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Mechanical Sensor for the Clearance Depth Control of a Non-explosive Demining System

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Abstract

After introducing a double-tracked mobile robot that was developed to remove antipersonnel landmines, we describe a mechanical sensor that enhances the system's precision. For non-explosive demining, the system rotates the rake assembly and translates the mobile robot that is used as a platform. In short, the system unearths buried landmines non-explosively. After completing the overall system, we continued several experiments but had to suspend the demining in the outdoor environment because of critical problems such as the downhill effect. To solve the problem, we used a mechanical sensor, the basic structure and function of which is described in detail. Finally, when we conducted the experiments in conjunction with the mechanical sensor, the outdoor performance of the system improved considerably.

Keywords: clearance depth control, mechanical sensor, downhill effect

1 Introduction

Nowadays, many landmines are buried in several parts of the world. Because the landmines generate vast human casualties every year, the problem is severe. Under increasing international pressure, many unmanned demining machines were developed to eradicate the problem of landmines. However, the problem is exacerbated by unavoidable limitations such as soil pollution and low adaptability to various types of terrain.

We now introduce a double-tracked mobile robot mounted with a demining unit. The overall system, which can overcome the problems just mentioned, has two fundamental mechanisms. The first mechanism translates the mobile robot on the basis of a variable track configuration; the second mechanism rotates the rake assembly to cultivate the soil in front of the robot. Therefore, in the demining operation, the robot can unearth and gather buried antipersonnel landmines.

To make the concept practical, we had to implement several features. First, we used a clearance depth control to overcome the structural problems and the downhill effect. The clearance depth control is also a key factor in adaptability to different types of terrain. Thus, we developed a new mechanical sensor, which enhances the system's precision. Finally, the experimental results show how the mechanical sensor contributes to the system's performance.

2 Preliminary Inspection

2.1 Structure of the System

The overall system can be basically divided into two subsystems: a double-tracked mobile robot and a demining unit.

We designed the double-tracked mobile robot in terms of the basic concepts of adaptability and passivity. Adaptability is an essential quality for overcoming any off-road terrains, such as stairs. Whenever adaptability is consistent with passivity, the system can adapt passively to external environments. Thus, the robot can travel with little energy loss.

To give the system this capability, we designed the robot's driving mechanism with a variably configured double track. The variably configured double track is shaped like a distorted triangle with an attack angle; it also has a sprocket in each track, which forms a double track as a link mechanism. Previous research has shown that when the design of a mobile robot is based on these design concepts, the vehicle can travel by in any off-road terrain.

The demining unit is an additional part that converts the robot to a non-explosive demining system. It is roughly composed of a rake assembly, a frame and a case. The rake assembly has 18 rakes that can bend with the phase angle in the lateral view. In the frame, we assembled various goods, such as a servo amplifier and a lead screw, which are helpful for raising and lowering the frame in operation. Moreover, to decrease the soil resistance, we assembled the demining unit on the mobile robot at an angle of 45°.

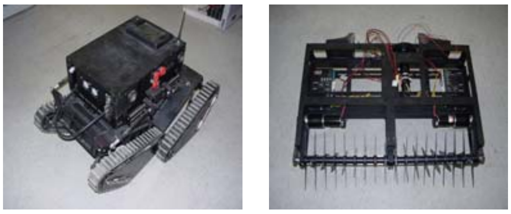

Figure 1: Mobile Robot vs. Demining Unit

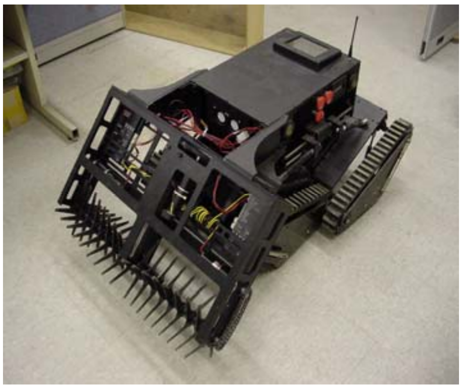

Figure 2: Non-explosive Demining System

Figures 1 and 2 show the developed non-explosive demining system and its two subsystems. It uses 400 W of power when moving forward, and 150 W when rotating the rakes.

2.2 Preliminary Experiments

After designing and manufacturing the system, we continually experimented on improving the system's performance. For all the experiments, we considered all the environments that the system was required to cover.

2.2.1 Indoor Experiment

First, we evaluated the preliminary performance of the system through several indoor experiments. After burying several antipersonnel landmines in a 1.5 m x 1 m soil bin, we tested the system's demining capability and clearly demonstrated that it could extract landmines through the rake rotation.

2.2.2 Outdoor Experiment

We conducted an outdoor experiment with an identical system to assess whether the demining system could perform consistently in an outdoor environment. However, in this experiment, the system failed to perform the required task because of the inclination, which is shown in Figure 3. In other words, while the rake assembly was penetrating the soil in front of the system, the overall system gradually inclined, eventually causing the rotation to be suspended. In the end, the rake assembly was unable to climb over the sudden increment of resisting force from the soil.

Figure 3: System Inclination

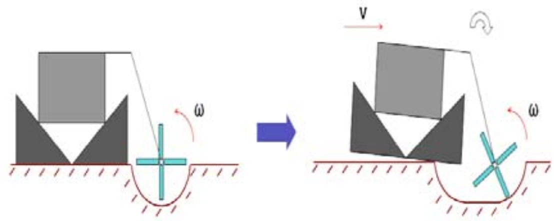

Figure 4: Downhill Effect

There are several reasons for this failure. For more discussion of the practicality of the system, we need to analyze and resolve the chief causes of the failure.

2.3 Problem Analysis

We now analyze the inclination problem and the suspension of the demining in an outdoor environment.

The system is statically unstable on a lateral plane. The platform of the mobile robot weighs 80 kg and, on the opposite side, the demining unit weighs 13 kg. Hence, if the weight of the demining unit is neglected when the platform is being positioned, a moment disparity occurs. Moreover, when the rakes begin to rotate, the resisting force from the soil adversely affects the system, thereby aggravating the moment disparity. Because these problems originate in the structure of the system, they cannot be mitigated without changing the external form. Hence, it is impossible to suggest any novel concepts while adhering to the current structure.

Another critical problem lies in the operating state. In the preparation state, the rotating rakes continuously cultivate the soil in the forward area. This cultivation softens the soil. In the operating state, the mobile robot moves forward while the rakes rotate. However, because the cultivated soil has already lost its hardness, the overall system begins to tilt, and the resisting force from the soil increases. Finally, the rotation of the rakes is suspended. This chain of events is known as the downhill effect, which means that the system operates as if proceeding downhill even when traversing a flat terrain (Figure 4).

The downhill effect is an additional problem that occurs in the operating state. Regardless of the system's structure, this issue must be resolved before the system can successfully demine non-explosively. Thus, we must resolve the downhill effect if we are to achieve practical results.

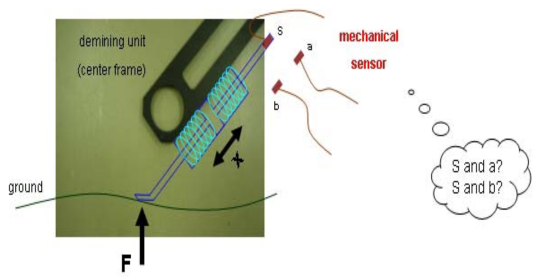

Figure 5: Basic Concept of the Mechanical Sensor

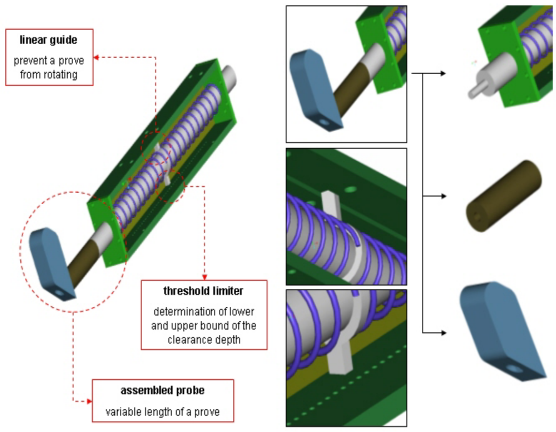

Figure 6: Structure of the Mechanical Sensor

3 Mechanical Sensor for Clearance Depth Control

3.1 Clearance Depth Control

We now present a mechanical sensor that can detect a force by determining variations in distance between the frame and the soil. The sensor is vital for overcoming the detrimental influence of the downhill effect.

The downhill effect causes an undesired change in the clearance depth. The clearance depth, which refers to the distance between the surface of the ground and the end of a buried rake, increases with respect to the inclination of the system. Thus, if we can control the clearance depth by raising and lowering the rake assembly, we may be able to compensate for the downhill effect.

3.2 Suggestion

To solve the problem of the downhill effect, we suggest a method of measuring the distance between the frame and the soil. Figure 5 shows the conceptual design of the mechanical sensor. The sensor, which is attached beneath the frame, accepts a force by contact. Because the force is inversely proportional to the distance between the frame and the soil, the system can determine the clearance depth. It can then control the raising and lowering of the frame and compensate

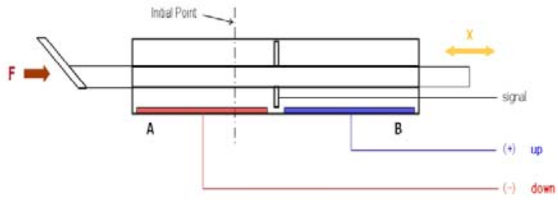

Figure 7: Functional Structure of the Sensor

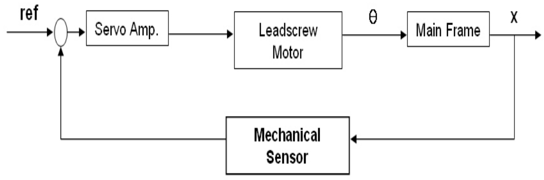

Figure 8: Block Diagram for Clearance Depth Control

for the aggravation of the moment disparity and the downhill effect.

Figure 6 shows the visible structure of the mechanical sensor. At the end of the sensor there is an assembled probe that has three parts that can sense the force of the contact with the soil. A threshold limiter receives an electric signal from a DC motor, which is the power source, and then induces a stick to move. Finally, a linear guide prevents the stick from rotating unnecessarily. Both sides of the threshold limiter hold a spring, which causes the stick to move smoothly.

Figure 7 shows the functional structure that we used to achieve our goal. First, we spread two metal sheets on the bottom of the sensor. One sheet had a positive voltage and the other a negative voltage. When the projected threshold limiter slid with the stick, the stick contacted one of the sheets, thereby generating a signal that indicates whether the frame should be raised or lowered. For example, if we set section A as a negative voltage and section B as a positive voltage, then A corresponds to the signal for lowering the frame, and B corresponds to the signal for raising the frame. In general, the clearance depth control enables the frame to be raised or lowered. This phenomenon is similar to the concept of an on/off switch. Figure 8 shows a block diagram of these concepts.

Several parameters of the mechanical sensor change its capability with respect to resolution, stiffness, and so on. The stiffness of the spring inserted in the shaft is a notable parameter, which determines the resolution of the sensor. In addition, the length of the spring defines the initial position of the threshold limiter and it can alter the timing of the raising and lowering transition.

3.3 Implementation

To simulate the motion of the mechanical sensor with respect to the force sensed at the probe, we enabled

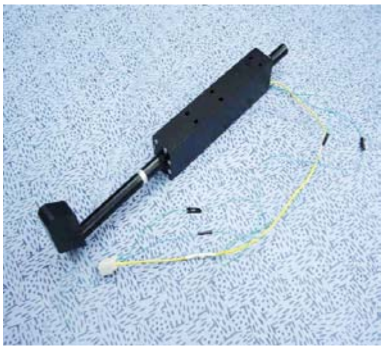

Figure 9: Mechanical Sensor

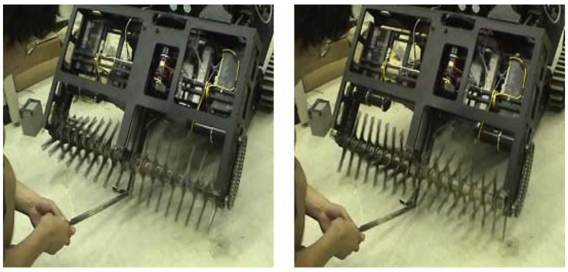

Figure 10: Motion Test of the Mechanical Sensor

the frame to be raised or lowered without any rotation of the rake assembly. As a result, we confirmed that the frame can move up and down smoothly in relation to the artificial variation of the force. Thus, as shown in Figure 10, the mechanical sensor is essential for controlling the clearance depth.

4 Experiments

4.1 Demining in a Flat Terrain

First, we attempted to demine a flat terrain. However, a preliminary inspection without a mechanical sensor showed that the demining system could not be completed because of the downhill effect, in addition to other problems. Hence, we used this experiment to validate whether the mechanical sensor was suitable for the system.

The four images in Figure 11 show the steps of the operation. They show that the clearance depth control with the mechanical sensor proceeded smoothly, and that all the buried antipersonnel landmines were recovered.

4.2 Demining an Angled Terrain

To test how the system adapted to different types of terrain, the system attempted to demine an angled terrain. Thus, the system passed over a flat, downhill, and uphill terrain, in that order.

Figure 12 shows that the demining operation is feasible in an angled terrain. However, in the uphill terrain, the rotation of the rakes was interrupted. This phenomenon was mainly caused by the short encasement of the rake assembly. That is, a longer frame must be used because the transformation to the

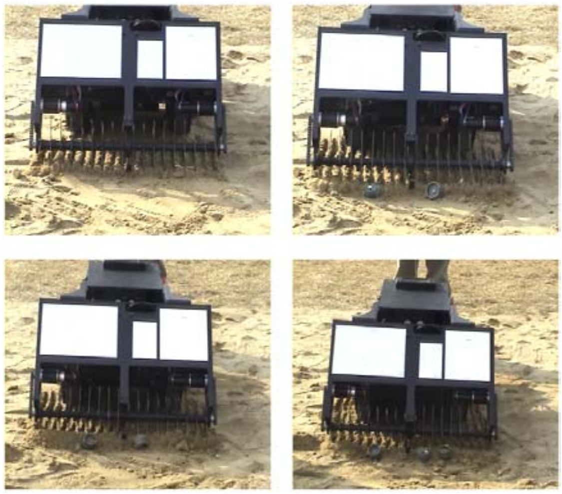

Figure 11: Experiment in Flat Terrain

Figure 12: Experiment in Angled Terrain

uphill terrain abruptly varies the force from the soil. Thus, the mechanical sensor failed to resolve the downhill effect. To solve this problem, we need to lengthen the encasement in future tests.

5 Conclusion

We briefly introduced a double-tracked mobile robot with a demining system, and we investigated an alternative method of resolving the system's critical problems.

To increase the feasibility and practicality of the design, we developed the clearance depth control. By using a mechanical sensor that perceives the force from the soil, we can raise or lower the frame. This capability enables the mobile robot to travel smoothly during the demining operation.

Finally, the outdoor experiment demonstrated that the mechanical sensor helps to overcome not only the downhill effect but also system's structural problems. A deeper investigation of the mechanical sensor may enhance the system's adaptability to different types of terrain.

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