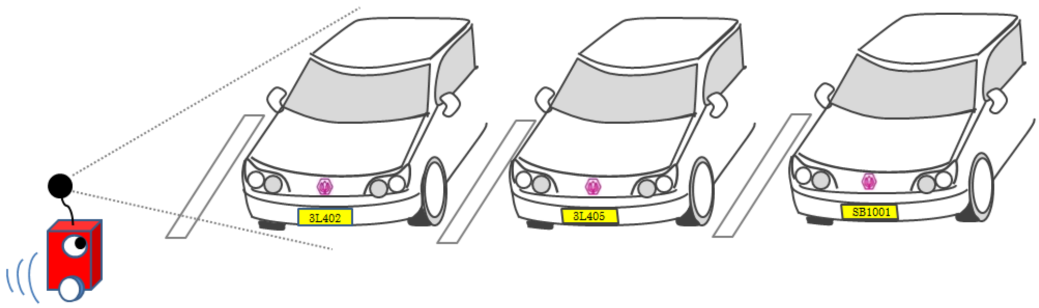


Figure 1.1: Mobile robot performs to vehicle inspection in parking lots

In large parking area, the parking lot information is hard work to realize by manual inspection, to inspect any parked vehicle for checking inside vehicle area and underside of vehicle to find anomalous object or dangerous object, these kind of inspection is difficultly operate through dark tinted of car window and hidden area at vehicle undercarriage by manual inspection. So, some type automated inspection is necessary.

Robotic application is role of important task to repeat the same sequential process, high accurate and robustness than human operation. The key point is it can operate the task in dangerous situation (e.g. toxic radiation, nuclear radiation, explode object, etc.) to assist human mission and safe human life.

The mobile robot is proposed to operate functional inspection and implementation. Author propose three tasks for the application of vehicle inspection, first task, the application of occupancy state recognition, second task, the application of inside vehicle inspection, and third task, the application of under vehicle inspection as follow this:

First task, in Fig. 1.2, the application of occupancy state recognition author want to create parking lot information from data inspections for checking an occupant which is long term parked without action or movement, so we present to use a mobile robot to patrol in parking lots by several time operations.

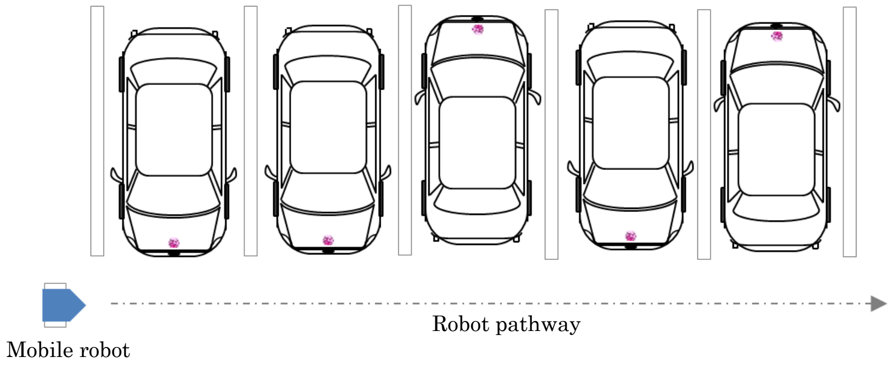


Figure 1.2: Mobile robot performs to the task of occupancy state recognition

Second task, in Fig. 1.3, a new application of inside vehicle inspection on mobile robot platform is proposed author want to inspect an interior of vehicle through car window for finding whether the state of inside vehicle changes or still same state from data inspections by several time operations. In case of state changes, author need to examine the object information as the address of the object or object sizing. In this application, mobile robot moves alongside of vehicle with the overall length of the vehicle.

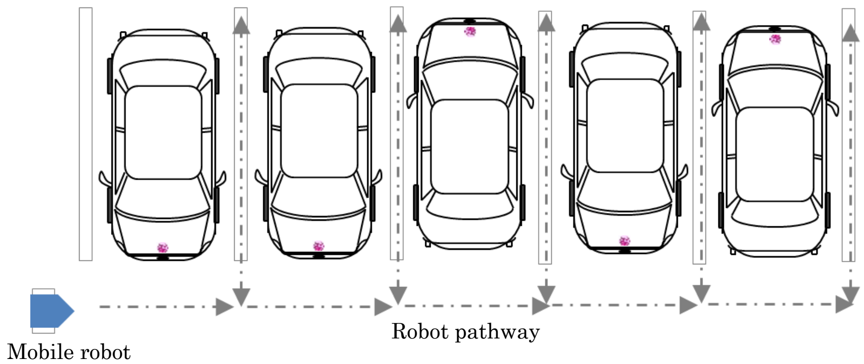


Figure 1.3: Mobile robot performs to the task of inside vehicle inspection

Third task, in Fig. 1.4 the application of under vehicle inspection author want to design and implement a compact robot to operate underside of the vehicle for inspecting at the vehicle undercarriage. To check the under vehicle state changes, author apply a compact robot to detect underside of the vehicle in several time operations. If the state change, author need to realize the anomalous object is appearing where location is, and object sizing.

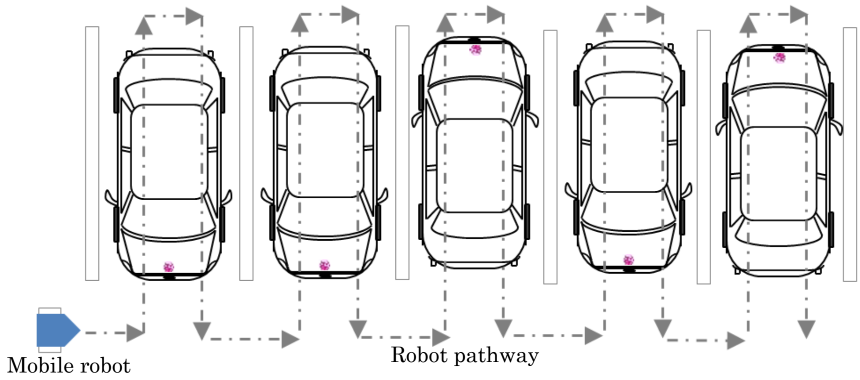


Figure 1.4: Mobile robot performs to the task of under vehicle inspection

Using these applications of vehicle inspection, author try to handle difficulties and challenges related to various vehicles for inspecting vehicle in real environment.

The key of inspection is to find the potential change of vehicle from previous archived scan and current scan. Author would like to present the solution of detected the potential changes between them, author propose the data alignment method to align the data from scans with the same place, and then data comparison method is applied to find the difference thing. From proposed tasks, the key common methods are following: 1) multiple time operation, 2) data alignment, and 3) data comparison. Above of key commons are presented in section 2.

1.4 Contributions

The major contribution with our research is in enhancing existing inspection robots with a 2D laser range sensor to acquire geometric information of vehicle in the parking lot and generate the 3D data from robotics system. Different from other approaches, our system performs to patrol in several time operations and performs nearby target inspection to obtain the vehicle framework, interior vehicles, and vehicle undercarriage from the target vehicles. From this vehicle information, author proposes three tasks of vehicle inspection in this research.

To examine the tasks, author try to realize the vehicle information from several time operations were difference position in world coordinate that its relate to the robot position and propose an approach to align the data between previously archived scan and current scan. Therefore the central problem that author trying to apprehend is to align precisely position data between previously archived scan and current one. And author tries to define the potential vehicle state changes from scans.

In trying to provide such a robotic system as a reliable solution for vehicle inspection, we enlist the following characteristics expected of vehicle inspection system as follows;

- Obtain geometric information of vehicle on multiple time stamps
- Examine the vehicle state changes
- Extract the anomalous objects from vehicle
- Identify the anomalous objects on the current state

1.5 Thesis Outline

The rest of this research is organized as follows. In Section 2, author briefly describe whole application of vehicle inspection in parking lot and the approach of tasks. In section 3, author explains the application of vehicle inspection which detects the vehicle in each parking slot for the occupancy state recognition. In section 4, author introduce a new technique for inspection inside vehicles through the car windows for detecting the inside vehicle state changes as item missing and the implemented system. In section 5, author explains the application of inspection under vehicle to detect the anomalous object appearing underside of the vehicle and introduce a new robotic platform to operate in this task. In section 6, author discusses the experimental results of the developed system of each application and author concludes with remarks on future directions of research and future work of this research.

Chapter 2

Vehicle Inspection System

In presents, the security task and safeguard place is one of important task to inspect the parked vehicles in the parking area and detect the potential changes, or difference from inspections. Most of them the manual operation was employed to patrol and check that target vehicle and/or recording information of each target vehicles. Author realized the task of inspection any vehicles in parking lot by manual inspection is hard work to perform the inspection any vehicles and some task has a limitation on working area at underside of vehicle. So, author proposes the automated inspection system that can assist to human mission for inspecting the parked vehicles in parking lot.

In this research works, author introduces the inspection tasks to operate the vehicle inspection for security and safeguard area by using the mobile robotic system. In this chapter, three applications are introduce in this research work and the solution to obtain the vehicle information of each task and sensor configuration. In section 2.1, author present the related work on various application of vehicle inspections were implemented. In section 2.2, author presents the approach strategy of each task for vehicle detection and its purpose. The approach is how to obtain the vehicle data from sensor and key common of task is described in section 2.3.

2.1 Related works

On application of vehicle inspection had been accomplished to perform the various tasks for vehicle detection in parking place by setting a base security check point at entrance gate. This technique was useful to inspect under vehicle for searching the explode object or dangerous object by using a simple technique with the mirror handheld. Other technique, the visual information was applied on bay inspection hardware for monitoring under vehicle scenes.

Many researchers were developed the application for parking lot inspection by using vision system and robotics system. The vision surveillance [10-14] is widely used to detect the parking slot for monitoring the state of parking slot which is occupancy or empty lot by fix camera station. In [15] presented the parking lot management system that include counting the number of parked vehicles and monitoring the changes of the parked vehicles over the time, and identify the free space of parking lot. In [16] presented the intelligent car-searching system from the vision information which is recognize the license plate number, car color and saved into database. This system could be recognize all plates and color classification in large outdoor park.

Moreover, mobile robotics system was presented to operate the application of vehicle inspection which is installed sensors equipment such as camera and laser range finder and so on. The mobile robotics security was presented on application of a license plate recognition system in [6]. The robot was operated to patrol in parking area for detecting bumper car by 2D laser range sensor and then processing the license plate recognition from camera that relate to the bumper.

Others application, many researches were developed a small robot [7-9], [17-22] for application of under vehicle inspection to inspect the vehicle undercarriage. There was developed robotic system to detect under vehicle for security and inspection operations, including features function for the robotics imaging system [17], the scene inspection underside of vehicle [18-19] and creating multi-perspective mosaics [20] from visual image sensor and generate the surface shape description of 3D data [21-22] from laser range scanner. Those techniques presented the under vehicle inspection for protection from threats.

In research work, author mainly study the inspection task for detecting the parked vehicles in parking lot from the mobile robotic system. Author interested to create the application of vehicle inspection for automated inspection system.

2.2 Tasks of Inspection

In this research work, author interested the task of vehicle inspection to operate the task utilizing mobile robotic system. The key of inspection task is use the mobile robot to perform the several inspections on multiple time operations ($t_1,t_2,\ldots,t_n$) in the same place.

With the inspection tasks, author considering three tasks of vehicle inspection, first, to create the parking lot information, second, to inspect inside the vehicle for protecting from threats such as car break-in, third, to inspect vehicle undercarriage for detecting anomalous object is appearing underside of vehicle. Above of these applications, three applications are proposed in this research. The inspection tasks are described as follows:

2.2.1 Task1: Occupancy State Recognition

The surveillance mission in parking area is one of important task for security and safeguard area that required in any parking area. The state of problem in this task, for inspecting various parked vehicles in any parking slot is difficultly inspect all vehicles, it take a long term and may not covering there, and hard to detect a small change in case of an occupant is move out and go back into a same place (such as position change, pose of vehicle change) by manual inspection. Other, in case of vehicle is parked for long term without movement that risk to be car stealing, car break in and other threat can be occurred.

In task 1, the purpose is to inspect the parked vehicles in parking lot on several time operations for creating the parking lot information and searching which vehicle is parked for long term without movement and vehicle changes by robotic platform.

In this task, shape and position of vehicle is needed to realize the position of vehicle is change or still same vehicle from multiple time operations. So, the shape or position of vehicle would be change by new occupancy. In case of same vehicle or shape is difficult to the parked with same position from previous state so the position of vehicle must be change. Therefore, position of vehicle within a parking lot is considered in this task.

Therefore, author want to detect the state of parking lot is occupancy or empty lot and create the parking lot information. In case of occupancy state, the state of vehicle each parking slot is recognized for checking vehicle state changes. The parking lot information as an occupancy or empty lot, and vehicle changes are declared, so the parking lot management system is proposed in this task. The task of occupancy state recognition is described in section 3.

2.2.2 Task2: Inside-Vehicle Inspection

Most of parking place, the security for protection from threat is desires any parking place by checking and inspecting the parked vehicle on several time operations which is not only vehicle configuration but also vehicle interior. To realize vehicle interior what is something wrong or something difference from inspections is necessary. So, some type automated inspection is required.

The state of problem of this task, inspection inside a car by manual inspection is difficult to detect inside through car window because the various type of car is attached dark tinted, lighting reflection. So, some type of sensor is applied to obtain information inside a car through car window.

In task 2, the purpose is to inspect and recognize the vehicle interior through car windows for checking inside vehicle state which is changes or still same state from multiple of time inspections by robotic platform.

In this task, the author interested to inspect the inside vehicle state of parked vehicles in parking lot for checking the object inside of a vehicle such as object is an existing or object is missing from data inspections. A new application of inside vehicle inspection is proposed to recognize state of inside vehicle as state changes or not. In case of inside vehicle state change, the object identification is proposed to identify the object which is including the detected object size and object location. The task of inside vehicle inspection is described in section 4.

2.2.3 Task3: Under-Vehicle Inspection

Security and safeguard area is one of important task to protect from threat underside of vehicle. To find anomalous object appearing underside of vehicle can be occurring in any parking lot to prevent the dangerous situation in worst case of explode object that risk to harmful human life. For checking status of underside vehicle is need to realize the state of underside of vehicle what is difference from scans. However, the underside of vehicle is narrow area and space limitation, there is hard to operate by human inspection so some type of automation is necessary.

In task 3, the purpose is to inspect underside of the vehicle and recognize under vehicle state for detecting the anomalous object from data inspections.

In this task, author need to recognize under vehicle state, for detecting the anomalous object appearing on current inspection. Author interested to inspect underside of a vehicle from threats (such as dangerous object, bomb etc.) that cause harmful human life. A task of under vehicle inspection is proposed to recognize underside of vehicle in a parking lot. In case of under vehicle state changes, the proposed method can be identified and located the threat object on current inspection. The task of under vehicle inspection is described in section 5.

The contributions of this work can be summarized as follows:

- Parking lot management system by a mobile robot is newly proposed
- New method for inspection inside a vehicle is proposed
- Detected underside of a vehicle from anomalous object is proposed

2.3 Approach

2.3.1 Sensor

The main function the robot must achieve is to inspect the target vehicle and to obtain the geometry information of vehicles. Therefore, it needs a set of sensors in field of the surveillance robot, author found the sensor from laser range finder and camera (e.g. stereo camera, infrared camera, thermal camera etc.), to obtain the vehicle information. From each sensor has its advantages and restriction.

A camera is helpful to obtain visual information with special data such as vehicle shape, color, license plate and so on. However, it has a limited detection distance and its distance detection is very sensitive to the light condition.

A laser range finger (LRF) performs an accurate distance measurement in range scanner which provides both the position and orientation of the surrounding in 270 degree. It also has independent from the lighting condition.

To measure the vehicles, the positioning from vehicle configuration is required in this research. Therefore, a laser range finder is select to direct measure target vehicles. From tasks of inspection, author want to set up a special hardware for supporting a LRF sensor on robotic platform which is use to perform inspect vehicles of each application and its purpose.

2.3.2 Vehicle Data Acquisition

The robot is intended to operate the inspection task for detecting the parked vehicle in the parking place. The mobile robot is installed the LRF sensor to obtain the geometry information of vehicle. For data acquisition, the LRF is mainly used to obtain the vehicle data that installed on robot platform to operate the tasks.

In our research works, three tasks of vehicle inspection are performed the vehicle detection of each application as follow this:

On task 1, in Fig. 2.1, the mobile robot operates the task to patrol outer parking slot area in free space, to measure the vehicle data in range scanner of LRF sensor. 2D plane scanner is setting up right on vertical plane perpendicular from the ground for detecting the vehicle configuration as vehicle shape, pose of vehicle, which is calculated in 3D world coordinate.

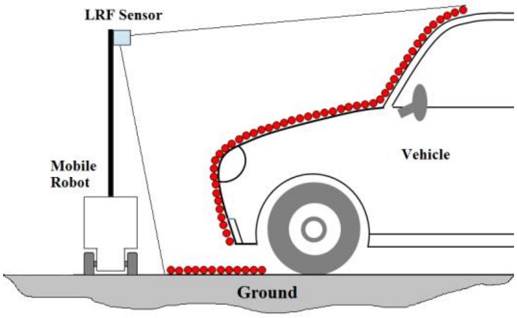


Figure 2.1: 2D Plane scanner for detection vehicles configuration in parking lot

On task 2, in Fig. 2.2, the robot moves parallel alongside the car window framework of whole vehicle length to obtain the geometry information of vehicle as side car framework, vehicle interior through car windows by using LRF sensor. 2D plane scanner is setting on vertical plane that perpendicular from the ground for measuring the vehicle inside data and car side framework data which are calculated in 3D world coordinate.

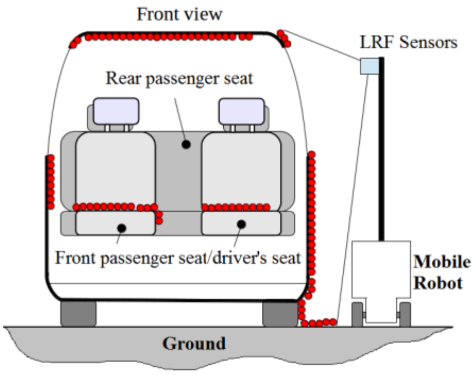


Figure 2.2: 2D Plane scanner of LRF for detection inside vehicles

On task 3, in Fig. 2.3, the robot moves underside of vehicle to obtain the geometry information of under vehicle by using LRF sensor. 2D range scanner is setting in vertical plane scanner that perpendicular from the ground for measuring the data of vehicle undercarriage in 3D world coordinate.

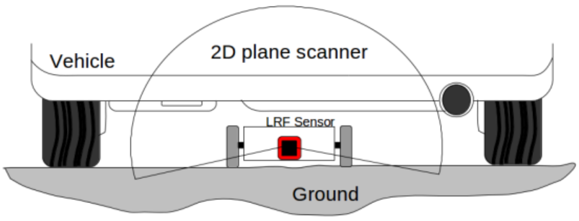


Figure 2.3: 2D Plane scanner of LRF for inspection under vehicles

Above these techniques, the key common of each task is to perform the data calculation in 3D data. For creating 3D data of the vehicle configuration, the 2D range data (range, r_{sensor} and angle, $\O_{sensor}$) from sensor and the robot position (x_{robot},y_{robot}, θ_{robot}) of odometry-based of self-position [23] are combined to calculate the point cloud data (X, Y, Z) in 3D world coordinates. In this research 3D point data is applied all application. This technique is described in Fig. 2.4.

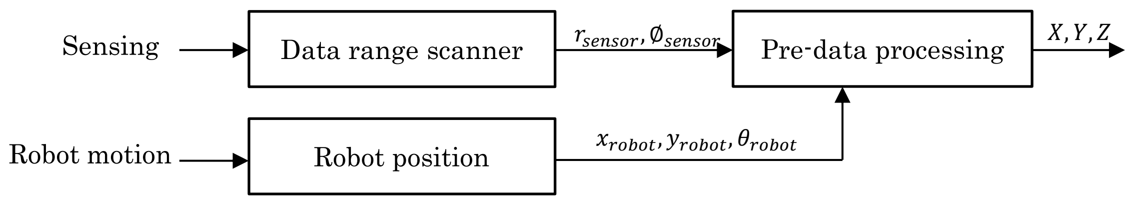


Figure 2.4: 3D data is calculated from 2D range data and robot position

2.3.3 Inspection Tasks

From above vehicle inspection tasks, the key commons on approach of each application concerns the data detection from multiple time operations by using robotic system, data alignment technique and data comparison from scans in our proposed tasks (Fig. 2.5).

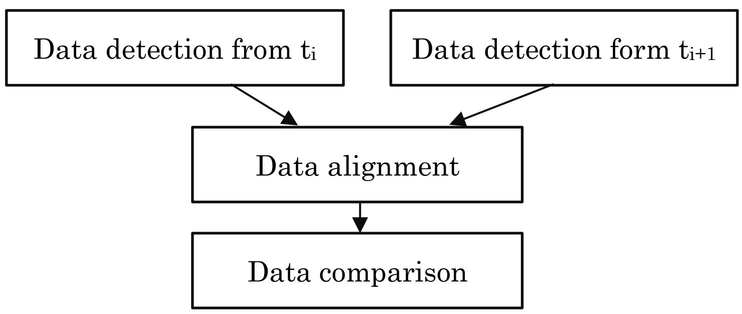


Figure 2.5: Key commons of approach strategy on inspection tasks

The data from scans on multiple time operations (t_1, t_2,…,t_n) on robotic platform which performs to obtain the vehicle configuration of each approach. The data from scans relate to robot position while robot operation on multiple time frames so the data from scans are difference in world coordinate. Therefore, the data from scans of time frame t_i and t_{i+1} are used to compute the data alignment between them until data convergence and then data comparison is applied to find the potential changes from scans. The data alignment technique and data comparison technique are applied to exam in our proposed applications.

Multiple time operations, this research work is developed the application of vehicle inspection on mobile robotic system, to patrol in parking lot for detection parked vehicle. Therefore, several time inspections (t_1, t_2,…,t_n) for sensing surround environment of parked vehicle is required. The 3D point data from multiple time operations is applied in data calculation of each target task.

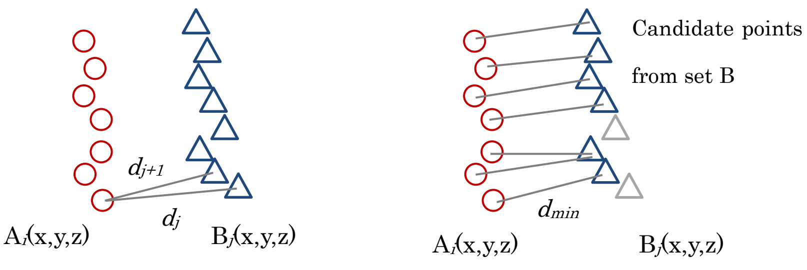
Data alignment technique, an ICP algorithm [24-25] is proposed to calculate the data position for matching data from scans. This technique is a key point of this system to align precisely position of data is essential function. The data alignment is applied to calculate the data from data scans of t_i and t_{i+1}. This method is described as follow this.

a) The data scan from t_i is set at $\mathrm{A}_i(\mathrm{x,y,z})$ and data scan from t_{i+1} is set at $\mathrm{B}_j(\mathrm{x,y,z})$.

b) Calculate the distance (d) of point pair from a point of A to all points of B by using Euclidean distance in equation (2.1).

$$\mathrm{d}(\vec{A},\vec{B}) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \tag{2.1}$$

To define closet point as a minimum distance (d_{min}) of point pair base set A and the candidate points from set B is collected into new set G.



c) The closet point between data set A and set G is applied to calculate the geometric centroid of A_c and G_c.

$$\mathrm{A}_c = \left[\mu_{A_x}, \mu_{A_y}, \mu_{A_z}\right] \text{ , where } \mu_{A_x} = \frac{1}{N}\sum_{i=1}^{N} x_i \text{ , } \quad \mu_{A_y} = \frac{1}{N}\sum_{i=1}^{N} y_i \text{ , } \mu_{A_z} = \frac{1}{N}\sum_{i=1}^{N} z_i$$

$$\mathrm{G}_c = \left[\mu_{G_x}, \mu_{G_y}, \mu_{G_z}\right] \text{ , where } \mu_{G_x} = \frac{1}{M}\sum_{i=1}^{M} x_i \text{ , } \quad \mu_{G_y} = \frac{1}{M}\sum_{i=1}^{M} y_i \text{ , } \mu_{G_z} = \frac{1}{M}\sum_{i=1}^{M} z_i$$

d) To calculate the rotation matrix base a singular value decomposition (SVD) technique [26-27] from detected point pair result. The SVD approach define by $\mathrm{H} = U\Sigma V^T$, where U is orthonormal eigenvector of HH^T, V is orthonormal eigenvector of $H^T H$ and Σ is a diagonal matrix containing of the singular value of H, which are non-negative square roots of the eigenvalues from HH^T in descending order. The least square method is applied to define H matrix for the cross covariance matrix.

$$\mathrm{H} = \begin{bmatrix} S_{xx} & S_{xy} & S_{xz} \\ S_{yx} & S_{yy} & S_{yz} \\ S_{zx} & S_{zy} & S_{zz} \end{bmatrix}$$

Where,
$$\begin{aligned} S_{xx} &= \textstyle\sum_{i=1}^{N} A'_x G'_x \ , & S_{xy} &= \textstyle\sum_{i=1}^{N} A'_x G'_y \ , & S_{xz} &= \textstyle\sum_{i=1}^{N} A'_x G'_z \\ S_{yx} &= \textstyle\sum_{i=1}^{N} A'_y G'_x \ , & S_{yy} &= \textstyle\sum_{i=1}^{N} A'_y G'_y \ , & S_{yz} &= \textstyle\sum_{i=1}^{N} A'_y G'_z \\ S_{zx} &= \textstyle\sum_{i=1}^{N} A'_z G'_x \ , & S_{zy} &= \textstyle\sum_{i=1}^{N} A'_z G'_y \ , & S_{zz} &= \textstyle\sum_{i=1}^{N} A'_z G'_z \end{aligned}$$

Where, $\mathrm{G}'_x = \{x_i - \mu_{G_x}\}$, $\mathrm{G}'_y = \{y_i - \mu_{G_y}\}$, $\mathrm{G}'_z = \{z_i - \mu_{G_z}\}$ and $\mathrm{A}'_x = \{x_i - \mu_{A_x}\}$, $\mathrm{A}'_y = \{y_i - \mu_{A_y}\}$, $\mathrm{A}'_z = \{z_i - \mu_{A_z}\}$

Above of matrix calculation as follow this step:

Step 1) Calculate HH^T

Step 2) Determine the eigenvalues of $|H^T H - \lambda|$, Let's get the $\lambda_1, \lambda_2, \lambda_3$

Step 3) Construct diagonal matrix Σ , to define a value of $\mathrm{S} = \sqrt{\lambda}$ when $\mathrm{S}_1 > \mathrm{S}_2 > \mathrm{S}_3$ and determine the diagonal matrix of Σ^{-1}

$$\Sigma = \begin{bmatrix} S_1 & 0 & 0 \\ 0 & S_2 & 0 \\ 0 & 0 & S_3 \end{bmatrix} \ , \ \Sigma^{-1} = \begin{bmatrix} T_1 & 0 & 0 \\ 0 & T_2 & 0 \\ 0 & 0 & T_3 \end{bmatrix}$$

Step 4) Define the eigenvectors by using the eigenvalue from step (2), to calculate each eigenvalue by $|H^T H - \lambda I| X = 0$

Where, $V_{\lambda_1} = \begin{pmatrix} a \\ b \\ c \end{pmatrix}, V_{\lambda_2} = \begin{pmatrix} d \\ e \\ f \end{pmatrix}, V_{\lambda_3} = \begin{pmatrix} g \\ h \\ i \end{pmatrix}$

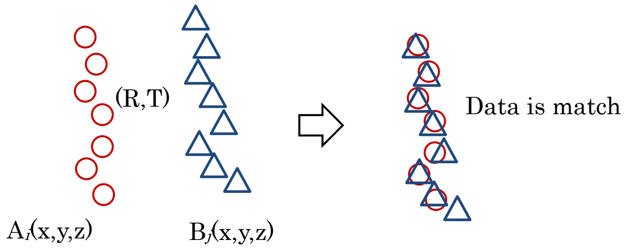
Step 5) Set matrix V from $V_{\lambda_1}, V_{\lambda_2}, V_{\lambda_3}$ by $V = \begin{bmatrix} a & d & g \\ b & e & h \\ c & f & i \end{bmatrix}$

Step 6) Calculate $U = HV\Sigma^{-1}$

e) Calculate the translation (T) and rotation (R) from value of U and V from the SVD algorithm. The optimal rotation $R = VU^T$ and translation $T = G_c - A_c * R$

f) Apply translation matrix, $G_{new} = R * A + T$, and define $error = G - G_{new}$

g) Repeatedly process in (b), until data convergence



Above this solution, author applied them to the data processing of our proposed applications. The solution of data alignment can be solving the problems of difference position from multiple time operations with the same position in world coordination.

Data comparison, the point data is applied to find the potential change as the difference point data from the data scans. In application tasks, the data comparison is a key function to calculate the position of data.

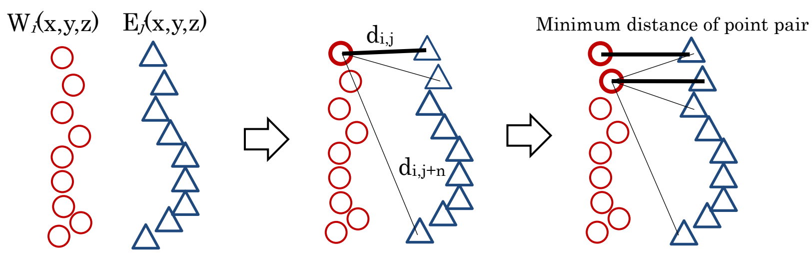
In application task 1, the data comparison technique is described as follow:

a) Set at $W_i(x, y, z)$ from data scan of t_i and set $E_j(x, y, z)$ from t_{i+1}

b) Determine the distance $d(\vec{W}, \vec{E})$ of point pair from a point of set W to each point of set E by using Euclidean distance in equation (2.2).

$$d(\vec{W}, \vec{E}) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \quad (2.2)$$

c) Define a minimum distance value from $d(\vec{W}, \vec{E})$, and collected into a set O_k.



d) Data from set O_k is applied to calculate the density of data and often for density estimation by using the histogram technique.

Step 1) set a threshold of interval range, *min.* and *max.* of interval range

Step 2) data from O_k is calculate in each unit of an interval range

Step 3) selected a density is high from the interval data

e) Minimum data from (d) is used to identify the position changes, or not.

In application task 2 and task 3, the similar data comparison technique is described as follow:

a) The data scan from t_i is set at $P_i(x,y,z)$ and data scan from t_{i+1} is set at $Q_j(x,y,z)$.

b) Set a threshold is constant value and create set $M_k(x,y,z)$

c) Determine the distance $d(\vec{P},\vec{Q})$ of point pair from a point of set P to each point of set Q by using Euclidean distance from equation 2.3.

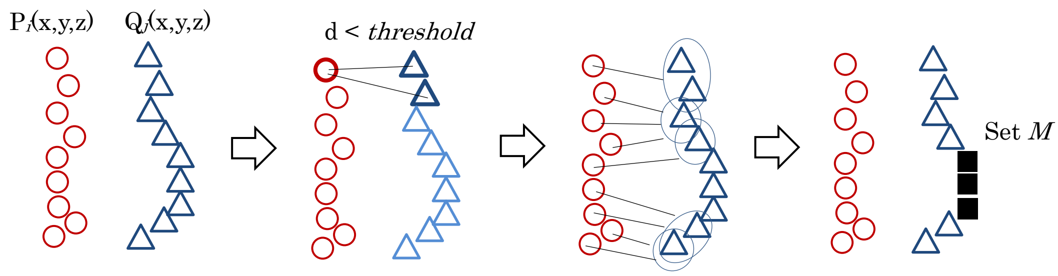
$$d(\vec{P},\vec{Q}) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \quad (2.3)$$

IF distance (d) is greater than a threshold, the candidate point is collected into set M

IF distance (d) is less than a threshold, the candidate point is ignored

d) Update set Q by the data from set M

e) Repeatedly process in (c) until completed all points from set P



Above these solutions, the data comparison technique is applied to the data processing of each proposed task, to define the existing of point data from scans. If the existing points is detected that means something is difference from previous state. In this research, author mainly interested to find vehicle state change from scans by using robotic system.

Chapter 3

Occupancy State Recognition

3.1 System Overview

Basically, the state of parking lot information in the parking area can be classified into two states as the occupancy state and the empty state. Within the occupancy state in a parking lot, the occupant is parked in a parking lot for long term parking or changing new occupant get into a parking lot, which is occurring in any parking place. In this application, the parking lot inspection is performs to recognize the vehicle in each parking slot and identify where it is located in the parking place. This kind of information assists the parking manager to manage the parking place. Typical of the parking lot information is shown in Fig. 3.1. Author designate a circular shape for an occupancy state of the vehicle, a rectangular shape for an empty space state, and the arrow shape for a continue state. For instant, within the parking lot number one, the occupant is a continue state from time t_1 until t_2 and while the state from time t_3 of parking lot is changing by a new occupant until free space on t_n.

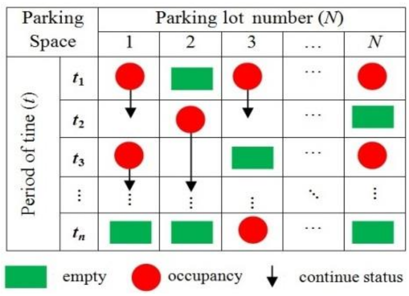


Figure 3.1: Demostrated of parking lot information

3.2 Approach: Occupancy State Recognition

In this application, our proposed application aims to inspect the occupancy state within parking lot, recognize the vehicle is parked in long periods and locate the parking lot number in the parking place by using a mobile robot with LRF sensor. In Fig. 3.2, author propose mobile robot performs to patrol (on multiple time operation t_1, t_2,...,t_n) from starting point until cover all parking slot and then go back to the initial point which it can repeatedly operate the mission in the same place.

To obtain the parking lot information, mobile robot installed with the LRF sensor is perform the measuring data in range scanner such as vehicle configuration of each parking slot, guideline on ground and so on. Using this information, author want to realize where the occupant is long term parked and create the parking lot information as well. From this information, author propose strategy approach of the guideline extraction from ground surface, guideline data alignment from data scans, and identify the vehicle is parked without action movement.

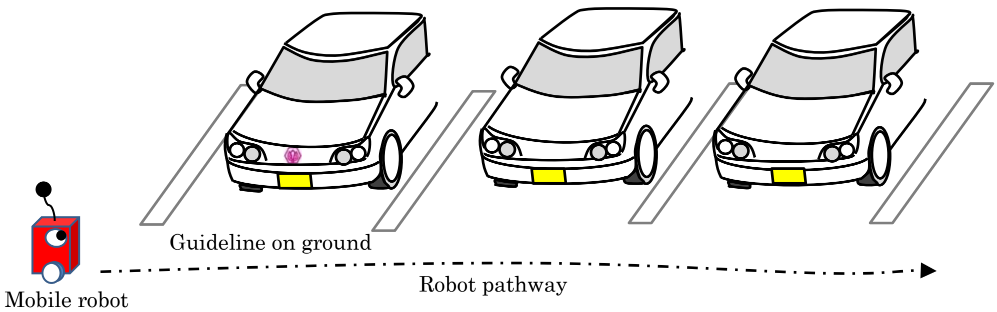


Figure 3.2: Mobile robot is patrol in parking lot for occupancy state recognition

In this application, author try to understand that parking lot environment have various types of guideline on ground such as a single line, double line, square, etc. and including various types of terrain such as high slope, rugged terrain, difference step platform, etc. Above these circumstances, the assumption of this application is a type of guideline as a single line and a flat terrain on the ground of parking lot inspection system.

3.3 Implemented System

The robot platform is called "Yamabico" [23] that developed in the intelligent robot laboratory. The laser range sensor is used to obtain the data, has been installed on top of the robot. The position height is 130 cm from the ground plane for the measurement in range of laser range sensor while robot is patrolling in the parking space. The robot platform is shown in Fig. 3.3. The main processor used is Corei5 2.67GHz, 4GB RAM based notebook computer running Ubantu 11 distribution of Linux (kernel 2.6.38-8-generic-pae) as operating system. The robot controller broad with SH2 processor provides robot locomotion and odometery-based self-position estimation function. The laser range sensor (UTM-30LX) is a compact size (W60xD60xH87 mm), cover detection range about 0.1 to 30 m, distance accuracy is 0.03 m, angular resolution is 0.25 degrees, and angle range is 270 degrees operating at 40 Hz.

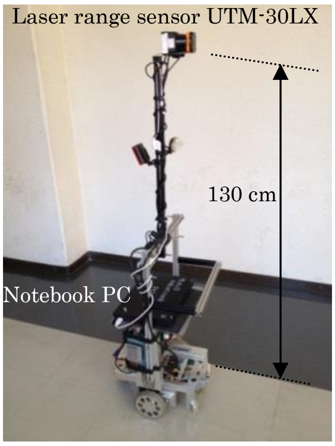


Figure 3.3: Robot platform is implemented on the application of occupancy state recognition

3.4 Data Processing

3.4.1 Data Acquisition

The 2D plane scan of the LRF provides the upright vertical plane scan that is perpendicular to the ground plane for data scanner in the parking space in Fig. 3.4. The 2D data range scan (angle and range) and odometery-base of self-positioning of the robot locomotion are calculated to the 3D point cloud data in world coordinates. The point cloud data from the LRF, not only the vehicle data is obtained in data range scanner but also included the guideline data. For clustering of these point cloud data, the constant height value of $H_{threshold}$ is applied for divide of all the point cloud data. The two clusters are consisted of both the point cloud of vehicle data ($C_j^{t_i}$) and the point cloud of the ground data ($L_j^{t_i}$). The vertical 2D plane scanner and the $H_{threshold}$ are shown in the Fig. 3.5.

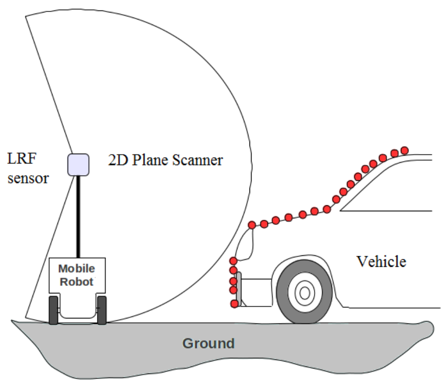


Figure 3.4: 2D plane scanner of LRF sensor

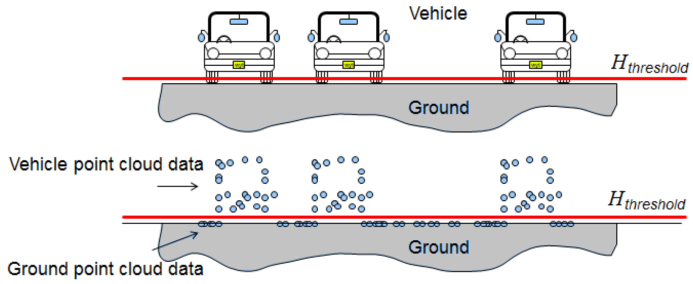


Figure 3.5: Point cloud data of parking lot inspection is divided by $H_{threshold}$

3.4.2 Guideline Data Extraction

The point cloud data is lower than the value of the threshold that provided to determine the guideline data of each parking lot. The LRF sensor also obtained the range data and the intensity data from the data scanner. Author considered the reflection intensity data of LRF [28-29] to determine the guideline (most of the standard color for guideline is white color) having the different laser reflection properties from other ground surface. The intensity data is obtained depends on the range, material, shape with smooth or rough of object detection. In the way, the ground surface and guideline is difference value of intensity data the intensity value of guide line is higher than the ground surface.

By guideline extraction, set the two points generate the straight line, the intensity data of each data point over the straight line is to determine whether the selected point data is on the straight line, other points data are ignored. The method of detecting the guideline based on the intensity data is illustrated in Fig. 3.6.

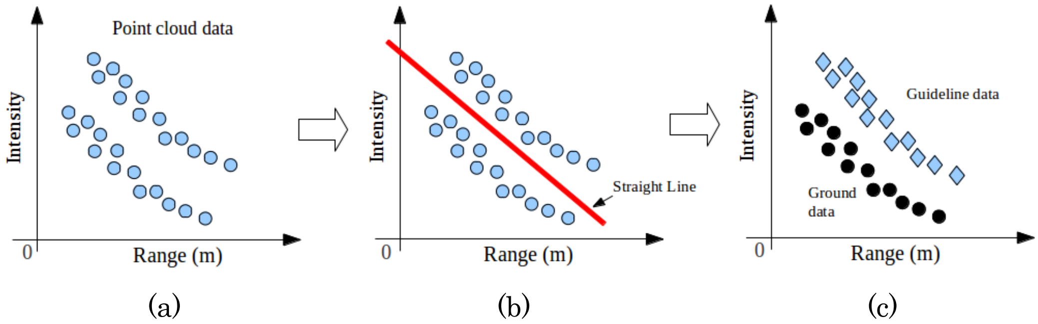


Figure 3.6: The data processing of the intensity data on ground surface, (a) the intensity data of the point cloud data, (b) guideline extraction by set a straight line, (c) intensity data of the guideline selection

We extracted the guideline data from all point cloud of ground data based on reflection intensity data of LRF sensor. In this part, the low qualities of guideline data for long range from data scanner have a less fewer point data, so author want to limit a range of guideline in detection range and other point data out of the range is removed. In Fig. 3.7, Determination of the guideline positioning of each parking lot as follow:

First, the data segmentation is used to determine each guideline of the point cloud data as shown in Fig. 3.7(a).

Second, the guideline data in the detection range is collected with set the constant value V_{offset} by defined the minimum point of each guideline data (along y-axis) add the set value V_{offset} as described in Fig. 3.7(b).

Finally, the position of guideline data is used to determine the location of parking lot with pair guideline data by defined the mean value of each guideline (along x-axis) as described in Fig. 3.7(c). Therefore, two points set from the guideline data is used to define where a parking lot is occupancy state or empty state.

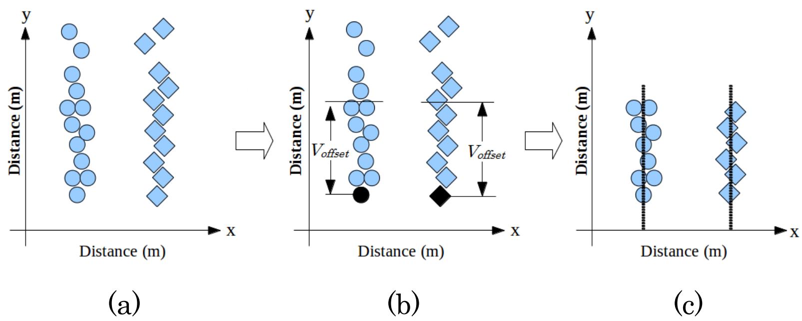


Figure 3.7: The data processing of guideline detection: (a) guideline segmentation (b) collected the guideline in range of V_{offset}, and pair guideline data of a parking lot in (c)

3.4.3 Vehicle Detection

Since, the vehicle point cloud data contains all the vehicle data in the parking lot, this data allow us to find the position of each vehicle in the parking lot. As the result of guideline detection, author determined the each vehicle data from the vehicle point cloud data by using the two points set. In this part, author need to fine of each parking lot is an occupancy state or empty state, and also counting amount of the parked vehicle.

Therefore, the vehicle in each parking lot can determine by pairing the two points set (pair of guideline) as follow: First, two points set are applied to determine the vehicle data from the point cloud data of vehicle. Second, shift two points set for parking lot detection and continue counting the number of parking lot also. In case of, having a vehicle in parking lot the vehicle data is recorded, free space is set zero. So that, this solution can define whether the parking lot is occupied by a vehicle or the parking lot is an empty space. This method is described in Fig. 3.8.

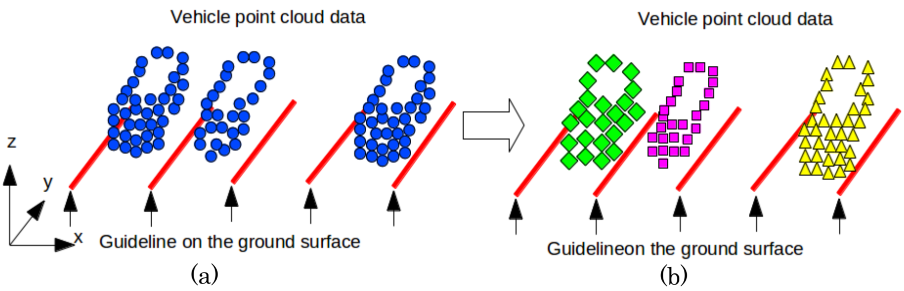


Figure 3.8: The vehicle point cloud data (blue point) with the guideline data extraction in (a) and the vehicle data separation in each parking lot (b)

3.4.4 Guideline Data Alignment

In this paper, the guideline data from data scanner by using a mobile robot which is difficult to match between pervious scan and current scan (multiple times) because the guideline position is related to the robot position with odometery based self-position, thus the error can occur while the robot is operational. Therefore, author provided the ICP algorithm for guideline data alignment and match between base point cloud data and target point cloud data.

With the guideline detection section, to collect the points set from the point cloud data of set L. Pair of guideline is used to compute the data matching between base point cloud $L_i(k)^{t_i}$ and target point cloud $L_j(k)^{t_{i+1}}$, where L is point sets of guideline data, k is the number of the parking lot and t is the multiple of duration time of data range scanner. The method of computing the guideline matching is described as follows:

a) Set base point data $P \leftarrow L_i(k)^{t_i}$, and target point data $S \leftarrow L_j(k)^{t_{i+1}}$

b) Pair each point of $L_i(k)^{t_i}$ to closet point in $L_j(k)^{t_{i+1}}$

c) Compute motion by translation *(T)* and rotation *(R)*.

d) Apply motion to $L_i(k)^{t_i}$

e) Repeat until convergence of data between $L_i(k)^{t_i}$ and $L_j(k)^{t_{i+1}}$

This solution is illustrated in Fig. 3.9, for guideline matching. The transformation matrix *(R,T)* is computing base on the point cloud data of vehicle data simultaneously.

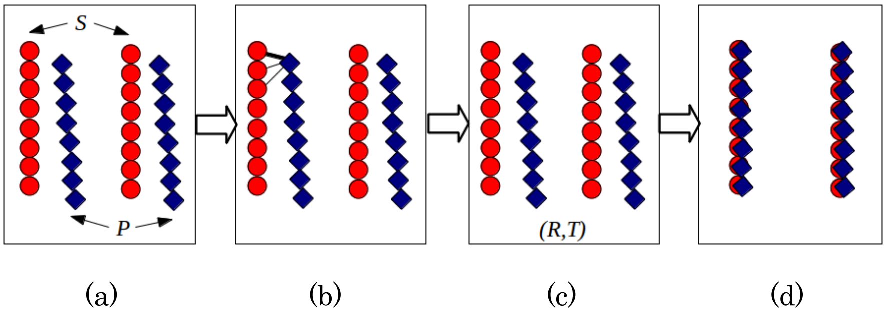


Figure 3.9: The pair guideline matching: (a) the set base point cloud (square shape) and target point cloud (circle shape), (b) pair of each point of base point cloud to closet in target point cloud, (c) compute Rotation (R) and Translation(T) matrix to base point cloud, (d) the guideline matching

3.4.5 Vehicle Data Comparison

In this section, author determined whether vehicle data in the parking lot is the continue occupancy state or change of the new occupant by data comparison between them. In this task, author mainly interested the state of parking lot is occupant by a vehicle and data comparison of both vehicle in the same parking lot position.

The vehicle data of base point cloud $C_j(m)^{t_i}$ (calculated Transformation matrix) and target point cloud $C_j(m)^{t_{i+1}}$ are applied for data comparison approach, where m is the value of vehicle in parking lot, t is the multiple of duration time of data range scanner.

For the data comparison, author described of the data processing as follow: First, set the vehicle data of $\overrightarrow{W_i} \leftarrow C_i(m)^{t_i}$ and $\overrightarrow{E_j} \leftarrow C_j(m)^{t_{i+1}}$. Second, define the minimum distance of each point pair of $\overrightarrow{W_i}$ to the closet point in $\overrightarrow{E_i}$ by using Euclidean distance, $d(\overrightarrow{W_i}, \overrightarrow{E_j})$ in equation (3.1) where $\overrightarrow{W_i} = (x_i, y_i, z_i)$ and $\overrightarrow{E_j} = (x_j, y_j, z_j)$.

$$d(\overrightarrow{W}, \overrightarrow{E}) = |\overrightarrow{W_i} - \overrightarrow{E_j}| = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2} \quad (3.1)$$

In this technique, author calculates the distance of each point *W* from all points of set *E*. Therefore, the distance of point pair is calculated to define the minimum distance of the point data, and then the distance from all point pair is collected. So, the density point data of closet distance from those data by using histogram technique.

The average value from point data is calculated. If the average value is very close to zero that means the same position of vehicle data (continue occupancy state). And if the average of distance is very large that means the position of vehicle is changing (new occupant).

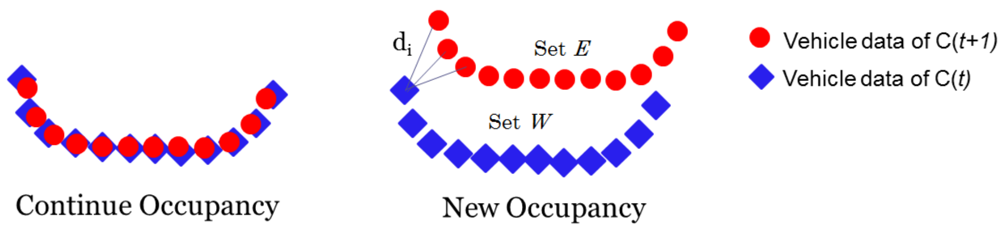
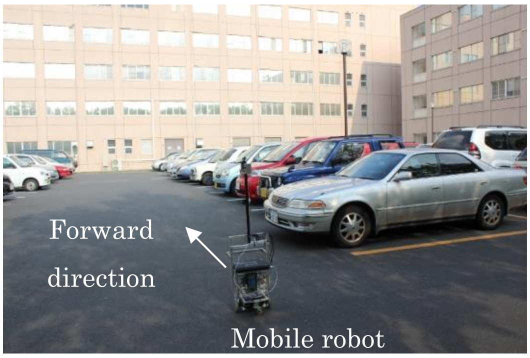


Figure 3.10: The point cloud (diamond shape) of set *W* and set *E* are calculated the distance *(d)* of each point pair between of them

3.5 Experimental Results

In the experiments, the mobile robot velocity is 0.15 m/sec for patrolling in parking lot, and measuring the vehicle parked in each parking slot and the guideline on ground by using LRF sensor, parking lot in our experiment is shown Fig. 3.11(a) and Fig. 3.11(b). Mobile robot is patrolling to create the geometry of parking place information on multiple time operations from laser range scanner.



(a)

(b)

Figure 3.11: Mobile robot is perform to inspection task in parking lot in (a), a typical of the guideline (line type) on the ground in (b)

For the experiments of this research, in Fig. 3.12, 14 parking lots approximately distance 35 meter, spend time about 16 second of each parking slot, four time frame operations of data scanner $t_1 \rightarrow t_4$ by the mobile robot which is operated at the same place. The data range scanner from sensor was read every 25ms by driver processes and registered in parallel into a shared memory system (SSM) [30] was recorded into Log data file. The data detection tests were performed off-line by playing back this log data file at the same rate of the sensor (40Hz) using SSM system. In experiment, a mobile robot is go straight on a forward (along x-axis) to data range scanner that obtained the vehicle data and ground data by using a LRF sensor and the feature function of reflection intensity data is included in this application of our experiment.

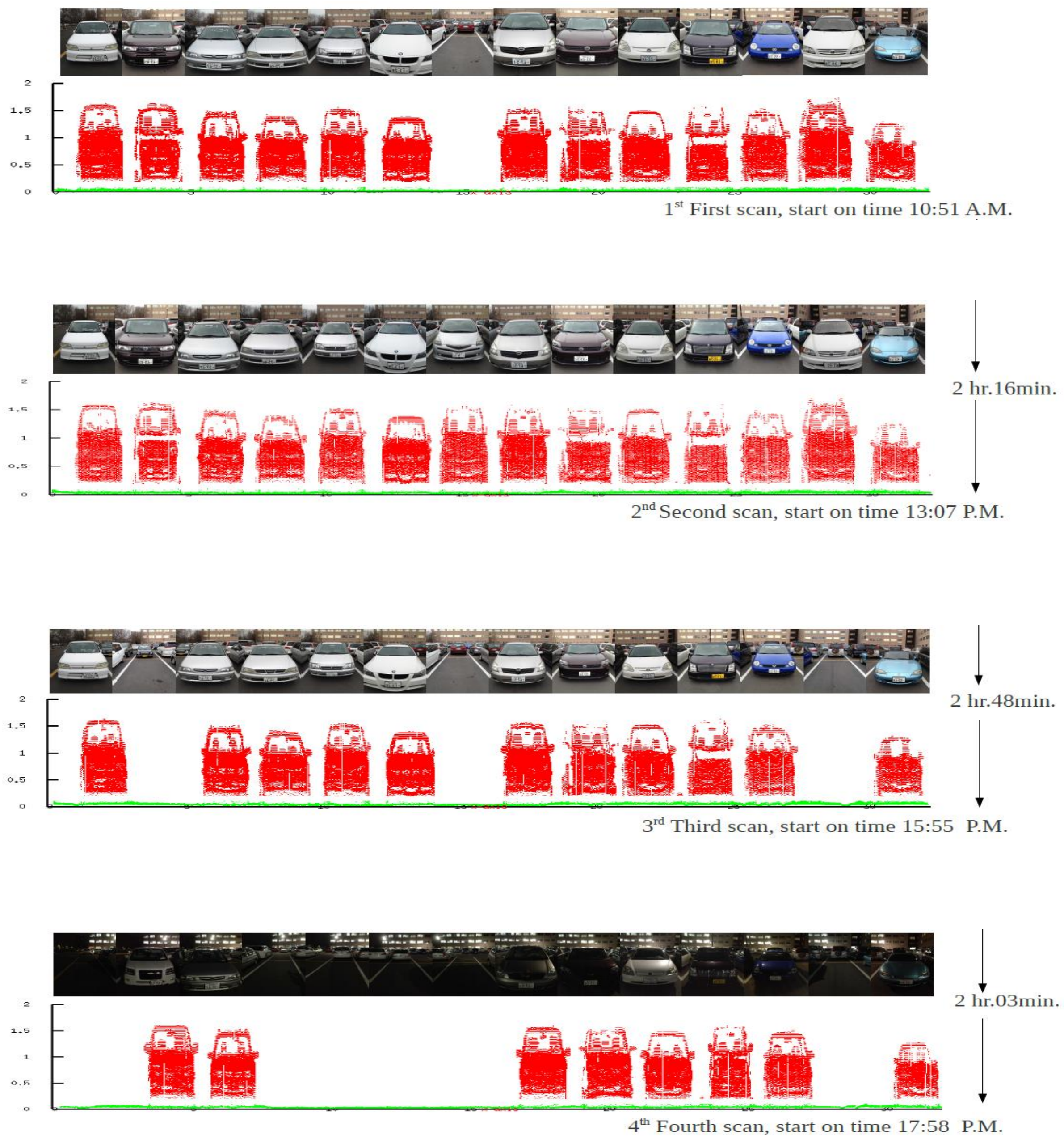


Figure 3.12: Experimental results on four time operations on day and night time

As the result of inspections, author use these data to calculate the proposed method of application on occupancy state recognition. In Fig. 3.13, the point cloud data from data scanner is applied to cluster the group of the vehicle data and ground data by using a constant $H_{threshold}$ set is 0.01 m.

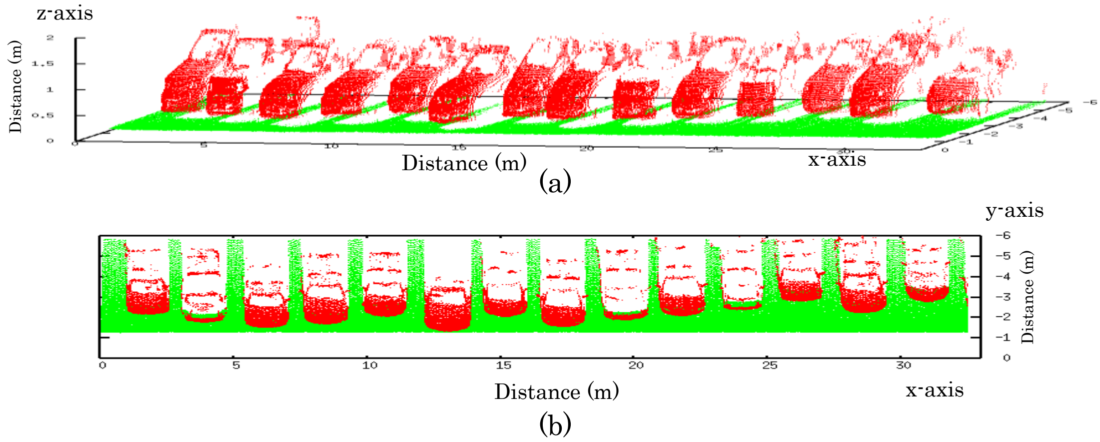


Figure 3.13: The experiment result of data range scanner in parking place, the vehicle point cloud data (red point) and ground data (green point) in prospective view in (a) and top view in (b)

As the result, author considers the ground data to define the guideline on ground for checking the state of each parking slot. For data measuring, the sensor is not only measuring the data of position and orientation but it also including the intensity data in range scanner. Because the data intensity from ground data and guideline is difference, as difference shade color, so author interested to extract the guideline data from the ground by using intensity value.

For guideline extraction technique, author propose the strength line by set two points for calculating the point cloud data which point data above a line is collected. In Fig. 3.14, a strength line is defined by linear equation $y = mx + b$ as from point of $S_1(x_1, y_1)$and $S_2(x_2, y_2)$ is manual set. Then, determine $b = y - mx$ where m is $(y_2 - y_1)/(x_2 - x_1)$, for example, determine b_{P1} and $b_{P2}$from points P_1 and P_2, which the value greater than b is collected, other is ignored.

Using above technique, two points are manual set to define a straight line which is applied to separate the data intensity from ground data and guideline data.

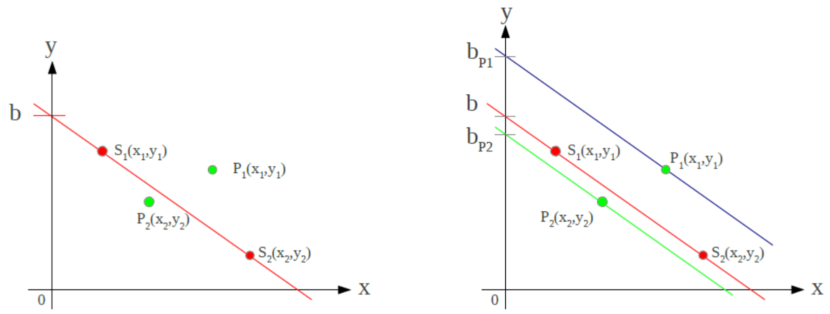


Figure 3.14: Two points for creating a strength line

In experimental results, points are set in several case for separating the point data by using a point pair as follows: $S_1(0,3900)$, $S_2(6,1700)$ in Fig. 3.15, and $S_3(0,3700)$, $S_4(6,1400)$ in Fig. 3.16, and $S_5(0,3500)$, $S_6(6,1000)$ in Fig. 3.17, where S(range, intensity).

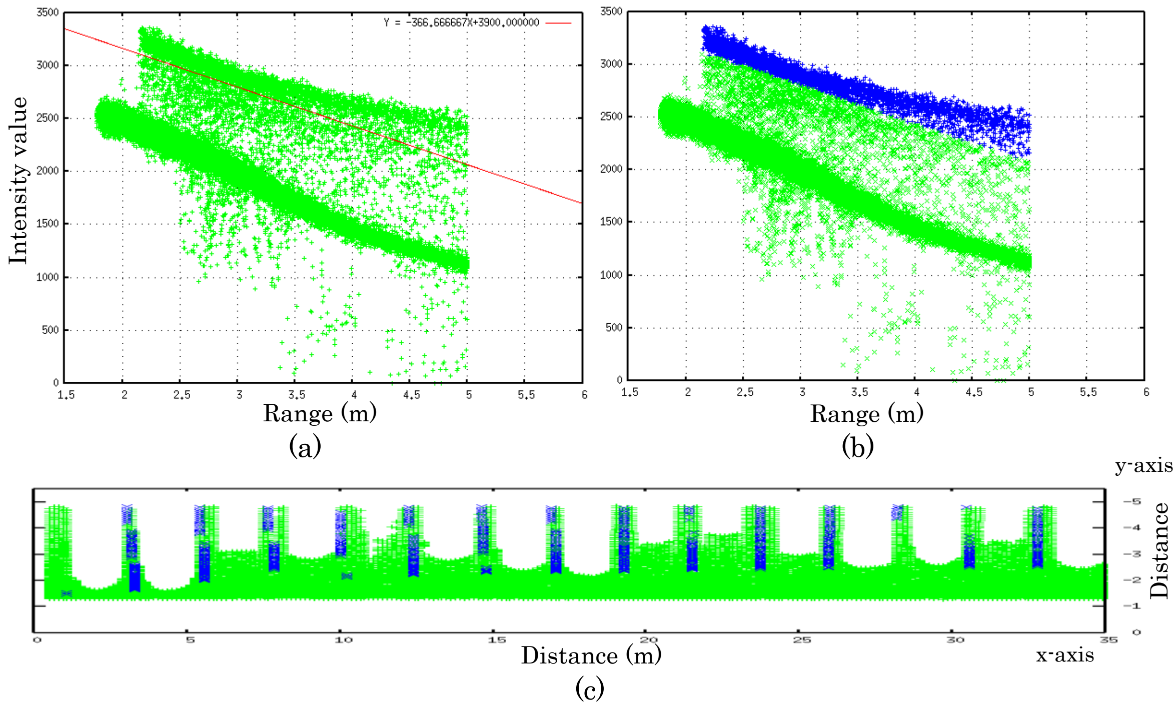


Figure 3.15: Two points $S_1(0,3900)$, $S_2(6,1700)$ of a straight line (a), intensity data of guideline above straight line (b), the guideline extraction (blue point) from ground (c)

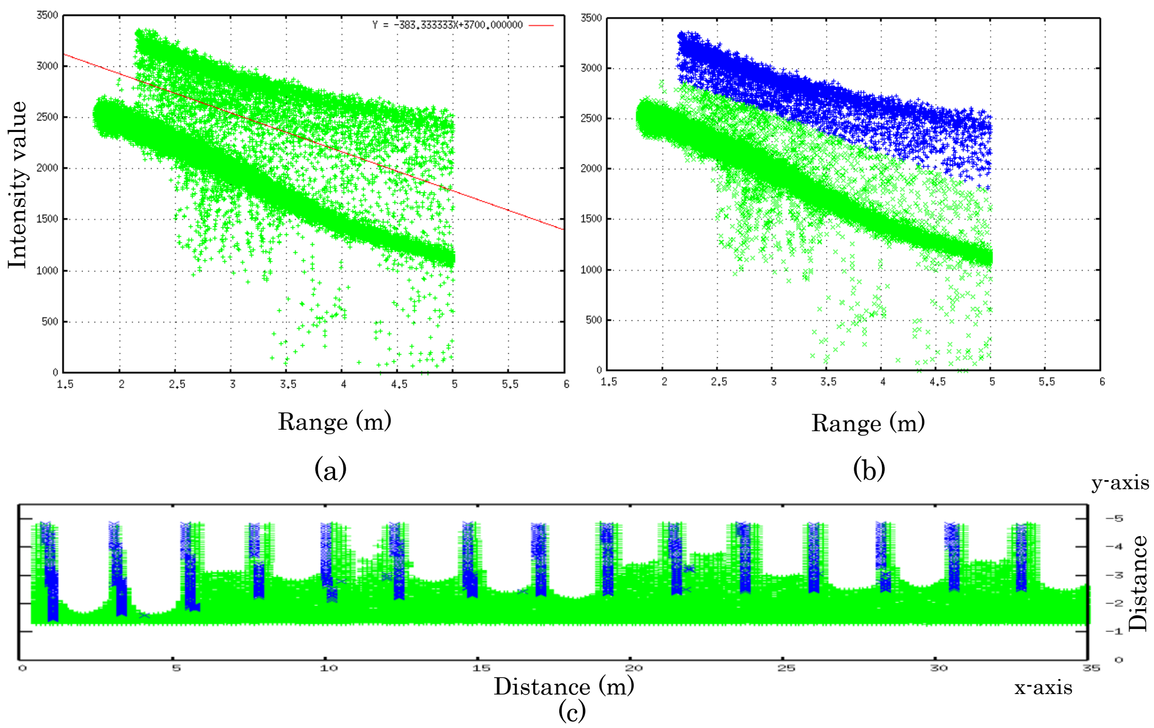


Figure 3.16: Two points $S_3(0,3700)$, $S_4(6,1400)$ of a straight line (a), intensity data of guideline above straight line (b), the guideline extraction (blue point) from ground (c)

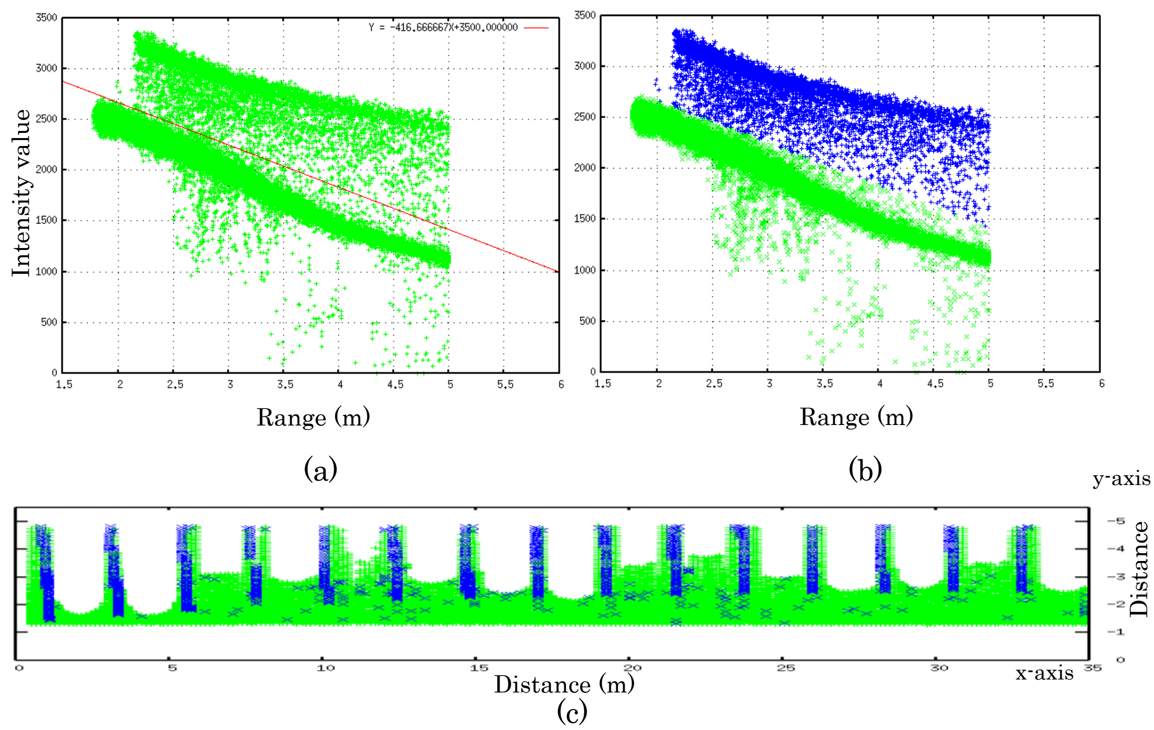


Figure 3.17: Two points $S_5(0,3500)$, $S_6(6,1000)$ of a straight line (a), intensity data of guideline above straight line (b), the guideline extraction (blue point) from ground (c)

A point pair of S_3 and S_4 is selected to calculate all experiments. The experiment result of the guideline extraction by using the intensity data is shown in Fig. 3.18.

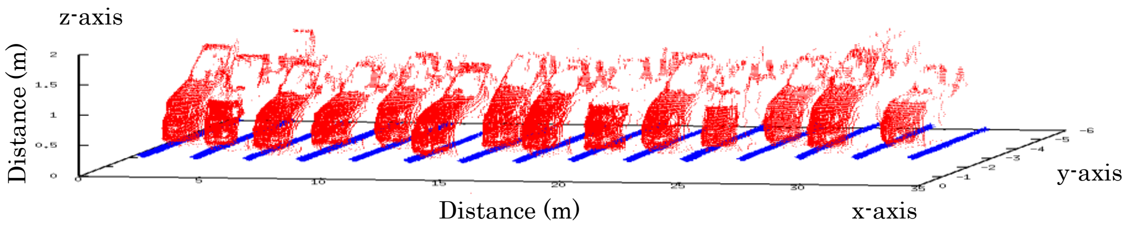


Figure 3.18: The guideline data (blue point) is extract from ground point cloud data and positioning of vehicle data (red point) in prospective view

After the guideline extraction, the guideline data is collected by set the range (V_{offset}) is 2 meter, thus other points is removed. This experiment result is shown in Fig. 3.19.

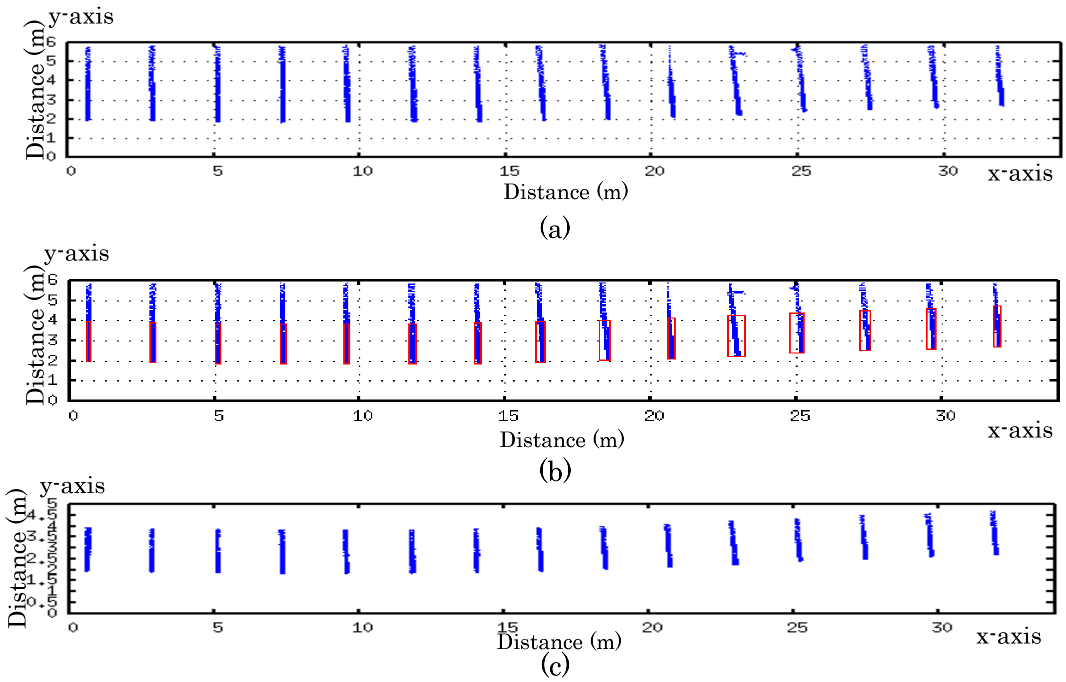


Figure 3.19: Data processing of guideline detection: (a) the data of guideline by using intensity data, (b) the guideline data detection by set range V_{offset}, (c) the guideline detection of each line

As the result of the guideline detection, that data is to determine the vehicle with pair guideline data. The guideline data is applied to detect the vehicle data with pair guideline data for checking a parking lot state which is occupancy or empty lot by counting the number of point between the guidelines. So, state pf parking lot can identify the state of each parking slot.

For the experimental result of parking lot checking, this experiment is in Table 3.1. In experiment result, the vehicle data in the parking place having 14 number of parking slot on working a day for four time data scanner. Various data were sampled on a timely basis (by mobile robot: 10:51AM, 13:07PM, 15.55PM and 17.58PM) where O is occupancy state and E is an empty lot state.

Table 3.1: Experiment result of parking lot state checking

Parking space		**Parking lot number**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Times	**t_1 =10:51 a.m.**	O	O	O	O	O	O	E	O	O	O	O	O	O	O
	t_2 =13:07 p.m.	O	O	O	O	O	O	O	O	O	O	O	O	O	O
	t_3 =15:55 p.m.	O	E	O	O	O	O	E	O	O	O	O	O	E	O
	t_4 =17:58 p.m.	E	O	O	E	E	E	E	O	O	O	O	O	E	O

The experiment of guideline alignment, in Fig. 3.20, pair of guideline data from ti and ti+1 is applied to match the guideline data from the parking slot (parking lot number 1 from inspection of time t_1 and t_2). The translation matrix is to calculate both of the guideline data and the vehicle of base point cloud data simultaneously.

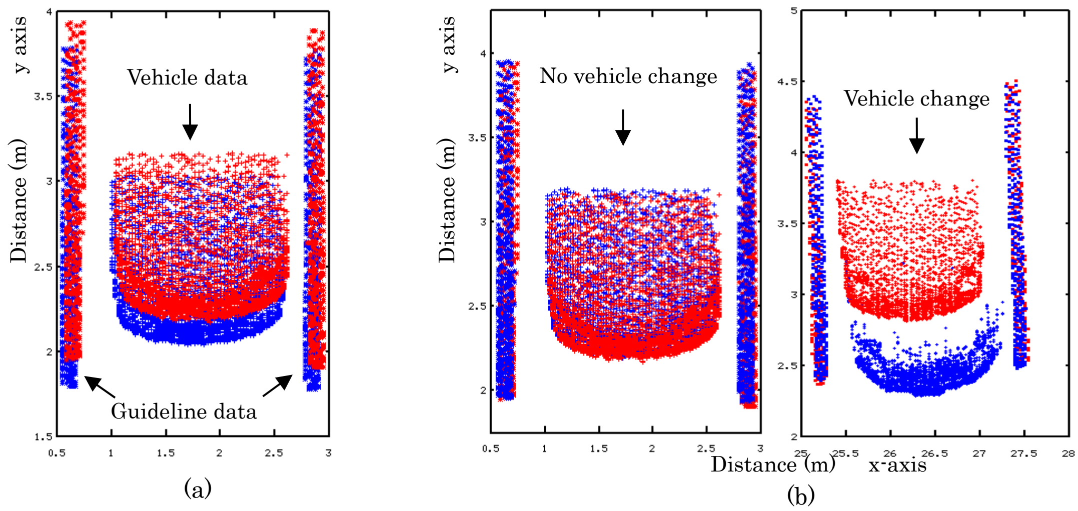


Figure 3.20: Pair guideline data before matching (a) and after matching (b) with base point cloud (blue point) and target point cloud (red point)

After guideline data convergence, in Fig. 3.21, the vehicle data from scans are applied to calculate the distance (equation 3.1) of point pair from base point data (t_i) to all points of target data (t_{i+1}). From among minimum distance of point pair, the result of average distance of vehicle data comparison is 0.02 meter that means the vehicle data implies the same position between base point cloud data and target point cloud data of the vehicle data.

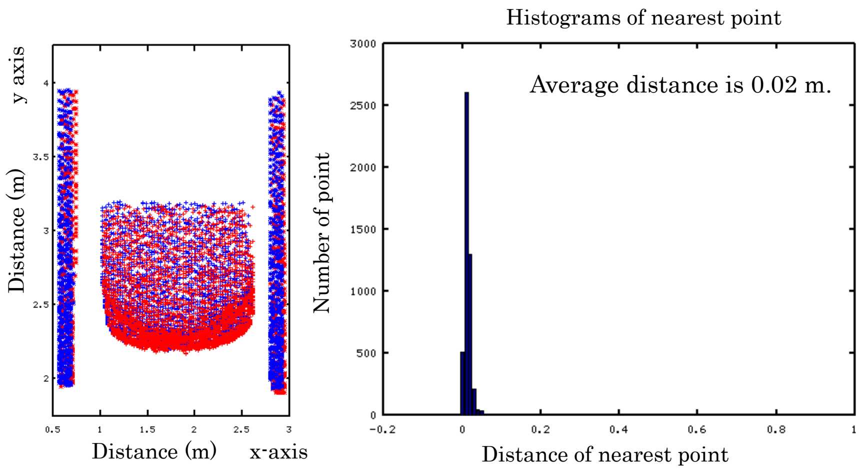


Figure 3.21: Average distance of vehicle data for data comparison

However, in experimental result author can determine where a parking lot is continuing occupancy state or new occupant by a vehicle change. In this experiment, the vehicle data in parking place in case of vehicle change is not appearing, so author change the data matching between differences of parking lot number that can be detected the position of vehicle changing as shown in Fig. 3.22 to Fig. 3.25.

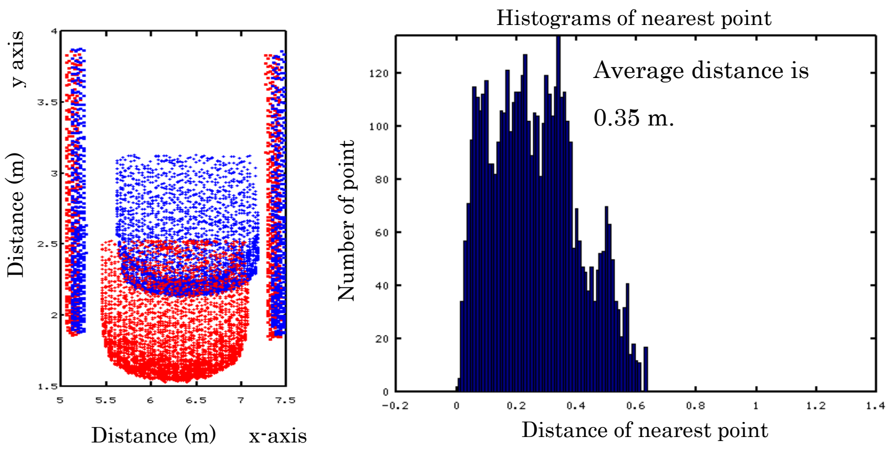


Figure 3.22: Experiment of vehicle data comparison between parking slot (1) and (3)

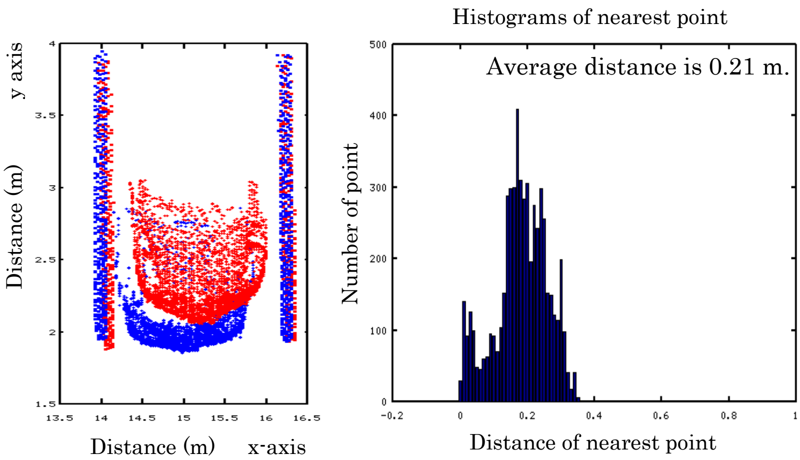


Figure 3.23: Experiment of vehicle data comparison between parking slot (2) and (7)

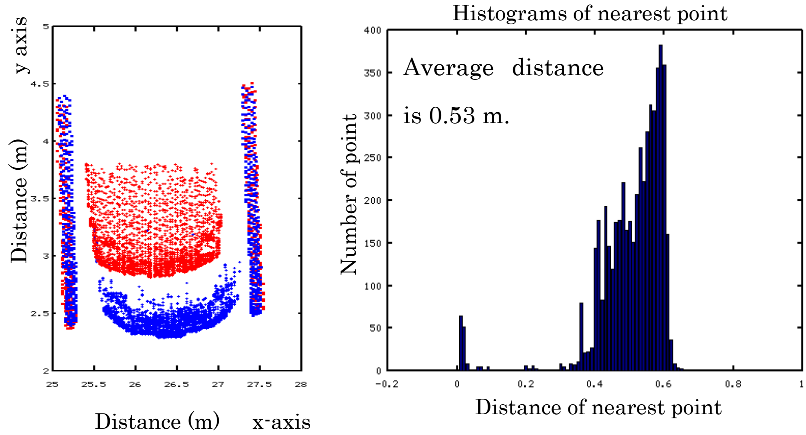


Figure 3.24: Experiment of vehicle data comparison between parking slot (9) and (12)

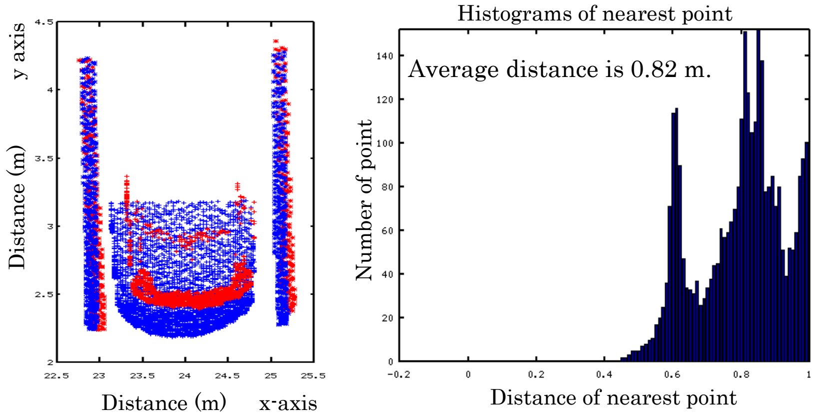


Figure 3.25: Experiment of vehicle data comparison between parking slot (4) and (11)

The vehicle comparison is calculated by determining the minimum distance of point cloud data between them. Next, to define the average of minimum distance by histogram technique which is set the interval range is 0.01 m. Finally, with the result of average minimum distance, a set $M_{threshold}$ value is 0.1 meter if the result is more than the $M_{threshold}$ that means vehicle state changes. The data comparison summaries are in Table 3.2. The parking lot information is summarized in Table 3.3, where circle shape is an occupancy state and square shape is an empty state and arrow shape is continue occupancy state.

Table 3.2: Experiments result of average distance of the vehicle data comparison. Unit is meter (*m*)

Data Comparison		Parking lot number													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Period of time	**t_1 - t_2**	0.03	0.01	0.02	0.02	0.01	0.01	-	0.02	0.02	0.02	0.03	0.03	0.02	0.02
	t_2 - t_3	0.03	-	0.03	0.02	0.01	0.02	-	0.02	0.03	0.03	0.03	0.02	-	0.03
	t_3 - t_4	-	-	0.02	-	-	-	-	0.03	0.03	0.02	0.02	0.03	-	0.03

Table 3.3: Experiment result of parking lot information on four time operations

Parking space		Parking lot number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Times	t_1	●	●	●	●	●	●	■	●	●	●	●	●	●	●
	t_2	↓	↓	↓	↓	↓	↓	●	↓	↓	↓	↓	↓	↓	↓
	t_3	↓	■	↓	↓	↓	↓	■	↓	↓	↓	↓	↓	■	↓
	t_4	■	●	↓	■	■	■	■	↓	↓	↓	↓	↓	■	↓

In our experiments, the proposed method of application on occupancy state recognition is achieved the inspection vehicle within parking lot and its purposed. The parking lot information could be created from our proposed application.

3.6 Discussions

Our implementation has demonstrated the feature for parking lot inspection, which achieved the practical use a LRF sensor utilizing a mobile robot in real environment. By multiple time of data scanner of patrol robot was introduced in this work. The laser reflection intensity was introduced to solve the problem of guideline extraction from ground surface. The guideline alignment and vehicle comparison were introduced for improving the state of parking lot. By analyzing this method, author accomplished the parking lot checking which are an occupancy status, an empty lot state and the parking lot inspection which is long term parking state in the parking space.

For vehicle change detection, in our experiments was found at a car lot number 2 from data operation of t_2 and t_4 by omitted the data operation of t_3. The average of distance is 0.84 meter that means vehicle change state from previously archived scan. For examining the vehicle change by our proposed method are shown in Fig. 3.26 and Fig. 3.27. The parking lot information is summarized in Table 3.4.

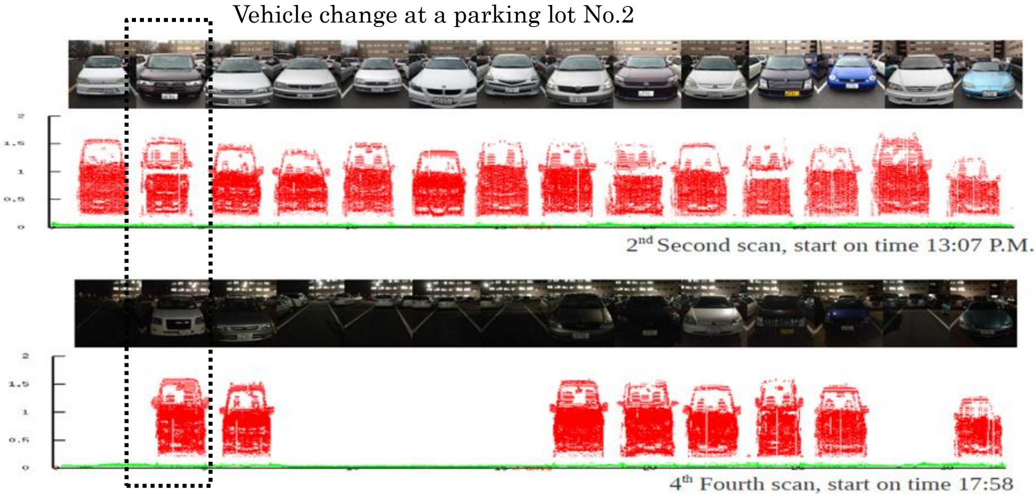


Figure 3.26: Experimental result of vehicle detection in parking lot with vehicle change

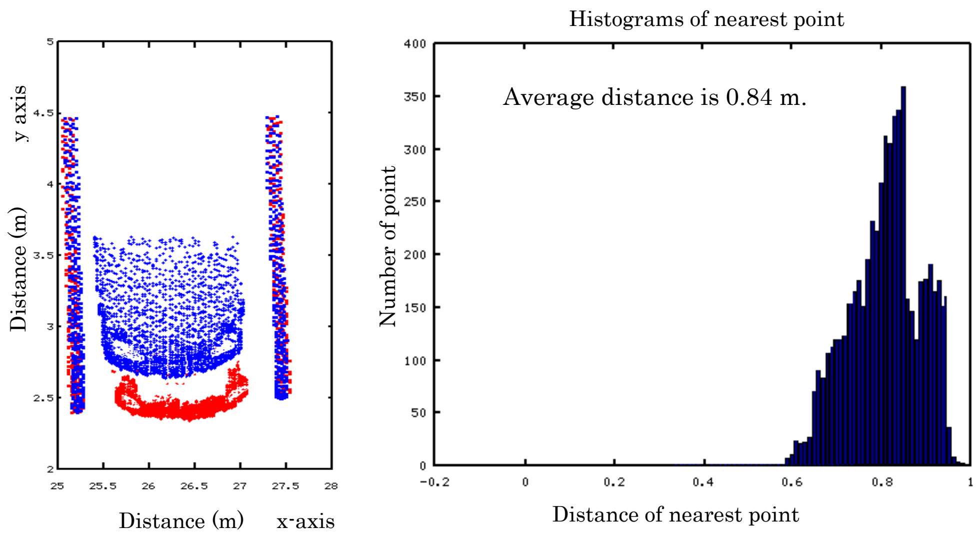


Figure 3.27: Data comparison of vehicle change from scans

Table 3.4: Experiment result of the parking lot inspection with vehicle changes

Parking space		Parking lot number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Times	t_1	●	●	●	●	●	●	■	●	●	●	●	●	●	●
	t_2	↓	↓	│	↓	↓	↓	●	│	│	│	│	│	↓	│
	t_4	■	●	↓	■	■	■	■	↓	↓	↓	↓	↓	■	↓

In our experiments were performed to detect various vehicles in day time until night time during a date at the same place. So, the capability of our proposed method was well obtained the shape of vehicle in 3D world coordinate.

In our experiments, mobile robot is move at lower speed with odometry base self-estimation function [23] so author assumption the position error of robot has a little bit so that measurement error of robot is not employed in this task.

The intensity data from guideline on the ground was well extracted because the guideline is white color so the intensity data is higher than the ground as dark color as shown in our experiments.

The guideline data alignment was calculated in 3D position to align the pair guideline between previously archived scan and current scan was well matched between them. The limitation of guideline detection, the parking area was not the guideline on the ground so the proposed method cannot operate.

The vehicle data was calculated by the transformation matrix from data alignment method, the vehicle data from multiple time operations was obtained, in case of same vehicle, the position of vehicle would be same position between them so the difference position of vehicle in worst case was 3 cm.

To improve data alignment much precisely position with 3D coordinate so data matching technique would be increased performance of our proposed method.

Chapter 4

Inside Vehicle Inspection

4.1 System Overview

Within parking lot, the information of parked vehicles is considering to check the state of inside vehicle. To recognize status inside vehicles is difference from previous state to compare with the current state is being considered and defines item missing by the item identification method as a state change.

To obtain information required inside of the vehicle through car windows, an LRF sensor is installed on an experimental mobile robot platform for the above objective. This task focuses on how to acquire, recognize and identify the state inside vehicles as follows:

- Obtaining data of shape objects inside vehicles
- Differentiating inside-vehicle data from other vehicle data
- Identifying items in the current state versus items no longer present since the previous inspection.

4.2 Approach: Inside-Vehicle Inspection

The main objective of this research is inspecting the inside state of vehicles in parking lots utilizing a mobile robot. To obtain information required from the target vehicle, the mobile robot moved along the side of the vehicle (Fig. 4.1) to obtain the vehicle configuration (car body, etc.), the inside states of the vehicle (car seat area, etc.) through car windows. Vehicle point cloud data is acquired by the LRF sensor.

Multiple data scanner time periods such as t_1, t_2,...,t_n for vehicle detection are collected accordingly by this system. Data were therefore compared between scanning data from consecutive time frames, e.g., between t_i and t_{i+1}, ..., where i = 1, 2,...,n.

An approach strategy is proposed for applications such as inspection inside vehicles as data processing by this system as follows:

- range data acquisition
- car-body data extraction

- detection inside vehicles
- car-body alignment between scans
- inside vehicle data comparison between scans
- item identification in current state

An overview on each of the above inspection applications is provided for a basic understanding of the system for inspection inside vehicles in this section.

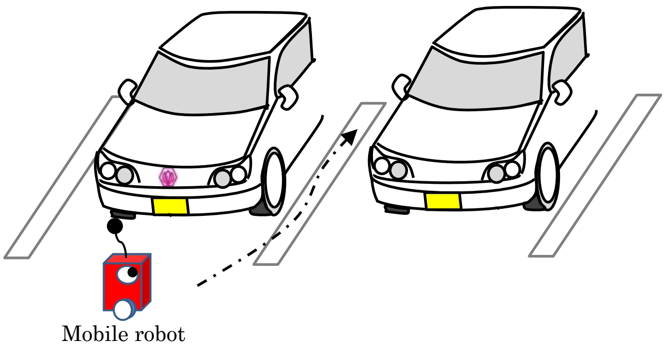


Figure 4.1: Mobot robot moves alongside a vehicle for inspection inside a car

In this application, author try understanding the parked vehicles in parking lot for inspecting inside through car windows from target vehicle, so the type of car as a bus, super cars, Taylor truck, is not employed in this research. The special manipulate mechanism is required to data measurement on these car types.

4.3 Implemented System

This section covers mobile robot hardware, in Fig. 4.2, the mobile robot platform [23] is equipped with two LRF sensors (UTM-30LX, Hokuyo Automatic Co., Ltd.) for vehicle data detection. In implemented system, these two sensors are installed on a special support at approximately 1.30 m above the ground.

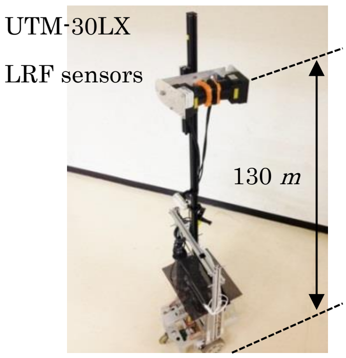
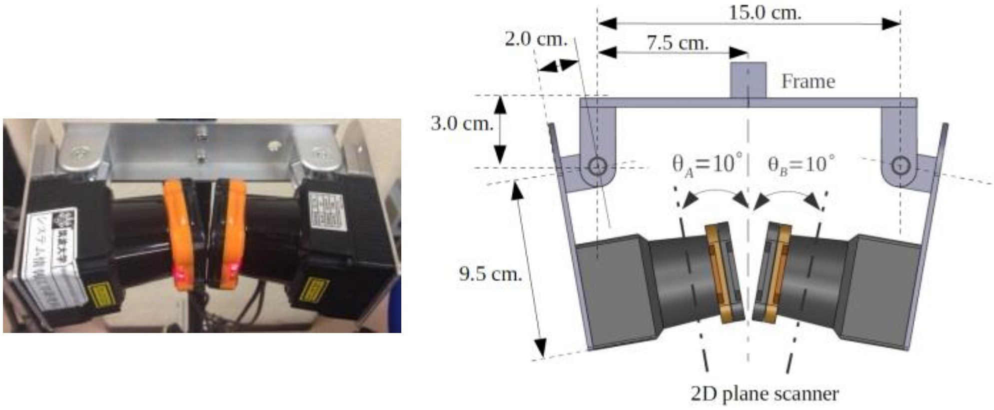


Figure 4.2: Mobile robot platform with LRF sensors

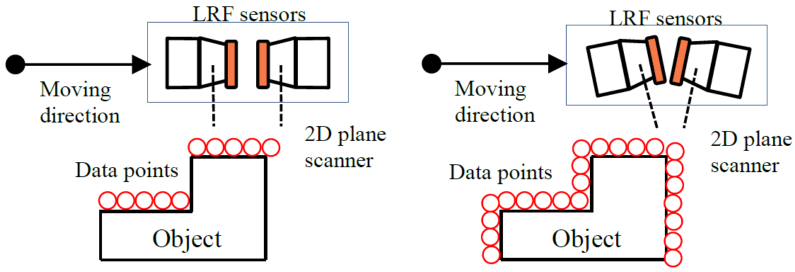
The hardware layout is designed to support two sensors, in Fig. 4.3, the frame is aluminum and the total weight of the frame is 0.3 kg without the sensors. The angle of the 2D plane scanner is for measuring part of the surface in order to facilitate detection inside vehicles through car windows. The angle of 2D plane scanners θ_A and θ_B are set at 10 degrees. The sensor is compact at 60 mm wide, 60 mm deep and 87 mm high. The device has a detection range from 0.1 to 30 m with accuracy of 0.03 m, the angular resolution is 0.25 degrees, and the angle range is 270 degrees in operation at 40 Hz.



(a) (b)

Figure 4.3: Pose of LRF sensors (a), (b) hardware layout for supporting two sensors with angles $\theta_A$and θ_B of 2D plane scanner

Detection object surface, author tries to understand how to obtain much more information of the object surface, for detecting all object surface, angle θ_A and θ_B are the angular adjustment of the 2D plane scanner of the LRF sensors. In Fig. 4.4(a), the object surface cannot measure because the surface plane is parallel to the plane scanner, so the angular adjustment of the 2D plane scanner is applied to measure the object surfaces as shown the concept in Fig. 4.4(b).



(a) (b)

Figure 4.4: Typical data points, (a) for object detection of 2D plane scanner without angular adjustment, (b) angular adjustment of 2D plane scanner

4.4 Data Processing

4.4.1 Rang Data Acquisition

A 2D plane scan of the LRF sensor is installed upright on a vertical plane scan that is perpendicular to the ground plane for the vehicle configuration data scanner. The LRF sensor mounted on top of the mobile robot platform obtains the data on both vehicle inside and outside, such as car body framework and car seat area through car windows. Robot moves alongside of vehicle to measure the vehicle configuration above this objective.

A 2D range data angle and range and odometry-based self-positioning data of robot locomotion are combined to obtain point cloud data in 3D world coordinates. Point cloud data from the LRF sensor consists of vehicle data and ground data. For separating the ground data from vehicle data, constant height value $H_{threshold}$ along the z axis is applied to divide point cloud data so that point cloud data above $H_{threshold}$ are collected and points below $H_{threshold}$ are ignored.

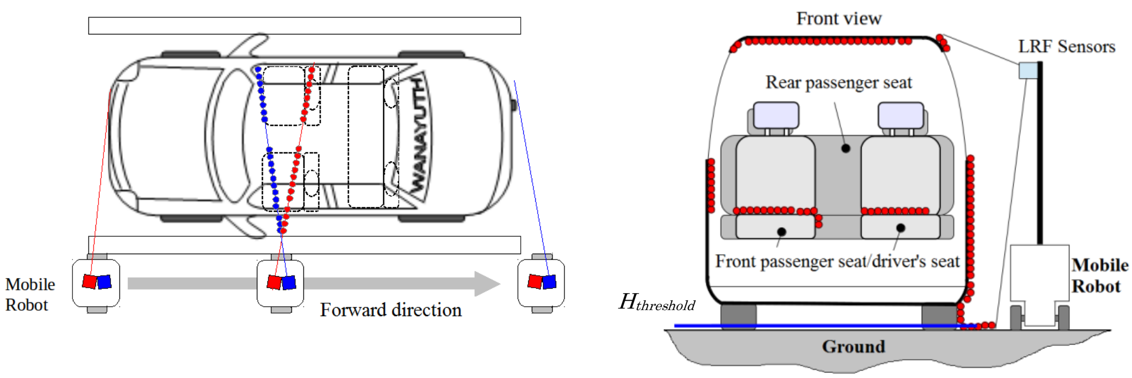


Figure 4.5: Mobile robot is moved alongside the vehicle with the LRF sensor for vehicle detection

4.4.2 Car-body Data Extraction

Car body frameworks are obtained from vehicle point cloud data using a data extraction technique. The car body framework is composed of numerous body components such as the radiator hood, vehicle roof, and car body framework. A car body framework e.g., edges of wheels and car window frameworks, is necessary for data alignment between scans. In this section, vehicle point cloud data is used to extract only car side frameworks $(C_j^{t_i})$, and remaining point cloud data are collected in point cloud data set $(Z_j^{t_i})$ as the data inside a car is described in section 4.4.3.

In the solution of car side framework extraction, dimensions (length and height) of a vehicle configuration are considered to determine car size. Vehicle length is defined by two points a minimum point and a maximum point along the x axis and vehicle height is defined by two points a minimum point and a maximum point along the z axis. The car size range is shown in Fig. 4.6.

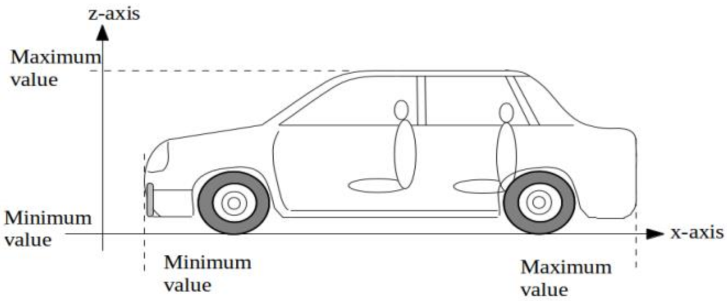


Figure 4.6: Range of vehicle with minimum value along x axis and maximum value along z axis

Grid cell array size (M×N) is applied to locate and separate the point data in cell array address, where M is the number of rows and N is the number of columns. To determine the interval range of row and column, the interval range of row is defined by (maximum value - minimum value)/M along the z axis. The interval range of column is defined by (maximum - minimum)/N along the x axis. In Fig.4.7, the car-body size is formed from data located in each grid cell address in 2D grid cell array (M×N).

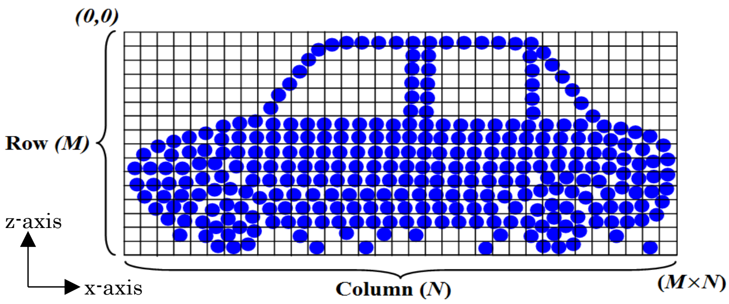


Figure 4.7: Grid cell array (M×N) for the point data location

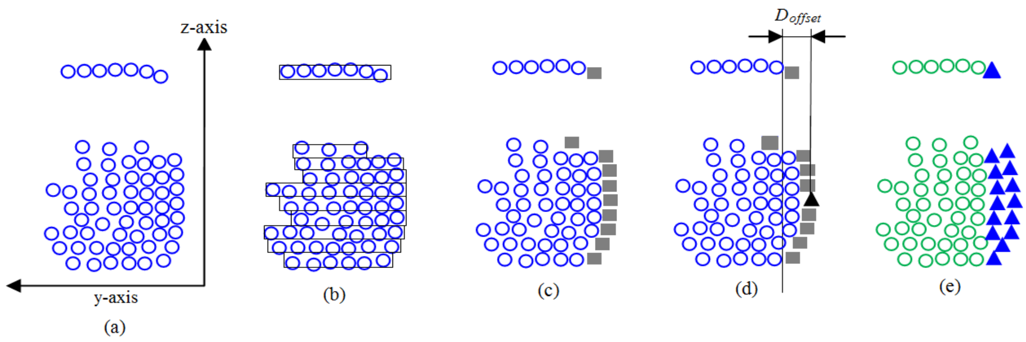


Figure 4.8: (a) Sample of cell column (filled circles), (b) data point in each row, (c) point of minimum distance (shaded squares) along y axis in each row, (d) car body extraction range (D_{offset} + a *min.* point), (e) car-body data extraction (filled triangles)

The data point in each cell column is considered to determine a minimum distance along the y axis, e.g., the data point in a cell column shown in Fig. 4.8(a).

In Fig. 4.8(b), within a cell column, data point is located in each row. To define the minimum point for each row for calculating the distance is near zero along y axis as shown in Fig. 4.8(c).

Minimum points of all rows are collected to determine the minimum point from all (Fig. 4.8(d)), constant value D_{offset} (unit is meter) is applied for extracting the car side framework. Point data is located within the range (D_{offset} + a *min.* point), so point data is collected as shown in Fig. 4.8(e). This technique is applied to all cell columns for car-body data extraction.

The side of car framework is extracted from the data detection. The car-body data in the range of the threshold (offset range), the car side framework and tires are obtained, so the car window framework is considered the data as a few point is not necessary for precisely position of data alignment technique (4.4.4).

To remove the data point below the car body framework, the histogram technique is applied by using the interval range of the grid cell array of a row to calculate car-body data (Fig. 4.9(b)).

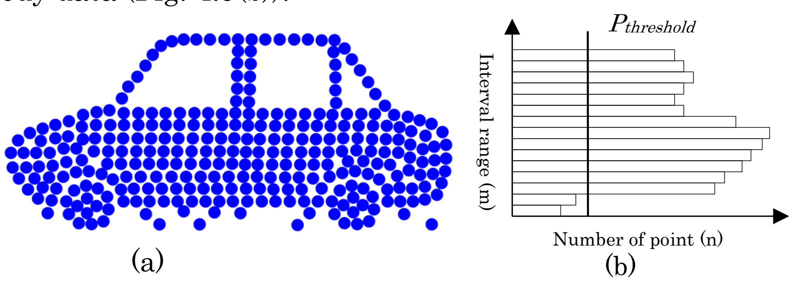


Figure 4.9: (a) Car-body data extraction, (b) histogram data of car body data extraction

Using histogram technique, set constant value $P_{threshold}$ is number of point. Car-body data are located by using the interval range of a row, and counting the number of data points in each interval range is determined. If the number of data points over $P_{threshold}$ is collected and the rest of the remaining points are removed as shown in Fig. 4.10.

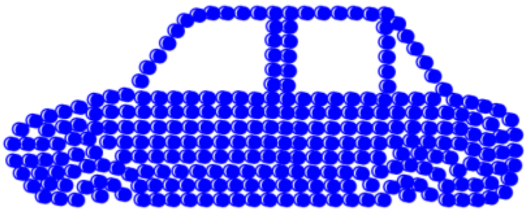


Figure 4.10: Car-body data with noise removed

4.4.3 Data Detection inside cars

From car-body data, the horizontal length of the car window framework is analyzed to figure out the inside limitations of the vehicle. In this work, the driver and passenger seat area inside the vehicle are considered for checking the items missing on car seat.

For detection inside vehicles, the height of car body data is obtained by a minimum point and a maximum point along the z axis. In Fig. 4.11, data are split into sets F_k, where k is 0,1,..., S. The interval range of set F_k is defined by (maximum – minimum) / S, where S is a number of data separations.

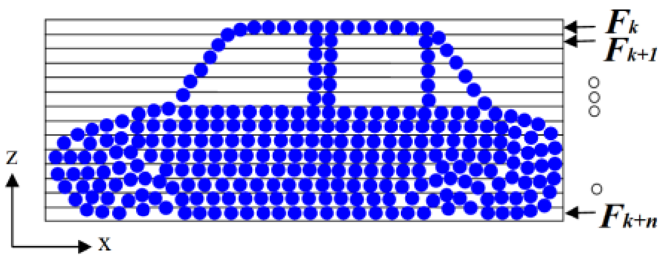


Figure 4.11: Car-body data is separated by the interval range of row

In Fig. 4.12, each set F_k provides distance (d) of point pairs as data alignment along the x axis. If the distance is greater than $L_{threshold}$, point pair data are analyzed. Constant parameter $L_{threshold}$ is the distance value in meters. As a result calculated of point pairs, a minimum point and a maximum point are determined with point alignment along the x axis in each set F_k.

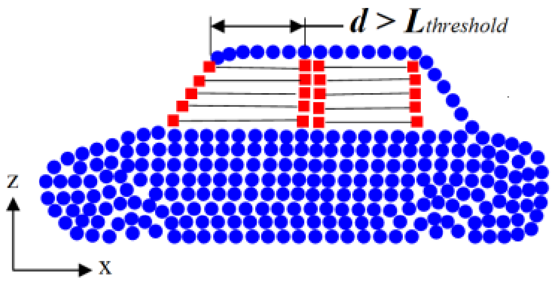


Figure 4.12: Point pair data (shaded squares) greater than $L_{threshold}$ is detected in range of car windows

To cluster these points, minimum points are grouped into set *A* and maximum points are grouped into set *B* as shown in Fig. 4.13. The point data from set A and set B are considered to detect the inside vehicle ranges by calculating four points from set A and B.

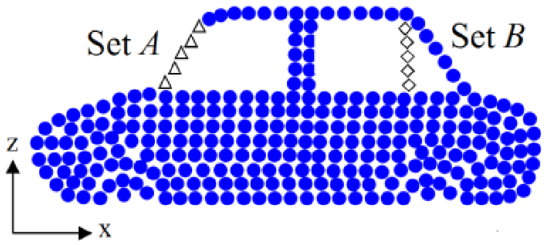


Figure 4.13: Minimum point data (open triangle) and maximum point data (open diamond) range of car windows

Two points the minimum point along the x axis (P_1) and the maximum point along the z axis (P_2) are used from set A. Two points the maximum point along z axis (P_3) and the maximum point along x axis (P_4) are used from set B. Point cloud data ($Z_j^{t_i}$) is considered to calculate data inside a car ($W_j^{t_i}$) by using information above four points from set A and B. Detection inside vehicles using the four points of information is shown in Fig. 4.14.

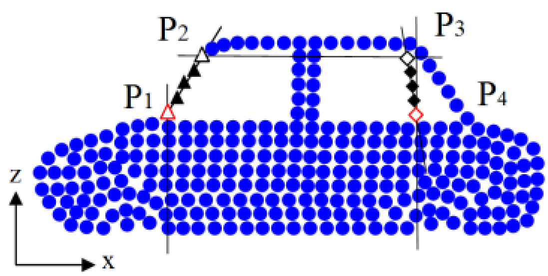


Figure 4.14: Limitation of the inside car area with four points from set A and set B

4.4.4 Car-body Data Alignment

In this section, car-body data from previous and current scans are utilized to calculate car-body data alignment between them from the same vehicle. Car-body data is related to the robot position with an odometry-based self-position, so errors may occur while the robot is collecting information from the vehicle. An ICP algorithm is therefore applied to car body data matching between base (from the previous scan) and target (from the current scan) point clouds

With the data alignment method, car-body data is used for data alignment between base $(C_j^{t_i})$ and target $(C_j^{t_{i+1}})$ point clouds by point pairs of car-body data is calculated, where C is car-body data and t is the multiple duration time stamps. The method of calculating data alignment is described as follows:

a) Set base point data $(C_j^{t_i})$ and set target point data $(C_j^{t_{i+1}})$.

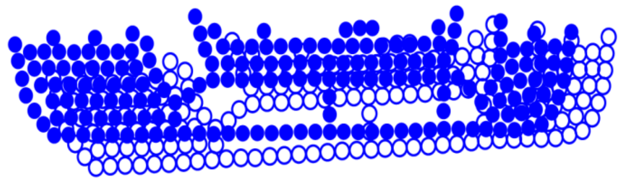
b) Pair each point of $(C_j^{t_i})$ to the closest point in$(C_j^{t_{i+1}})$.

c) Calculate transformation (R, T).

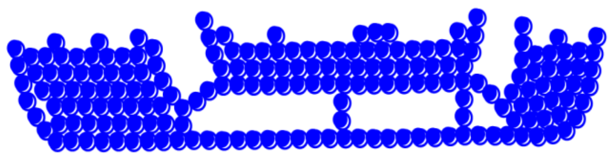
d) Apply motion to $(C_j^{t_i})$.

e) Repeat until data convergence is completed.

Results are shown in Fig. 4.15. Two car-body data before data alignment and car-body data after data processing between them are shown in Fig. 4.15(a) and Fig. 4.15(b). With the car body alignment method, transformation matrix (R, T) is also calculated with data inside a car $\left(W_j^{t_i}\right)$ simultaneously, where R is the rotational matrix in case 3x3 and T is the translational matrix.



(a)



(b)

Figure 4.15: (a) Car body data alignment between pervious scan and current scan, (b) after car body data alignment

4.4.5 Data Comparison inside cars

In the data comparison technique, inside vehicle data $\left(W_j^{t_i}\right)$ is used to compare the status inside vehicles and any status changes are detected inside the vehicle, such as items missing or new items appearing in the current state. Different point data (O_j) is defined inside vehicle changes as follows:

$$O_j = W_j^{t_{i+1}} - W_j^{t_i} = \left\{ O_j \in W_j^{t_{i+1}} \mid O_j \notin W_j^{t_i} \right\} \tag{4.1}$$

Where t is the duration time stamp on the data range scanner and j is the number of points of different point data. To identify the inside vehicle state, function $A(u)$ is created to determine the inside vehicle state in the current state as follows:

$$A(u) = \begin{cases} 1, & \text{if } O_j \neq 0 \\ 0, & \text{otherwise.} \end{cases} \tag{4.2}$$

The different state inside the vehicle is found only when $A(u) = 1$, where u is the time in the current state and otherwise it is not. Typical inside vehicle data in the previous state is shown in Fig. 4.16 (a). The inside vehicle data in the current state is shown in Fig. 4.16(b).

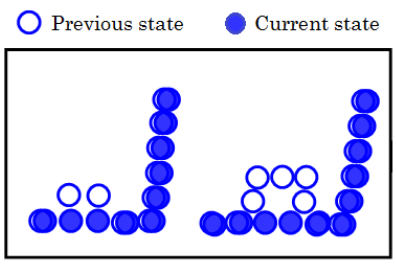


Figure 4.16: Typical inside car data between previous state and current state

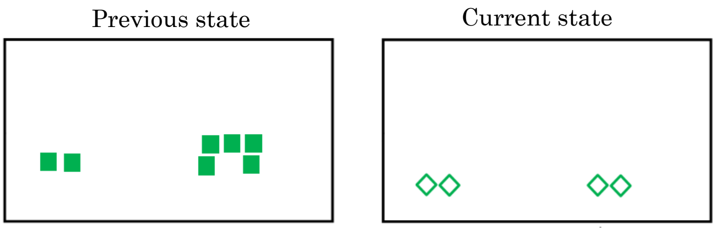
The data comparison approach processes all of the data as follows: Set the data inside a car of base point cloud data $P_i \leftarrow W_j^{t_i}$ and target point cloud data as $Q_j \leftarrow W_j^{t_{i+1}}$ where W is data inside a car and t is the duration time stamp of the data range scanner. Set the constant distance value of $S_{threshold}$ in meters. For calculating the distance, distance (d) of point pairs from $d(\vec{Q},\vec{P})$ is determined by using the Euclidean distance in equation (4.3).

$$d(\vec{Q},\vec{P}) = |\vec{Q_j} - \vec{P_i}| = \sqrt{\left((x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2\right)} \tag{4.3}$$

If the distance (d) value is greater than constant value $S_{threshold}$, point data is grouped into set O_j (different point data) and others are ignored.

Data inside a car in the previous state and current state and data comparison between them with the $S_{threshold}$ value are calculated to define data points change. Point data provides different images (shaded square) as shown in Fig. 4.17(a). Additional calculation is done to determine distance $d(\vec{P},\vec{Q})$ between them. Different point data is recorded in new set U_k and other points are ignored. Point data provides different images (open diamonds) as shown in Fig. 4.17(b).

In cases of inside vehicles within the same state information, different point data of data comparison between them is near zero.



(a) (b)

Figure 4.17: (a) O_k the point data in different images (shaded squares), (b) point data U_k (open diamonds)

4.4.6 Data Segmentation and Identification

In this section, point data O_k and U_k are used to identify item location and item identification as inside vehicles state changes. To define item specification, clustering point data of O_k and U_k are performed to check the number of items and item identification (dimension size, address inside vehicles).

The method of data segmentation with noise removed and the method of identification are proposed based on Euclidean distance to define data specification. In this solution, distance (d) of point pairs is calculated. If the distance (d) value is less than threshold $S_{threshold}$, point pair data is collected and recorded in $G_{p,f} \leftarrow O_k$. A new group of data is being created for the rest of point pair data and recorded in $G_{p,f+1} \leftarrow O_k$ where p is the number of points in each group and f is the number of groups.

If the number of points in group $G_{p,f}$ is less than the threshold ($N_{threshold}$) value, this group is removed. Threshold ($N_{threshold}$) is a set value in experiments. For each of the remaining groups, two sets of data are calculated, i.e., 3D dimensional size (*width× length× height*) of data points and average of height distance along the z axis from ground.

Function $K(t)$ is created to determine the item status disappearing or not. The item identification method is applied to check the object with the average of height distance between the previous state and current state as follows:

$$K(t) = \begin{cases} 1, & \text{if } Avg.of\ height_{current} < Avg.of\ height_{previous} \\ 0, & \text{otherwise.} \end{cases} \qquad (4.4)$$

To check the status of objects inside a vehicle, the average distance along the z axis of an object is calculated by comparing the previous state and current state. If the average distance of the current state is shorter than the average distance of the previous state, the related object is missing; otherwise, the object existing on current inspection.

4.5 Experimental results

The mobile robot operates within a typical parking lot to detect and obtain vehicle information about a car framework, and inside vehicles through car windows using the LRF sensor. In experiments, in Fig. 4.18, mobile robot velocity is 0.15 *m*/s when the parking lot is being checked. Set maximum distance at 5 meter, the mobile robot moves forward straight line on parallel to the side of the vehicle for data detection and repeatedly same task for data scanning of vehicles in a multiple time frame (t_1, t_2,…,t_n).

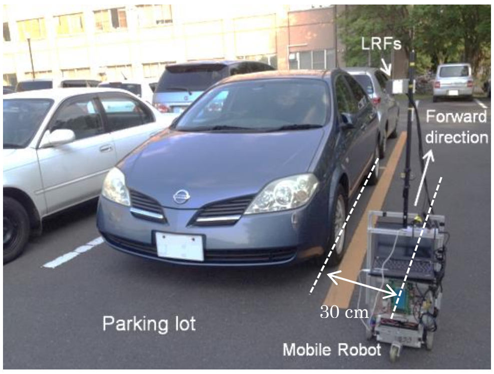


Figure 4.18: Mobile robot operation is move alongside of parked vehicle

For data detection, at least two rounds of data scanning are required by the mobile robot for the same vehicle. The data range scanner reads new sets of data every 25*ms* and registers incoming data in parallel to shared memory [30] as a log data file. Data detection tests were performed off line by playing back log file data at the same sampling rate of 40*Hz* using the sensor sharing manager (SSM).

Point cloud data on the ground included in experimental data. For removing the ground data, threshold value $H_{threshold}$ of 0.02 *m* is set. Point cloud data are shown in Fig. 4.19(a) and vehicle point cloud data without ground data is shown in Fig. 4.19(b).

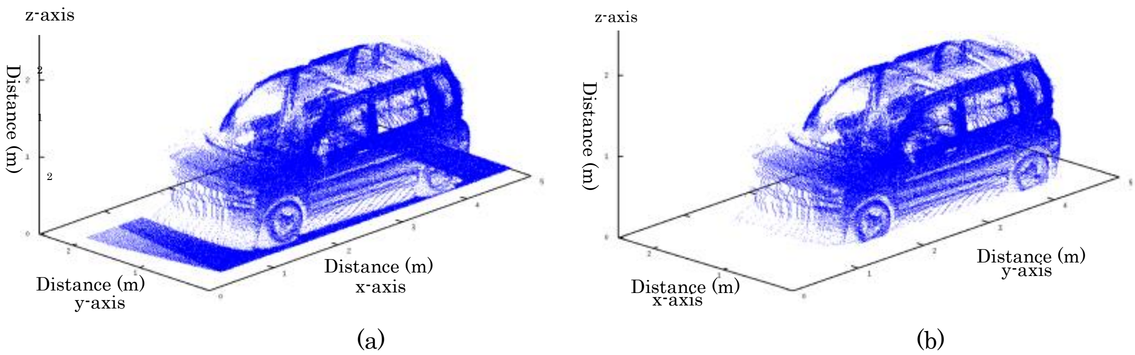


Figure 4.19: (a) Vehicle 3D point cloud data, (b) vehicle point cloud data without ground data

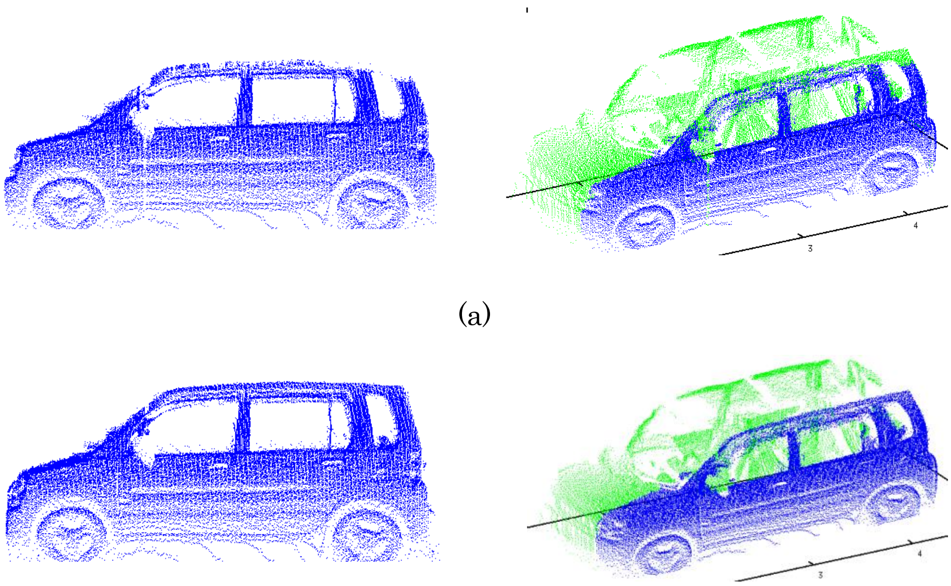
Vehicle point cloud data are therefore determined to extract the side of a car by setting grid cell array M×N at (100×200) as the number of rows (M) and columns (N). The interval range of rows and columns are calculated. For experiments with this vehicle, the interval range of each row is 0.015 *m*. and each column is 0.019 *m*.

Car body extraction is applied to extract the side of the car body from vehicle point cloud data by using threshold D_{offset} value. Two purposes are considered for the car body extraction method.

First, the side car data is calculated to align data between previously archived inspection and the current one.

Second, it is calculated to define the range of car windows for determination of the vehicle interior. In experiments on car body extraction, author set thresholds at various values for checking results.

For a threshold of 0.2 *m*, the car window shape is incomplete extracted as shown in Fig. 4.20(a), so the range of the car window is not calculated correctly. For 0.3 *m*, the range of the car window is extracted completely (Fig. 4.20 (b)), so a threshold of 0.3 meters is applied in experiments.



(a)

(b)

Figure 4.20: Car body data with car window determined as car window (a) incomplete, (b) completed

Results obtained by the method checked in section 4.4.2 are shown in Fig. 4.21. To remove noise of car-body data, the interval range of histogram data is 0.017 *m* and the number of point $P_{threshold}$ is 500 points. Car-body data with noise removed is shown in Fig. 4.21.

Based on results of car-body data extraction, the length of the car window frame is then used to define the range limitation of the car seat area. Set the interval range along the z axis by (maximum value – minimum value) / *S,* where *S* is a constant value of 100. The interval range along z axis is 0.0107 *m* for this data.

For car window detection following the method in section 4.4.3, threshold value $L_{threshold}$ is set at 0.03, 0.15, 0.3 *m*.

If a the small threshold value of 0.03 *m* is set, the range limitations of the car window are of a wider range than expected as shown in Fig. 4.21(a).

If a the large threshold value of 0.3 *m* is set, the range limitation of the car window is a shorter range as shown in Fig. 4.21(b), so $L_{threshold}$ 0.15 *m* was used in all experiments. The range of car windows is calculated as shown in Fig. 4.22. Result of data detection inside cars is shown in Fig. 4.23.

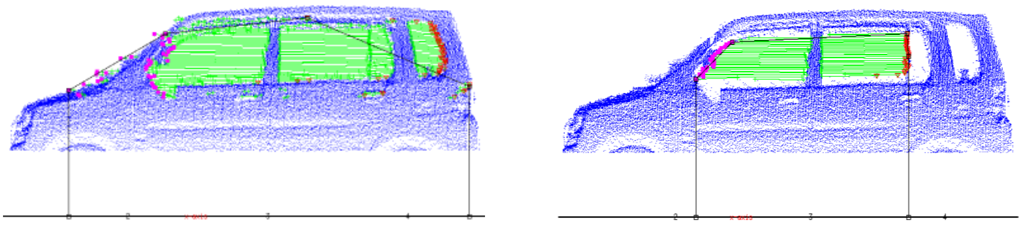


Figure 4.21: Threshold of $L_{threshold}$ value determined over range of car window (a), (b) short range of car window

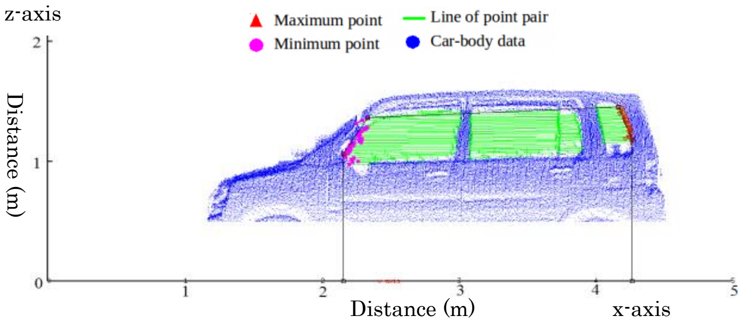


Figure 4.22: $L_{threshold}$ value determined cover range of car window

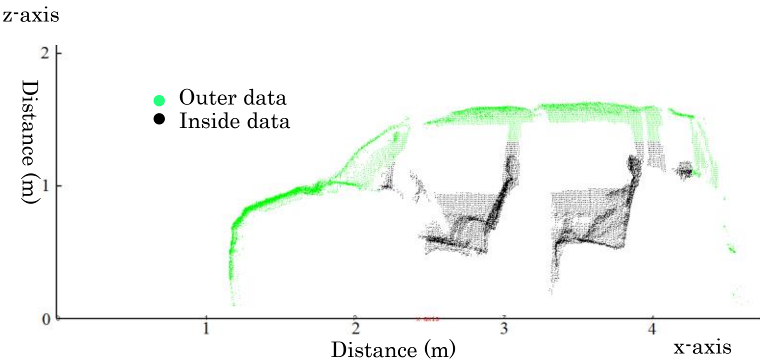
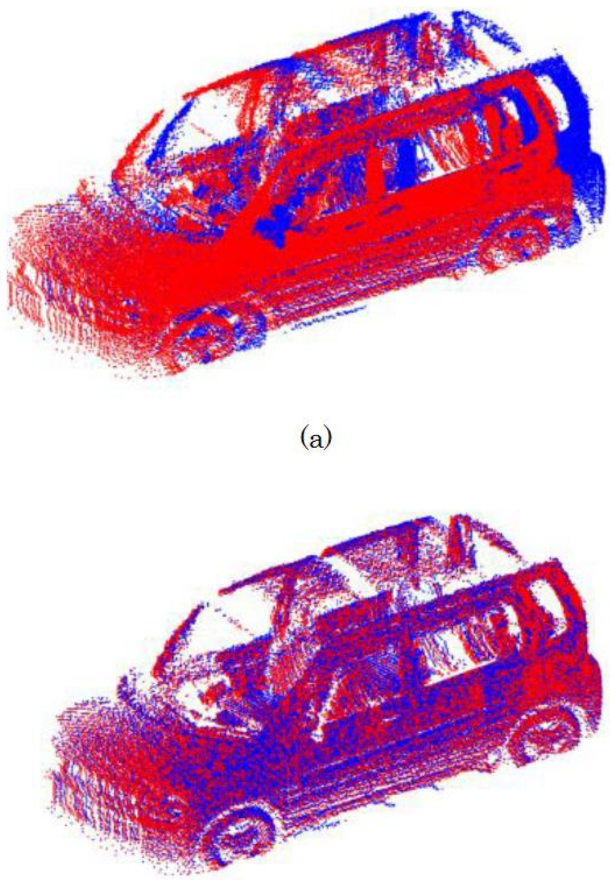


Figure 4.23: Car inside detection by detection car range window

Results of car-body data extraction are processed to obtain car-body data alignment from the previous inspection and from the current one as shown in Fig. 4.24(a). In these experiments, car-body data alignment between them is then calculated using transformation matrix (R,T) applied simultaneously to both car-body data and data inside a car. This method is shown in Fig. 4.24(b).



(a)

(b)

Figure 4.24: (a) 3D vehicle points before data alignment, (b) data alignment

From car-body data alignment, inside vehicle data is also calculated the transformation matrix simultaneously while car-body data alignment processing. Therefore, inside vehicle data from scans are obtained by calculating the distance of point pairs between scans with data comparison technique. So, threshold of constant value $S_{threshold}$ is set in several cases as small value until large value. The small threshold at 0.002 *m*. the existing point from scans are much more detected and a larger threshold at 0.1 *m*. the existing point is not appeared from scan, so, threshold at 0.02 *m*. is better than expected detection as shown in Fig.4.25 to Fig. 4.27 respectively. Threshold of 0.02 *m* is applied in all experiments.

From experimental results of data comparison in the case of different states, the data points are grouped by a data segmentation method. A Euclidean distance with a threshold distance of $S_{threshold}$ is the key point for grouping the above data.

For each group, if the number of points exceeds the threshold value, point data from the group is collected by setting the number of points $N_{threshold}$. The point value of $N_{threshold}$ is set at 50 points by defining the threshold value from the minimum number of points in each group. Threshold $N_{threshold}$ is applied in all experiments.

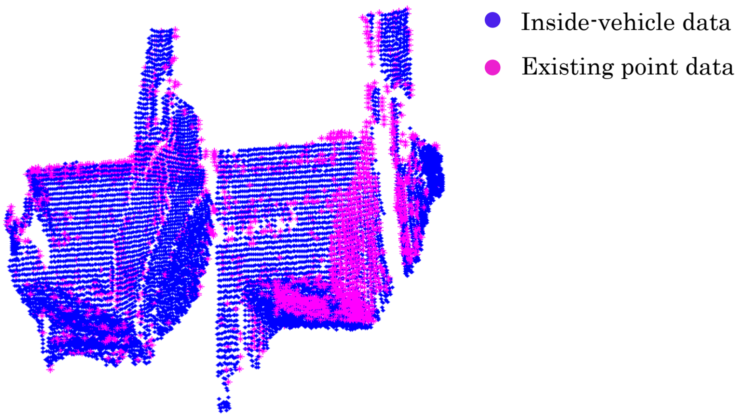


Figure 4.25: Existing point data from scan of t_i and t_{i+1} with $S_{threshold}$ is 0.002 m

Figure 4.26: Existing point data from scan of t_i and t_{i+1} with $S_{threshold}$ is 0.02 m

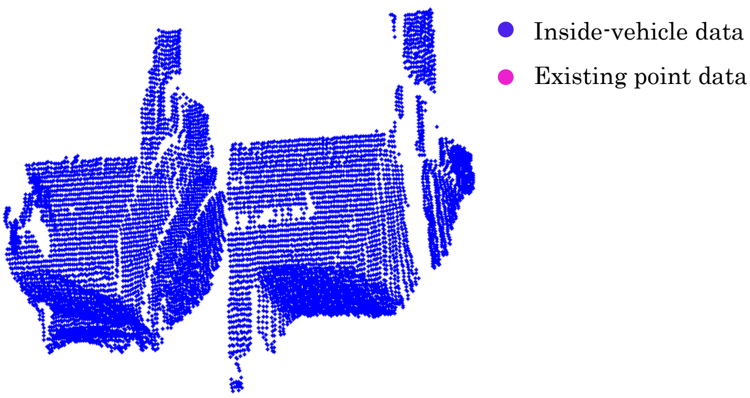


Figure 4.27: No existing point data from scan of t_i and t_{i+1} with $S_{threshold}$ is 0.1 m

An item identification method is applied to calculate the average height along the z axis and dimensions ($W \times L \times H$), where W is the width range along the x axis, L is the length range along the y axis and H is the height range along the z axis. In experimental results, the car window of car type A was included in the dark tinted window for the rear seat as shown in Fig. 4.28(a). A car window of car type B was cleared as shown in Fig. 4.28(b).

(a)

(b)

Figure 4.28: (a) car type A with dark tinted, (b) type B without dark tinted

Experiments method approaches are presented in Fig. 4.29 to Fig. 4.31 for detecting items inside a car such as bag, wallet, notebook PC, etc.

Detected sizes of items in experimental results are summarized in Table 4.1. The minimum height of 0.02 meter of an item is detected by this method. The item a mobile phone whose actual height of 0.017 meter was not be detected, as shown in Fig. 4.32. Experimental results for the inside of the vehicle have no state changed, as shown in Fig. 4.33.

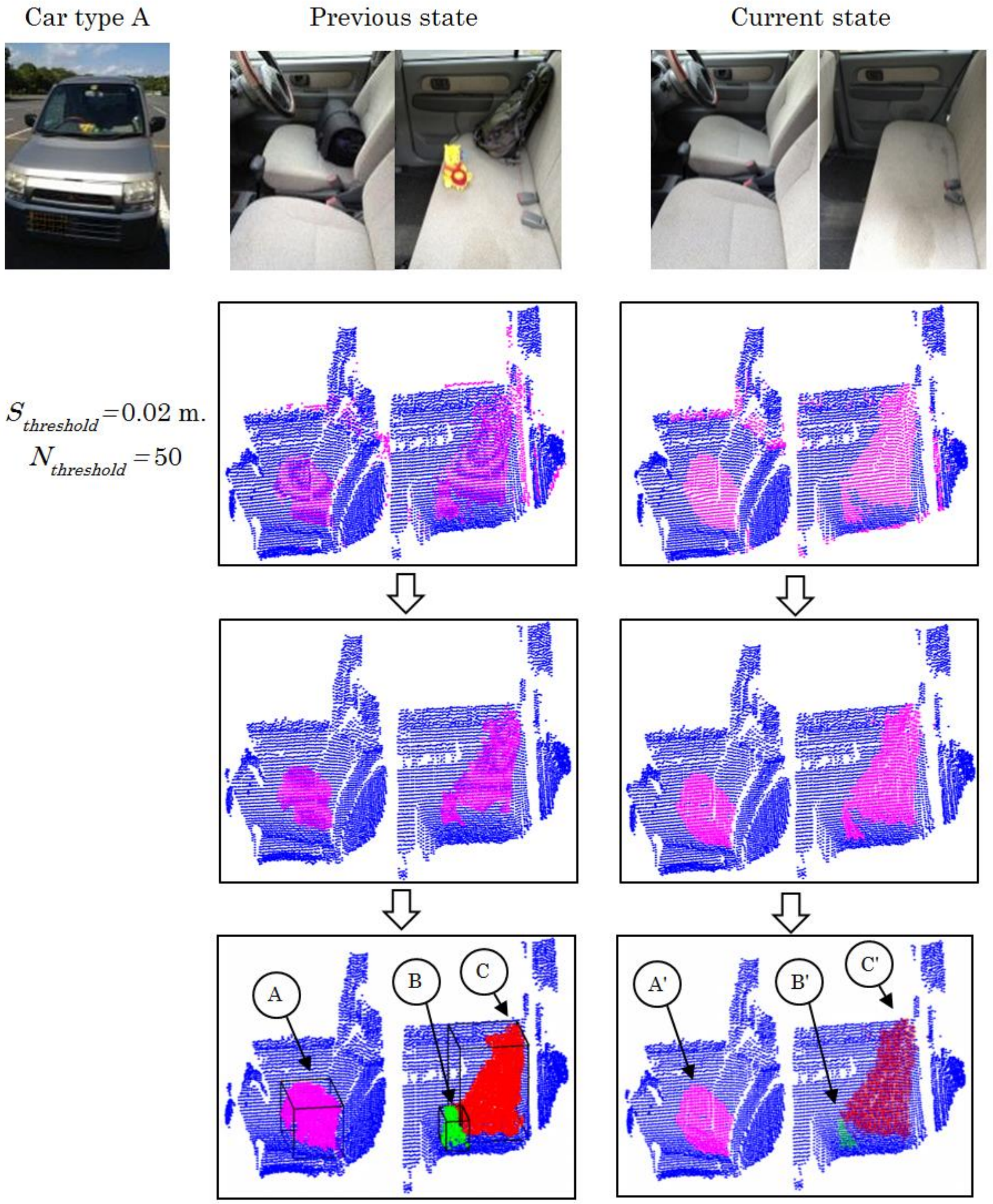


Figure 4.29: Inside vehicle scenes with three items two bags and doll, and missing from current state, (a) the data point of object, (b) item missing on current state

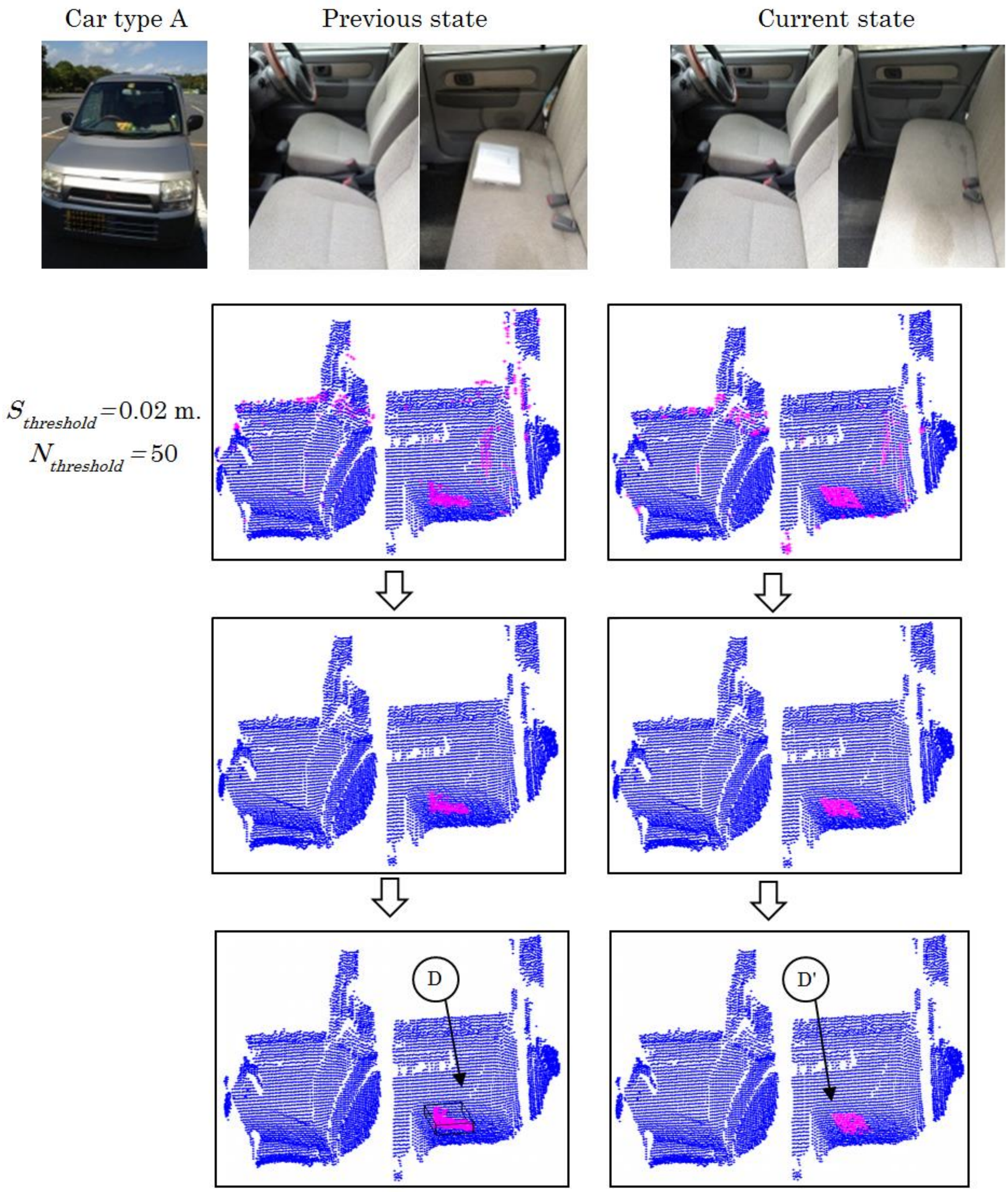


Figure 4.30: Inside vehicle scenes with item notebook PCs and missing on current state, (a) the data point of object, (b) item missing on current state

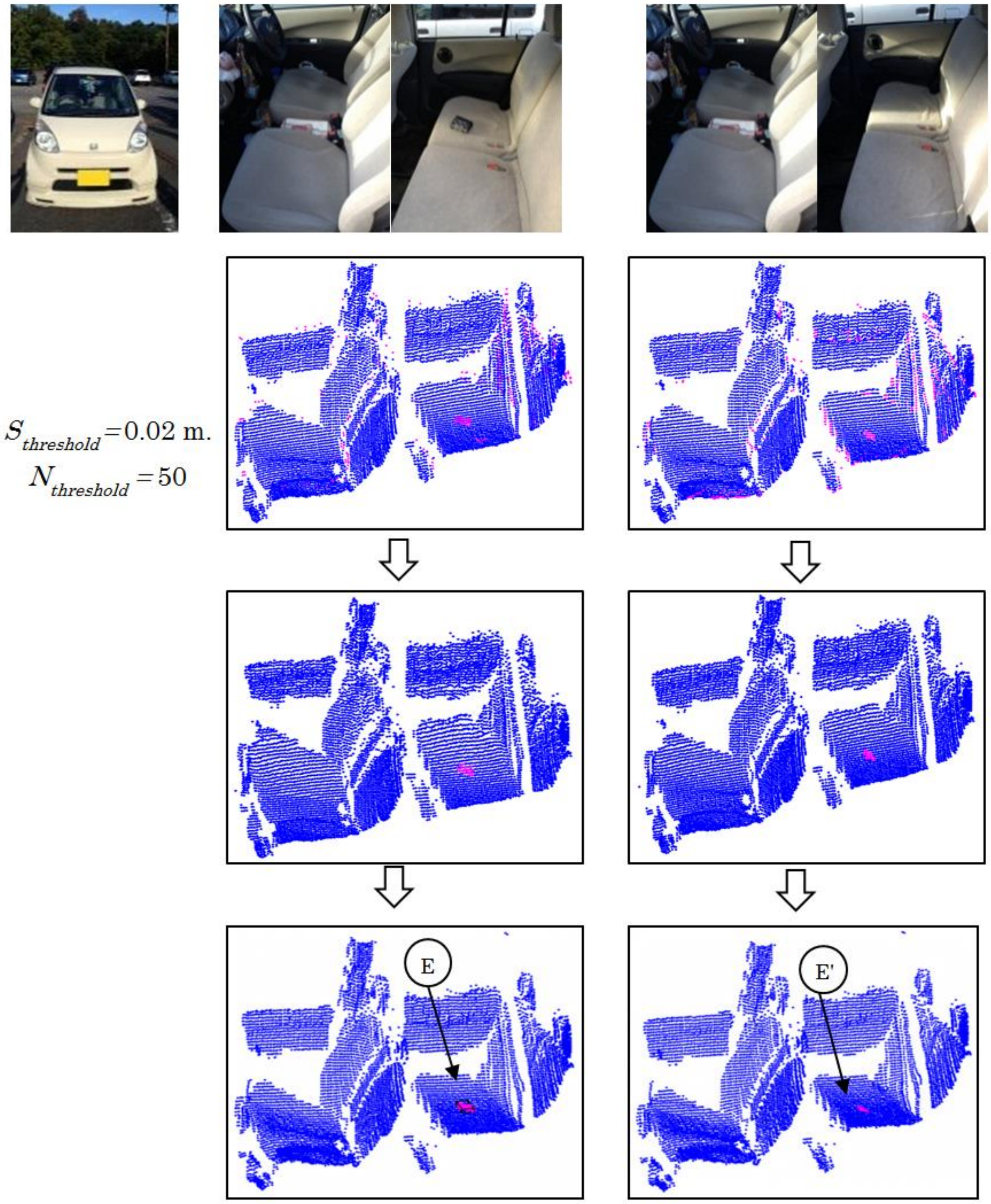


Figure 4.31: Inside vehicle scenes with item wallet and missing on current state, (a) the data point of object, (b) item missing on current state

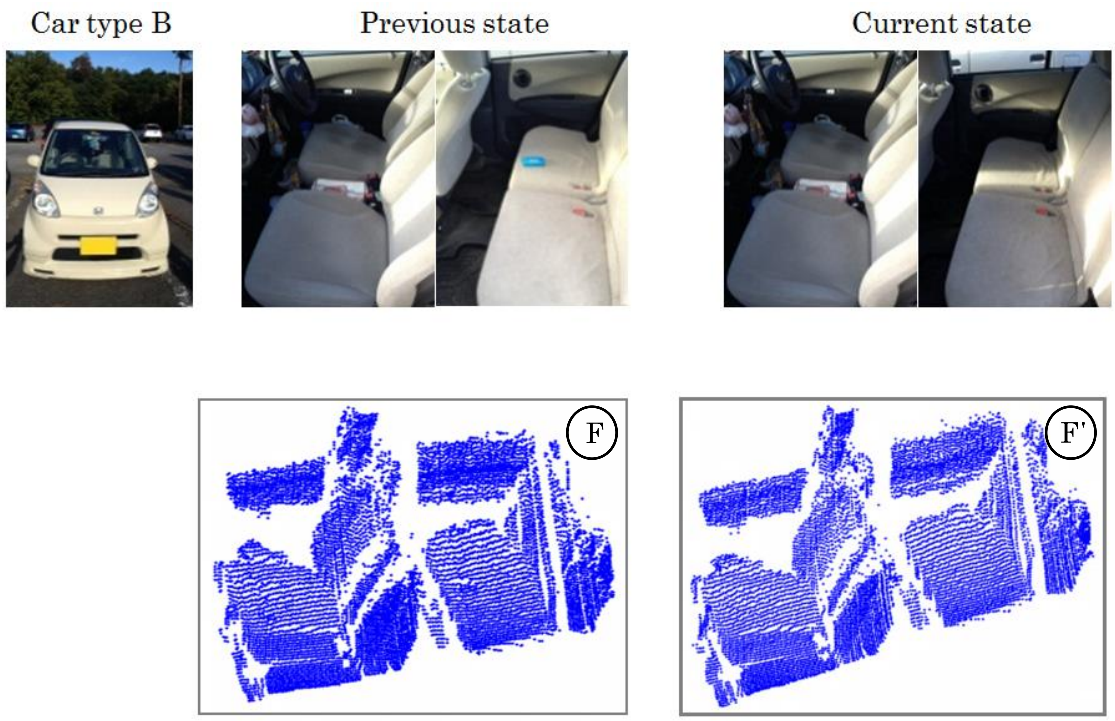


Figure 4.32: Inside vehicle scenes with a mobile phone, proposed method could not detected on current state

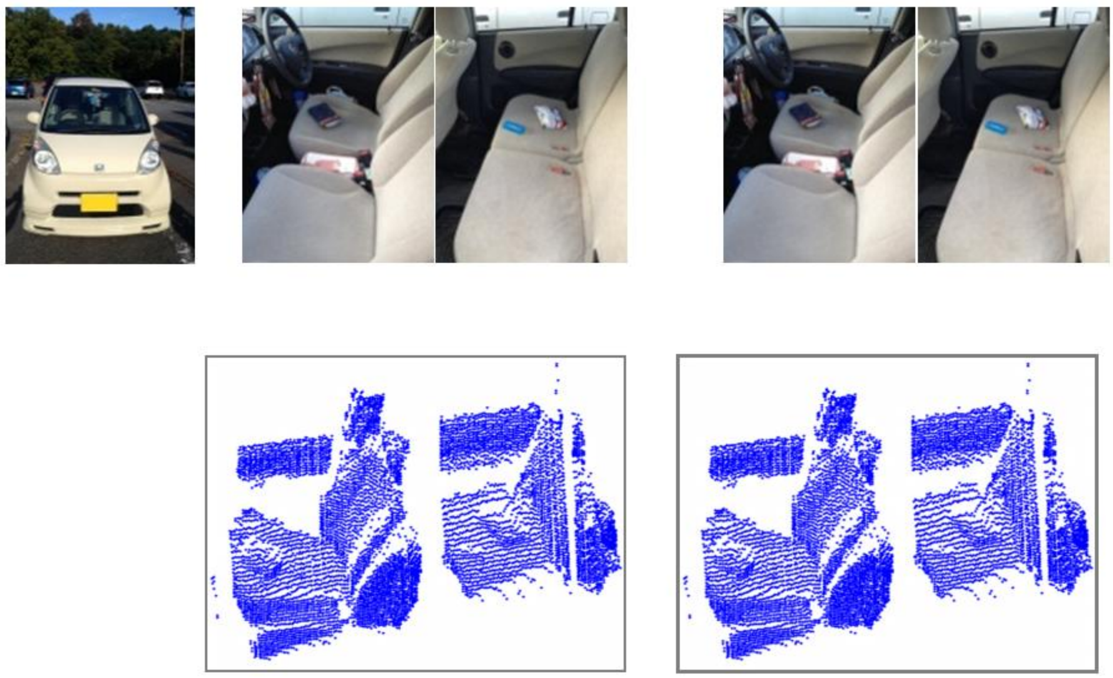


Figure 4.33: Inside vehicle scenes with three items, item missing are not found on current state

Table 4.1: The average height of items for inside vehicle data inspection (Unit: *m* is meter)

Items	Actual size (*m*) (*W*×*L*×*H*)	Detected size (*m*) (*W*×*L*×*H*)	Average of height (*m*)		Item height (*m*)
			Previous	Current	
A	0.20×0.30×0.25	0.25×0.34×0.24	0.69	0.55	0.24
B	0.15×0.18×0.20	0.11×0.18×0.14	0.65	0.57	0.14
C	0.40×0.41×0.50	0.34×0.34×0.46	0.78	0.66	0.46
D	0.22×0.28×0.06	0.19×0.25×0.04	0.61	0.55	0.04
E	0.09×0.12×0.04	0.06×0.09×0.02	0.66	0.61	0.02
F	0.06×0.09×0.015	NOT detected			

Measurement errors for proposed methods included robot odometry, laser range sensor, and data alignment. Among these errors, the maximum distance of robot movement is 5 meters. Robot odometry was evaluated experimentally and is 6 *mm* at 5 meters of movement.

In sensor accuracy, LRF measurement was accurate at ±30 *mm* (range of 0.1 to 10 *m*). For data alignment, car body data was extracted to align measured data between previous and current inspection.

After the data alignment method was applied, the average distance between the point data was calculated by equation (4.3) and was less than 0.008 *m* for all experimental data. In robot vibration, author ignored error due to robot vibration because the robot was moving at a low speed with a suspension mechanism.

Measurement position error in the worst case was 0.044 meters, so items larger than 0.044 meters were detectable. The capability of the proposed method was thus actually better than this value in experiments.

Items were declared missing if the average height value of the current state was less than the average height value of the previous state. In this paper, the application of inspection inside vehicles is proposed for checking the state inside vehicles between previous and current states. Experiments showed this method located and identified items missing in the current state.

In processes repeated of the same vehicle, if the value of average height was near zero, then there was no change inside vehicle state. There were minor limitations with material that did not provide data reflection such as material used in mobile phones, so appropriate sensors must be used to overcome such obstacles.

4.6 Discussions

Our implementation has demonstrated that additional detection inside vehicles is achieved by utilizing a mobile robot equipped with an LRF sensor for patrolling typical parking lots. Car-body data detection that extracted the car side and calculated data alignments between data scans was introduced to solve the problem of the vehicle state in typical parking lots. The data detection inside cars and data comparison inside cars was also introduced to improve vehicle state inspection. By analyzing these methods, our approach has presented and demonstrated a new application for inspection inside vehicles.

The limitation of this application, for inside vehicle data detection, the hidden area was found because the limitation of sensor position and robot displacement so author fixes hidden area by robot moves both side of vehicle as shown in Fig 4.34.

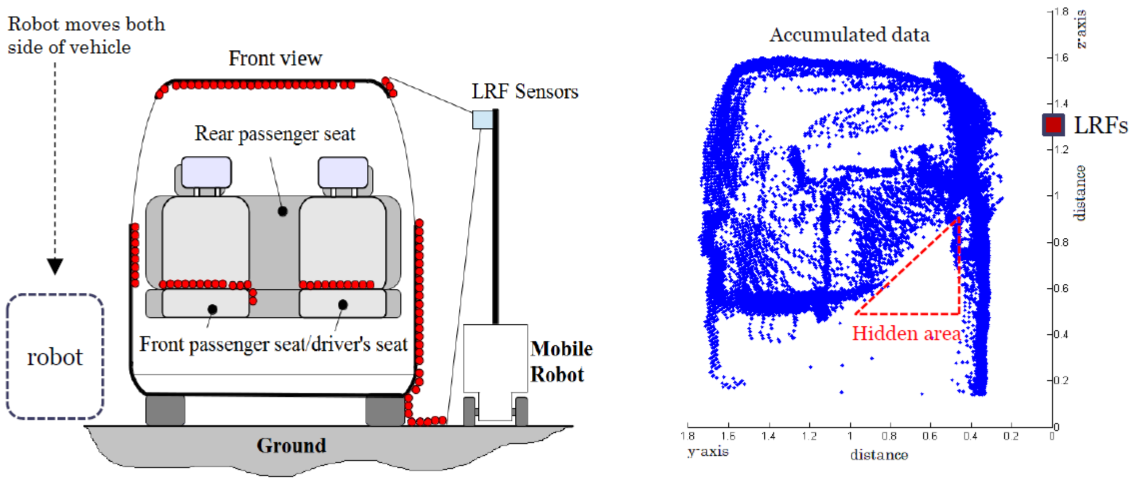


Figure 4.34: Limitation of sensor position and robot displacement for detected data inside a car

In our experiments, the robot moving alongside a vehicle is lower speed so robot position error was occurred a little bit while robot operation. Therefore, the assumption of measurement error of robot position is not employed in our experiments.

The robot motion alongside vehicle was operated with the same displacement that was well obtained the inside vehicle data of our experiments. The limitation of task, the free space between vehicles was less than 30 cm the robot could not operate. And our proposed method cannot detect through car window with curtain inside a car or occluded vehicle interior.

Extraction of car window framework was completely extracted when large threshold was set as shown in our experiments. The data alignment was applied to align car window framework was well matched between them. The capability of our proposed method could detect the object size above 2 cm. as shown in our experiments.

To approve this proposed method, the sensor is to obtain the vehicle data with high accurate is required. The solution of data alignment technique for precisely position much is better than our proposed method. To find a small change such as thin object or small object is need to improve our proposed method.

Chapter 5

Under Vehicle Inspection

5.1 System Overview

In this section, the main research aims to inspect the underside of the vehicle within parking lot utilizing a mobile robot with the LRF sensor. Author want to inspect the status of underside of vehicle in several time operations for searching something is different from inspections. So, author developed a compact mobile robot to operate underside of the vehicle which is narrow area and limitation of height from ground. The mobile robot is perform to recognize the under vehicle status and detects the anomalous object when the under vehicle status is changes from data inspections. To identify the anomalous object which is appeared underside of the vehicle and determine the object location, object size at vehicle undercarriage.

5.2 Approach on Under Vehicle Inspection

In this application, in Fig. 5.1, mobile robot moves underside of the vehicle to acquire the geometric information underside of the target vehicle which it performs to patrol with multiple time data scanners. The point cloud data is acquired by a LRF sensor. The multiple periods of time of scanned data (period of time stamps as t_1, t_2,..., t_n) for under vehicle detection is collected the data accordingly in this system. Consequently, data comparisons was done between scanned data from consecutive time frames between t_i and t_{i+1},... (where $i = 1,2,...,n$).

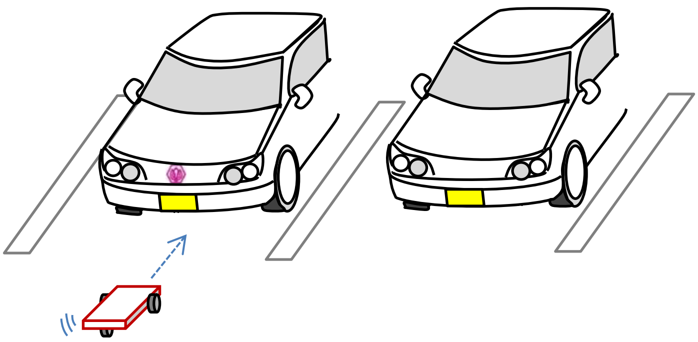


Figure 5.1: Mobile robot is perform to inspect underside of the vehicle

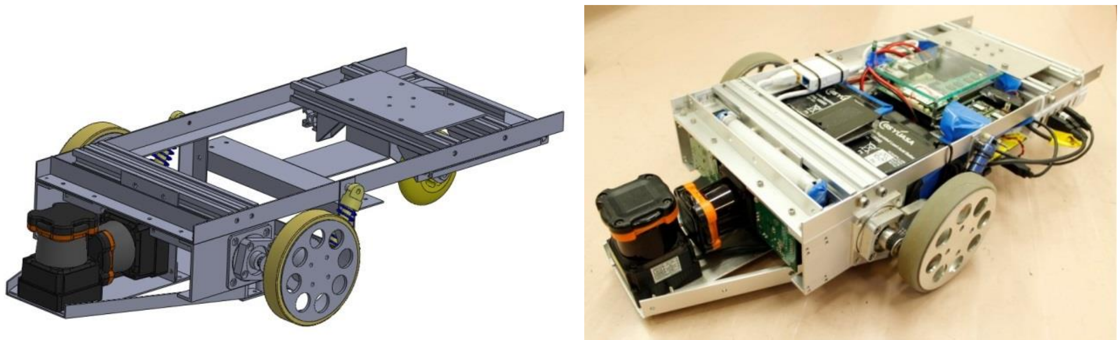
Under vehicle area have limit of height level form ground which is depending on the car types. In this application, the free space of under vehicle above height 12 *cm*. from the ground. In addition of the rugged terrain, high slope up or down of a parking lot status is not employed in this research.

5.3 Implemented System

5.3.1 Hardware Design

In this application, author wants to design and develop a compact robot to perform the inspection mission under cars with the inspection system and its purpose. Performance of robots is requiring the dexterous movements and low-profile platform for operating under the vehicle space, there is narrow area and hard to operate by manual inspection.

Above of circumstance, author created a compact robot platform with the wheel types with suspension mechanisms (two wheel drives, a wheel for supporting) and low-profile of robot platform as shown the conceptual design in Fig. 5.2(a). The robot platform size is 0.32 *m* (width), 0.11 *m* (height), and 0.52 *m* (length) with the aluminum material. A prototype robot with the hardware of the circuit boards is shown in Fig. 5.2(b). The total weight is less than 4 kg without the battery source as low light weight and it easy to carry on the mission.



(a) (b)

Figure 5.2: A conceptual design of a compact robot platform in (a), (b) a prototype of mobile robot platform

The sensor (UTM-30LX, Hokuyo Automatic Co., Ltd.) is used in the application as laser range finder sensors. Two sensors are installed on robot platform for data measurement of the vehicle undercarriage and robot localization. A sensor is installed upright vertical plane that perpendicular on the ground plane in order to acquire geometric information under the vehicle and another one sensor is installed in front of robot in horizontal plane (parallel to ground) to perform the robot localization function (Fig. 5.3). The sensor is a compact size (W60×D60×H87, *mm*), cover detection range about 0.1 to 30 *m*, distance accuracy is 0.03 *m*, angular resolution is 0.25 degrees, and angle range is 270 degrees operating at 40 Hz.

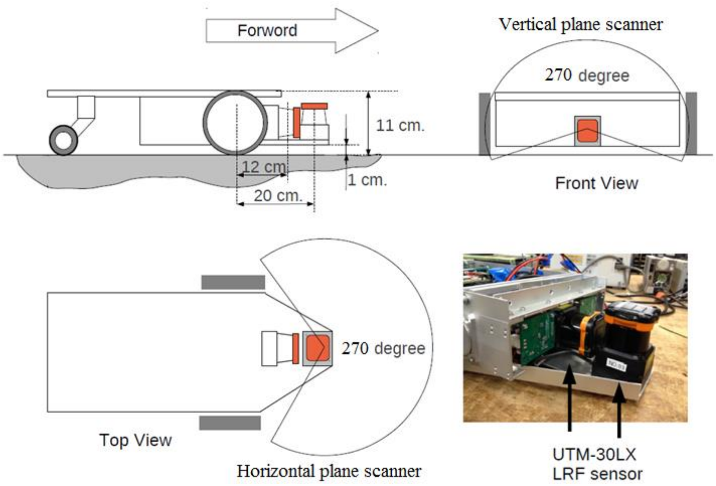
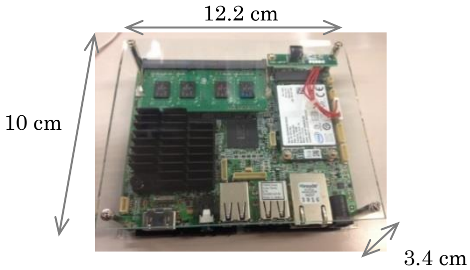


Figure 5.3: 2D plane scanner of LRF sensor on vertical and horizontal plane scans

In this application, a main processor used is Intel 1.6 GHz, 2GB of RAM based small-size PC board running Ubantu12 distribution of Linux (kernel 3.2.0-36-generic-pae) as operating system. The dimension of small-size PC board is W10×H3.4×L12.2, where unit is centimeter (*cm*) in Fig. 5.4(a). The robot controller board with SH2 processor provides robot locomotion and odometry based self-position estimation function. The compact wireless communication module (IEEE802.11b/g/n, 2.4GHz, max. 150 Mbps) is applied for data communication between robot and operator as enable manual mode in order to control the robot.

The hardware components are installed on robot platform that included the main power supply (12 Vdc, 5 Ah) as a lead-acid battery; two batteries are used in this system. The converter module is used to supply electrical power to the laser sensors and the circuit boards. The hardware components are installed on mobile robot platform as shown in Fig. 5.5.



(a)

(b)

Figure 5.4: Components of the main processor in (a) and wireless module in (b)

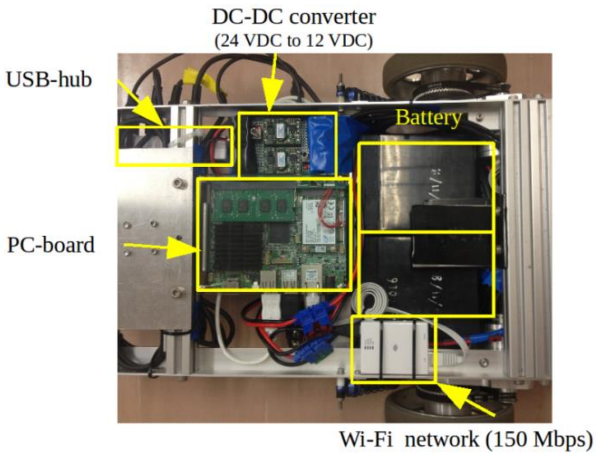


Figure 5.5: Hardware components on a mobile robot platform

5.3.2 Software Design

For robot system of this application, In Fig. 5.6, author design a robot system and develop the software on a main processor on board for the application of under vehicle inspection. The embedded PC is core of this system to compute the data from laser sensors via USB port connection and it also connect to a wireless module for data communication from base station via Ethernet port which is able to interrupt by manual control. The controller part is perform to control the robot motion with two dc motors of left and right wheels and it received a feedback signal from the encoder with the function of self-localization.

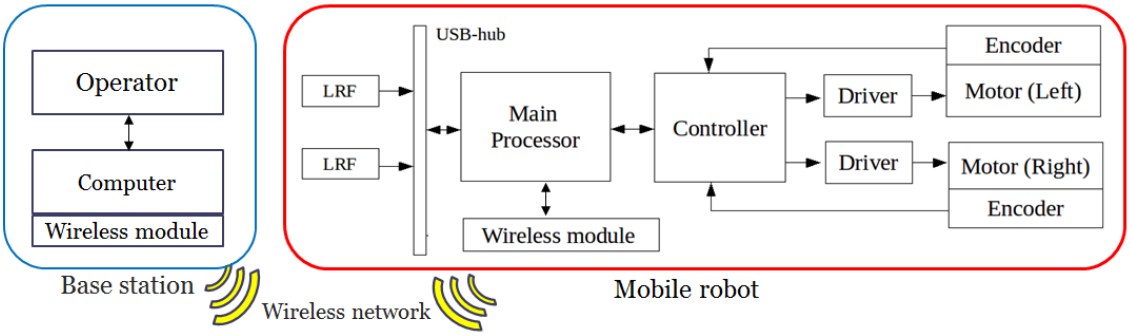


Figure 5.6: Implemented system for the application of under vehicle inspection

For implemented system, in Fig. 5.7, author design the software architectures of this application for implementing on the embedded PC board. The feature functions are considering in our application which are including the sensor shared manager (SSM) technique, pre-data processing, data processing, and localization function. To implement the type of communication, author use a SSM to share the data or applications data using shared memory management.

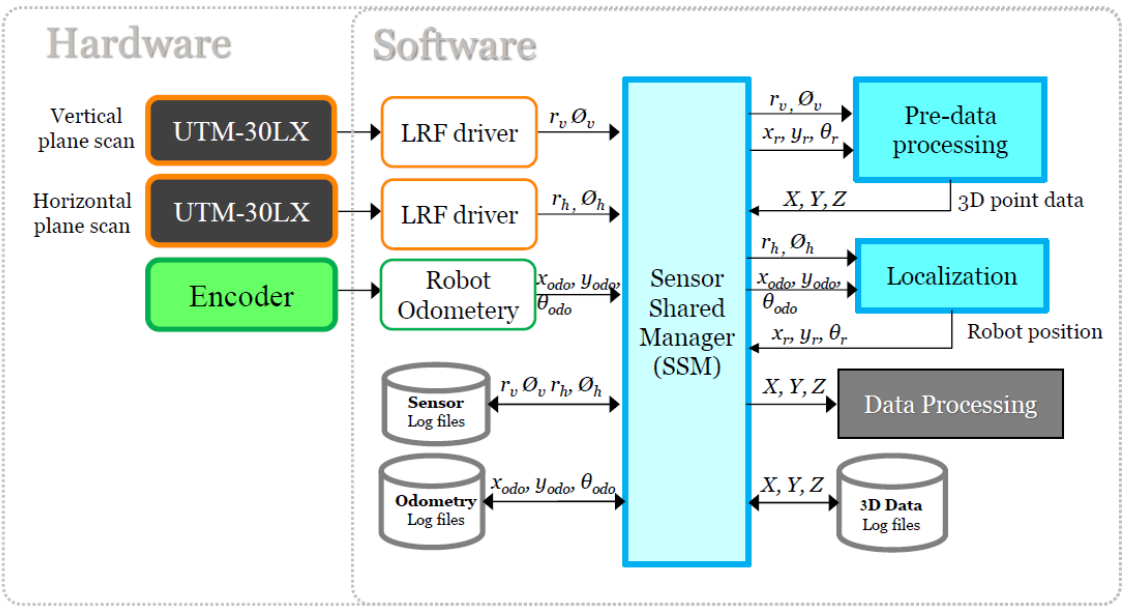


Figure 5.7: Software architecture on application of under vehicle inspection

The data $(r_h, \emptyset_h)$ from sensor of horizontal plane scan and the data $(x_{odo}, y_{odo}, \theta_{odo})$ from robot odometry function uses to process the robot localization function which are calculate the positioning of robot while robot performs underside of vehicle. The function of pre-data processing is applied to calculate the under vehicle data by using the vertical plane scan from sensor $(r_v, \emptyset_v)$ and the positioning of robot (x_r, y_r, θ_r) from localization function which are calculating the data to 3D point data (X, Y, Z) in world coordinate. Therefore, the data processing function is use the 3D point data to process the strategy method of this application. The SSM function is to share the data from sensors and the application data of each feature function as well as recording the data from sensors, robot position, and 3D point data into the data log file.

5.4 Data Processing

5.4.1 Data Acquisition

The 2D plane of LRF provides the upright vertical plane scan that is perpendicular the ground to acquire under vehicle data as shown in Fig. 5.8. The 2D data range scan (angle and range) and self-positioning of the robot locomotion are combined to point cloud data in 3D world coordinates. The point cloud data from the LRF sensor consists of the under vehicle data (U_j) and ground data. For separating the point cloud data, the constant height value of $H_{threshold}$ along z axis is applied to divide the point cloud data. Point cloud data exceed $H_{threshold}$ are conducted and other points below the threshold are ignored.

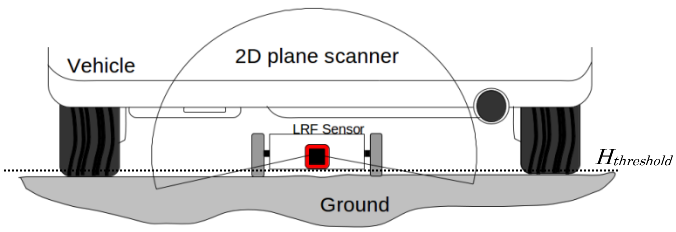


Figure 5.8: 2D plane scanner of LRF for under-vehicle detection

Using robot path way, author setting a start point, target point and range for robot motion. This data is to create the robot path way as *U*-curve (Fig. 5.9) for robot motion whole under vehicle area from start point to target point.

For robot motion, a robot with the 2D plane of laser range sensor provides horizontal plane is to detect tire wheels during robot navigation, to avoid colliding to those tires. Four tires can be used as the landmarks for robot localization relative to those tires. Author provided the localization technique underside of a vehicle. The

2D range scan matching technique [31-33] is applied to relative position tracking and localization.

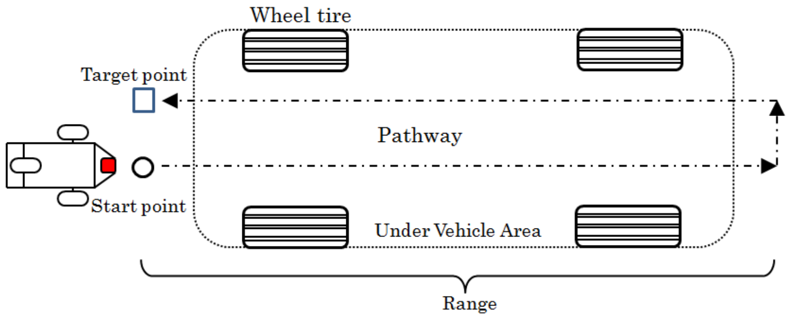


Figure 5.9: Robot pathway under vehicle area

5.4.2 Data Alignment

In this section, the under vehicle data from previously archived scan and current scan are used to compute under vehicle data alignment between them. The under vehicle data is related to robot position with odometry base self-position, thus some coordinate error can occur while the robot collects information between multiple time operations and the data from these inspections are difference position in world coordinate as well. Therefore, author proposed data matching technique for data alignment. The ICP algorithm is applied for matching under vehicle data between base point cloud from previously archived scan and target point cloud from current scan.

With the data alignment method, the under vehicle data is conducted for data alignment between base point cloud data $(U_j^{t_i})$ and target point cloud data $(U_j^{t_{i+1}})$ by a point pairs of under-vehicle data is calculated, where U is under vehicle data and t is multiple of duration time stamp. The method of computing the data alignment is described as follows:

a) Set base point data $(U_j^{t_i})$ and set target point data $(U_j^{t_{i+1}})$.

b) Pair each point of $(U_j^{t_i})$ to closest point in $(U_j^{t_{i+1}})$.

c) Compute transformation (R, T).

d) Apply motion to $(U_j^{t_i})$.

e) Repeat until data convergence is completed.

A concept is shown in Fig. 5.10, two groups from under vehicle data before data alignment is shown in Fig. 5.10(a). Under vehicle data after data processing between them is shown in Fig. 5.10(b). With data alignment method, the transformation matrix (R,T) is computed to under vehicle data, where R is rotational matrix and T is translational matrix.

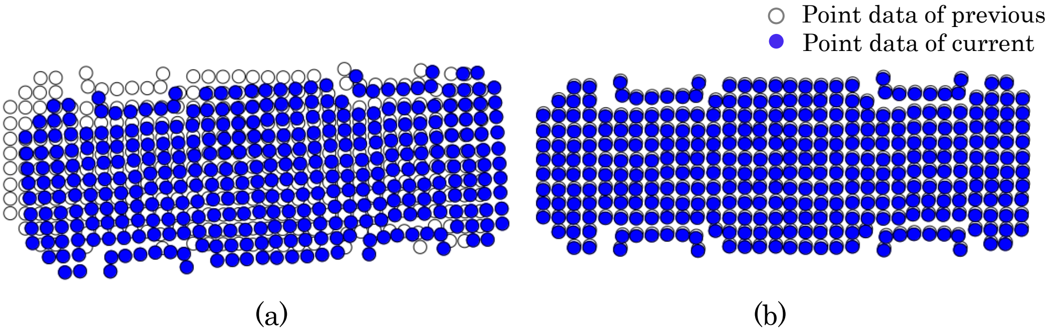


Figure 5.10: Point data between previous scan and current scan, (a) before state, (b) after under vehicle data alignment

5.4.3 Data Comparison underside Cars

Within data comparison technique, under vehicle data (U_j) is used to compare from previous under vehicle data for detecting items underside of the vehicle such as an anomalous item is appearing on current state. In this section, to determine whether underside of the vehicle is status changes or same status by data comparison between previously archived scan and current scan. Author mainly interested to inspect underside of vehicle for finding potential changes from the vehicle undercarriage in Fig.5.11.

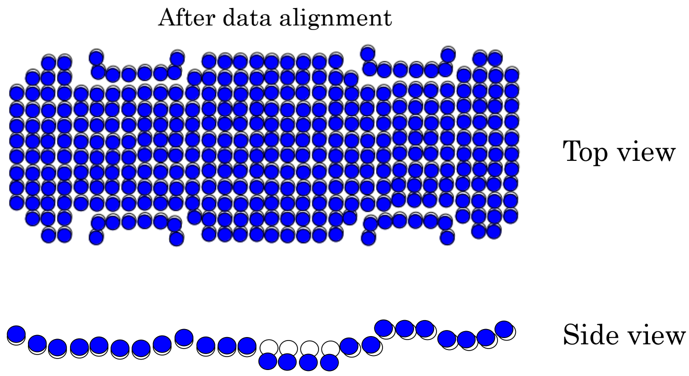
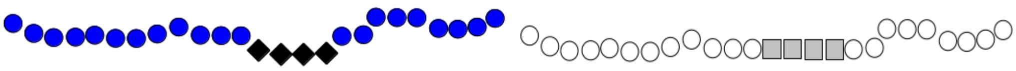


Figure 5.11: Concept of under vehicle data between previously archived scan and current scan.

The data comparison approach processes the data as follows: First, set under vehicle data of base point cloud data $W_i \leftarrow U_j^{t_i}$, and target point cloud data $Q_j \leftarrow U_j^{t_{i+1}}$, where U is under-vehicle data, and t is time duration of data scanner. Set $P_{threshold}$ is constant distance value. Second, searching the closet points by determine the distance (d) of point pairs from $d(\vec{Q},\vec{W})$ by using Euclidean distance in equation (5.1).

$$d(\vec{Q},\vec{W}) = |\vec{Q}_j,\vec{W}_i| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \quad (5.1)$$

To calculate the distance (d), if d is less than a constant value $P_{threshold}$, the point data is ignored. If distance (d) is greater than a constant value $P_{threshold}$ the point data will be collected in set M_k as different point data. A concept is shown in Fig. 5.12, under vehicle data of current scan with difference point data M_k as shown in Fig. 5.12(a). Finally, additional calculation is done to determine distance (d) of point pairs from $d(\vec{W},\vec{Q})$. The different point data is collected in set N_k as shown in Fig. 5.12(b). In case of under vehicles within the same state information or under vehicle state is no state change, the different point data is near zero.



(a) (b)

Figure 5.12: (a) Difference point data of M_k (diamond points), (b) difference point data of N_k (square points)

5.4.4 Data Segmentation and Identification

In this section, the point data M_k is used to calculate the item location and item identification as different state of vehicle undercarriage. To define item identification, clustering point data of M_k is performed to determine group of item, dimension size, and item location. The method of data segmentation based on the Euclidean distance (with noise being removed) and data identification method are proposed to define data specification. This solution is described as follows:

First, the distance (d) of point pairs is calculated from equation (5.1). If the distance (d) value is less than threshold $S_{threshold}$, the point pair data will be collected and recorded in set $O_{q,b} \leftarrow M_k$. A new group of data is being created for the rest of point pair data and recorded in $O_{q,b+1} \leftarrow M_k$ where q is number of points in each group, b is group number.

Second, if the number of point in each group $O_{q,b}$ is less than the threshold $N_{threshold}$ value, that particular group will be removed where $N_{threshold}$ is set number of point. Finally, for each remaining groups, two sets are calculated, a 3D dimensional size (*width× length× height*) of data point and an average of height along the z-axis from ground. This technique is shown in Fig. 5.13. To check the status of object underside of the vehicle, an average height along z axis of object is used to compare between previous and current states. If average height of previous state is lower than an average height of current state, so the related object is appearing otherwise the object is missing.

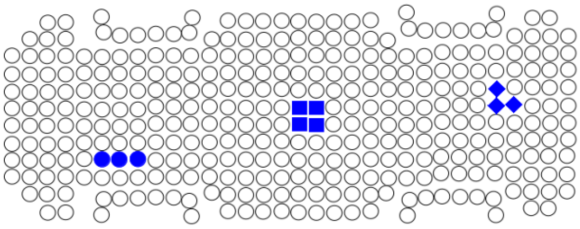


Figure 5.13: Data segmentation of the different data points

5.5 Experimental Results

In the experiments, Fig. 5.14, a mobile robot velocity is 0.15 m/sec for robot motion underside of the vehicle. A mobile robot is moved under vehicle to obtain under vehicle data that operate to data scanner underside of the vehicle in multiple period time duration ($t_1, t_2, \ldots, t_n$). For the experiments at least two time stamp of data from mobile robot operation is required with the same a parking lot. The data from sensor was read every 25 *ms* by a driver process, registered in parallel into a shared memory system (SSM) and was recorded in data log file.

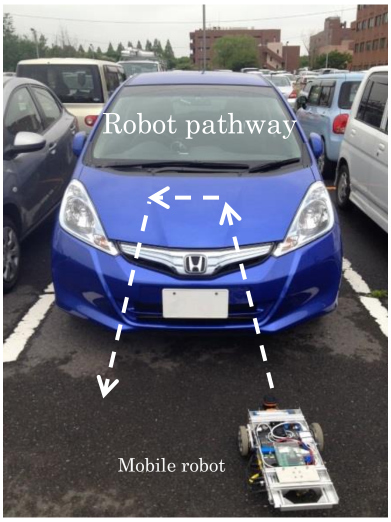


Figure 5.14: Robot pathway underside of target vehicle

For pathway as *U*-curve, a robot moved forward direction from a start point with the range set is 4.5 meter over the vehicle length and then rotated at 90 degree, and moved forward at 0.5 meter and then rotated back 90 degree for moving 4.5 meter and stop. The robot motion with the robot odometry function and localization function by [33] was shown in Fig. 5.15.

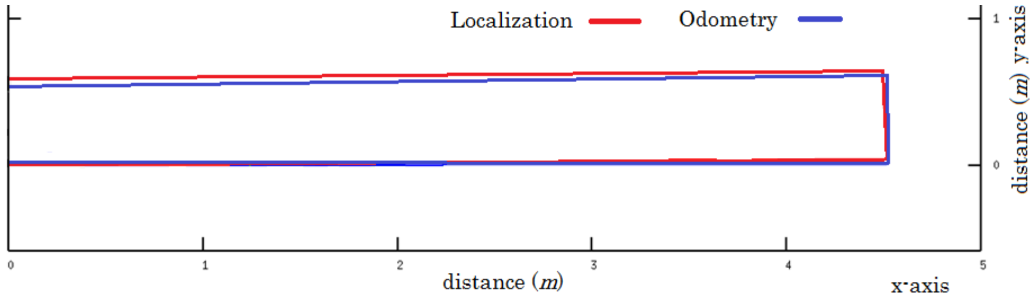


Figure 5.15: Robot motion with odometry and localization function

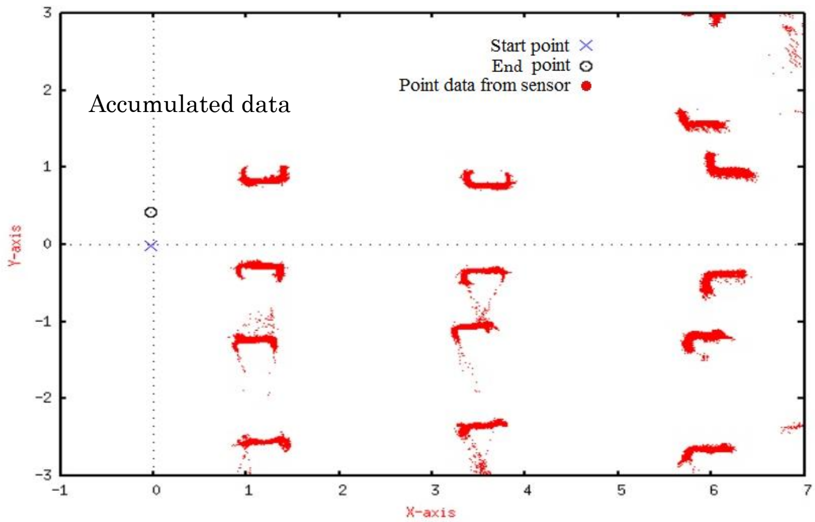


Figure 5.16: Wheel tires of vehicle as landmark underside of vehicle

In the experiment, mobile robot moves underside of vehicle on pathway *U*-curve with the robot position estimation of odometry base function, while a robot operation the data measurement under vehicle data is operated in simultaneously. The under vehicle data is collected until robot move to target point, the under vehicle data is relate to the positioning estimation while robot motion under vehicle area in Fig. 5.16. The point cloud data is calculated from sensor data and position estimation, as the result of the point data is overlapped as shown in Fig. 5.17. The measurement position error of robot at target point is greater than 0.1 meter with odometry base function.

The robot localization function enable is to perform under vehicle area by using LRF sensor which is installed in front of robot. Four tire wheels are used as the landmark for position estimation function. The robot operates under vehicle area and detection data at vehicle undercarriage simultaneously. Under vehicle data is obtained from the position of under vehicle to relate the robot position of localization function. Under vehicle data is aligned the position of under vehicle while collected point data from sensor relative to localization function as shown in Fig. 5.18. The measurement position error from target point is less than 0.1 meter with the localization function. Therefore, the robot localization function is applied for all experiments. The 3D image with difference of height distance along the z axis is shown in Fig. 5.19.

In our experiments, the ground point cloud data is included in the experiment data, so the $H_{threshold}$ at 0.015 m. the point cloud data below $H_{threshold}$ is removed.

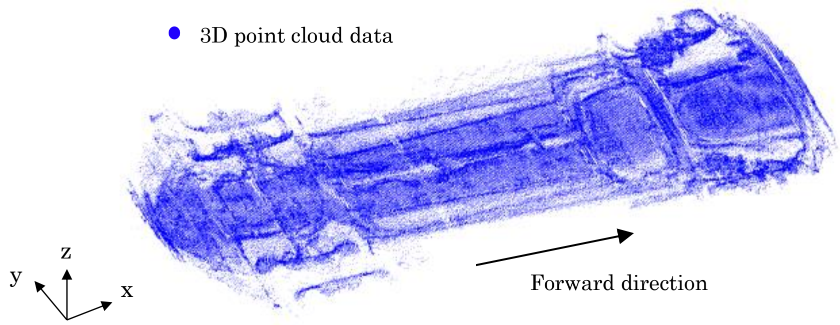


Figure 5.17: 3D point cloud data is overlapped with odometry base function

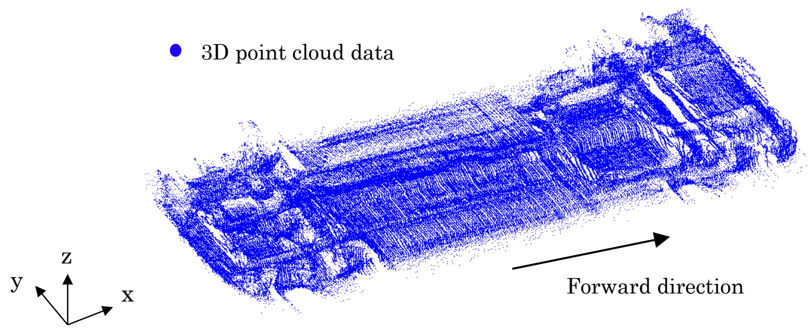


Figure 5.18: 3D point cloud data convergence with localization function

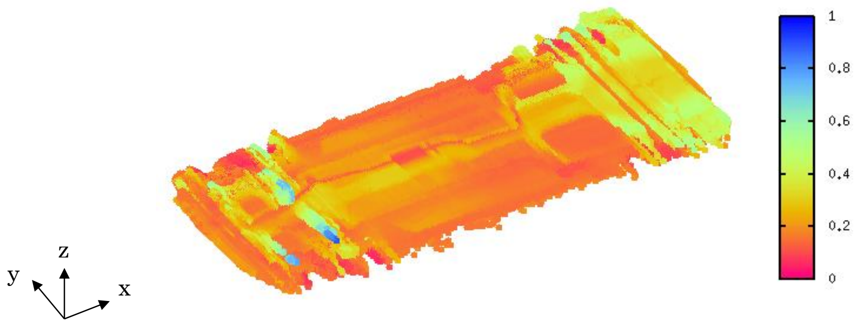
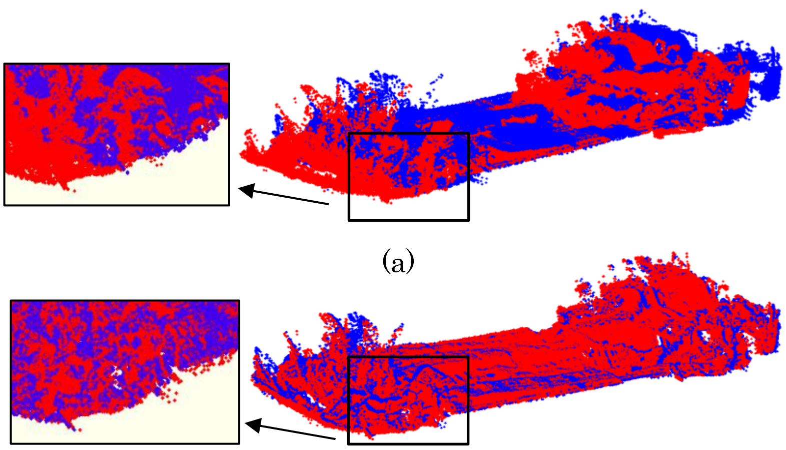


Figure 5.19: Image of under vehicle data with the height distance along the z axis (color bar unit is meter)

The result of the under vehicle data detection is being processed to calculate the data alignment. The data inspection from multiple time operations is difference position in world coordinate. Pair two point cloud data are applied to calculate for data alignment method until data convergence between them.

In this experiment, the data from inspections are difference position as shown in Fig. 5.20(a). The data alignment method is applied to calculate the under vehicle data until data convergence between them. Our proposed method mainly interested to calculate precisely position of under vehicle data alignment. The data from inspections are closet position between them as shown in Fig. 5.20(b).



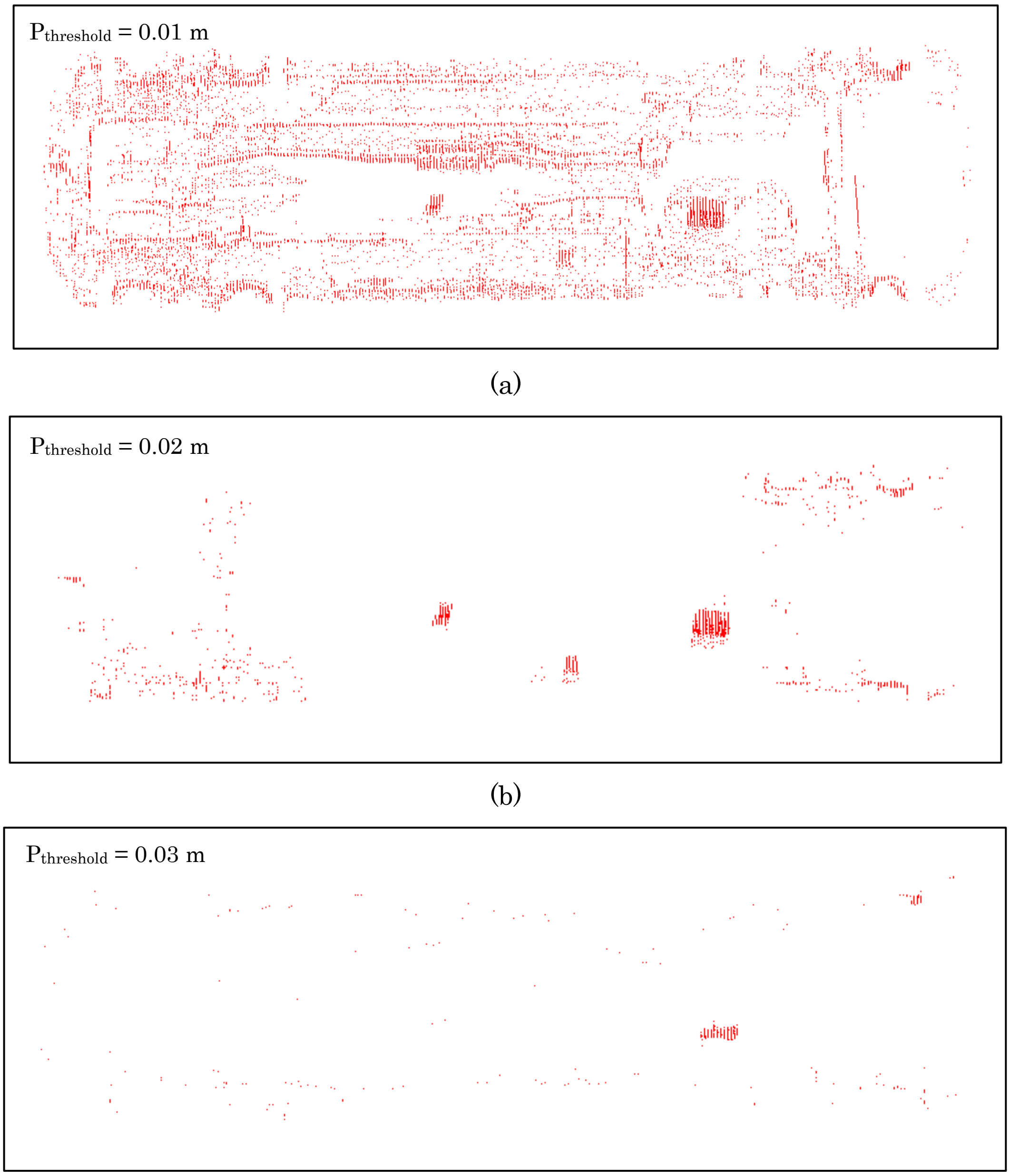
(a)

(b)

Figure 5.20: Difference position of the under vehicle data from previous and current scans, (a) difference position, (b) closet position between them

After the data alignment method was applied, the average distance between the point data was calculated by equation (5.1) and was less than 0.02 *m* for all experimental data.

From under vehicle data alignment, the data comparison technique is proposed to calculate the distance of point pairs from equation (5.1) between previously archived scan and current scan to fine potential change between them. The thresholds in several values of $P_{threshold}$ are used to calculate the data comparison as 0.01, 0.02, 0.03 meter in experiments as shown in Fig. 5.21. If a small threshold value of 0.01 *m* is set, the anomalous object is difficult to extract from vehicle data (Fig. 5.21(a)). If a large threshold value of 0.03 *m* is set, the small anomalous object could not found (Fig. 5.21(c)). If a threshold value of 0.02 *m* is set, the anomalous object could be found (Fig. 5.21(b)). The constant value $P_{threshold}$ is set at 0.02 *m*, applied to all of experiments.



(c)

Figure 5.21: Experimental results of data comparison with $P_{threshold}$, the constant of threshold is set 0.01 meter (a), 0.02 meter (b) and 0.03 meter (c)

From the experimental result of data comparison, the data points could be extracted from the proposed method. Euclidean distance with the threshold distance of $P_{threshold}$ is the key parameter to calculate above the experiments data. In case of state changes, the point data of the object is applied to the item identification method. In case of no state changes, the point data is a few points.

As the result of data comparison, the data segmentation method is proposed to find the amount of anomalous object. The data points are calculate the distance by equation (5.1), author set the threshold of $S_{threshold}$ is 0.1 m for clustering the point data into the group, if the distance is less than $S_{threshold}$, the points are collected into a same group, if the distance is greater than $S_{threshold}$, the points are collected into a new group. For counting the point data in each group, the number of point of each group is calculated. In experimental results were found that less than 10 groups are detected so the group with a few point data is needed to remove.

From each group, if the number of points is lower than the threshold value of $N_{threshold}$, the point data from group is ignored, if the number of point is greater than the threshold value of $N_{threshold}$, the point data from group is collected. A threshold value $N_{threshold}$ is set at 50 point for removing a group with a few points from groups. A threshold $N_{threshold}$ of 50 point applied to all the experiments. Finally, an average of height distance from ground (along z axis) and dimension size ($W \times L \times H$) of each group was calculated, where W is width along x axis, L is length along y axis and H is height along z axis.

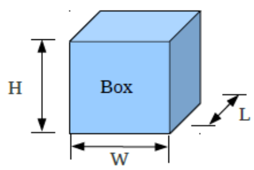
In experiments, the threat object is assumed to test performance of the proposed method. The shape of object is box and cylinder that seem the sizes of dynamic or plastic bomb (explode object, dangerous object or contraband object etc.) that attached underside of vehicle in experiments.

The objects are use the box shape and cylinder shape in our experiments. The objects size are described as follow this: four Box size (W×L×H), five Cylinder size (d,h):

Object (A) is 0.065×0.065×0.035 *m.*

Object (B) is 0.065×0.065×0.035 *m.*

Object (C) is 0.14×0.14×0.045 *m.*

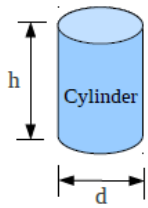


Object (D) is d = 0.03, h = 0.12 *m.*

Object (E) is d = 0.07, h = 0.14 *m.*

Object (F) is d = 0.025, h = 0.10 *m.*

Object (G) is d = 0.015, h = 0.15 *m.*



The experiments of method approach are presented in Fig. 5.22 and Fig. 5.23 in order to inspect threat objects underside of the vehicle. Threat object could not detected in Fig. 5.24. The detected size of item is summarized in Table 5.1.

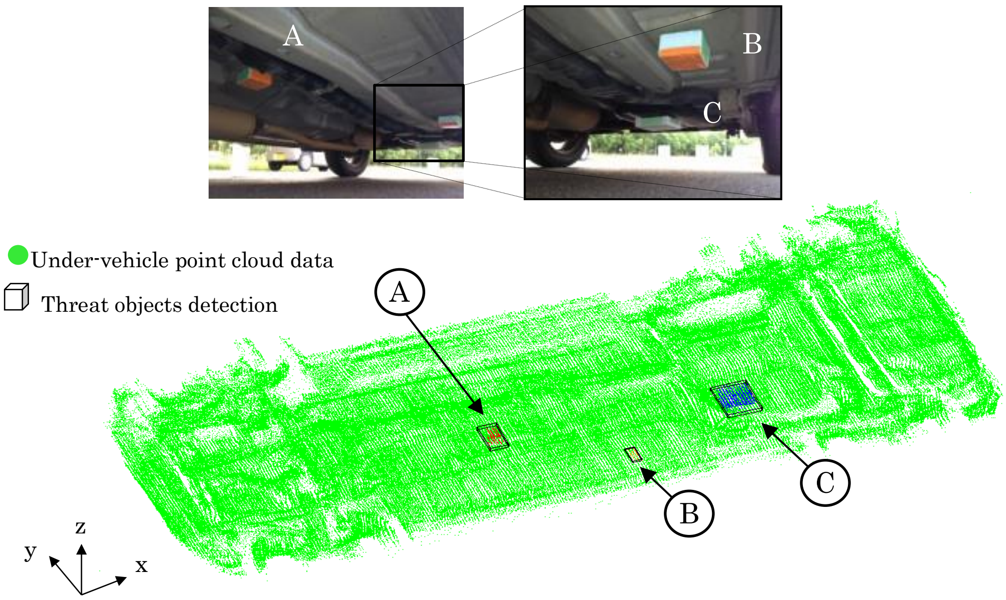


Figure 5.22: Three threat objects (three boxes) are appearing on current inspection

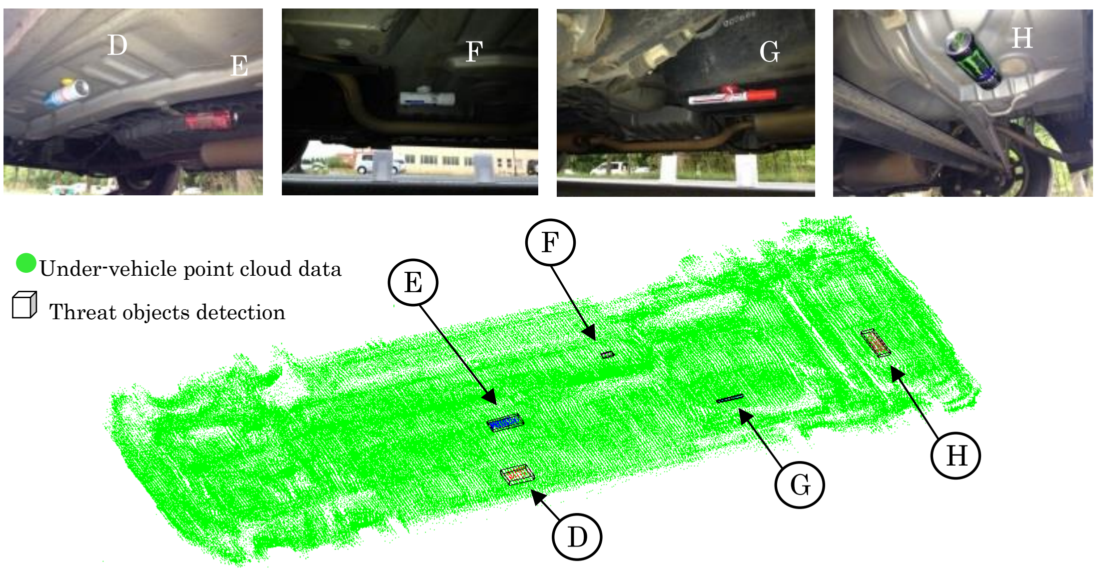


Figure 5.23: Five threat objects (five cylinders) are appearing on current inspection

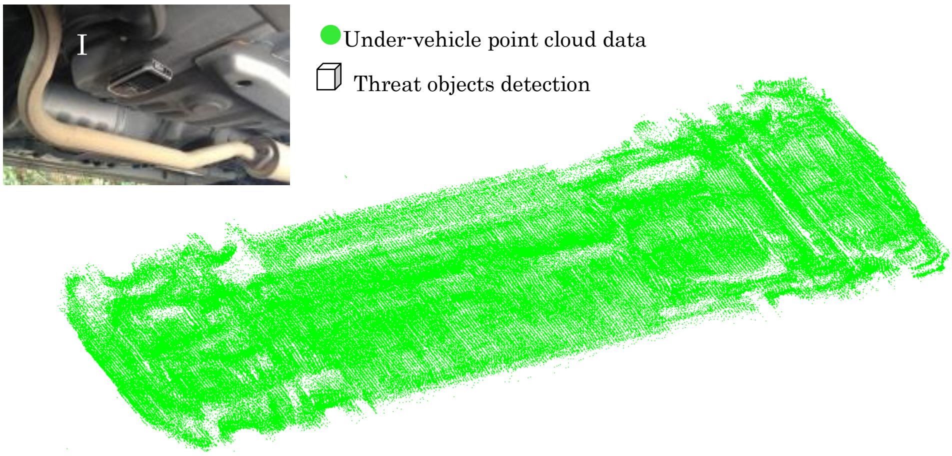


Figure 5.24: Threat object (mobile phone) is appearing in current state and the proposed methods could not detect.

Table 5.1: Detected object, average of height distance for object detection (unit: m is meter)

Items	Actual object size (W×L×H)	Detected object size (W×L×H)	Average of height from ground		Item height (m)
			Previous	Current	
A	0.065×0.065×0.035	0.07×0.05×0.03	0.11	0.17	0.031
B	0.065×0.065×0.035	0.08×0.04×0.02	0.07	0.12	0.025
C	0.14×0.14×0.045	0.12×0.13×0.04	0.03	0.09	0.041
D	0.03×0.12×0.03	0.028×0.09×0.025	0.11	0.16	0.027
E	0.07×0.14×0.07	0.06×0.13×0.05	0.12	0.17	0.058
F	0.025×0.10×0.03	0.03×0.066×0.02	0.09	0.12	0.026
G	0.015×0.15×0.025	0.017×0.11×0.02	0.08	0.10	0.021
H	0.065×0.155×0.08	0.06×0.12×0.07	0.21	0.27	0.064
I	0.045×0.11×0.015	NOT Detected			

In condition object appearing was declared when an average of height distance value of current state is greater than the previously state. In this paper, the application of under vehicle inspection was proposed for checking under vehicle state changes. From the experiments, the proposed method could locate and identify the threat object appearing on current state. However, in case of repeated processes on the same vehicle, the difference point data was a few point data as noise and it was removed from data comparison and data segmentation method, so there is no state change of underside of the vehicle.

5.6 Discussions

In this application, our implementation has demonstrated the functional feature of underside of the vehicle inspection in the parking lot, which achieved the practical use a LRF sensor utilizing a mobile robot in real environment. By multiple time operations from robotic platform was introduced in this work. The proposed application was applied to protect underside of vehicle from threat in parking lots for automated inspection under a vehicle. Our experimental results could be detected the anomalous object underside of the vehicle.

The laser sensor was introduced to obtain the geometry of a vehicle's undercarriage that was well detected at underside of vehicle by using a mobile robot. The low-profile of mobile robot was developed to exam under vehicle area that could be operated there above height 12 cm. from ground.

The robot motion at underside vehicle area with lower speed was achieved to locate the position of robot by detected four wheels tired as the landmark with localization function [33]. The scan matching was well performed to track and correct robot position while robot was collected information of vehicle undercarriage as shown in our experiments.

The under vehicle data from multiple time operations were detected and applied to align between previously archived can and current one by data alignment that was well matched in 3D data. The difference position after data alignment in worst case was 0.01 m. but in experiment better than expected as shown in experimental results. The capability of proposed method could be detected object size above 2 cm. of our experimental results.

To improve the proposed method, the sensor is high accurate and fast scanning rate is required. The solution of data alignment much more precisely position to align between them for increasing performance of proposed method that possible to find thin object underside of vehicle.

Chapter 6

Conclusions and Future works

Our implementation has demonstrated the functional feature for vehicle inspection system within parking lots, which achieved the practical use a LRF sensor utilizing a mobile robot in real environment. Sensor was introduced to acquire the geometry of a vehicle such as shape, interior a car, and a vehicle's undercarriage. In this research, the proposed application could be applied to protect vehicles from threats in parking lots for automated vehicle inspection system.

6.1 Application of Occupancy State Recognition

The parking lot information could create from parked vehicles state and proposed method for long term parking could was achieved to detect the parked vehicle while position of vehicle changes. From proposed methods, the guideline data extraction method was successful detected the guideline data from the ground by using intensity data of feature function on the LRF sensor. The guideline data alignment was proposed to align the guideline data from multiple time operations it could be calculated the position in 3D point data between a pair data to align them unit data convergence with closet the position. The data comparison was succeeded for detection potential change by calculated the position of vehicle between previously archived data inspection and current data inspection.

6.2 Application of Inside-Vehicle Inspection

The application on robotic system for inside vehicle inspection is newly proposed. The inside vehicle information could obtain through the car window with dark tinted or clear screen by using LRF sensor. The proposed method of this application was achieved to detect inside vehicle data and checking a potential change of state of inside vehicle from multiple time inspections on robotic application. From several inspections, the data alignment method could be succeeding to align the position of car side framework with car window from scans. The data comparison technique was achieved to detect the difference thing from scans and detected object size is missing as inside vehicle state changes on current inspection.

6.3 Application of Under-Vehicle Inspection

The protection from threat underside of vehicle from robotic system was proposed by the application of under vehicle inspection. A low-profile robotic platform was succeeded for operating under vehicle area to obtain a vehicle undercarriage on multiple time operations. The proposed method was achieved to find the anomalous object from data inspections. The detection data was collected the geometry of vehicle undercarriage from a LRF sensor, with enable function of robot localization under vehicle area. The data alignment method was achieved to align the data from previously archived inspection and current inspection, position of point data could be matched between them. The data comparison technique could be detected the anomalous object at vehicle undercarriage and detected object size could be detected and it's located.

Above these applications on robotic system were intended to field of the mobile robot security for safeguard area in the parking place.

6.4 Future Works

As future works, sensors (e.g. thermal camera, IR camera, radiation sensor, etc.) will be installed to increase performance of inspection tasks. Improvement of mobile sensing for data detection and data alignment for much small object detection will be enhanced of approach of strategy method. Furthermore, the navigation system will be integrated for mobile robot navigation in parking lots.

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