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Proposal of lateral inhibition real time map updating method for simultaneous localization and mapping by using LIDAR

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Abstract

In this paper, a novel real-time map updating algorithm using a concept of lateral inhibition was proposed, and it was evaluated by simple 2D room mapping experiment. In a map creation and updating process, the position of the external environment "wall" such as woods, leaves and grasses would vibrate and be measured unstably. And it would lead an instability of the map creation. Our proposed method is to apply the lateral inhibition process to the real-time map updating process; it can inhibit the probability distribution creeping of the wall position in long-time map updating process. The experimental result of map updating process of 6.0×3.5 m 2D room with many obstacles shows the x-y positional and the rotational estimation precision was measured as Δx, y = 1.8×10^{-6} m (less than the laser range finder measurement error about 0.04 m) and the Δθ= -0.03 deg (1-hour measurement). After the 38 min outdoor experiment, the occupancy map was stably maintained, and there is also slight rotation and position estimation errors (Δx, y= 0.0 m, Δθ= 0.083±0.22 deg, N=5). The proposed method could suppress the wall existence probability distribution creeping induced by the natural environment vibration such as tree or leaves.

Keywords: *Real-time map update, forest situation, lateral inhibition, occupancy grid map, LIDAR (Laser Range Finder)*

1. Introduction

In all fields of mobile/static robotics system, the position estimation and mapping process have been one of the dispensable functions [1-5]. It was denoted as SLAM (Simultaneous Localization and Mapping) problem, even if today, and there are many studies by changing the approaches. There is a large demand to use the SLAM algorithms in outdoor natural environment and the algorithms would be necessary to robust against not only the sensor noise itself, but the vibration (such as leaf, branch and trees) affected by unpredictable natural wind [6]. However, in the map creation and updating process, the position of the external environment "wall" such as wood, leaves and grass would vibrate and be measured unstably [6]. And it would lead an instability of the map creation (Figure 1a) [5-10].

In previous SLAM applications, the instability of the wall position was little concerned and it was considered that there was a hard wall by the reason that the distance vibration would have been considered as lower than a noise level in the case of the few hundred-meter map creation. In outside situation SLAM studies, in [6], many challenges of SLAM problems and a few km practical mobile experiments were attempted. In [11], high height object position features of many trees and buildings were used as upper landmarks to stable the position of the landmarks. In [10], baseboards of the wall were used to improve the accuracy of mapping. In [12,13], IDC method was used, and view range of the SOKUIKI sensor was considered. These methods can realize real-time localization and mapping process by related enormous studies, and it works very well in many

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situations [5,7,14]. And many probabilistic methods are proposed now [11-17]. However, above studies would not account the effect of the natural object's wall position instability, in addition, this effect was appeared even if the mapping area was relatively small such as a few [m] square room by the reason of the noise of the LIDAR (Light Detection and Ranging) distance measurement. In the map creating process, natural object's wall position instability and the sensor noise effect would tend to deform or creep the map shape and the deformation / creeping effect would become serious as the map creating time gets longer. The effect is appeared in many SLAM application studies, for example, the method of the high height object position features of many trees and buildings [11] was one of the solution of the wall position stability.

The main object of this paper is to consider and discuss the situation of simple outdoor natural environment surrounded by trees. In those situations, the part of the wall will be not hard material (concrete wall) and not passages with many straight lines. To reduce the SLAM computational cost, the information of the straight lines in the map is useful and in [18,19], the method of assuming the wall part as a set of many straight lines was proposed, and it could reduce the enormous map matching calculation costs by applying it to corridors of the indoor situation. On the other hand, even if the LIDAR sensor would measure precise distance information and the map matching calculation would be realized correctly, in the natural environment, the vibration and noise of the natural object such as trees would always be measured. Also, the vibration and noise problems prominently appear in a long-time map creation process.

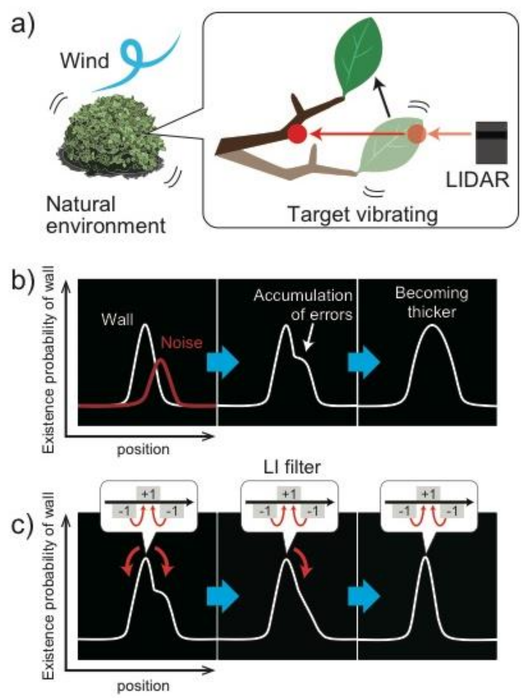

Figure 1. Distance measurement error factor of LIDAR in natural environment. (a) The distance measurement of the LIDAR is vibrated in natural environment. (b) Distance measurement error leads the wall existence probability distribution to become thick (conventional). (c) By applying the proposed LI filter as map updating algorithm, the probability distribution would be transformed to become slim and the peak position would tend to maintain.

In the present study, a real-time map updating algorithm using a concept of lateral inhibition (LI) was proposed and it was evaluated by an indoor room and outside trees existence situation. Our approach of the proposed method is to inhibit the instability of the wall position estimation by using the concept of lateral inhibition, and it can inhibit the probability distribution creeping of the wall position in long-time map updating process. In Figure 1b (conventional method), the probability distribution of existence of the leaf was shown as white line and in the case that a new position measurement distribution of the vibrating leaf was the red line, the updated probability distribution would be shifted right (or left) side (creeping) and the distribution would be thicker and blurred. This phenomenon anytime occurs, and it could not reject even if the LIDAR sensor accuracy has been much improved. Our approach (Figure 1c, proposed method) is to use the lateral inhibition filter (the concept is used in image processing fields) as real-time map updating algorithm to modify the probability distribution of the wall. By applying the lateral inhibition (LI) filter (Figure 1c left is same with the middle of Figure 1b), the probability distribution was transformed to become slim, and the peak position of the probability distribution would tend to maintain. The proposed method could suppress the wall existence probability distribution creeping induced by the natural environment vibration such as tree or leaves.

2. Methods

In many application studies such as [1,7,8], a concept of occupancy grid map of walls and obstacles was used for the map creation processes in the SLAM algorithm [3,20,21]. And it is necessary to update the internal map (the occupancy grid map) after the distance measurement [21]. To improve the precision of the internal map, the localization (most important estimation factor is the direction of the mobile platform) is a major factor [22-24] and the localization can be realized by a matching algorithm between the real distance map and the internal map. And many new algorithms were proposed and confirmed [13,25]. If the position of walls and obstacles would not change for a long time, the developed grid map would tend to be created stably and the reliable grid map would be created. However, as shown in Figure 1b, the vibration and noise of the wood and tree would deform the occupancy grid map and the thickness of the wall of the map would tend to be increased by the vibration and noise. It generally would collapse and deform the map.

In the proposed method, the internal map is real timely updated by a lateral inhibition filter (LI filter) donated by Figure 1c and Figure 2. The LI filter is one of the methods using in the computer image processing field and biologically neural system to extract the border or reduce the noise of the objects in the image [58-60]. The mechanism of the proposed method is that by applying LI filter for all (x, y) positions of the map real timely, it could reduce the noise and emphasize the border (such a wall) as shown in Figure 2. The mathematical structure and the occupancy map inhibition process of the LI filter was shown in Figure3 in the case of one dimensional case. In Figure 3, the white line shows the wall existence probability and it is considered that there is a probability deformation (denoted as A in t=0) by the reason of the natural object wall position vibrations. The LI filter contains the positive part (center of the filter) and the negative parts (left and right of the center), the LI filter was applied to all the x-axis positions. The probability distribution was suppressed along with winner takes all fashion [29,30], the noisy part such as A in 3 was suppressed by the LI filter negative parts (the left side suppression is largely affected in point A) when t=1. By applying the LI filter, the wall existence probability was brushed up and the distribution was shrinking. Created blurring map by the wall position vibrations is continuously being brushed up (when t=2 and later), and the distribution of the existence probability of the wall is shrinking by the continuous filtering.

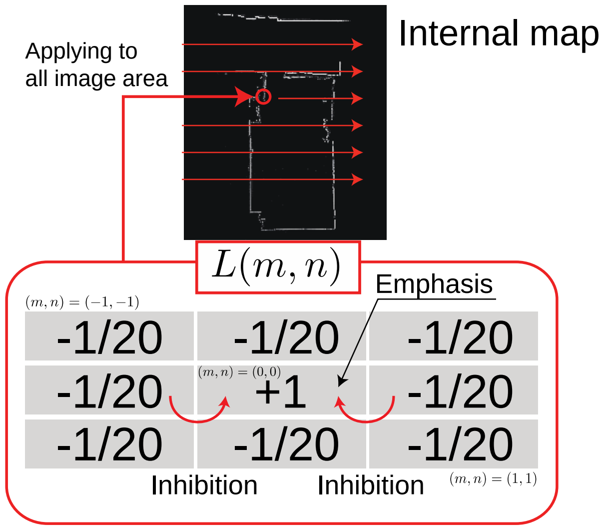

Figure 2. The process of the wall position occupancy grid map updating by lateral inhibition (LI) filter. Two dimensional 3×3 case was illustrated. White points mean the wall position.

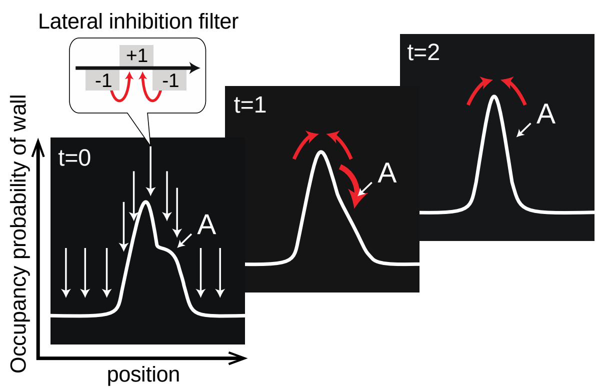

Figure 3. Mechanism of the LI filter occupancy grid map updating process in the case of 1D map.

The LI filter was mathematically described in the two dimensional occupancy grid map $map(x,y)$ as

$$map(x,y) = \sum_{m=-1}^{1} \sum_{n=-1}^{1} map(x+m, y+n) \cdot L(m,n) \tag{1}$$

where $L(m,n)$ was 3×3 lateral inhibition filter that was defined in Figure 2 bottom. The center parameter o $L(m,n)$ f was 1 and the lateral parameters of L were adjusted to -1/20 in all experiments. m, n were the x and y axis position shift variables and it were changed from -1 to 1 in the 3×3 lateral inhibition filter.

Lateral inhibition is one concept of neural systems which emphasizes the contrast and boundary of the information such as vision [26]. Its essence is that the adjacent elements inhibit each other and the filtered value is changed by the ratio of the original value to the adjacent values.

In the present study, the simple method of localization referenced as ICP (Iterative Closest Point) was used to match the internal map and measurement distance information by the LIDAR [24]. Since the proposed method is just a map updating algorithm, basically it is not affected by kind of ICP matching methods and, on the other hand, it can be applied regardless of the type of the algorithms.

2.1 Device

As distance sensor, the two-dimensional laser rangefinder (LIDAR) was used (URG-04LX-UG01, max measurement distance about 5 m, range 240 degrees, 12 fps, Japan Hokuyo Denki Corp.) The precision of the distance is about 3 cm (at 4 m distance), and the one division (1 pixel on the map) of the occupancy map was taken as 4 cm. Walls or obstacles of the internal map are represented by gray pixels which mean existence probability of obstacles. The measurement environments have selected a room (6.0 × 3.5 m), two rooms connected with the aisle (two 6.0 × 3.5 m rooms), and three trees existence area (10 × 6 m). In all experiment, the height of the LIDAR sensor was positioned at 0.8 m height.

3. Experiment and Results

Firstly, in experiment 1, the proposed method's fundamental performance of the map creation was confirmed. A room of 6.0 × 3.5 m and the connected 2.2 m width corridor area was used (outline of the room is illustrated in Figure 4a and the picture is shown in Figure 5.) In this situation, the position of the walls and objects did not move, and the position of the LIDAR was moved from the position A to D with 0.8 m height four wheels cart. The LIDAR sensor firstly sets into the depths direction (position A) and is changing the direction to the entrance of the room. After the change the sensor direction, the sensor position was moved to D position via B, C points. Total experiment time was about 192 sec.

Figure 4b shows the result of experiment 1. Since the LIDAR sensor was moved (and rotated) from the point A to D by four wheels cart, the map with the corridor via the room door could be created. Many obstacles and room shape was correctly mapped even if there is a narrow room door (width about 0.8 m) passing process. Green triangles represent the position and direction of the LIDAR sensor, and the green crosses represent the estimated position on the map. For example, the precision of the position estimation was measured 0.829 m (the distance from E to F) where the real distance was 0.824 m (the difference is 5 cm, about 6 % error was found while the movement from A to D). Position estimation error was calculated as Δx = -0.12 $\pm$ 0.022 m, Δy = -0.02 $\pm$ 0.023 m (N=5). And the rotational estimation error was calculated as $\Delta\theta$ = 0.17 $\pm$ 0.85 deg (N=5). This experiment was intended to confirm that the occupancy map creating process was not affected by the proposed LI filter.

Next experiment 2 shows the effect of the creeping while the map creation in the case without/with the proposed LI filter in the 6.0 × 3.5 m room (Figure 4a, position A). In this experiment, the LIDAR sensor firstly sets the depth direction (position A). Total experiment time was 30 sec (without the LI filter) and 1 hour (with the LI filter).

Figure 6 shows the result of experiment 2. In the case without LI filter (Figure 6a), even though the LIDAR sensor was not rotating while the experiment, the rotation estimation was continuously creeping. About -10.5 deg angle creeping appeared after 30 sec experiment. The occupancy probability of the wall position becomes rotationally creep, and the wall becomes thicker. On the other hand, in the case with LI filter (Figure 6b), there are a small rotation and position estimation errors after 1-hour experiment. Position estimation error was calculated as $\Delta x, y = 1.8 \times 10^{-6}$ m, less than the LIDAR measurement error about 0.04 m. And the rotational estimation error was calculated as $\Delta\theta$ = - 0.03 deg. This experiment shows the basic role of the proposed LI filter.

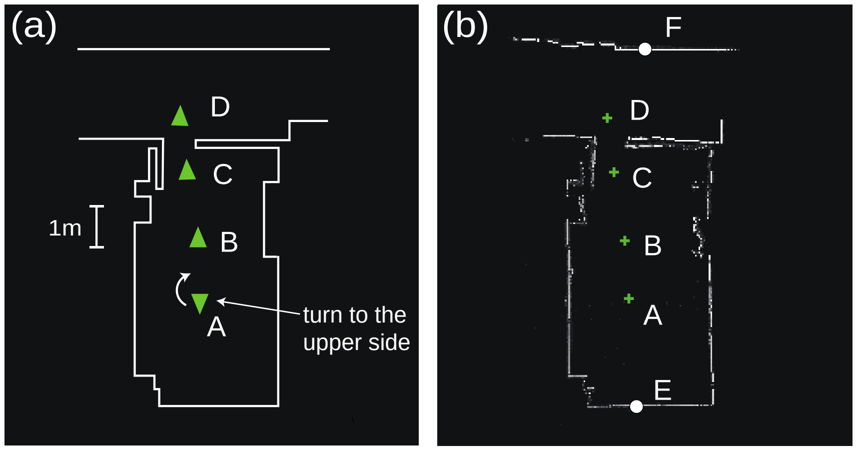

Figure 4. Experimental condition and the result of experiment 1. 6.0 × 3.5 m distance room SLAM process example. In position A, the LIDAR sensor was rotated 180 deg and moved from A to D by hand. Triangles shows the position and direction of the sensor. Total experiment time was 192 sec.

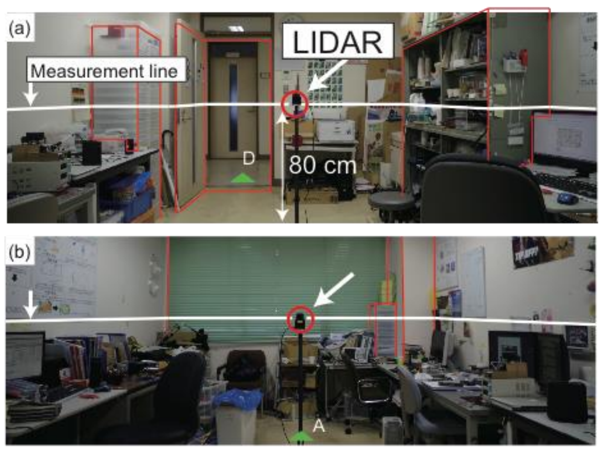

Figure 5. Experimental condition of the experiment 1. (a) The LIDAR sensor was in position A and faces upward. About 0.8 m height 2D distance measurement values were used. (b) The sensor was in position A and faces downward (initial position and direction).

In experiment 3, the map creation in the natural outdoor situation - three trees existence condition was measured with/without the proposed LI filter (Figure 7a and the layout was illustrated Figure 7b). There is not stable small wind situation (about 1 m/sec). The LIDAR sensor was rotated 360 deg right direction by hand during 3 min (without the LI filter) / 38 min (with the LI filter) with 0.8 m rotational table.

The result of experiment 3 was represented in Figure 7c with the LI filter case. In the experiment, the LIDAR was rotating 360 deg / 2 min by hand while 38 min experiment in the outdoor situation. After the 38 min experiment, the occupancy map was stably maintained, and there is also slight rotation and position estimation errors after 38 min experiment ($\Delta x, y$ = 0.0 m, $\Delta\theta$ = 0.083 $\pm$ 0.22 deg, N=5). On the other hand, if there was no LI filter case, the result was shown in Figure 8 while 3 min experiment in the same outdoor situation. After the 3 min experiment, the occupancy map was rotated and shifted the estimating position (Δx = -1.52 m, Δy = 0.04 m, $\Delta\theta$ = -25.41 deg). The green cross mark (estimated the LIDAR position) was moved from "start" to "end" points while the 3 min experiment. In the experimental condition, since the rotation/position estimating algorithm [50, 60] was same, the occupancy map deformation was induced by the existence of the LI filter or not.

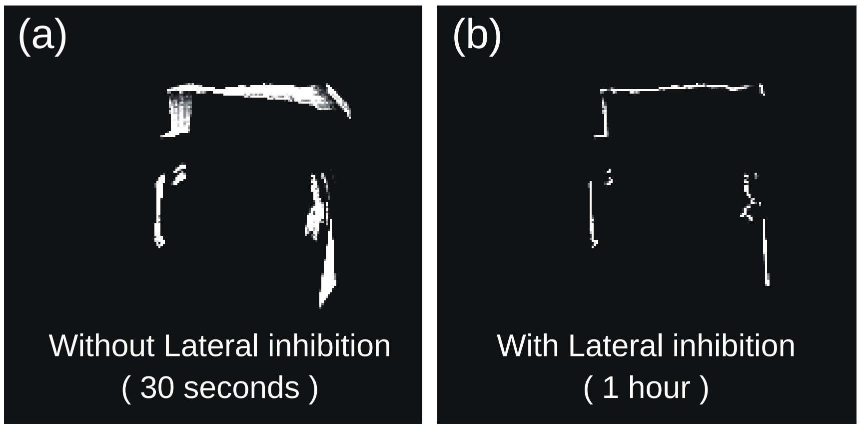

Figure 6. Result of experiment 2. (a) The occupancy map of the 6.0 × 3.5 m room without the LI filter condition (30 sec). There was rotational and position shift creep in the map creation process. (b) With the LI filter condition (1 hour). There was no rotation and position shift creep.

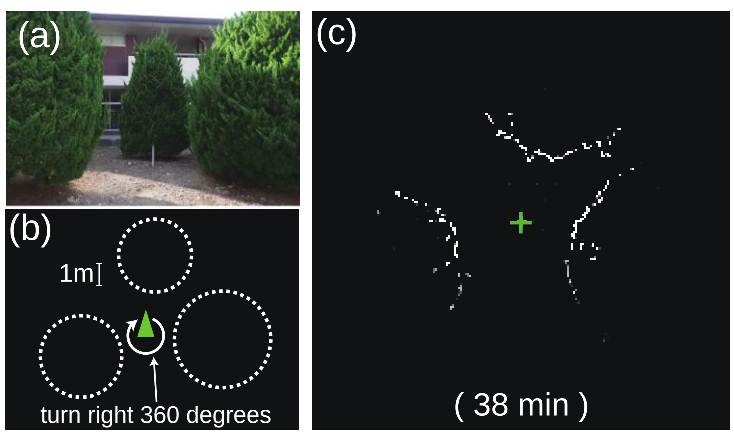

Figure 7. Result of experiment 3. (a) Outdoor environment surrounded by three trees. (b) The layout of the trees. (c) The occupancy map was created by 38 min experiment.

4. Discussion

In this research, the effect of the proposed LI filter real-time map updating algorithm was confirmed by three experiments that included outside environment with a wind flow. The characteristic point of the method is that the estimation algorithm of the position and rotation was used previously proposed and researched methods [28], and it means that the present result represents only the effect of the LI filter. The proposed method assumed the situation of vibrating the environmental factor of walls such trees or leaves, but the position of the distance sensor was also moving when the sensor was positioned on the mobile platform in the general situation. As shown in Figure 1, even though the sensor position was moving while the mapping process, our proposed LI filter could be modified the occupancy map real timely, and there is a possibility that the noise reducing and map wall position modifying ability could be realized.

From another point of view, biological system maybe has the mechanism that it would not only accumulate the mapping information but organize the map and brush up the internal map to create the internal map inside the head. The mechanism of the organizing and brushing up in the biological system have not been revealed clearly so far [69, 30], and there are few studies about this research fields [5,27]. Though the proposed method adopts the LI filter, it cannot proof the reason by the biological system architectures so far. However, it probably could show one of the practical reasons for using LI filter by the biological systems.

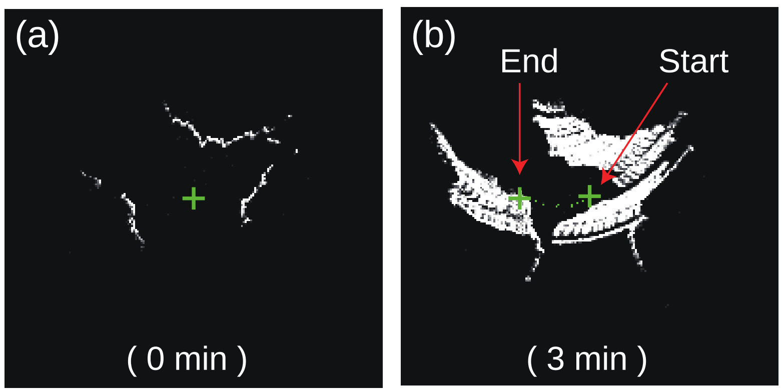

Figure 8. Result of experiment 3 in the case without the LI filter. (a) The occupancy map when the experiment start. (b) After 3 min the occupancy map.

5. Conclusions

In this paper, a real-time map updating algorithm using a concept of lateral inhibition was proposed, and it was evaluated by simple 2D room/outside situation mapping experiment. In a map creation and updating process, the position of the external environment "wall" such as woods, leaves and grasses would vibrate and be measured unstably. And it would lead an instability of the map creation. Our proposed method is to apply the lateral inhibition process to the real-time map updating process. It can inhibit the probability distribution creeping of the wall position in long-time map updating process. The experimental result of 6.0 × 3.5 m 2D room with many obstacles shows that the x-y positional and the rotational estimation precision would be measured as $\Delta x, y$= 0 m and the $\Delta\theta$= - 0.03 deg (1-hour measurement), and the map was updated real timely without the wall becomes thicker when the LRF sensor was moving from a position to another room position with low speed. After the 38 min outdoor experiment, the occupancy map was stably maintained, and there is also slight rotation and position estimation errors ($\Delta x, y$= 0.0 m, $\Delta\theta$= 0.083 $\pm$ 0.22 deg, N=5). By using the lateral inhibition mapping update algorithm, the long-time stable position and rotation estimation and mapping process could be realized.

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