Inspection Robot in Complicated 3D Environments.

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ABSTRACT

Half century ago, Japan started to increase her national wealth and to invest social infrastructures. Those activities could have accelerated its economy and brought further national wealth. Now spending many years almost all those facilities get old and are severely damaged. We started the limb mechanism project almost 20 years ago aiming at the robot application for rescuing as well as for inspection tasks in complicated 3D environments. We design and build first prototype, what we call ASTERISK, and demonstrated dexterous locomotion and manipulation capabilities including walk on ceiling underside, climbing up and down stairs and ladders, tightrope walk, and, of course, walk on rough terrains. Now we are applying our robot to attain the inspection of the underside of bridge. The robot has electro-magnetics at the tip of legs to approach and to access the underside. In the inspection task the robot has to walk around on side wall as well as underside, then to move from plane to plane. In the paper we will discuss the feasibility of walk on the underside of iron plate and the gait strategy in the transit from vertical plane to underside.

Keywords – Bridge inspection, Electro-magnetic, Asterisk Robot, Robot.

1 Introduction

There are lots of steel bridges all around the world. However, due to age, these bridges require regular inspection and maintenance for safety reasons. Unfortunately, bridge checkup requires a lot of time. Since the bridge will, sometimes, need to be closing down. As a result, traffic jam is undeniable during the inspection period. Steel bridge inspection also requires a lot of man power. Human errors could occur and these errors reduce the overall safety of the bridge.

There are some researches related to the problem stated above. The climbing robot with wheel along with permanence magnets [1] [2] are adopted to use in solving the problem. However, with the wheel, the robot will find difficulty in going over the obstacle ahead. There are also climbing and upside down walking robots which use permanent magnetic force [3] [4] and sticky elastomer adhesives [5]. Unfortunately, due to the size and the shape of the robot, the application is limited to sticky cases. In term of steel inspection, there are also several projects toward both outer side steel inspection [6] [7] [8] and overall steel inspection [9] [10].

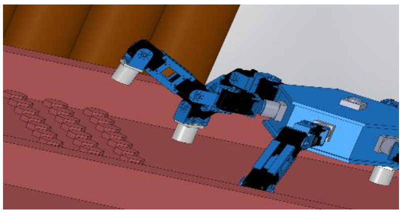

Figure 1. Limb mechanism ASTERISK

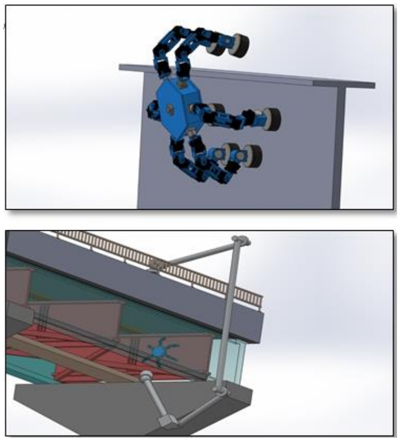

Figure 2. ASTERISK in steel bridge inspection mission

In order to solve the problem and to fulfill the gap of abilities, our 6 limb machine called “ASTERISK” will be one of the candidates to this challenging task. ASTERISK is an insect like robot with various abilities such as ladder climbing [11], usage of limbs for picking up object [12], scanning end-mounted sensor to detect a target, and walking upside down on the grid ceiling [13]. We will install the electro-magnetic to its feet to attach the robot to wall and/or ceiling of iron-made bridge. Since we could control the electro-magnetic, the ASTERISK will be able to climb and walk, on both normal and upside down surface, efficiently. As shown in Figure 2, ASTERISK will walk along the backside of bridge, it will be able to walk over from wall to ceiling and vice versa if necessary while ASTERISK will inspect the quality of steel by different methods.

In the following we will discuss the configuration of the inspection robot hardware, how to move in narrow space on iron surface, and finally will demonstrate preliminary experiment results.

2 Inspection Robot Hardware and System

Inspection robot is a robot that is designed to do the inspection at the desired contractures. Inspection Robot is designed to exam and report any defect detection to the user. The inspection robot is equipped with a lot of different sensors, such as camera, range finder or ultrasonic. However, the prototype model of the base robot for this paper, six limbs mechanism named Asterisk, is not equipped with sensor now. Never the least, the limb mechanism will be equipped with several of sensor; camera to analyse the working screen, range detector to analyse the walking plane and microphone to examine hammering test.

Figure 3. ASTERISK is symmetric, so the workspace remain the same for both side.

According to Figure 3. ASTERISK is made symmetric on both side of the body. As a result, the workspace remains the same for both side of the robot. The total weight of the limb mechanism is 3.3 Kilograms and the height of the initial pose is 270 mm.

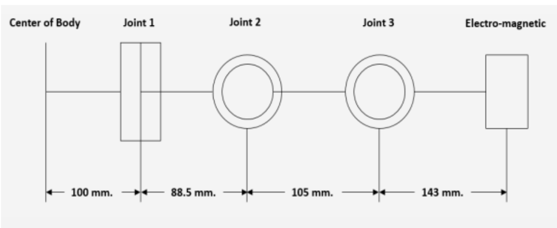

Figure 4. Diagram of the ASTERISK's limb

This section will contain 3 sub-sections of the limb mechanism installed parts. The first part is motion controlling part, this part will give the detail on the hardware which related to the overall movement of the robot. This section also give the reason on why this type of motor is selected. The second part is the electro-magnetic controlling part. This part will be responsible for the electro-magnetic controlling. It will also describe the driving circuit, which give the electromagnetic the power it needed. The last part is the overall picture toward the system. This part will describe the detail on each component that will be consisted in the system and how each part related to one another.

2.1 Specification of Actuator

In order to work on its mission and to produce the requiring torque (maximum toque of 48.87 Kg-cm) limb mechanism will be equipped with smart actuator module Dynamixel DX – 117 by ROBOTIS, as shown in Figure 5. This module contains a servo motor, reduction gear, controlling unit and communication interface.

Table 1 Dynamixel DX – 117 specification

Weight	66g
Dimension	31mm * 46mm * 37mm
Resolution	0.29°
Stall Torque	3.7N.m
Running Degree	0° - 300°
Running temperature	-5°c - +80°c
Voltage	12V – 18V

From Table 1, this series of motor could provide us with the requirement, as a result DX – 117 is used as our rotational joint actuator.

2.2 Specification of Electro-magnetic System

Since electro-magnetic consumes a large amount of power and the micro-controller, alone, could not provide the power it needed. This section will give you the detail of the selected electro-magnetic and its driving circuit.

Figure 5. DX-117 actuator

Figure 6. ZYE1 – P34/18 Electro-magnetic

2.2.1 Electro-magnetic model

In order for the ASTERISK to climb or walk upside down, electro-magnetic will play a vital role. Limb mechanism must be able to stick to the ceiling by only two legs attaching to the steel ceiling. At the same time, electromagnetic must not be too heavy. In other words, each electro-magnetic must be able to withstand at least half of the robot weight. Figure 6 show the ZYE1 – P34/18 Electro-magnetic. The Table 2, show us that the ZYE1 – P34/18 could provide us the holding force required without overweight the ASTERISK.

Table 2 Electro-magnetic specification

Type	ZYE1 – P34/18
Diameter	34mm
Centre Diameter	16mm
Height	18mm
Weight	90g
Holding Force	180N
Voltage	12V
Current	0.3A

2.2.2 Electro-magnetic Driving Circuit

As you could see From the Table 2 that electro-magnetic requires 12V and 0.3A in order to provide the maximum holding force. Unfortunately, our micro-controller could not provide enough power. The driving circuit is adapted in to solve this problem. Micro-controller will send the control signal to channel D6, D5 or D3. Then the driving circuit will provide the power to the electro-magnetic. Once the driving signal from micro-controller is cut-off, so do the electro-magnetics.

2.3 Configuration of Inspection Robot

The overall system of ASTERISK is consisted of the PC workstation, Mbed board, driving circuit, ASTERISK (with installed electro-magnetic) and joy stick. From Figure 7, you will see that the user will put the command to the ASTERISK by using Joy stick as an input. The input data will, then, be forwarding by two USB ports. The first output will go directly to the ASTERISK. This set of output will give the execution order on which direction the robot should walk to. On the other hand, the second output will be sent to Mbed board. This set of output will give the execution order to electro-magnetic in order to co-operate with the movement controller. Unfortunately, Mbed board could not send enough power to enable electromagnetic (as showed in the Table 2, this series of electro-magnetic require 12V along with 0.3A). As a result, limb mechanism need to be installed with the driving circuit that would work as switching circuit. When the output send from Workstation to the Mbed, the microcontroller board will send out the signal to driving circuit, which will then switch the activation and deactivation of electro-magnetic sets according to the movement at that moment.

3 Walking in Narrow Space Methodology

The spider is one of the most successful predators and one of the reasons behind is the ability to move in various different direction. ASTERISK, which inspired by the spider, also contain a lot of different pattern of moving itself. For example, it could stand up and roll [14] or detect and go up stair [15]. However, this paper will focus

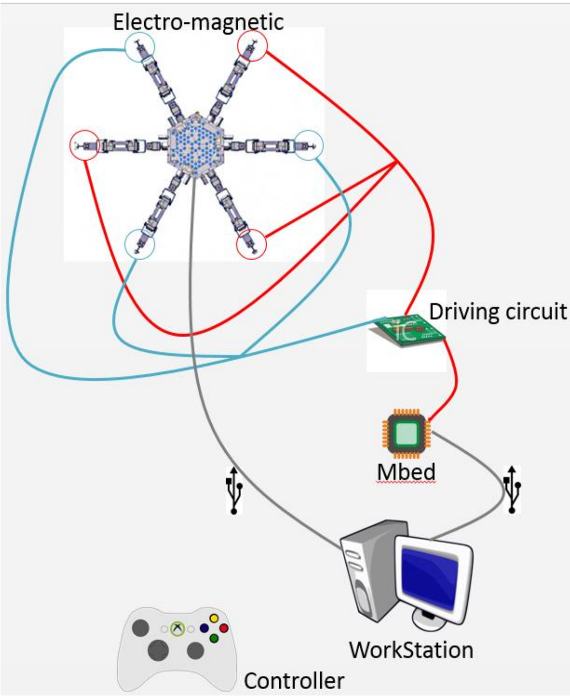

Figure 7. The Overall picture of ASTERISK System.

only on the narrow upside down walking, which is the latest way of moving for Asterisk. Since inspection or maintenance mission might require a working in a very limited space, so this method of movement was initialized. This section will be divided in to two sub-sections. The first sub-section will cut down the movement to six steps and it will explain the reason behind those step. Since electro-magnetic will have to work co-ordinately with the movement of the legs. As the result, the second sub-section will give the detail about the electro-magnetic controlling sequence according to those six steps of movement.

3.1 Legs Movement Methodology

Labelled the ASTERISK's leg to 10, 20 and so on to 60. In order to finish one cycle of movement, the walking methodology could be cut down in to six steps.

First Step: The first pose, or the initial state, in order to obtain the narrowest pose, the robot will stand up straight, as you could see from Figure 8 (a). During this pose, the robot weight will be divided equally to all 6 legs.

Second Step: This is the first state of movement. The robot will lift up leg 20, 40 and 60. Meanwhile, leg 30, 50 and 10 will lend backward, in order to shift the centre of mass forward. As you could see from Figure 8 (b).

Third Step: As you could see from Figure 8 (c), in order to pull the support legs (which, at this moment, is leg 30, 50 and 10) forward in the fourth step. The robot will lay down leg 20, 40 and 60.

Forth Step: Once leg 20, 40 and 60 already become the support leg. Leg 30, 50 and 10 will be lift and move forward as shown in Figure 8 (d).

Fifth Step: The leg 60, which is the only leg that has not be moved, will move forward as you could see in Figure 8 (e). By the end of this step, the robot's leg will be ahead of robot centre of mass.

Last Step: The last step, the robot will simply move to initial pose once again and all of the processes are done, as you could see from Figure 8 (f).

3.2 Electro-magnetic Control Methodology

Since electro-magnetic will have to work co-ordinated with the movement of the leg, so the control methodology also contain six step. In control methodology, dividing six legs in to two groups of three as you could see from Figure 8. The red (R) group will contain leg 20, 40 and 60, while the rest will be in blue (B) group. In the first stage, both set of electro-magnetic will be on. However, In the second step, set R will go off. Once the movement is completed the third step will take place. As soon as the third step is completed, set R will be activated and set B will be deactivated in order to perform the next step of movement. At the end of the forth step, set R and B will work vice versa. When leg 60 moves to its position in fifth step, both set of electro-magnetic will be turned on and the walking cycle is yielded.

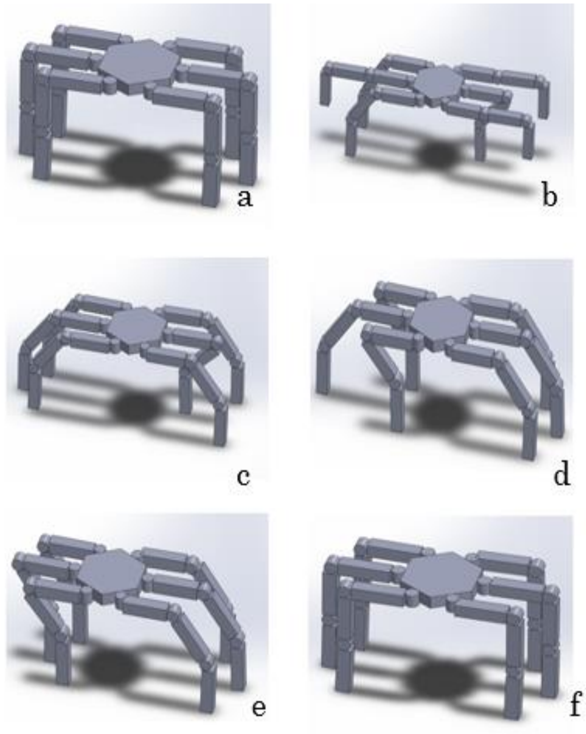

Figure 8. 6 Steps of walking respectively from (a) to (f).

4 Experiment on Walking and Result

The experiments in this paper could be separated in three different phases. Each phase will contain the different purpose, however one phase does lead to the next one.

The first phase: This phase of the experiment is to confirm that the movement methodology proposed could be use in the real walking. For the simplicity of the process, the electro-magnetic will not be used in this phase experiment. The robot could walk, however not so stably due to the slipperiness of the steel surface.

The second phase: This second phase of the experiment will be focused on the co-operation between the movement and the electro-magnetic. The robot will have to walk with the electro-magnetic functionally use on its feet. However, in this second experiment, the robot will still walk on the normal steel surface. The reason is to ensure that the movement could co-operated well with the magnetic controlling program. The ASTERISK could achieved its goals of this experiment, as you could see in Figure 9. By adding in the electro-magnetic, the problem from the first phase experiment was solved.

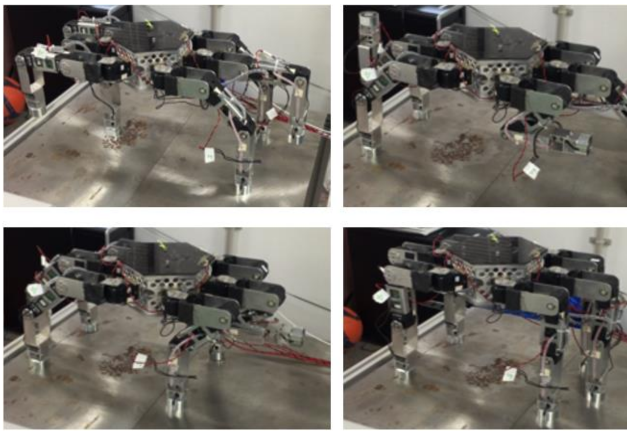

Figure 9. The ASTERISK could walk on a normal steel surface in the second phase experiment.

The Third phase: The last phase experiment for this paper. In this experiment the robot will have to perform an upside down walking on a steel surface. The first attempt, however, did not turn out as expected it to be. Since there are some errors in the rotational joint actuator, so the electro-magnetic could not have enough contact to the steel surface to generate sufficient holding force to maintain the weight of the whole robot. In order to solve the problem, the parameter has to be changed. In the second experiment of phase three, the robot could walk upside down without running in to any problem, as you could see from the Figure 10.

5 Conclusion and Future Work

As a conclusion, the purpose of this paper is achieved,

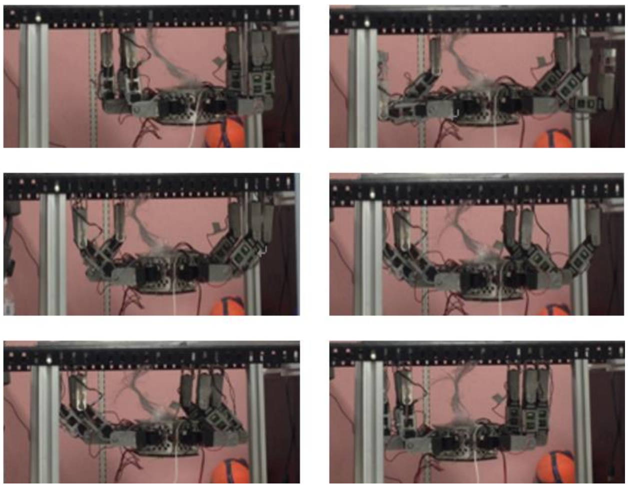

Figure 10. The second attempt of third phase. The ASTERISK performed the task correctly.

which is finding a new way of walking to ASTERISK, which will give it an ability to work in upside down walking on a steel surface. The result from the experiment indicated that this method could be adapted in to the real world. As for the future work, since in the real world there are a lot of complicate structures, as refer to the section 1, so the robot will have to be more flexible. For example; ASTERISK might have to change plane where it is walking on, or it might have to walk or climb across some obstacle. Moreover, different method of steel bridge inspecting.

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