DEVELOPMENT OF THE CONNECTED CRAWLER ROBOT FOR ROUGH TERRAIN

Realization of the Autonomous Motions

Sho Yokota, Yasuhiro Ohyama, Hiroshi Hashimoto and Jin-Hua She
School of Bionics, Tokyo University of Technology, 1404-1 Katakuramachi Hachioji, Tokyo, Japan

Kuniaki Kawabata
RIKEN, 2-1 Hirosawa Wako, Saitama, Japan

Pierre Blazevic
Institut des Sciences et Techniques des Yvelines, 7 rue Jean Hoet, Mantes, France

Hisato Kobayashi
Faculty of Eng., Hosei University, 2-17-1 Fujimi Chiyodaku, Tokyo, Japan

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Abstract: The purpose of this paper is to develop a rough terrain mobile system. Our mobile system adopts the connected crawler mechanism. It had 3 connected stages with the motor-driven crawler tracks on each side. RC-servo motors were used for driving joints between the stages. This system also has a high mobility. In this paper, we showed the mechanical features, and proposed the operation strategies for autonomous motions. We have also made verification experiment of proposed operation strategy. For this verification, we did 2 types of experiment. One was that the robot passes over bumps with different heihgts. The other was stairs ascending. Both experiments had a great success. There were remarkable points in these experiments. These experiments showed that the robot can pass over the different height and different structual obstacles by using only (same) strategy. Moreover the sensors which realize proposed strategy were very simple, and the number of sensor was very small. Therefore it can be concluded that proposed strategy has extremely high usefulness.

1 INTRODUCTION

Since there is a great meaning to use crawler mechanisms as a mobile function on rough terrain, the construction machineries, the tanks, and a lot of rough terrain mobile robots adopt a crawler mechanism. Especially many rescue robots use the crawler mechanisms. Because, in general, crawler mechanisms can obtain big impulsion on rough terrain than the leg mechanism and the wheel mechanisms. On the contrary, it also has weak points as a poor stability in complex geographical features. And the mobility on the area such as stairs is inferior to that of the leg(Hirose, 2000).

Therefore, a lot of researches have tried to supplement with these weak points. The main theme common to those researches is to improve the mobility performance on rough terrain. Generally the variable crawler structure is adopted as an approach for this main theme. In order to realize this transformation, many research proposed connected crawler mechanisms which crawler stages were connected by active joints. Lee et al (Lee, 2003) designs two stages one active joint type resucue robot that uses tow triangular crawlers, and shows the high mobility by the comparison of climb-able step height between proposed mechanism and a usual one track type. ”Souryu-III” (Takayama, 2004) is the connected crawler robots of 3 stages 2 joints type for resuce operations, and it shows high mobility by some basic experiments such as climbing up a step and passing over a gap. ”MOIRA”(Osuka, 2003) is also rescue robot which is 4 stages 3 joints type connected crawler. As mentioned above, the mobility performance was improved by using connected crawler mechanisms.

Although we can see such research, there are no robots which can move autonomously. The one of the most important reason to introducing rescue robots to disaster places is to automate a sufferer searching in place of the manpower searching. If many

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rescue robots can search sufferers automatically, it is enable to search wider and faster than conventional manpower searching, that brings early detections of sufferers. However current rescue robots don't realize the autonomous operations, therefore that has not achieved above mentioned important reason of introducing robots to disaster places.

Thus this research proposes a rough terrain mobile robot which can realize autonomous motion in disaster places. Especially, this paper proposes operation strategies for passing over obstacles autonomously, as well as constructing of connected crawler robot as the first step of this research.

Also this paper is organized as follows. Chapter 2 introduces the outline of our prototype robot. This mobile robot consists of 3 connected stages with the motor-driven crawler tracks on each side. RC-servo motors were used for driving joints between the stages. Chapter 3 presents operation strategies. Chapter 4 addresses the verification experiments. This experimental results will show that the proposed operation strategies can be adapted to various shape of terrain. Chapter 5 describes the conclusions and future works.

2 THE PROTOTYPE

This chapter shows the outline of the prototype. The mobile function of our prototype adopts crawler mechanisms. Because The crawler mechanism shows the high mobile ability on various terrains; moreover it is simple mechanism and easy to control. But conventional single track mechanism has also mobility limitations; the limitation is determined by attacking angle, radius of sprockets, and length of crawler. In order to improve its mobility, we add some active joints to conventional crawler tracks, namely that is connected crawler mechanisms.

2.1 Mechanical Structure

Our mobile mechanism has 3 connected stages with the motor-driven crawler tracks on each side(Fig. 1). The features of the proposed mechanism are as follows.

- This mechanism has high mobility to passing over the obstacles.
- It can adjust the size of the robot.
- It can adjust the attack angle.
- It can minimize the grounding area.

Table. 1 also shows the specifications.

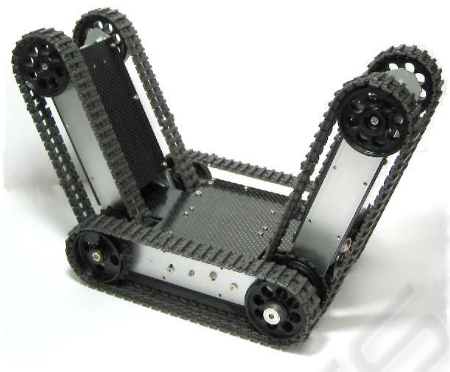

Figure 1: The overview of Connected crawler robot.

Table 1: Specifications of the test model.

Length(maximum)	354.0[mm]
Length(minimum)	118.0[mm]
Width	125[mm]
Mass	0.608[kg]
Radius of the sprockets	20.0[mm]

RC-servo motors are used for driving joints between the stages. The left and right crawlers are driven by 2 DC motors independently, while the 3 crawlers on each side are driven by a motor simultaneously (Fig.2). The output of each motor is transmitted to the sprockets of the three crawlers through several gears.

2.2 Control Structure

We adopt a hierarchical control structure by installing an intelligent servo driver to each actuator. We connect each of them to the master contoll unit by UART serial line. The parts marked by red line in Figure 3 are servo drivers. Each servo driver consists of one

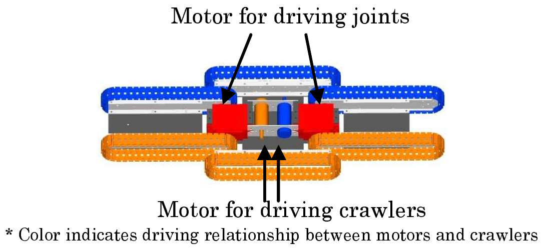

Figure 2: The driving system.

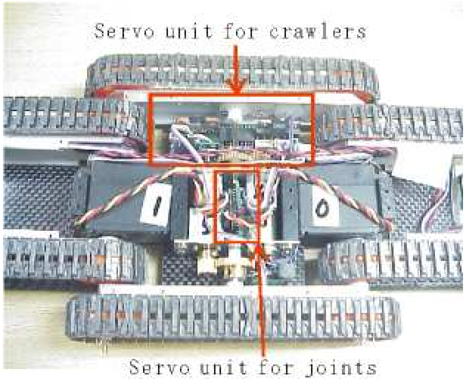

Figure 3: The overview of the servo unit.

Table 2: Communication data format.

1 byte								2 byte	3 byte
Data 1								Data 2	Check Sum
7	6	5	4	3	2	1	0	0∼254	Data1|Data2
Mode=0∼2				ID=0∼3					

microcontroller (PIC16F873) and 2 DC motor drivers (TA8440H). One microcontroller is installed to control the two RC-servo units for the joint control, where RC-servo is controlled only by PWM signal.

Figure 4 shows the control structure of this system. The master unit is equipped with several sensors which are increnometers, PSD distance sensor and photo reflector. The usage of these sensors will be shown in Chapter 3. Master unit culclates high level task (setting trajectory, sensing environment, etc), and servo driver works for low level tasks. The master unit processes the high level task, and derive the data to low level task (crawler velocity, joint angel and so on), and send them to the servo drivers. After receiving these data, the servo drivers control their motor by conventional feedback control low. Table 2 shows the communications data formats. The command sent by master unit consists of 3 bytes. First byte indicates mode ID and motor ID. The mode ID distinguishes 3 kinds of control modes: position control, velocity control and compliance control. The motor ID is used for selecting motor to control. Second byte shows the data depends on control modes (crawler velocity, joint angle). The third byte is checksum.

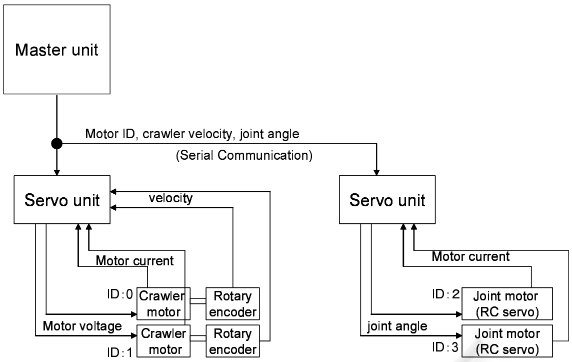

Figure 4: The control system.

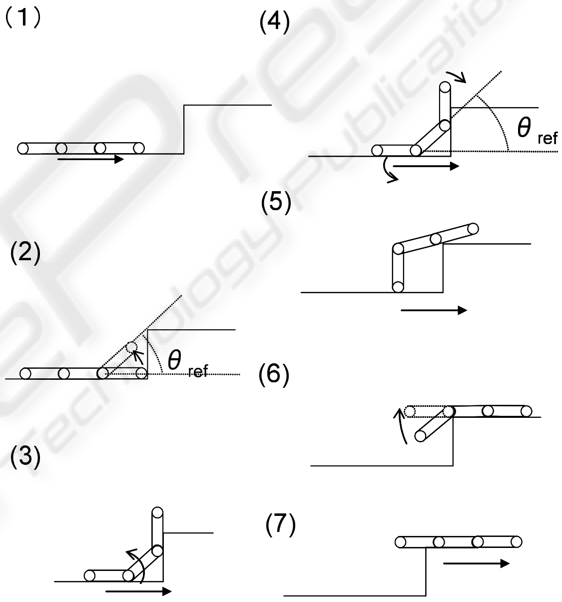

Figure 5: Proposed operation strategies.

3 OPERATION STRATEGIES

A rough terrain such as disaster places has various shapes. Hence, it is difficult to derive each autonomous motion relative to each shape. But it can be assumed that these shapes are consisted of many bumps. Therefore, in this paper, we set the environment to one bump, and consider about the operation strategies to climb up this one bump. Because the climbing bump ability is important as one of the most fundamental mobility index (Inoh, 2005), in addition climbing bump experiment is adopted by many researches as an evaluation experiment for mobilities. The proposed operation sterategies has 7 steps (Figure 5). It is low level operations(tasks), namely it is not high level operations such as path planning etc. In this paper we assume that the trajectory of the robot is already given. Therefore the proposed operation deals with how the robot can pass over the obstacles. Following sections will show the details of each steps.

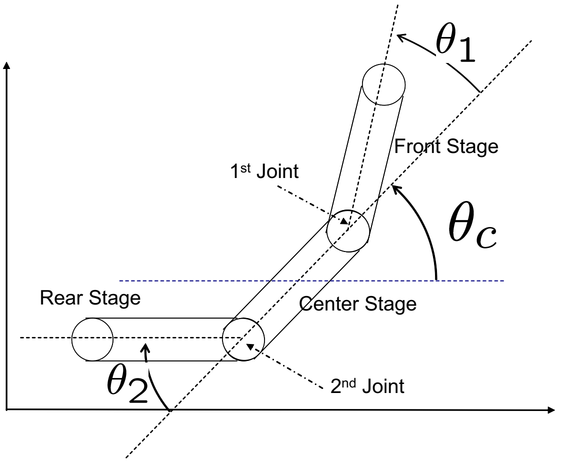

Figure 6: The definition of the parameters.

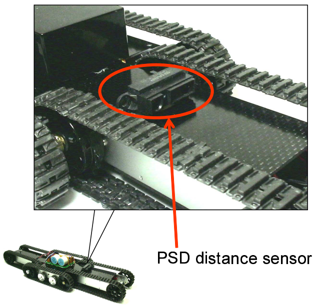

Figure 7: The PSD distance sensor.

Figure 6 is the difinition of the parameters. Here θ_c is the orientation of the center stage. θ_1 and θ_2 are the 1st and 2nd joint angle related to the θ_c. Our proposed operation sterategies can work by using only 3 very simple sensors.

3.1 First Step

First, the robot goes forward until detecting the wall. If the robot faces the wall, then robot stops moving. PSD distance sensor which is attached to the 1st stage is used for detecting the wall (Figure 7). The information of the PSD sensor is managed by the main controller (Figure 4).

3.2 Second Step

In this step, 1st joint are driven to detect θ_{ref}. θ_{ref} is the 1st joint angle when the tangent of front stage meets the edge of the bump (Figure 8).

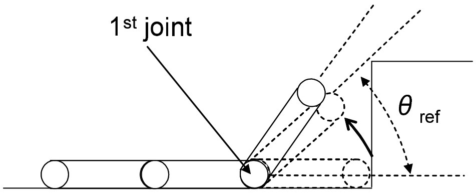

Figure 8: The definition of θ_{ref}.

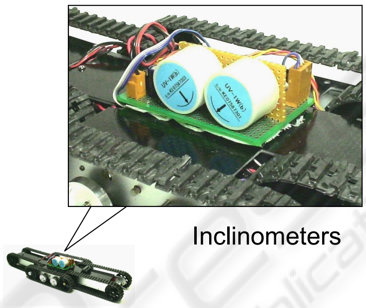

Figure 9: Inclinometers for detecting θ_c.

3.3 Third Step

In third step, 2nd joint is driven while the robot goes forward. The purpose of this step is to get the traction forces by keeping a grounding of rear stage. If the robot goes forward without driving 2nd joint, then robot could not get enough traction forces due to the lift of rear stage. In order to keep the grounding of rear stage, 2nd joint angle should be set to angle of center stage, namely the 2nd joint is driven in the following condition.

$$\theta_2 = \theta_c$$

Here, the inclinometers which are attached to the center stage are used to detect the angle of the center stage (Figure 9).

3.4 Fourth Step

In this step, 1st joint angle is set to 0 rad, 2nd joint is driven to let the angle between rear stage and ground be right angle. At this moment, the robot continues moving. There are two purpose in this step. One is to obtain the traction forces, that is the role of 1st joint motion. The other is to lift up the robot as high as possible, that is the purpose of 2nd joint motion. 2nd joint angle is determined by following condition. By this condition, rear stage can always stand with keeping right angle to the ground.

$$\theta_2 = \frac{\pi}{2} - \theta_c$$

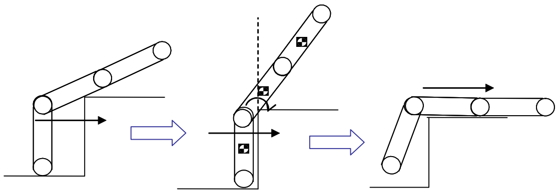

Figure 10: The situation of climbing up a bump.

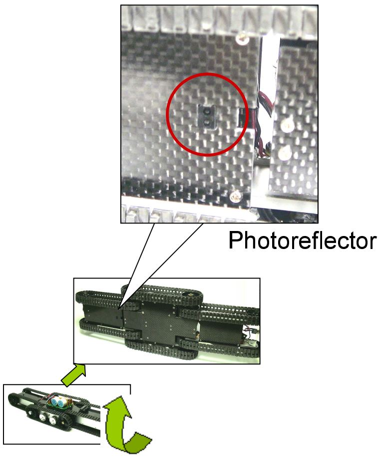

Figure 11: Contact detection device.

The trigger to shift third step to fourth step is the θ_{ref}. In the third step, when the orientation of center stage θ_c is equal to θ_{ref}, operation step is shifted.

3.5 Fifth Step

The robot goes forward with keeping above mentioned conditions. When the center of gravity of the robot is in the right side of the bump edge, then the clock wise moment is generated around the edge, the robot can climb a bump. Figure 10 shows the situation of this case.

3.6 Sixth and Seventh Step

At the end, 2nd joint angle is set to the initial position, not to interfere robot's moving. The trigger for this motion is contact between bump and rear stage. The photoreflector is adopted to detect this contact. This photoreflector is attached to root and bottom of the rear stage (Figure 11).

By above steps, climibing a bump is completed.

4 EXPERIMENTS

In order to confirm proposed operation strategies, verification experiments are conducted. We prepare two kinds of experiments. One is that the robot passes over two bumps with different height. The other is stairs ascending. There are remarkable points in these experiments. These experiment verifies whether the robot can pass over the different height and different structures obstacles by using only proposed strategies. Moreover the sensors which realize proposed strategies is very simple, and the number of sensor is very small. Therefore if these experiments success, it can be concluded that proposed strategies has extremely high usefulness.

4.1 Passing Over the Different Hight Bumps

In this chapter, the robot passes over the different height bumps. The heights of bumps are 150 mm and 40 mm. The experimental environment is indoor, and robot goes only forward, does not rotate and reverse. We made the experiment by implementing proposed strategies to main controller.

The result is shown in Figure 12. This Figure shows that the robot can pass over the different hight bumps autonomously.

4.2 Stairs Ascending

Next experiment is stairs ascending. The height between stairs is 150 mm, that is conventional stairs. The implemented software to main controller is the same as experiment in 4.1, namely we do not add any modification, that is completely same. Then we conducted the experiment.

The result is Figure 13. From this Figure, it is turned out that the robot could ascend stairs autonomously with driving joints.

5 CONCLUSIONS

The purpose of this research is to develop a rough terrain mobile robot which can realize autonomous motion in disaster places. Especially, this paper proposed autnomous operation strategy for passing over obstacles, as well as constructing of connected crawler robot as the first step of this research. The connected crawler robot consisted of 3 crawler stages with active joints. The operation strategies was proposed in Chapter 3. This operation strategies was consisted

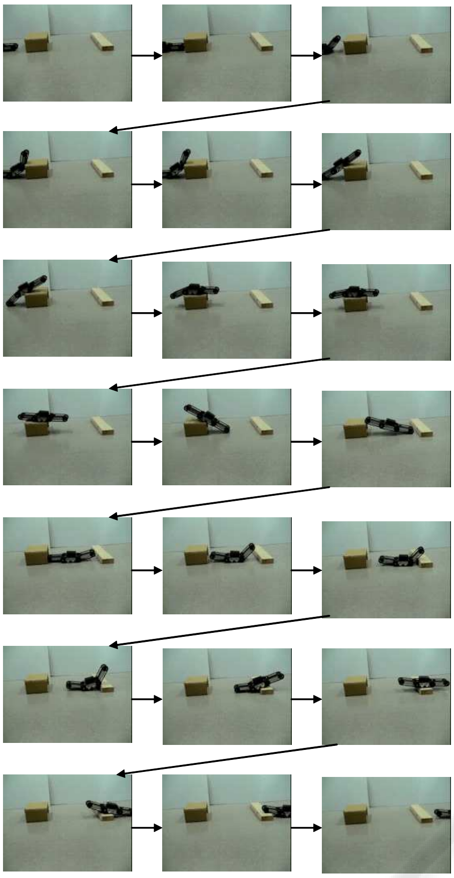

Figure 12: The experimental results of passing over bumps.

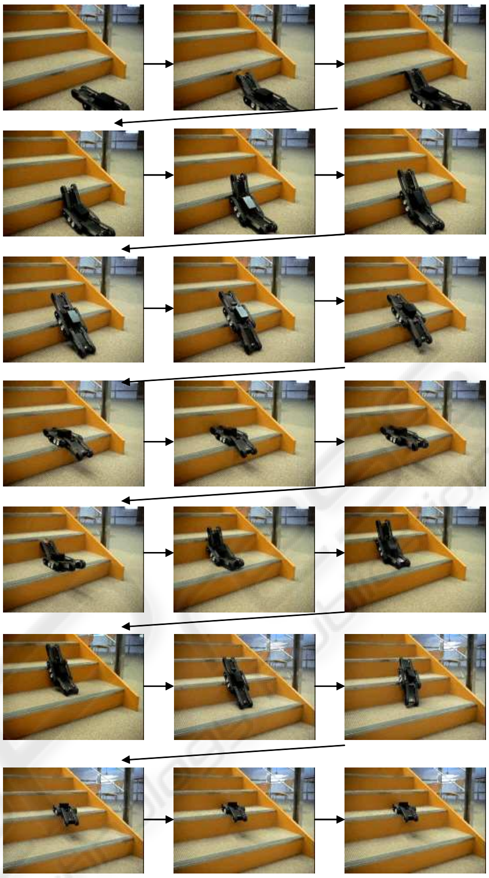

Figure 13: The experimental results of stairs ascending.

of 7 steps, and it needed only 3 simple sensor which were PSD distance sensor, inclinometers and photoreflectors. We have also made verification experiment of proposed operation strategy. For this verification, we did 2 types of experiments. One was that the robot passes over bumps with different heights. The other was stairs ascending.

Both experiments had a great success. There were remarkable points in these experiments. These experiments showed that the robot can pass over the different height and different structual obstacles by using only (same) strategy. Moreover the sensors which realize proposed strategy were very simple, and the number of sensor was very small. Therefore it can be concluded that proposed strategy has extremely high usefulness.

Future works: Proposed method was verified by two experiments. In addition, we are going to verify proposed method by many different types of experiments. Moreover, this paper derived the autonomous motion empirically. Therefore we have to analyze motions of the passing over the obstacles as next step. Furthermore we have to compare empirical results and analytical results.

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