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Development and Experimental Study of a Novel Pruning Robot

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Abstract: This paper presents the development progress of a timberjack-like pruning robot. The climbing principal is an imitation of the climbing approach of timberjacks in Japan. The robot's main features include having the center of its mass outside of the tree and an innovative climbing strategy fusing straight and spiral climbs. This novel design brings both lightweight and high climbing speed features to the pruning robot. We report our progress in developing the robot, focusing on straight climbing, the behavior for uneven surface, and pruning.

Keywords: Pruning Robot, Climbing Robot,

I. INTRODUCTION

The timber industry in Japan has gone into a decline because the price of timber is falling and forestry workers are rapidly aging. This has caused the dilapidation of forests, resulting in landslides following heavy rainfall and the dissolution of mountain village society. However, a pruned tree in a suitably trimmed state is worthwhile because its lumber has a beautiful surface with well-formed annual growth rings. The development of a pruning robot is important for the creation of sustainable forest management. The research and development of a pruning robot [1,2,3,4,5] has been scarce and only one commercial product was available in Japan [6]. The machine climbs a tree spirally and cuts brunches using a chainsaw. This machine's weight (25 kg) and slow speed hinder it from being an optimal solution to resolve the forest crisis. A lightweight platform is required, because most of the mountains in Japan have high slopes, and transportation of a pruning robot is a demanding task. To advance the state of the art of pruning robots, we present an innovative pruning robot that locates the center of its mass outside of a tree. The wheel mechanism is designed for a hybrid climbing method, i.e., the robot is able to switch between straight and spiral climbs. This method ensures both lightweight and high climbing speed features of the robot.

In earlier paper [7], we introduced the basic design concept and described experiments with the prototype robots in detail. Moreover, hybrid climbing method have proven that the proposed pruning robot can climb up and down at high speed [8]. Here, we report our progress in developing the robot, focusing on straight climbing, the behavior for uneven surface, and pruning.

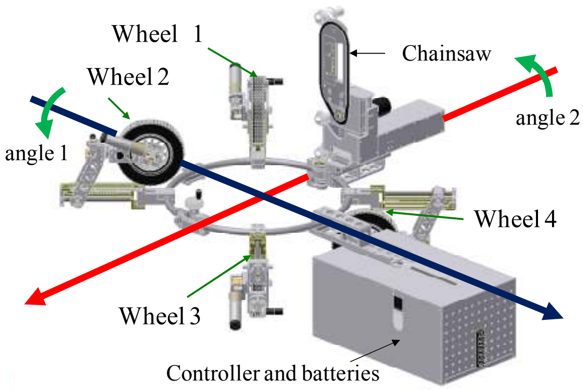
II. DEVELOPED PRUNING ROBOT

With the ultimate goal of building a lightweight pruning robot, we have developed a novel climbing method that uses no pressing or grasping mechanism but relies on the weight of the robot itself, like a Japanese traditional timberjack does when climbing a tree (Fig. 1). The timberjack uses a set of rods and ropes, which is called "Burinawa," and does not hold or grasp the tree strongly while his center of mass is located outside of the tree. That is, the timberjack can stay on the tree using own weight.

Fig. 1 Tree climbing method using "BURINAWA"

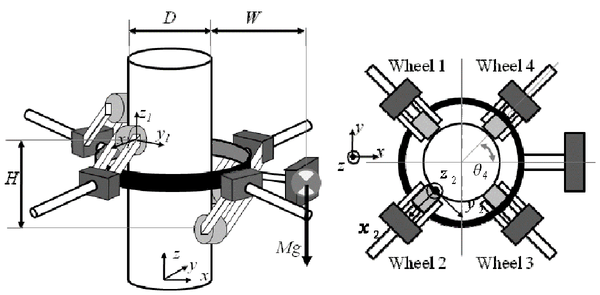
Based on this new design concept and the requirements from the forestry industry, the pruning robot has been developed. As shown in Fig. 2, the robot is equipped with four active wheels. Wheel 1 and wheel 2 are located on the upper side, and wheel 3 and wheel 4 are located on the lower side. Each wheel is driven by a DC servomotor and a warm wheel reduction mechanism which has non-back-drivability. The steering angle of each wheel is also driven by the DC servomotor and warm wheel reduction mechanism. Based on the analysis[7,8,9], the center of mass was located outside of the tree with the help of weight of controller and batteries. The center of mass was located with margin, because the friction coefficient is unclear and the position of center of mass may be moved by disturbance. For example, the robot will be tilted when the robot climb up on uneven surface. In the Fig. 2 (a), the center of mass was located with parameter as follows: H is 0.3[m], W is 0.22[m]. As shown in Fig. 3, where, H is distance between upper side wheel and lower side wheel, W is distance between trunk surface and center of mass. The robot is robustness from the analysis when D is 0.25[m], even if the robot is tilted about 0.1[rad].

(a) Photo image



(b) CAD image

Fig. 2 3rd prototype of pruning robot



(a) side view (b) top view

Fig. 3 3D figure of pruning robot on a tree

The controller is constructed using CPU board, which is equipped with wireless LAN. The controller is able to communicate data/command with personal computer via wireless LAN. Each wheel is controlled by velocity PI control. Feedback input, velocity through high-pass filter, is appended.

By comparison with 2nd prototype[8], 3rd prototype is lightweight expect controller and batteries. Also, controller and electrical source were located outside when the 2nd prototype. Also, the 3rd prototype is equipped with wireless LAN and a chainsaw. Although detail of the chainsaw is omitted in this paper, an experiment will be performed to show an ability of cutting branch using the 3rd prototype.

III. EXPERIMENTS

Three experiment were performed to evaluate the 3rd prototype. The 1st experiment was performed to evaluate basic performance of the 3rd prototype. The 2nd experiment was performed to evaluate the robustness for uneven surface. The 3rd experiment was performed to show whether the robot can prune a branch. All experiment were performed using substitute tree in doors. The diameter of substitute tree was 0.25[m]. The frictional coefficient of the substitute tree was about 0.4, which was smaller than natural tree. To collect the experimental data, motor current, position of the robot, and orientation of the robot were measured. The motor current was measured using shunt resistance. The position were measured by a 3-D position measurement device (OPTOTRAK, Northern Digital Co.). The orientation were measured by a 3-D orientation sensor (InertiaCube2, InterSense Inc.).

3.1 Basic performance

Straight climbing experiment was performed to evaluate basic performance. The desired speed of four wheels was given by trapezoidal profile. A acceleration was 0.2[m/s2], a speed was 0.2[m/s] as 0.075[m] of wheel radius.

The experiment result is shown in Figs. 4, 5, and 6. Fig. 4 shows the speed of the robot. The speed of each wheels was calculated from values of rotary encoder. The robot was able to be climbed up at 0.2[m/s]. Although the delay of start was about 0.5[sec] owing to control law, it was not a problem. Fig. 5 shows the movement distance. "3D" is measured value by a 3D position measurement device, and movement distance of each wheel was calculated from value of rotary encoder. In the Fig. 5, we found three kind of error as follows: (E1) errors of movement distance between each wheel and 3D position measurement device, (E2) error between wheel 1 (or 3) and wheel 2 (or 4), (E3) error between wheel 1 and wheel 3 (and error between wheel 2 and wheel 4). We considered two reasons. The 1st reason is difference of deformation of each wheel. The movement distance of each wheel was calculated as 0.075[m] of wheel radius. The wheel was composed of urethane and inner tube, which was deformed by acting force. The deformation volume is depend on the force magnitude. From the theoretical analysis[7,8,9], the force magnitude of 3rd prototype tends toward as follows: the normal force at nearer the center of mass becomes bigger than it of opposite side. Hence, Fn4 = Fn2 > Fn3 = Fn1 was considered, where Fni is magnitude of normal force of wheel i. (E1) and (E2) can be explained by 1st reason. Also, we considered that reason of (E3) was slippage of wheel on the trunk. Fig. 6 shows the electric current of wheel motors that were measured by shunt resistance. The theoretical analysis[7,8,9] also has shown that the tangental force at lower side become bigger than it of upper side. Fig. 6 tends toward the theoretical analysis.

3.2 Behavior for uneven surface

To use the robot safely, the robot must be robustness for uneven trunk. The bump is caused by the growth of remnant of pruned branch. Therefore, straight climbing

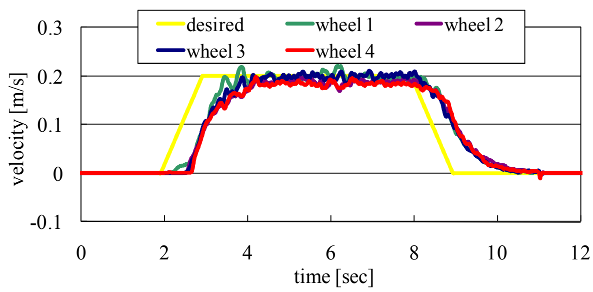


Fig. 4 Climbing speed

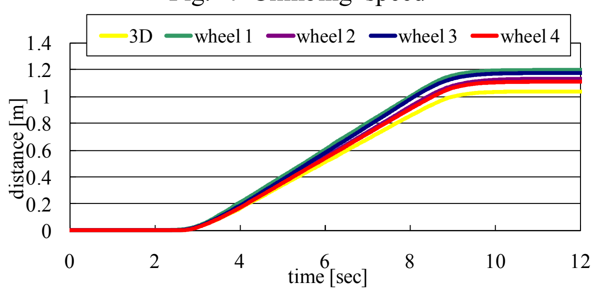


Fig. 5 Climbing distance

experiment were performed to evaluate the robustness of the developed pruning robot for bump on trunk. This experiment was performed substitute bump. The bump was made of ABS plastics, which was bigger size than natural bump. Also, the desired speed of four wheels was given by trapezoidal profile. A acceleration was 0.2[m/s2], a speed was 0.2[m/s] as 0.075[m] of wheel radius.

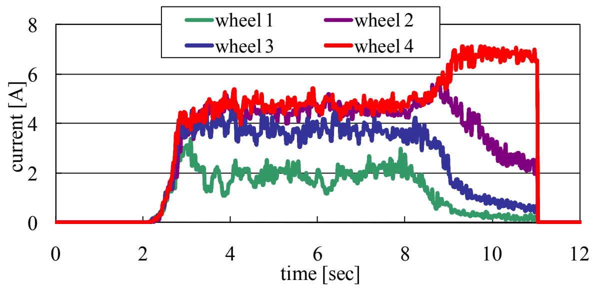
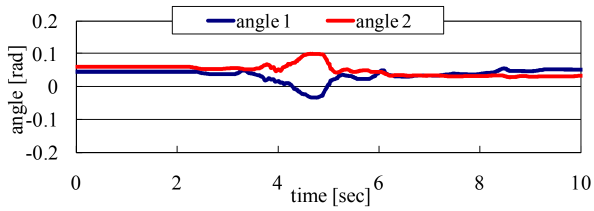
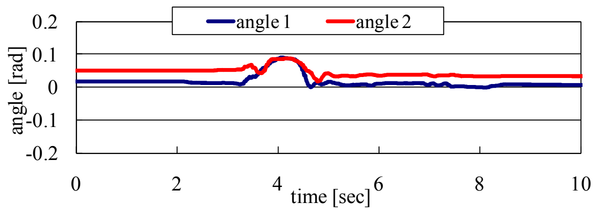


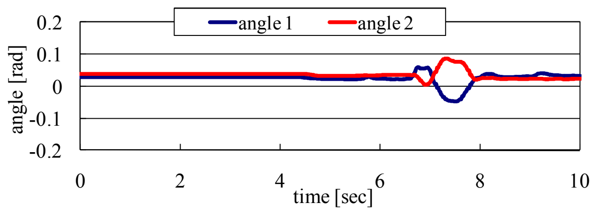
Fig. 6 Electric current of each wheel



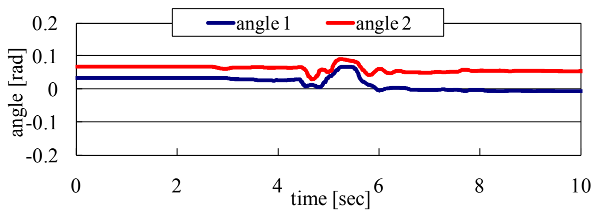
(a) Wheel 1 goes over the bump



(b) Wheel 2 goes over the bump



(c) Wheel 3 goes over the bump



(d) Wheel 4 goes over the bump

Fig. 7 Roll angle and pitch angle each case

The experimental results are shown in Figs. 7. Figs. 7 shows the trajectories of angle 1 and angle 2 (About angle 1 and 2, see in Fig. 2(b)). The angle 2 rotated toward the plus direction in all cases, that is the controller box was uplifted. This means that the center of mass moved toward the tree. Equally, the center of mass moved toward the tree when angle 1 rotates toward the plus direction. It means decreasing of the friction force to stay the robot on the tree. However, the electric currents of wheel 2 and 4 were bigger than continuous current in the experiment. Therefore, there were no danger of falling down. On the other hand, those angles were returned back to former angles, although both angle 1 and angle 2 were changed when the each wheel get over the bump . This results shows the good robustness.

3.3 Pruning Experiment

An experiment was performed to show whether the 3rd prototype can prune a branch. An attached chainsaw was driven by DC motor with 24[V] battery. The robot climbed up spirally at 0.03[m/s] speed. The diameter of target branch was 0.01[m].

The experimental scene is shown in Fig. 8. As the result, the branch was cut with short remnant, which was less than 0.005[m]. Also, the trunk was not injured.

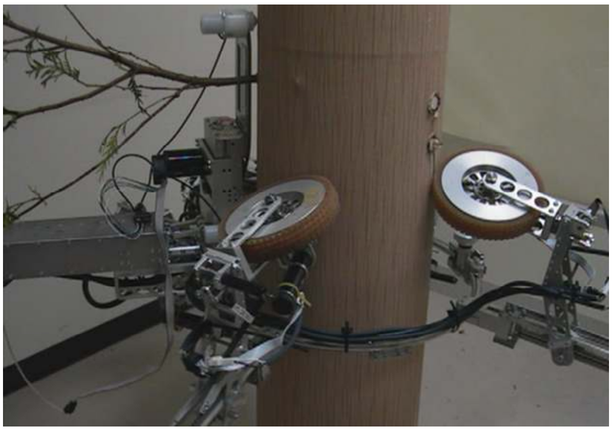


Fig. 8 Pruning experiment with pruning robot

VI. CONCLUSION

The development progress of a timberjack-like pruning robot is presented, focusing on straight climbing, behavior for uneven surface, and pruning. The straight climbing experiment has proven enough basic performance of 3rd prototype. The experimental result of climbing up on the uneven surface has proven the good robustness for the bump, because most bumps on the tree of afforested area is smaller than it in general. Moreover, pruning experiment has proven that the 3rd prototype can prune a branch.

In the future work, we would like to test in the real environment, and improve the robot more.

V. ACKNOWLEDGMENTS

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