Design of Emergency Response Robot Platform K-R2D2

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Abstract: This paper presents a mechanical and electrical design of tripedal mobile platform for emergency response in man-made environments. Previously, we described design concepts of K-R2D2, which has 14 degrees of freedom (11 for active motions and 3 for passive motions), 120cm tall and weighs 93kg. It has three legs which are linearly extendable along each length to change the mass center during walking. The proposed leg mechanisms is modeled for gait locomotion based on walking up the stairs and each leg is connected with its foot by a variable stiffness ankle which runs free or is rigidly fixed. This paper also explains the robot controller architecture which is easily reconfigurable.

Keyword: Emergency Response Robot, Hybrid Mobile platform, Triped Robot, Variable Stiffness Ankle, Distributed Control Architecture.

1 Introduction

When we design a mobile robot platform for emergency response in man-made environments, it would be considered the robot is working in or around collapsed structures of a building [1]. So such a robot is expected to move through narrow corridors, stairs and even over rubbles.

On the reflection of various mobile robots competed in DARPA Robotics Challenge [2], they had some difficulties in such a point of view. Bipedal locomotion is not yet fully suitable for maintaining stability in such highly irregular terrains. Even though quadrupeds are easier to stabilize their motion, but relatively large form factor of them limits its mobility when trying to go through narrow passageway where human can overcome easily in normal situations.

Since McMurray and MacLaren proposed a three-legged robot for lunar base construction [3, 4], researches have been investigated various aspects of the design involving robots with three appendages [5]. Additionally, research interests are focused on a biologically inspired tripod walking robot [6]. However, triped robots are compromise between the two kinds of robots, but they could not reveal their effectiveness till now [7].

Thus this paper introduces a new tripedal mobile platform as shown in Fig.1. It has three legs in total; one of them is under the body, two others support the body in left and right sides. The legs are linearly extendable along each length to change the mass center during walking. Each leg is connected with its foot by a variable stiffness ankle which runs free or is rigidly fixed. They have also tracked mechanisms as their feet which can crawl to get rid of the necessities for time-consuming walking motion on nearly even surfaces.

This paper also explains the distributed control and sensor system architecture which is easily reconfigurable.

Fig.1 Robot platform for K-R2D2

2 Mechanical Design

2.1 Analysis for gait locomotion

From the analysis for gait locomotion based on walking up the stairs as shown in Fig. 2, we can obtain a link length (L_1) by the following equation (1).

$$L_1 = L_3 \rightarrow L_1 = \sqrt{(L_1 - H)^2 + D^2} \rightarrow 2L_1H = H^2 + D^2 \quad (1)$$

where the stairs' width D and height H are 0.24~0.4m and 0.18~0.2m. The link length (L_1) is $0.9m$.

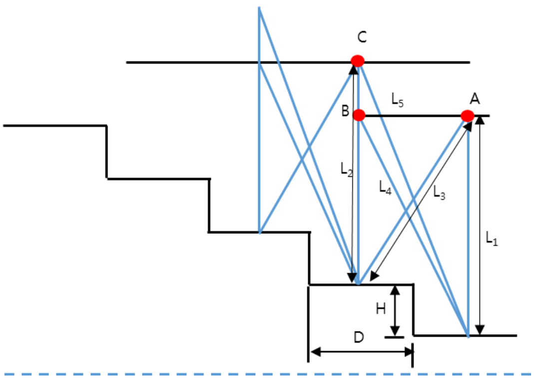

Fig.2 Gait locomotion for walking up the stairs

2.1 Minimizing degree of freedom and modularization

We tried it to have minimized 11DOFs for mobile monitoring tasks. As shown in Fig. 3, we designed the drive unit of a combination of the three drive modules. Yaw head, the left and right pitch shoulder and yaw torso use the same rotational drive module. Left, right and middle legs to expand and contract legs use the same linear drive module. Four tracks also use the same track drive module. These driving system can be conveniently used to minimize a degree of freedom and modulation.

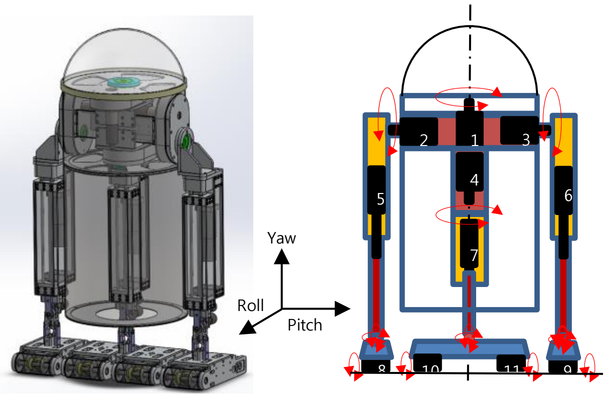

Fig. 3 3D structure for K-R2D2

2.2 Rotational drive module

In the rotational drive module, we use a brushed 24V, 200W DC motor (Faulhaber 3863-024CR) that is attached with a 134:1 gear head and a 512 pulse optical encoder. It is designed to reduce the twisting problem of electric wiring by allowing the hollow shaft to be connected to 2:1 pulley.

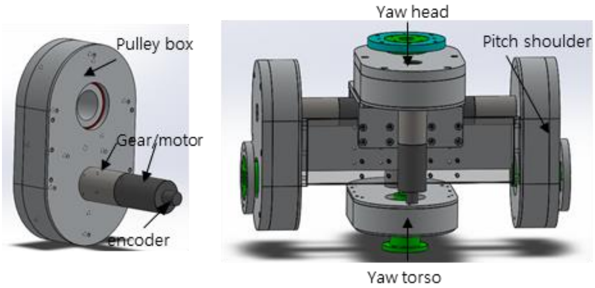

Fig. 4 Rotational drive module

2.3 Linear drive module

Fig. 4 shows the linear drive module which is composed of a brushless 24V, 180W BLDC motor (BL10057+IG52 with Encoder), a linear guide and pulley. The linear motion is generated through a linear guide, a ball screw with the pitch of 10mm and a pulley.

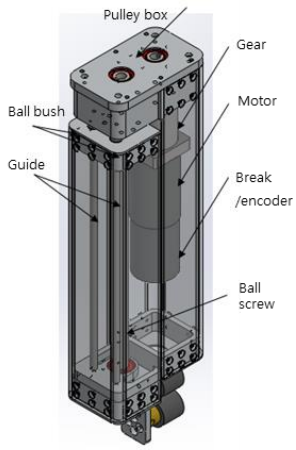

Fig. 5 Linear drive module

2.4 Water pressure cylinder ankle module

As for an ankle joint, we designed that is possible for robot to drive by using 3 legs with active-dynamic tracks on plat or uneven slopes. A water pressure cylinder is used for ankle joint that consists of 2 DOF revolving joints. The joint angles can be changed according to the terrain gradient of the ground when landing at three points.

In a two legs supporting state with left and right legs or a one leg supporting state with a middle legs, the joints to be fixed so that static stability can be maintained. At this time, the holding torque should be 30kgfcm or more.

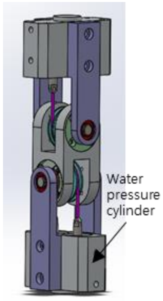

Fig. 6 Water pressure cylinder ankle module

2.5 Track drive module

The track module for flat travel is connected with each leg. Each one attached to left and right leg and only middle leg attached two track modules in order that it is statically stable to maintain equilibrium. We use a brushless 24V, 110W BLDC motor (BL10057+IG52 with Encoder) that is attached to a 3:1 speed reducer. It drives the drive pulley through a bevel gear. And the driven pulley is designed to rotate the both-side toothed timing belt. The sum of forces for 4 tracks is 30kgf for 30-degree slope climbing.

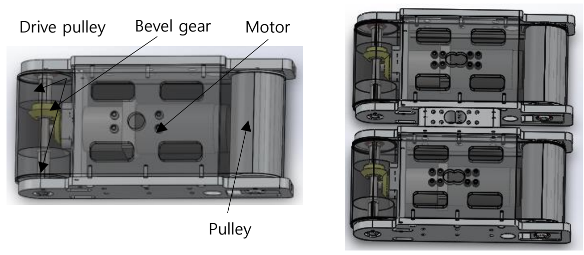

Fig. 7 Track drive module

3 Electrical Design

3.1 Distributed control system

Fig. 5 shows the overall block diagram of robot controller architecture. K-R2D2 communicates with the remote control computer via the wireless LAN. The control commands are distributed to the motor controllers through the Ethernet-CAN converter. And the status information of the motor controller and various sensor information are transmitted also to the remote control computer via CAN communication.

Besides, it is configured to be able to shut off the power supply of the battery by using the wireless emergency switch in case of malfunction.

All the necessary electrical components such as motor, motor drive, battery, etc. are installed in the robot body itself so that it can walk in working environments without having any wiring connection with external controller.

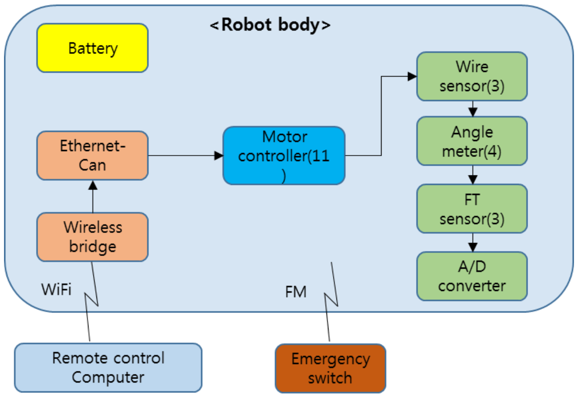

Fig. 8 Robot controller architecture

3.2 Motor controller

We use Elmo solo whistle motor drivers to control the shoulder, torso joints and tracks. It is capable of controlling 24V DC motor up to 10A. Advance motion control motor drivers are used for extention and contraction drive actuator, it is capable of controlling 24V DC motor up to 20A and is also installed inside the linear drive module.

3.2 Sensor

K-R2D2 is equipped with a variety of sensors for monitoring the operation status. Generally, after the power is supplied, the rotation angle can be measured by the motor encoder. However, since the absolute rotation angle cannot be known, it is necessary to perform the initialization process.

3.1.1 Inclinometer sensor

A single-axis inclinometer sensor is mounted to measure the inclination of the torso and legs. It is MEMS type and can transmit the gradient values by CAN communication periodically.

3.1.2 Angle sensor

In order to measure the absolute and rotational angles of the left and right legs and the body of leg, the non-contact type rotation sensor of the CAN communication type is installed so that it is not required the process of setting the origin of the rotation joints at the initial stage.

3.1.3 Wire Sensor

In the case of the leg extension part, the wire sensor is mounted so that the absolute position can be recognized without the origin initialization process. An A/D converter module with CAN communication interface is prepared for reading analog signals from the wire sensors

3.1.4 Force Torque Sensor

In order to recognize foot contacts with land and the magnitude and center of the contact force, we use a six-axis force/torque sensor. It is mounted to the between the extension leg and the track module. This sensor is capable of measuring two moments up to 45Nm along roll and pitch axes and one normal force up to 2000N in the vertical direction. It transmits the measured signal to the remote control computer via CAN communication.

3 Conclusion

In this paper, we have presented the design architecture for a tripedal walking. Our mechanical design perspective is based on the gait locomotion of walking up the stairs. We explain the minimizing degree of freedom and modularization, as well as the actuators, the variety of sensors and distributed control system. All the necessary electrical components such as motor, motor drive, battery, etc. are installed in the robot body itself so that it can walk in working environments without having any wiring connection with external controller.

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