Design of a 2DOFs Pantograph Leg Mechanism for Rapid Response Robot Platform in Nuclear Power Plant Facilities

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1. Introduction

If an accident occurs in nuclear facilities and emergency work is required in a hazardous area where human workers cannot access it, the use of robots can be a good alternative way to doing the work. However, in order to perform emergency operations quickly and successfully in the emergency situations, rapid mobility of the robot is very important.

We visited nuclear power plants several times to investigate the situation in the areas that need to be accessed in order to perform emergency tasks in the event of accidents and built a test mockup with many obstacles for robots as depicted in Fig.1 and Table 1.

It is believed that the passages to those areas do not allow fast access not only to wheels or track-type robots, but also to biped robots walking like humans [1,2]. In order to overcome large obstacles, the legs of a biped robot have a large workspace. It is also very important for bipedal walking robots to lighten their legs for fast walking, and it is advantageous that heavy actuators driving each joint of the legs are placed as close to the body as possible [3].

Fig. 1. Test mockup for a nuclear power plant facility.

Table 1: Size of passages in typical nuclear power plants

	dimension
Minimum width (cm)	40
Minimum height (cm)	120
Maximum step height(cm)	60

Since biped robots need to move horizontally for most of the time, recti-linear leg mechanisms can greatly simplify the control problem compared to the serial leg mechanisms with active rotary joints that typical bipedal robots use. The 2DOFs pantograph mechanism with small recti-linear actuators [4] is a good candidate for obtaining large rectangular workspace because the mechanism can amplify the small actuator motion to the large foot motion.

Therefore, we intend to develop a new bipedal walking robot with fast mobility in such a complex environment and propose a lightweight leg mechanism design with a wide workspace based on the recti-linear 2DOFs pantograph mechanism.

2. Pantograph mechanism description

2.1 2DOFs pantograph leg mechanism

The 2DOFs pantograph mechanism is actuated by two linear actuators. When the mechanism is driven by the horizontal linear actuator or the vertical linear actuator, the foot can be driven independently in the horizontal or vertical direction. This structure is suitable for high energy efficiency because of a gravitationally decupled actuation system [5]. In other words, the motion of the foot in the gravitational direction is decoupled from the other directions.

The leg mechanism consists of a four-bar linkage with passive revolute joints, vertical and horizontal linear guide drive module. In this design, the amplification ratio is four times in the horizontal direction and three times in the vertical direction each.

Besides that, this leg is designed to have suitable strokes for the environments of the passages as shown in Table 1. It has a stroke of 60cm or more in the vertical direction to cross the high step in the narrow passage. And the width between the left and right foots is limited to 40cm.

Fig. 2 shows that its vertical stroke (VD), horizontal stroke (HD), step height (H) and step length (L) are 200mm, 150mm, 600mm and 600mm. To meet the specification for the locomotion workspace of the robot leg, each length of link1, link2, link3 and link4 is determined as 480mm, 170mm, 360mm and 680mm.

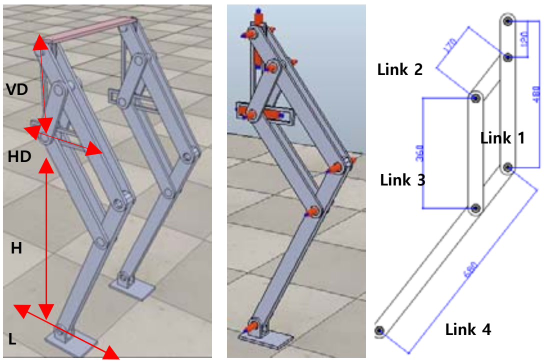

Fig. 2. 2DOFs pantograph leg mechanism.

2.2 A static FEM analysis of leg

The proposed leg can be light-weighted using CFRP compared to conventionally used aluminum.

The 2DOF leg is designed by using CFRP material to reduce the weight of leg and achieve the rapid mobility. A static FEM analysis has been carried out considering CFRP material properties. The length and the thickness of the link, etc. are derived in consideration of the maximum deformation of the leg's end less than 1 mm when 100 kg of the total load including the robot weight is applied to one leg under the four support conditions as shown in Fig. 3.

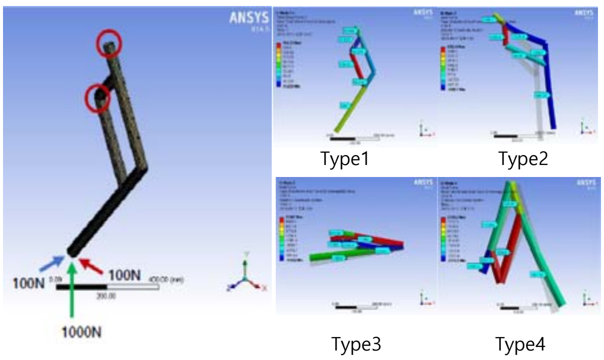

Fig. 3. A static FEM analysis model and results for 4 support conditions.

Table 2 shows that the resulted total weight of the linkage is approximately 3700 g.

Table 2: The total weight of linkage.

	Part weight(g)	Quantity(EA)	Total Weight(g)
CFRP Plate 1	366	2	732
CFRP Plate 2	141	2	282
CFRP Plate 3	284	2	568
CFRP Plate 4	516	2	1032
Shaft	90	6	540
Ball bearing	10	40	400
Bolt	9.2	12	110.4
Washer	3.2	12	38.4
1 set Weight			3702.8

2.3 The proposed leg design

Fig. 4 shows 3D structure of the proposed 2DOFs pantograph leg mechanism. Ball screws are used in the linear drive module, it can have higher driving efficiency than conventional harmonic reducers with rather low efficiency.

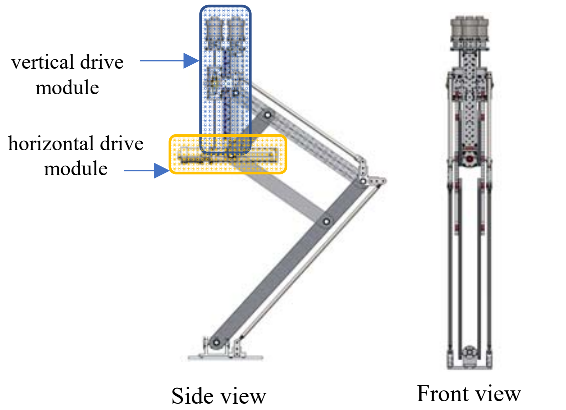

Fig. 4. The proposed pantograph leg design.

3. Conclusions

This paper has presented a 2DOFs pantograph leg design. it was developed on the purpose of rapid response instead of emergency workers to the various terrain environments of nuclear power plant facilities. This mechanism consists of four-bar link and drive modules by using ball-screw.

The main advantage is that the pantograph leg is light-weighted and easy to control the foot trajectory in compared to those of conventional humanoid robots.

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