Research on Traversability of Tracked Vehicles on Slope with Unfixed Obstacles

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論文内容要約

Japan is located in the circum-Pacific volcanic belt and has 111 active volcanoes, which correspond to 7% of all active volcanoes of the world. Considering that Japan's land corresponds to 0.25¥% of the world, this is a very large percentage. These "active volcanoes" are volcanoes that erupted within the last 10,000 years and volcanoes that are currently active with fumarolic activity and have a high risk of eruption. When the active volcanoes erupt, various phenomena such as cinder, pyroclastic flow, snow melting type volcanic mudflow, lava flow, volcanic ash, volcanic gas occur. They lead to disasters, and Japan has suffered much damage from disasters. Such volcanic disasters will be difficult to avoid in the future. Thus, prevention or mitigation for volcanic disasters is essential, and the observation of active volcanoes is required for this purpose. On the other hand, when an active volcano erupts, a restricted access area is set around the crater, and it is difficult for humans to approach, work and observe on the volcano directly. Therefore, volcano survey robots that conduct surveys on behalf of humans are required.

Although various robots have been researched and developed for volcano surveys, they can be roughly divided into two types: flying robots and surface mobile robots. The flying robots are useful for rapid observation of the wide area. On the other hand, the surface mobile robots are useful for detailed observation of the ground and long-term observation. The surface mobile robots include wheeled robots, tracked robots, and legged robots. Among them, the tracked robots are suitable for the volcano surveys because they have high traversability on uneven terrain.

When tracked robots move in volcanic environments, it is necessary to climb over obstacles in their path. Those target obstacles can be divided into obstacles that are fixed on the ground, such as buried rocks, and obstacles that are not fixed on the ground, such as loose rocks. In this study, the former is defined as "fixed obstacles," and the latter is defined as "unfixed obstacles". When the robots climb these unfixed obstacles, sliding-down and tipping-over are caused by obstacle rolling. They must be solved because they lead to the failure of survey missions. However, many types of research related to obstacle climbing focus on climbing over fixed obstacles such as steps and stairs. Regarding unfixed obstacles, although there are studies on experiment and simulation of tracked robots on debris, they do not focus on the movement of obstacles and the behavior of robots and obstacles are not analyzed in detail. It can be said that this issue is close to "terramechanics" in that the target moves. However, the target ground of terramechanics is fine particles, and the size of the target is different. Therefore, this research focuses on the analysis of obstacle climbing for unfixed obstacles.

The purpose of this thesis is (1) to understand phenomena that occur when tracked robots climb unfixed obstacles, and (2) to improve the climbing performance of tracked robots on unfixed obstacles. As a first step to understanding the phenomena, a model in a two-dimensional plane simplified by a single-tracked robot, a cylindrical obstacle with a circular cross-section, and a flat slope is considered. The phenomena of the robot and the obstacle are discussed from the three occurrence conditions: climbing-over, tipping-over, and sliding-down. Moreover, to improve the climbing performance for unfixed obstacles, the effect of grousers and sub-tracks are evaluated.

Chapter 1 introduces the background, motivation, purpose, and approach of this research. A literature review is also given in this chapter.

In Chapter 2, to understand phenomena that occur when tracked robots climb unfixed obstacles, the fundamental occurrence conditions of each phenomenon for a single-tracked robot is revealed. In the beginning, phenomena that occur when a tracked robot climbs an obstacle are defined by dividing into three: climbing-over, tipping-over, and sliding-down. Also, a model dealt with in this research that is simplified by a single tracked robot, a cylindrical obstacle, and a flat slope is defined. The climbing-over condition for fixed obstacles is derived from only the geometric relationship between the center of gravity of the robot and the contact point between the robot and the obstacle. The robot climbs over a fixed obstacle when the center of gravity of the robot reaches just above the obstacle. On the other hand, the climbing-over condition for unfixed obstacles is related to not only this geometric relationship but also the rotation direction of the obstacle. The robot climbs over an unfixed obstacle when the center of gravity of the robot reaches just above the obstacle and the obstacle is rolled to the higher side of the slope. However, single-tracked robots can never satisfy the second condition for unfixed obstacles, and can never climb over an unfixed cylindrical obstacle. The tipping-over condition is derived from the geometric relationship between the center of gravity of the robot and the contact point between the robot and the slope. The robot tips over when the center of gravity of the robot reaches just above the contact point. The sliding-down condition is derived from statics.

In the case of fixed obstacles, the robot slides down when the frictional force at two contact points of the robot reaches the maximum static frictional force. In the case of unfixed obstacles, the robot slides down when only the frictional force at the contact point between the robot and the slope reaches the maximum static frictional force. By calculating each condition based on the above, a curved or plane surface of the condition can be obtained. The phenomenon that occurs when a robot climbs an obstacle with a diameter of D on a slope with a slope angle of ϕ can be identified by piling up each surface. Also, the derived conditions were verified by experiments. As a result, it was founded that the conditions are reasonable, and the occurrence phenomena can be estimated from the obstacle diameter and the slope angle. From a comparison between fixed and unfixed obstacles, it was revealed that the difference between fixed and unfixed obstacles is the tendency of the sliding-down, and unfixed obstacles more easily cause sliding-down than fixed obstacles. This is due to the difference in the number of contact points to support the tracked robot and prevent sliding down. Furthermore, the two methods to improve the climbing performance for unfixed obstacles are proposed based on the derived conditions and the experimental results: (1) to increase the supporting points and (2) to control the angle θ between the robot and the slope.

In Chapter 3, to improve the climbing performance for unfixed cylindrical obstacles, the effect of grousers is considered from the sliding-down condition and experiments. This corresponds to the method (1) to improve the climbing performance for unfixed obstacles in Chapter 2. Here, also in the case of having grousers, it is assumed that sliding-down occurs in the same flow as the case of single-tracked robots without grousers. The sliding-down condition is derived regarding a model which is simplified the rigidity and position of grousers. Although it is derived from the maximum static frictional force of only the contact point between the robot and the slope as same as in Chapter 2, the position of contact point which receives force differs from the model in Chapter 2 because of grousers. Also, experiments using track belts with various grousers were conducted. In the experiments, the parameters of the grouser's height and the distance between grousers were changed, and the changes of the maximum slope angle that the robot could climb over the obstacle were confirmed as the climbing performance. Furthermore, the calculation results of the sliding-down condition and the experimental results were compared to verify the validity of the sliding-down condition. As a result, it was revealed that the climbing performance of tracked robots for unfixed obstacles is improved by grousers. Regarding the parameters of grousers, the higher grousers have higher climbing performance, and the climbing performance is maximized when the distance is larger than the distance at which the obstacle just fits. Moreover, comparing the calculational results of the derived sliding-down condition and the experimental results, the proposed sliding-down condition is relatively accurate for low height grousers. Thus, although the model for the condition is a simple model with assumptions, it is found that the sliding-down can be accurately predicted from the proposed sliding-down condition when the grouser's height is lower than the radius of the obstacles.

In Chapter 4, to improve the climbing performance of tracked robots for unfixed obstacles, sub-tracks are dealt with. This corresponds to the method (2) to improve the climbing performance for unfixed obstacles in Chapter 2. As mentioned in Chapter 2, it is necessary to satisfy two climbing-over conditions to climb over unfixed obstacles: (1) the center of gravity of the robot reaches just above the contact point 2 between the robot and the obstacle and (2) the obstacle is rolled to the higher side of the slope. Here, they are extended to the case of having sub-tracks and the effect of sub-tracks on the climbing-over conditions is evaluated. By calculating each condition, it is revealed that the effect of front sub-tracks on the conditions is small, and the conditions are particularly affected by rear sub-tracks. Considering the case of having only rear sub-tracks, the range of rear sub-track angles to climb over an unfixed obstacle exist in some cases depending on the obstacle and the slope. Moreover, they are verified by experiments. As a result, it was revealed that the derived conditions are reasonable and the climbing performance for unfixed obstacles can be improved by rotating the sub-tracks to a sub-track angle in the range that is obtained from the climbing-over conditions. Furthermore, the motion strategies of sub-tracks are considered based on the results. For rear sub-tracks, two strategies are described: (1) not to move the obstacle as much as possible and (2) to roll the obstacle to the higher side of the slope. Also, it is described that the front sub-tracks should be contacted with the ground as soon as possible or be brought as close to the ground as possible.

Chapter 5 summarizes the results of this research. The contribution of this thesis and directions for future research are also discussed in this chapter.

The research outcomes in this thesis will be a basis to understand the climbing-over of tracked robots for unfixed obstacles. By advancing research of this field based on this research, more safe and reliable surveys by tracked robots in not only volcanic environments but also various environments where the unfixed obstacle exists will be realized.