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Design and Control of a Hydraulic Dual-Arm Robot for Vegetation Management to Enhance Fire Safety in Nuclear Power Plants

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1. Introduction

Fire incidents in nuclear power plants pose unique risks compared to those in conventional buildings or industrial facilities, making fire safety a critical aspect of plant operation. Following the 1975 Browns Ferry Nuclear Plant fire in the United States, awareness of fire hazards in nuclear facilities significantly increased [1]. Effective safety management requires not only fire suppression systems but also preventive measures to reduce the potential for fire spread. In particular, vegetation around the plant represents a considerable hazard due to its low ignition temperature and rapid combustion propagation. Moreover, overgrown vegetation near fences, entrances, and perimeter zones can obstruct surveillance systems, thereby compromising both security and safety. For these reasons, systematic vegetation control and the removal of combustible materials are essential components of nuclear power plant safety management.

In advanced agricultural regions such as the United States and Germany, lawnmower robots have been actively researched and developed. However, existing systems, including Bosch Indego (Germany), Husqvarna Automower (USA), and MoeBot (Australia), are generally limited to mowing grass on flat surfaces. For trimming trees and shrubs, heavy machinery is often required, and in many cases, specialized equipment and complex robot control strategies must be employed to adapt to specific environments. In this study, we propose a novel mechanism design methodology that enables both mowing and branch trimming by integrating a commercially available lawnmower tool with a humanoid robot. Unlike conventional approaches, the proposed mechanism allows the robot to perform versatile vegetation management tasks without relying on specialized machinery, thereby broadening the applicability of lawnmower robots in unstructured outdoor environments.

2. Mechanism design

2.1 Adaptive mechanism structure

The structure of the adaptive mechanism for irregular environments is illustrated in Fig. 1. The mechanism consists of three main components: a modular coupling unit designed for attachment to the humanoid robot hand, a fixture unit that securely holds the commercial brush cutter tool, and an adaptive joint unit that enables passive motion to accommodate unstructured terrain. The modular coupling unit is fastened to the robot hand using bolts, allowing for easy attachment and detachment by the operator, while ensuring that the mechanism remains firmly secured against external forces. The fixture unit employs an interference fit combined with bolted connections to prevent detachment of the commercial tool under external loads, thereby enhancing structural reliability.

The adaptive joint unit incorporates a pin-and-joint configuration, which allows the fixture to rotate in response to forces exerted on the tool during operation in irregular terrain, thus enabling continuous cutting performance.

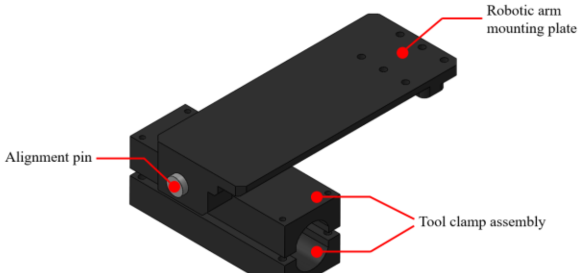

Fig. 1. Adaptive mechanism for irregular environments

2.2 Stability Assurance Mechanism structure

The operational stability of the robotic arm is significantly enhanced by the structure shown in Fig. 2. This design, which can be securely attached to the robotic arm, consists of two main components, a stopper that limits the rotational angle of the lawnmower and a vibration damping unit that minimizes residual vibrations. The stopper is affixed to the robotic arm with bolts, ensuring it remains secure even under external forces. This component prevents the lawnmower blade from pointing toward the ground when the robotic arm is raised to cut leaves or branches. As illustrated in Fig. 3, this prevents the blade from facing away from the target, ensuring effective operation.

The U-shaped vibration damping unit is specifically designed to minimize residual vibrations in the yaw direction. These vibrations can occur when the lawnmower impacts a stone during mowing or are caused by the inertia of the lawnmower itself.

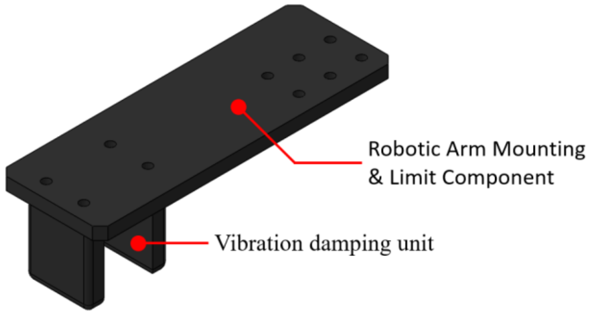

Fig. 2. Structure of the Stability Assurance Mechanism

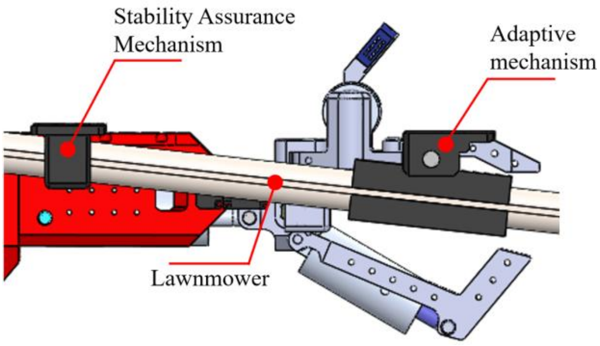

Fig. 3. Stability Assurance Mechanism Preventing Downward Sag of the Lawnmower

3. Experimental Results

3.1 Demonstration of the Mechanism

In this study, a commercially available lawnmower auxiliary disc was employed not only to maintain a constant distance between the mower blade and the ground during mowing operations but also to reduce the complexity of robotic control (Fig. 4). For the experiments, we utilized the ARMstrong robot, developed by the Korea Atomic Energy Research Institute (KAERI), which consists of a hydraulic system and has a payload capacity of 100 kg per arm [2].

For the performance evaluation of both the adaptive mechanism and the stability assurance mechanism, the proposed system was mounted on the robot hand as shown in Fig. 5. To verify whether the lawnmower, attached to the robotic arm, could passively climb a 25° inclined surface without active arm control, an experimental environment was constructed as illustrated in Fig. 6. The results confirmed that the lawnmower successfully traversed the inclined surface through the passive rotation of the pin-joint structure, thereby demonstrating the effectiveness of the adaptive mechanism.

Furthermore, an additional experiment was conducted to assess the feasibility of branch trimming, as shown in Fig. 7. The results indicated that the stopper effectively prevented the lawnmower from rotating downward toward the ground, while the U-shaped vibration damping unit suppressed residual vibrations in the yaw direction. These outcomes confirmed that the proposed stability assurance mechanism enables stable branch trimming operations.

Fig. 4. Lawnmower auxiliary disc

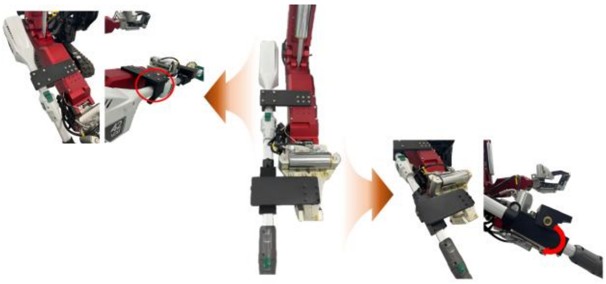

Fig. 5. Mounting Process of the Proposed Mechanisms

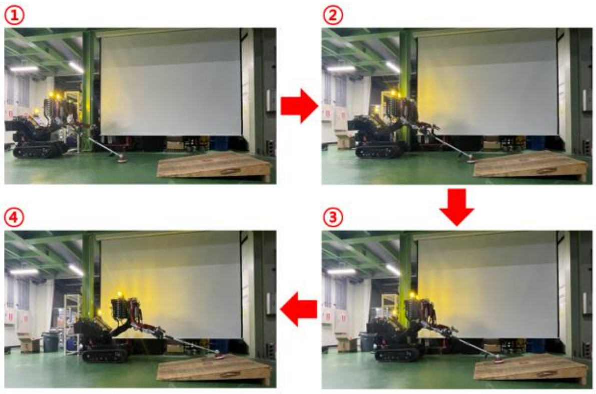

Fig. 6. Performance Evaluation of the Adaptive Mechanism

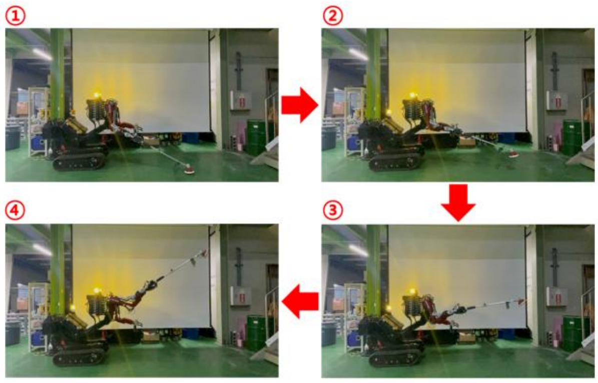

Fig. 7. Experimental Validation of the Stability Assurance Mechanism

4. Conclusions

In this study, we successfully developed a modular and versatile robotic mechanism for both grass mowing and branch trimming. The system's design, which includes a passive adaptive joint unit and a novel vibration damping unit, significantly simplifies robot control while improving performance in unstructured environments. The experimental results confirm that this mechanism enhances both operational stability and cutting efficiency. This work provides a robust and adaptable solution for automating tasks in complex outdoor settings, offering a valuable contribution to the field of robotic manipulation.

ACKNOWLEDGMENT

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