A FOUR-LEG LOCOMOTION ROBOT FOR HEAVY LOAD TRANSPORTATION

Kiyoshi Kuroi
Intelligent Mechanical Systems Engineering
Kagawa univ.
2217-20 Hayashi, Takamatsu, Kagawa, JAPAN
s05g511@stmail.eng.kagawa-u.ac.jp

Hidenori Ishihara
Intelligent Mechanical Systems Engineering
Kagawa univ.
2217-20 Hayashi, Takamatsu, Kagawa, JAPAN
ishihara@eng.kagawa-u.ac.jp

Abstract: This paper proposes the new innovated 4-legged Locomotion mechanism with pantograph-jack structure as its leg. This study aims at developing the practical robotic system, especially focusing on the carrying task of heavy load. Transportation of heavy load occupies the important parts among the real applications such as disaster relief and rescue activities. The jack-like leg enables to hold a heavy object without any active control and consumption of energy. Additionally, it can lift up an object easily by smaller power than weight of object. Prototype uses the crawl walking which is a typical locomotion way of a reptile, and it has achieved this step by bending its waist. The prototype realized the 0.001m/s walking and payload of 45 kg. This paper deals with the concept of locomotion mechanism with jack-type leg, details of design of prototype and some properties by some basic experiments.

Keywords: 4-leg locomotion robot, Transportation of heavy load, Pantograph Jack, Crawl step

1. INTRODUCTION

Various applications of locomotion robots have recently been introduced into many practical fields. Especially, mobile robots in new applications such as disaster relief and demining are required to apply them into the practical use. Such kinds of robots must be mounted the movability at any rough terrain. For such request, the leg locomotion is advantageous to move on irregular terrain.

In such applications, real demand is to carry the heavy load such as a victim in the rescue activities. However, present leg mechanism is not suitable for carrying the heavy load. For example, quadruped robot driven by DC motors realizes smooth action like as an animal, but its loading capacity is so small that it can only carry its own body. This is caused by shortage of torque generated by motors. Additionally, it consumes the large amount of energy because a motor requires electric current at any time when it generates the torque. On the other hand, the hydraulic actuators can generate larger torque than DC motors. It however contains the large driving unit such as compressor and electrical valves. Furthermore, it is difficult to design the autonomous robotic system by the hydraulic system because it is required to occupy the large space for the driving unit in its body. Table 1 shows characteristics of each actuator.

We have taken account into the energy consumption as a key for the design of robot. At this view point, the hydraulic system is better than the motor-driven system, but it is difficult to design the small robot driven by the hydraulic system because of above-mentioned problem. We focused a pantograph jack that is used for lifting up a heavy load such a car. The pantograph jack can lift up a several ten-time heavier load than the driving force, and hold it without energy consumption.

Table 1 Characteristics of each actuator

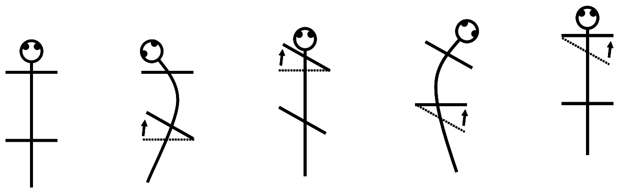
	Power	Response	System size
Electric motor	poor	good	good
Hydraulic system	good	fair	poor

This paper proposes the way to introduce the jack system into the mechanism of mobile robot. In the second chapter, design concept and crawl step that robot uses as locomotion way are explained. The third chapter introduces the prototype designed based on the design concept. In the fourth chapter, effectiveness of proposed mechanism is discussed through the performance of developed prototype. The fifth chapter introduces the loading platform designed for crawl step. The final chapter discusses the properties of the prototype and future works as the conclusions.

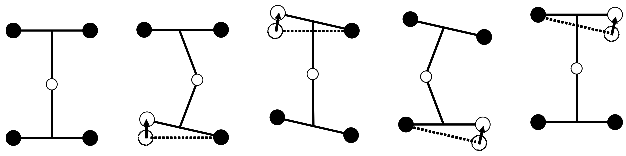
2. DESIGN CONCEPT

The pantograph jack enables to hold the heavy load without active control by actuators. Therefore, this mechanism enables to reduce the energy to hold the load. Moreover, it is expected to lift up the heavy load by small power. However, the jack has the simple mechanism that stretches toward a single direction. Therefore, it requires the mechanism to bring the leg forward to move for realizing the moving performance.

There are various kinds of steps such as Trot step, Pace step and Gallop step in nature. The crawl step is a typical step of reptile such as a crocodile and lizard. This step is static motion and slowest step in tetrapod. However, we focused on the crawl step as the mobile principle for proposed robot with jack-like leg. Because we think stability is the most important for the robot to transport the heavy load. The crawl step has the following features:

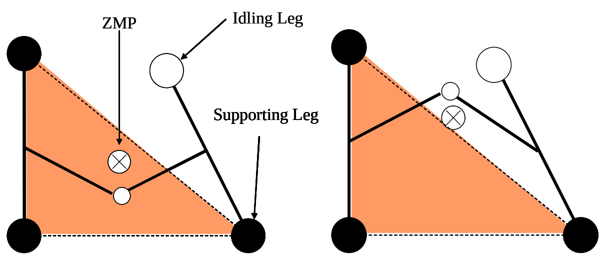


(a) Animation of steps of reptile



(b) Animation of steps of proposed mechanism

Fig.1 Locomotion principles of reptile and proposed mechanism



(a) Stable (b) Unstable

Fig.2 Stability of posture

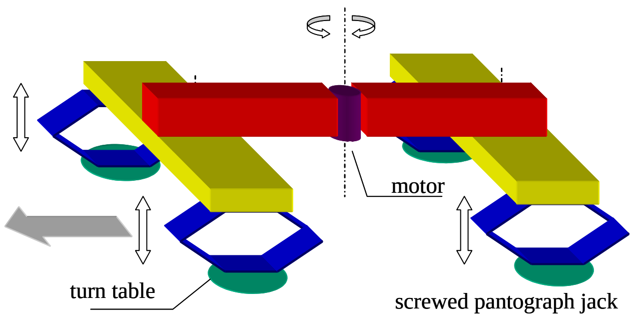


Fig.3 Image of prototype

(1) At least three legs are always in touch with the ground during walking.
(2) An idling leg is moved forward by bending its waist.
(3) Its body keeps its height always during walking.

The moving principle of jack-leg robot proposed was designed based on points (1) and (2) among above features.

Figure 1 shows the moving principles of reptile and proposed mechanism. In Fig. 1 (a), it manipulates an idling leg and bends its waist when it moves forward. Meanwhile, the proposed architecture in Fig. 1(b) obtains the stroke of step only by bending its body.

Figure 2 shows the stability condition of posture when it is moving. If all legs are touching the ground, the robot is standing stably. However, when it lifts up its single leg, it is required that the ZMP (Zero Moment Point) is kept in the triangle which is formed by three legs touching the ground in order to stand stably. However, this step can not lift single leg in initial posture such as Fig.1 (b). Because the ZMP is not kept in that triangle, there is a possibility of falling. Then, the ankle to prop up the posture of the robot is important. Based on the consideration in Fig.2, the respective specifications must be designed under the restriction of stability of posture.

Figure 3 shows the concept of prototype with jack-leg and crawl step.

3. DESIGN OF PROTOTYPE

The prototype robot was developed in order to confirm the effectiveness of proposed mechanism by jack-type legs and crawl step. The design conditions of first prototype robot were defined as follows;

Dimension of prototype is 300 x 300 x 300 mm.
Loading capacity is 40 kg.
Weight of robot is under 5 kg.

Figure 4 shows the developed prototype, and table 2 shows the specification of prototype. Legs using the pantograph jack consists of the jack-leg and turn ankle. The turn ankle needs the functions of supporting the weight of the robot and turning the leg. To satisfy the above requirements, the rotational joint and low-friction support are installed. The waist consists of a DC motor, a warm gear and a rotational joint.

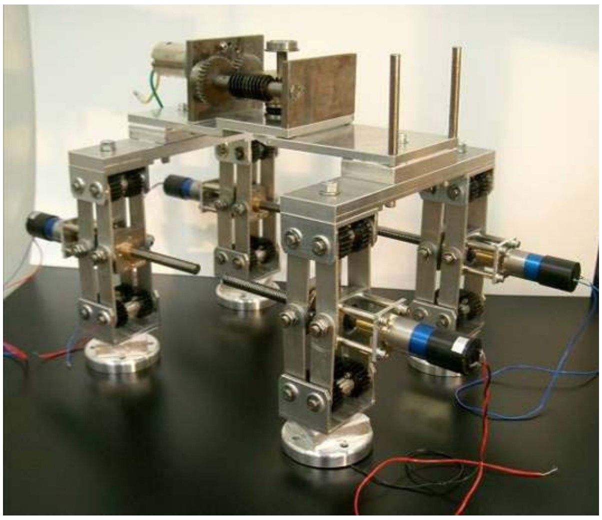


Fig.4 Developed prototype

Table 2 Specification of prototype

Length of prototype	378 mm
Width of prototype	242 mm
Height of prototype	254 mm
Weight of prototype	4.9 kg
Motors	DC motor x5 (Waist x1, Leg x4)

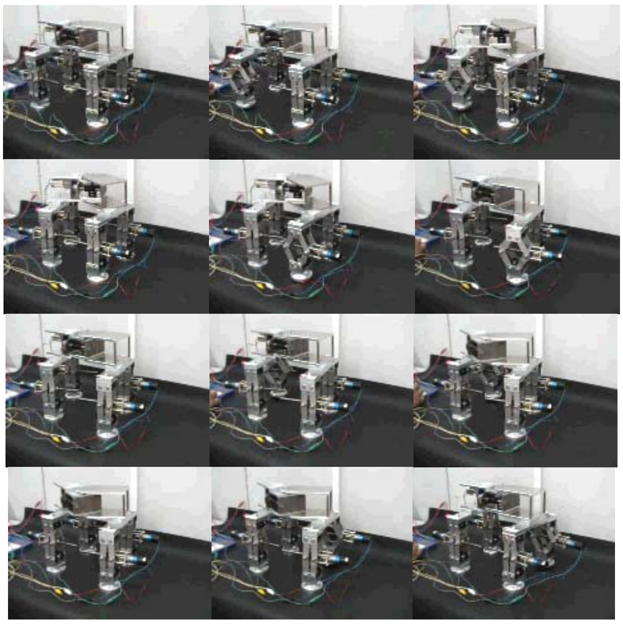


Fig.5 Walking appearance

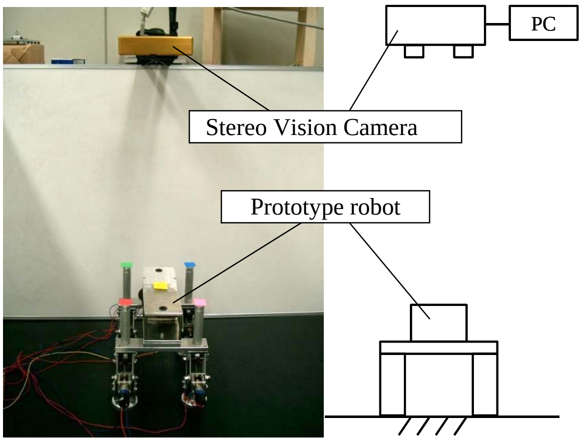


Fig.6 Measuring environment

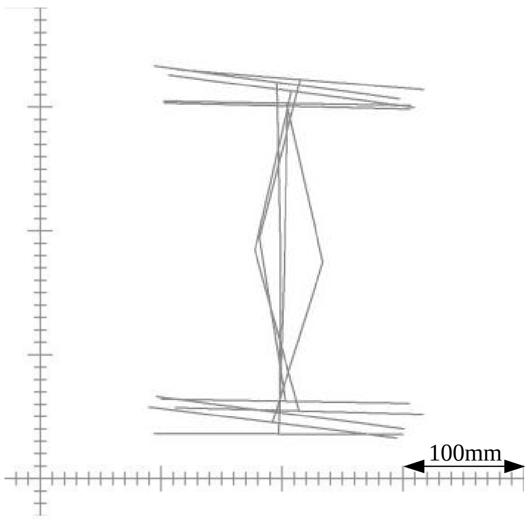


Fig.7 Trajectory of prototype

4. EXPERIMENTS

Currently, the basic prototype for walking was developed. This chapter shows the basic properties of robot.

4.1 Basic walking

Figure 5 shows the basic walking behavior. When prototype is walking, trajectories of each legs and waist are got by using stereo vision camera, BunbleBee (Point Grey Research). Figure 6 shows measuring environment and figure 7 shows trajectories of prototype.

The walking speed was about 0.001m/s. This was related to the speed to bend its waist and the decline of body frame. Especially, the decline of body was bigger than we designed. Therefore the leg must be lifted up larger than we expected. Also, the bending speed was slow because the worm gear is used.

4.2 Loading capacity

This research aims at the development of the robot for heavy load transportation. The loading capacity is the most important factor of its function for this robot.

The loading capacity was about 30 kg when the robot was standing. We tested the capacity at walking, but it could not be measured because it is impossible to put the heavy load on the back of the robot stably. When the developed robot is walking, it twists its waist. The heavy load is swung by bending its waist. Therefore, the robot can not keep balance because the center of gravity is moved dynamically. In other word, the developed robot needs the loading platform that keeps its posture independently of actions of body and legs.

5. DESIGN OF LOADING PLATFORM

The previous chapter shows necessity of the loading platform. This chapter introduces the loading platform designed for the robot with crawl step.

5.1 Design of loading platform

The developed robot required the following from the loading platform.

1) It is necessary to equate gravity point of the prototype and gravity point of heavy load.
2) The loading platform must not move sideways.

The purpose of the first demand is the decrease in load of the waist motor. The second demand prevents the heavy load from moving sideways.

However, the robot with crawl step has no point moving to the only traveling direction. It makes method of fixing the loading platform difficult.

Then, we propose the development of the loading platform with the linear guide. The loading platform with linear guides is expected the following.

1) It is not interfered in the movement of the waist.
2) The loading platform doesn't move sideways.

Figure 8 shows the structure of the loading platform with the linear guide. The props to support load only by the legs

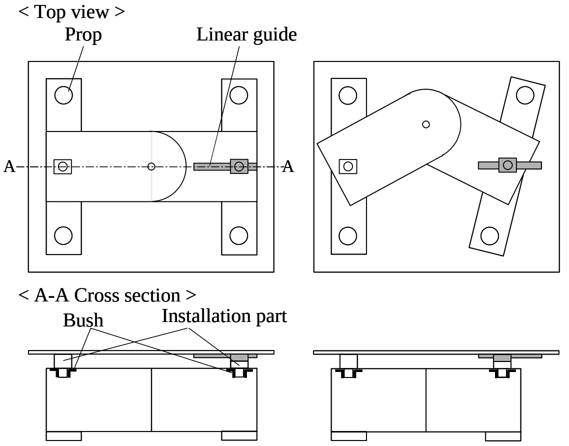


Fig.8 Structure of the loading platform

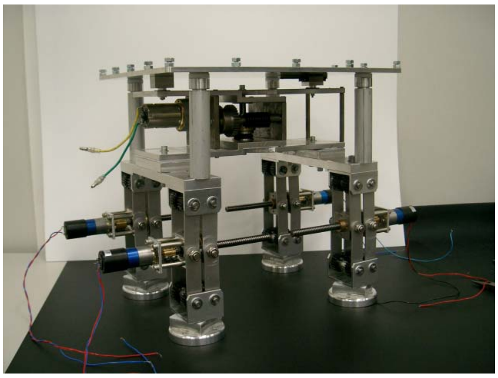


Fig.9 prototype with loading platform

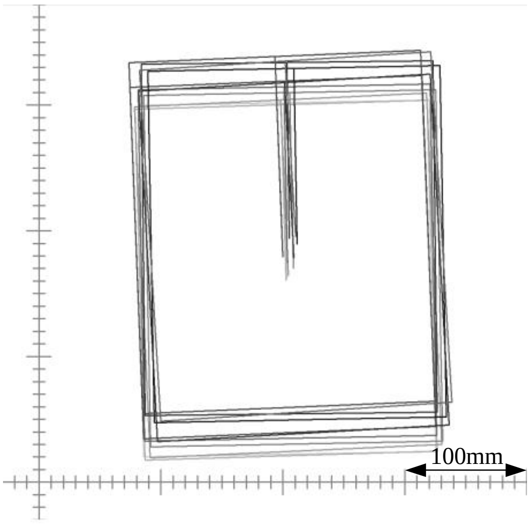


Fig.10 Trajectory of loading platform

are installed on each leg because of decrease of load in the waist motor.

The loading platform is designed so that it doesn't rise as much as possible. The design conditions of the loading platform were defined as follows;

The loading capacity 40kg,

The size is 280x240x5.

Figure 9 is prototype with developed loading platform.

5.2 Basic experiment of loading platform

The prototype of the loading platform with linear guide was experimented to confirm basic movement. The experimental apparatus of Figure 6 was used to get trajectories of the loading platform while walking. Figure 10 shows trajectories of the loading platform.

The movement of the waist in Fig.7 is about 50mm. The other hand, movement of lording platform in Fig.10 is about 5mm. These show that the loading platform with linear guide can transport the heavy load without interference in the movement of the waist. However, Figure 10 shows that the gap is caused by the inclination of the posture explained in Chapter 4. This inclination has the possibility of making the robot unstable because the heavy load slips on the loading platform. Therefore, the inclination of posture is a big problem for the carrier.

6. CONCLUSIONS

This paper proposed new mechanism of 4-leg robot for heavy load transportation. The prototype robot has the jack-type leg, and it moves using crawl step. The pantograph jack structure was installed in the prototype leg. The jack-type leg enables to lift up heavy load without large torque. And it can keep up its posture without any power. Crawl step enables to walk for the prototype robot with the proposed leg mechanism.

It was confirmed that it is possible for the robot with the jack-type leg and crawl step to walk. The prototype robot also gave proof that it can lift the heavy load and hold it without power.

The loading platform with linear guide was installed the robot with crawl step. And it can transport the heavy load without interference in the movement of the waist.

Now, we are designing next prototype with the ankle walking on irregular terrain. Then, we will try improvement of walking speed and stability.

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