Development of rough terrain mobile robot by self-position estimation used single marker and outer Product

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Abstract
In the present study, a mobile robot control strategy of rough terrain capable of position and direction estimation by a single marker was proposed, and the effect was performed. To realize wheel/caterpillar mobile robot movement on the rough terrain such as house farm, two major problems (1) the precise position estimation and (2) the direction estimation are important before the development of the control theory. Generally, the position/direction have been estimated by the wheel rotation (odometry) and gyro or acceleration sensor's output integration, but there are many problems such as many impacts from the ground and the wheel slipping on the rough ground to the precise estimation. The aim of this study is to develop a method (algorithm) to estimate the mobile robot direction using a single marker placed at the top of the robot by changing the front movement and the target direction movement periodically. The reason using a single marker is that it is difficult to process to find and analyze positions of the many markers attached on the robot in the camera image from a long distance, and the positions of many markers have been unstable by the tilting of the robot, agricultural product's shadow, getting dirty of the body and so on. Our proposed method would be effective in the difficult situation to find or analyze the marker position of the robot surfaces by the reason of camera position and the environment, and it could realize wheels/caterpillar type mobile robot movement on the muddy situation.

Keywords: Odometry, Caterpillar Mobile Robot, Outer Product, Marker

Introduction
In this paper, a mobile robot control strategy of rough terrain capable of position and direction estimation by a single marker was proposed, and the effect was performed. Current agriculture in Japan has a problem of aging of agricultural workers, and the substitution of agricultural work by robots is becoming increasingly important socially [1]. To realize wheel/caterpillar mobile robot movement on the rough terrain such as house farm, two major problems (1) the precise position estimation and (2) the direction estimation are important before the development of the control theory.

Fig 1: Difficulty of the position estimation of the wheel / caterpillar type mobile robot platform in the rough terrain house farm
Figure 1a shows the major situation of the mobile robot movement environment for application in the house farm. Previously proposed robot application in house farm used multi aluminum/stainless rails on the ground to realize correct position/direction movement of the robot [2], however many costs are necessary for the equipment and the rails become a factor hindering effective use of agricultural ground. Even if the rail is set up on the farm, the problem of measurement and movement of the mobile robot's current position is caused by dirt or slippage on the rail. The need for long-term maintenance has not yet been discussed. As another solution of the mobile robot localization and control, colored markers attached on the mobile robot (ex. Fig. 1b) could be used, and the position would be measured by camera attached on the ceil. But the extracting position of the markers are generally difficult by the reason of mixing with environment colors, marker shape (area) instability, the distance from the camera to the markers, and multi markers geometric position combination problem [3]. To estimate the position and the direction of the robot, two markers are necessary at least in 2D map. But it is not always possible to detect the two markers in the rough terrain field in the house farm by above some reasons, especially a marker fusion is a serious problem (Fig.1d) in this situation. This causes disable robot direction detection. In addition, since the wheel/caterpillar rotations affected by the slip on the dirt (Fig.1c), the position estimation by the wheel / caterpillar rotations (odometry) was failed generally. Our proposed method uses one marker of the mobile robot to improve the detection performance of the robot with the camera on the ceiling, and estimates the direction of the robot with a new two-phase motion control algorithm using the outer product. In this paper, we performed a basic study of position estimation / movement control of a caterpillar mobile robot on rough terrain.

Previous Study
Auto-runner [4] is a previously proposed unmanned pesticide spreader in house farm environment. It could realize the pesticide spread by moving the all area on the house railed with metal rail. Since the robot does not estimate its own position, it cannot manage with slippage on the rail, and it is expensive setup. In University of Shimane [5], it represents omnidirectional mobile robot to convey objects in a complicated and narrow environment by using a special wheel called a omni-wheel, it can move in all directions. It have constructed an algorithm that estimate the position and orientation of the mobile robot with high accuracy acceleration and gyro sensors mounted on the robot, and the rotation angle of the driving wheel. Since the wheel usually slipped on the farm, the acceleration and gyro sensor values could not correspond to the real wheel rotation angle information and it is impossible to estimate the correct position and direction.

Method
A. Experimental Devices and The Setup
Figure2 shows the experimental setup devices, (a) Caterpillar mobile robot (BLIZZARD SR, Kyosyo Corp., 35cm ×30cm ×8cm) attached red marker (0.18m ×0.18m), (b) Setup of the experiment. Camera (640 pixels ×480 pixels, 30 fps) was attached on the ceiling and two markers (the robot and target) were found by red color image analysis.
A in Fig. 3b. Method (a) was previously proposed general direction estimation algorithm and the caterpillar rotations only were used to estimate the direction in this study. On the other hand, Method (b) was a proposed strategy, and there is two control phases in the strategy - (A) Forward movement phase to estimate which is the head direction of the robot, and (B) Approach phase to control the robot to the target position. In the Forward phase, the R and L channel power balances of the caterpillar robot were set same values eg.100% while 300ms period, and the red marker position movement was measured and set as $\alpha$ in the 300 ms phase. Next approach phase use $f_R$ and $f_L$ as R and L channel powers of the robot defined below in the period of 300 ms,

$\text{Cross}_z = \hat{a} \times \hat{b}$  \hspace{1cm} (1)

$f_R = a\text{Cross}_z + \beta_R$ \hspace{1cm} (2)

$f_L = a\text{Cross}_z + \beta_L$ \hspace{1cm} (3)

where $\alpha$ is constant, $\beta_R$ and $\beta_L$ are power bias parameters depended on the machine.

The parameters were set to move the robot forward direction if the cross product value $\text{Cross}_z$ is zero. In the Method (b) control, the (1) to (3) are used

**Experiment**

Experiment 1 performs basic forward movement test when the right caterpillar power changed 40% to 100% and the left power was fixed 100% (power supply was 12 V DC, the power was changed by 1 kHz PWM and the ON time ratio). Experimental time was 500 ms. From this experiment, the power bias parameters $\beta_R$ and $\beta_L$ were determined. The ground condition of the room was flat (polished concrete), but slippy surface for the plastic caterpillar.

Experiment 2 performs movement control to the target position on the slippy surface of the polished concrete when Method (a) and (b) control strategy. The area of the experiment was 4 m ×3 m field, and the target position was set (-0.4, 2.3) m from the start position.

Experiment 3 confirms the effectiveness of the outer product. The robot is moved by the control method using the outer product and angle algorithm. Compare the relationship between the distance to the target, the angle, and the value of the outer product.

**Result**

Figure 4 represents the trajectory plotting result of experiment 1. The robot was started from (0,0) position. Since 100% plot is tilting to the left side (x,y)=(-0.13,0.45), the movement power of the right motor is large comparing with the left. Even if the power input to the motors were completely same, the real robot movement would be affected by another factor such as caterpillar surface friction, gear friction loss and so on. From this result, the robot was moved to almost straight ahead when the power of $R:L = 70\%:100\%$. As a result, we set $\beta_R=35\%$ and $\beta_L=50\%$ respectively in later experiment. Figure 5 represents the trajectory plotting result of experiment 2. Red and green circle were start and target position respectively. Blue colored plot was the result of Method (a) control. The trajectory largely deviated to the left side, and the front direction of the robot was different from the target direction (black arrow). Red colored plot was the result of our proposed Method (b). 300 ms periodical "forward" and "approach" switching control could realize the movement control to the target direction even though in the slippy surface of the polished concrete, and the estimated direction a was estimating correctly in all the situation.

The mechanism of the Method (b) was summarized in Fig. 6 especially in the slipper situation. If the left caterpillar was slipped in a situation (Fig. 6A), even though the power balance was 50:50, the robot position was moved left top side and the direction also changed at the same time. In the situation B of Fig. 6, the robot performs "Forward" phase (Fig. 3), and the vector a would be obtained. In a small area of the slippy environment, the direction of the a would be a kind of pseudo "straight" direction of the robot. Next in the approach phase, the robot would calculate the wheel power on the condition that the vector a is regarded as "straight" direction in the small slippy area. This periodical control process was assumed in the proposed algorithm, and it could realize the performance of rough terrain movement.
Figure 7 represents the trajectory plotting result of experiment 3. The red and blue lines represent the relationship between the angle and the outer product when approaching the target. As the robot approaches the target, it can be seen that the value of angle gradually increases. On the other hand, it can be seen that the value of the outer product gradually decreases. When the target is far away, the angle value is small, so it is almost straight. However, you need to make a sharp turn because the angle increases rapidly when you get close to the target. However, the robot cannot suddenly turn and cannot reach the target. On the other hand, the outer product value is equal to the area of the parallelogram created by the two vectors, so the farther the distance from the target, the larger the outer product value and the coarse movement. As you get closer, the value of the outer product becomes smaller and moves finely. So you can achieve your goals naturally.

Conclusion
In this paper, a mobile robot control strategy of rough terrain capable of position and direction estimation by a single marker was proposed, and the effect was performed. To realize wheel / caterpillar mobile robot movement on the rough terrain such as house farm, it is necessary to solve the precise position estimation and the direction estimation are important before the development of the control theory. This study developed a method to estimate the mobile robot direction using a single marker placed at the top of the robot by changing the front movement and the target direction movement periodically. Experimental result shows that even if there is slip while the forward phase, obtained vector $\alpha$ could treat as a kind of pseudo "straight" direction of the robot, and cross product between $\alpha$ and $b$ would be useful for R and L channel power control. Our proposed method would be effective in the difficult situation to find or analyze the marker position of the robot surfaces by the reason of camera position and the environment, and it could realize wheels / caterpillar type mobile robot movement on the muddy situation.

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