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QuadTrack-II:A Remotely Operated Mobile Robot with Four Articulated Tracks

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Abstract: This paper introduces a remotely operated robotic system being developed for urban search and rescue. QuadTrack-II has four modular track arms which can be driven independently to get a traction force. The modular track arms can also be rotated with respect to their arm axes to lift the body or step over larger obstacles. It has some observation module for gathering information of disaster areas. Inside main body frame, it can carry a small serial multi-linked mobile robot to collapsed areas to find human victims under the rubbles. This paper describes the structures of the robot and some advantages of mobile robotic system with articulated modular tracks and shows some experimental result for various environments.

1. INTRODUCTION

Remotely operated mobile robots with track mechanisms in are used a lot outdoor applications such as EOD and USAR (Casper *et. Al.*). Many of them have only two tracks in both sides of the body and are so simple to operate in 2 dimensional terrains. Some of them have additional articulated tracks called flipper in front of them to step over vertical obstacles or change the inclination of the body. To overcome very large obstacles and adapt to very irregular terrains, some have four articulated track mechanisms in spite that their mechanisms are complex and their remote operation is not easy(Miyanaka *et al.*). To reduce the complexity of these mechanisms, a few of them adopt modular design concepts in the track design. With modular track design concepts, all the required parts of the track mechanism including the motors and controller are embodied inside the track module and track mechanisms can be connected to main body frame with simple structures, thus it is easy to design and to change a whole body shape according to the environments where they will be used. In this respect, we developed a remotely operated mobile robot named "QuadTrack-I" having four modular track arms (Jeong *et.al.*)and we are also developing a new mobile robot platform named "QuadTrack-II" to have more power and mobility with the same concepts of a modular track. This paper describes the structures of the mobile robots and provides some experimental results conducted over various terrains including steep stair-ways.

2. ARTICULATED TRACK MECHANISM

The modular track mechanism of QuadTrack-II uses a chain-sprocket mechanism as shown in Fig. 1. The arm axis and the wheel axis are driven independently by two 200W BLDC motors. The modular track embodies two motor controllers for the motors. The controllers receive command signals and send their status information through CAN bus with CANOpen protocol. Thus the track modules are connected to main controller with only four wires. Slip rings are mounted in each arm axis for providing endless turn.

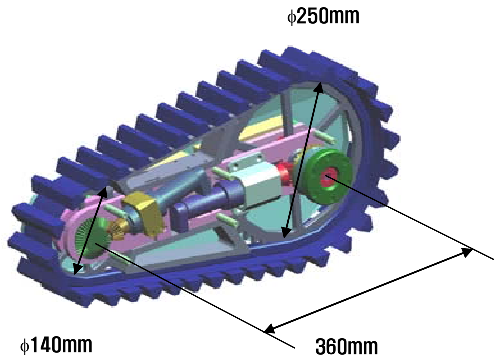


Fig. 1. 3-D model of modular track of QuadTrack-II

Fig.2 shows the main body frame with four modular tracks. The main body frame can be easily designed and modified to implement various shape and size for specified applications. The front modular track and the rear modular track are overlapped in the middle of the body and the width between the two front tracks is larger than that of the rear tracks. The arm axes are lower than the main body frame to reduce collisions with obstacles in uneven terrain.

Fig. 3 shows the internal structure of the modular track mechanisms and Fig. 4 shows overall structure of

QuadTrack-II. As shown in Fig. 3, driving motors and controllers are embedded in the track module.

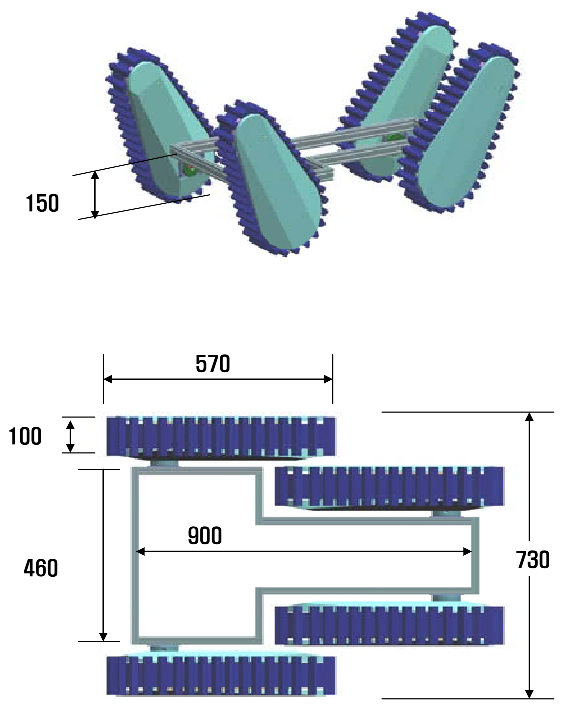
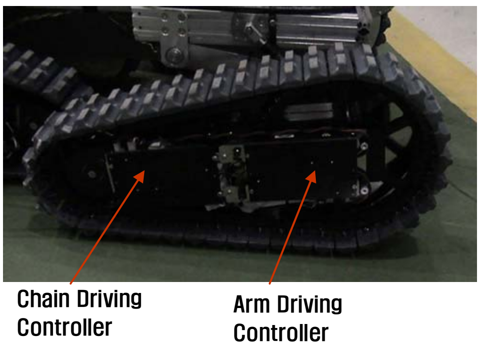


Fig. 2. A main frame structure of QuadTrack-II



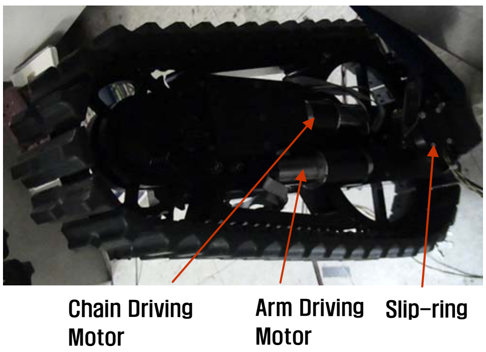


Fig. 2. Modular track of QuadTrack-II

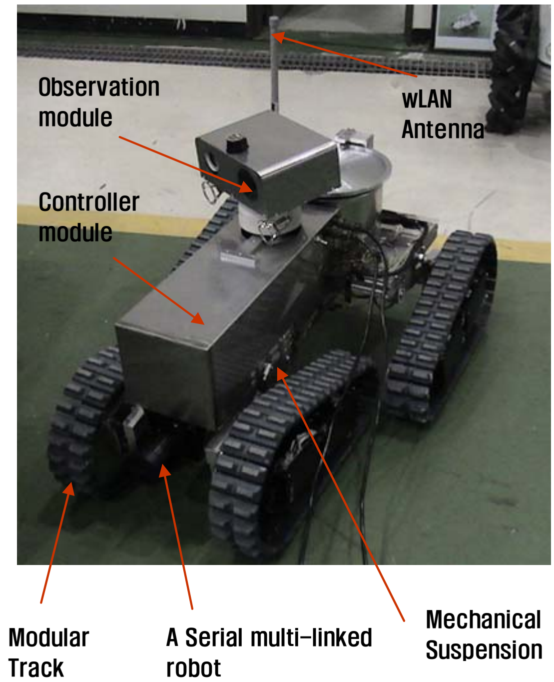


Fig. 4. Overview of QuadTrack-II

Fig.5 shows the observation module. The observation module has one color CCD camera, one IR camera, and one laser range finder.

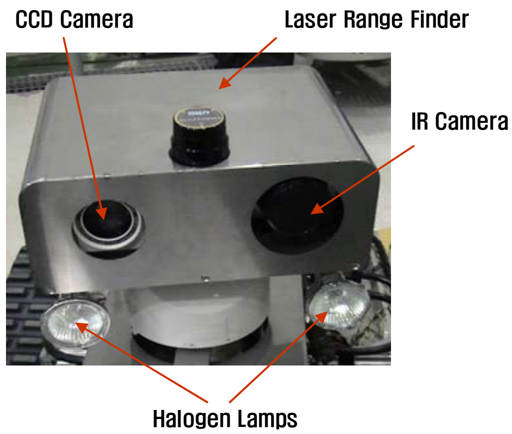


Fig. 5. Observation module

In the following table, the specifications of QuadTrack-II are provided.

Table I Specifications of QuadTrack-II.

Width	760mm	
Height	600mm	
Length	1100mm	Arm folded
weight	70kg	Battery Included
Max. Height of Obstacle	400mm	

3. SOME ADVANTAGES OF ARTICULATED TRACKED ROBOT

It is well known that a skid steering that tracked vehicles usually use requires large driving torques when they turn.
The torques required to turn the vehicle around the center of mass are closely related with the distribution of the contact points with the ground.
If we denote the equivalent contact point of i-th track modules by P_i, the reaction force at the point can be resolved along the vertical direction, the longitudinal direction and the lateral direction. The forces along the three directions are denoted by F_{zi}, F_{xi}, F_{yi} as shown in Fig. 6 (Shailesh).

Based on the assumptions that the configuration of the robot is symmetric with respect to the longitudinal x-axis, and there are no slips along the longitudinal direction and the left two tracks drive the body backward, and the right two tracks drive the body forward, and the driving torques are all the same and denoted by T, The torque T required to turn the body count-clockwise is derived as follows.

$$T = r_p \mu_k W \frac{b}{t} \frac{2a/b}{a/b+1} \tag{1}$$

where μ_k is the kinetic friction coefficient and W is the weight of the body.
Eq. (1) shows that the turning torque T can be reduced according to a/b.

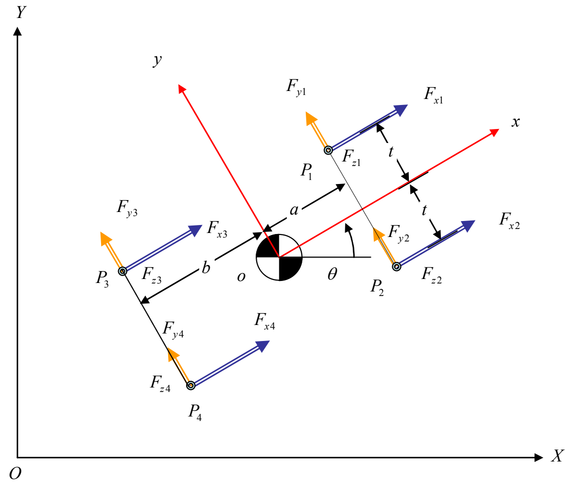


Fig. 6 Free body diagram of vehicle

One of the advantages that articulated tracked vehicles such as QuadTrack-II have is to change the contact points with the ground and to reduce the required torque when they turn. Such a torque reduction is possible because each arm can be rotated thus the contacting points are relocated to such a configuration by reducing a/b.
One another advantage of a modular tracked vehicle is that the modular tracks are so heavy that the ground reaction forces can be relatively equal to the others.
In a simple rectangular supporting configuration where the mass center is located at the geometric center of a rectangle, the vertical reaction forces are not statically indeterminate but can be represented by introducing an extra parameter, λ.

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} F_{z1} \\ F_{z2} \\ F_{z3} \\ F_{z4} \end{bmatrix} = W \begin{bmatrix} 1 \\ 1/2 \\ 1/2 \\ \lambda \end{bmatrix}$$
$$\begin{bmatrix} F_{z1} \\ F_{z2} \\ F_{z3} \\ F_{z4} \end{bmatrix} = W \begin{bmatrix} 0 \\ 1/2 \\ 1/2 \\ 0 \end{bmatrix} + W \begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \end{bmatrix} \lambda \tag{2}$$

If we assume that each vertical ground reaction force is larger than 0, the parameter λ should satisfy the following condition.

$$0 \le \lambda \le \frac{1}{2} \tag{3}$$

Thus we can find that each vertical reaction force can be varied between 0 and W/2. This variation can result from the contact conditions of the supporting point with the ground. In an extreme case, one of the tracks can be off the ground and this track can not drive the body because friction is required to drive the body.
In modular tracked vehicles, the tracks are inevitably heavier and the body is lighter because the driving parts including the motors, gear trains and controllers are located in the track module instead of the body. Because the weight of body W, can be small, the variations of the vertical grounding reaction forces are smaller. In order to distribute vertical ground forces as evenly as possible, the connection between the body and the tracks should not be rigid but be soft in addition that the body should be light.

4. EXPERIMENTAL RESULTS

Fig.7 and Fig.8 show some experimental scenes for QuadTrack-II climbing over various obstacles.
Fig. 9 shows climbing sequences for stepping over a vertical obstacle 400mm high.

Fig. 7 Climbing over rocks

Fig. 8 Climbing over slopes

ACKNOWLEDGEMENTS

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4. CONCLUSIONS

We introduced two modular tracked vehicles and the structures of their modular tracks. Also we proposed some advantages of modular tracked vehicles. From some experiments, we have experienced that it is not easy to control four articulated tracks maintaining stability even such an additional degree-of-freedom provides the possibility for climbing over hazardous obstacles. We need to work further for 3-dimensional terrain recognition and control strategies for terrain- adaptation.

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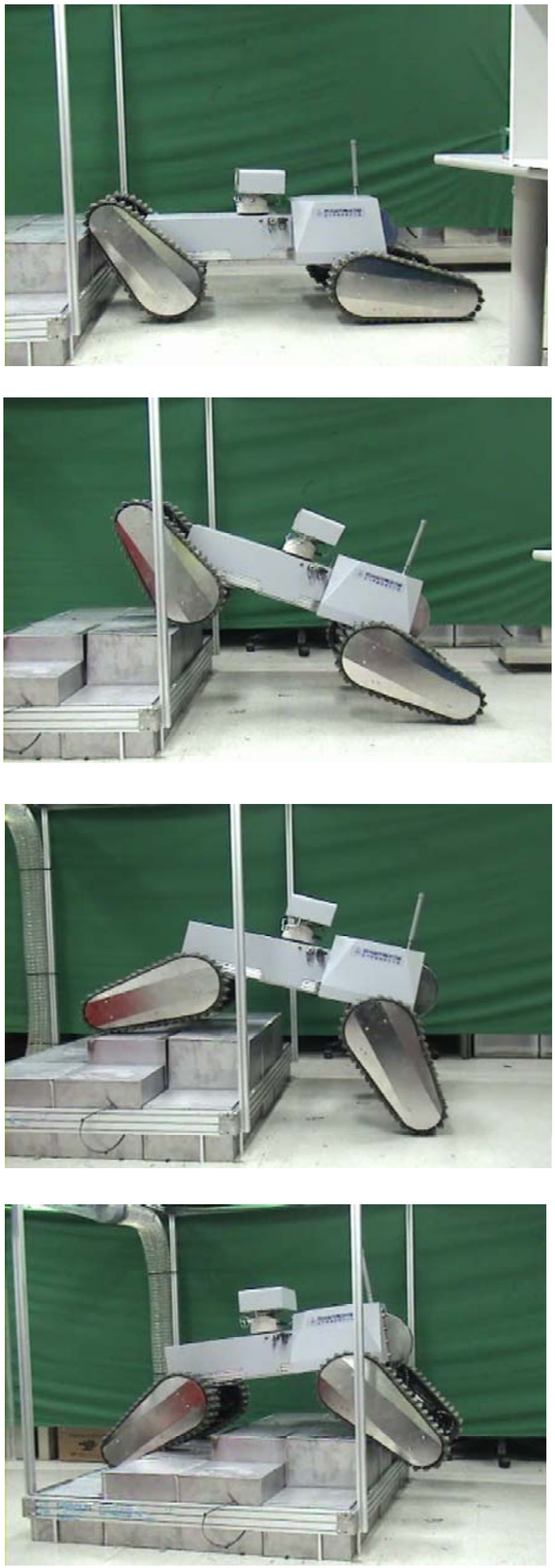

Fig. 9 Vertical Step Climbing Sequence