Kalpa Publications in Engineering
Volume 3, 2020, Pages 168–174
Proceedings of International Symposium on Applied Science 2019

Development And Operation Of Wire Movement Type Bridge Inspection Robot System ARANEUS

Kazuhide Nakata[1], Kazuki Umemoto[1], Kenji Kaneko[2], Fujisawa Ryusuke[3]
[1]Nagaoka University of Technology
[2]Hachinohe Institute of Technology
[3]Kyushu Institute of Technology
fujisawa@ces.kyutech.ac.jp

Abstract

This study addresses the development of a robot for inspection of old bridges. By suspending the robot with a wire and controlling the wire length, the movement of the robot is realized. The robot mounts a high-definition camera and aims to detect cracks on the concrete surface of the bridge using this camera. An inspection method using an unmanned aerial vehicle (UAV) has been proposed. Compared to the method using an unmanned aerial vehicle, the wiresuspended robot system has the advantage of insensitivity to wind and ability to carry heavy equipments, this makes it possible to install a high-definition camera and a cleaning function to find cracks that are difficult to detect due to dirt.

1 Introduction

As the aging of the bridge progresses, the risk of collapse accident increases. Therefore inspection and repair are necessary. It is desirable to conduct inspections regularly for early detection of bridge anomalies. Bridge inspection is currently carried out by hand in many cases. However, the current inspection method has the following two problems. 1) Danger of inspection workers falling from the bridge, 2) High cost for visual inspection by inspection workers. In order to solve these problems, various studies have been conducted to realize robot inspections. Broadly speaking, the inspection robot can be classified into the following four:

a) Adsorption inspection robot: Adsorption type inspection robots use a magnet to perform adhesion inspection on steel bridges. The robot developed by Anirban et al., Mag-Foot, inspects the surface of steel bridge elements [1]. The robot has two front legs and one back leg, and permanent magnets are mounted on thier toes with air gap. The robot can move on the surface of a steel bridge with three legs. The robot developed by Nhan H. et al. is also equipped with permanent magnets on the

T.T. Truong, T.N. Tran, Q.K. Le and T.N. Nguyen (eds.), ISAS 2019 (Kalpa Publications in Engineering, vol. 3), pp. 168–174

four wheels of the airframe [2]. This enables the robot to move on the steel bridge by four-wheel drive. Since these adsorption type inspection robots can stably stick to the surface of the bridge using permanent magnets, the robot can accurately carried out the photographing inspection and the hitting sound inspection. However, because of the use of magnets, adsorption type inspection robots cannot apply to concrete bridges. Also, movement may be limited by the condition of the surface of the bridge.

b) Flight inspection robot: The advantages of the flight inspection robot include the following two. 1) Flight robots can approach anywhere regardless of the bridge surface condition. 2) The preparation time is very short. Junwon et al. showed the effectiveness of a flying inspection robot in bridge inspection [3]. In [3], Junwon et al carried out a photography inspection of the crack of the bridge by the camera mounted on the drone. Operation of the drone is difficult, and thus there are also variation for the skill of the operator. Prajwal et al. tryied to solve this problem by autonomous flight using a LIDAR sensor [4]. Other problems with flying inspection robots include that flight robots cannot be inspected in stormy weather, and there is a risk of falling.

c) Crane type inspection robot: The crane inspection robots assist the inspection workers. The robot developed by Je-Keun Oh et al. made it possible for workers to carry out visual inspections such as crack detection under the bridge safely by creating a platform by a crane under the bridge [5]. However, it is a disadvantage that the operation time is long because the inspection is performed visually by the workers.

d) Wire-suspended inspection robot: Since the wire-suspended type inspection robot can mount large weight load, inspection using a plurality of sensors can be performed. The authors developed a wire-suspended bridge inspection robot system ARANEUS [6]. The robot can moves under the bridge using eight wires and winches, and can take pictures of cracks . There are no restrictions on the bridge material compared to the adsorption type. Compared to the flight type, the payload capacity is larger and the risk of falling is smaller. Moreover, the working time can be shortened, and the safety of workers can be secured compared with the crane type robots.

In this research, For the reasons that the wiresuspended robots have few defects, and can use multiple sensors, thus the wire suspension type inspection method is adopted. In the literature [6], we performed the photographing inspection of the crack under the bridge, and confirmed the effectiveness of the proposed robot system. However the photographing inspection of the bridge pier part did not be performed. Therefore, we develop a robot system that can perform a stable inspection of the bridge pier to make a crack map. In addition, we will conduct operation experiments on an actual bridge to confirm effectiveness of the proposed robot system.

Section 2 describes the developed robot system. In Section 3, The actual bridge operation experiment using the developed robot system is shown. In Section 4, we describe the conclusion of this paper and future prospects.

2 The Developed Robot System

2.1 System configuration

Figure 1 shows the developed robot system composisiton. The purpose of this research is to inspect the bridge piers that support the bridge girder among the bridge. As shown in Figure 1, the robot is suspended by four wires. By changing the four wires length by the winches, the robot can move on the surface of the bridge piers. In addition, we attached the camera and camera platform to the robot body to take pictures of cracks on the pier surface. The configuration of a system created based on this inspection model is shown in Figure 2. The red line connecting each device shows a power supply line, and the black line shows a communication line. The load cell and winch motor, PC, camera and camera platform mounted on the robot are DC voltage driven. The power of the load cell and winch is supplied by converting AC voltage from the battery into DC voltage by the AC/DC converter. Thereby, the power source of the winch can be maintained even by remote control. In addition, a small PC and a tension load cell are mounted on the robot to control and operate the winding amount of the winch. When the power supply to winch motors in emergency, the PC is preferable to work without stopping. For this reason, we separated the power supply to the PC and the motors. In addition, we mounted a attitude sensor on the robot for attitude control, and mounted LRF for position information acquisition.

2.2 Robot configuration

The developed robot is shown in Figure 3. The camera for taking pictures of the crack was mounted at the center of the robot. The robot mounted castors to reduce friction between the surfaces of the piers. Each device was arranged such that the distance between the robot's center of gravity and the surface of the bridge was increased in order to prevent the caster from leaving the surface of the bridge. We attached four winches, one at each corner of the robot. The wire is directed from the robot to the bridge pier via the winch, the guide rollers and the guide roller boxes as shown by the red line in Figure 3. Also, in order to prevent the wire cutting, it is desirable that the wire does not contact parts other than the guide roller. For this purpose, we developed a wire guide roller box and mounted it on the robot.

The specifications of robot are shown in Table 1. The dimensions of the robot were determined to realizing the three matters as follows; securing the angle of view of the camera; increment of the force from the robot toward the bridge surface; and capability of installation of the cleaning function and the hitting sound inspection functions.

2.3 Control system

The robot moves and changes its posture by winding and unwinding the wire. The three directions of Z direction, X direction position and posture around Y axis are controlled by winding and unwinding the 4 wires. The tension of each wire is measured by the sensors to prevent slack and breakage. The winding speed of the wire is determined by the linear sum of the following four controls:

a) Movement control: To move in the positive X direction, the wires 1 and 2 are wound and 3 and 4 are sent out. When moving in the positive Z direction, all wires are wound.

b) Attitude control: When the posture is tilted counterclockwise direction on the Y axis, the wires 1 and 3 are wound and 2 and 4 are sent out. The amount of winding is determined as linear feedback of the attitude.

c) Tension control: There is a risk of breakage if the tension of the wire is too much. On the other hands, if slack occurs, there may be a problem that the wires come off the pulley. Therefore, the maximum tension is set, and the amount exceeding the maximum tension is fed back to determine the winding amount. The minimum tension is also set and controlled similarly.

d) Anti-rotation control around the X axis: If the tension of the wires 1 and 4 at the top is relatively weaker than 2 and 3, the robot may rotate around the X axis. Therefore, if the tension of the wire 3 is smaller than 4 then the wire 4 is wound and 3 is sent out according to the their difference. This prevents rotation around the X axis. The wires 1 and 2 are controlled in the similar manner.

In a) and b), it is assumed that expansion and contraction of the wire does not occur. Therefore, when the wire length is long, there is a risk of destabilization of the control system.

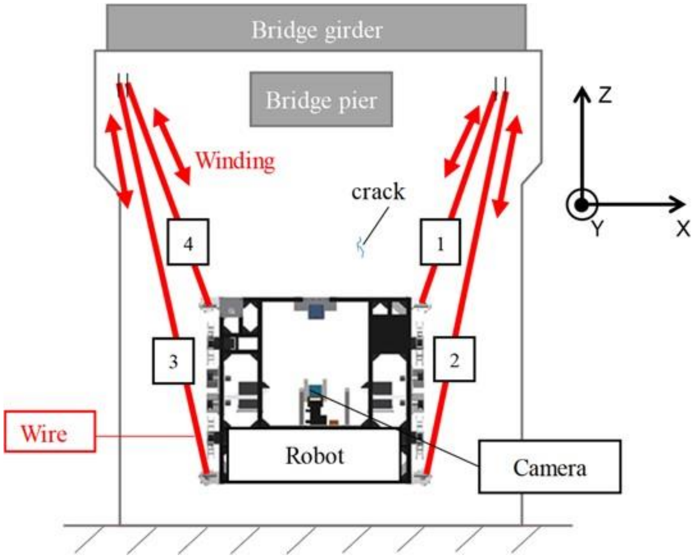

Figure 1: The developed robot system

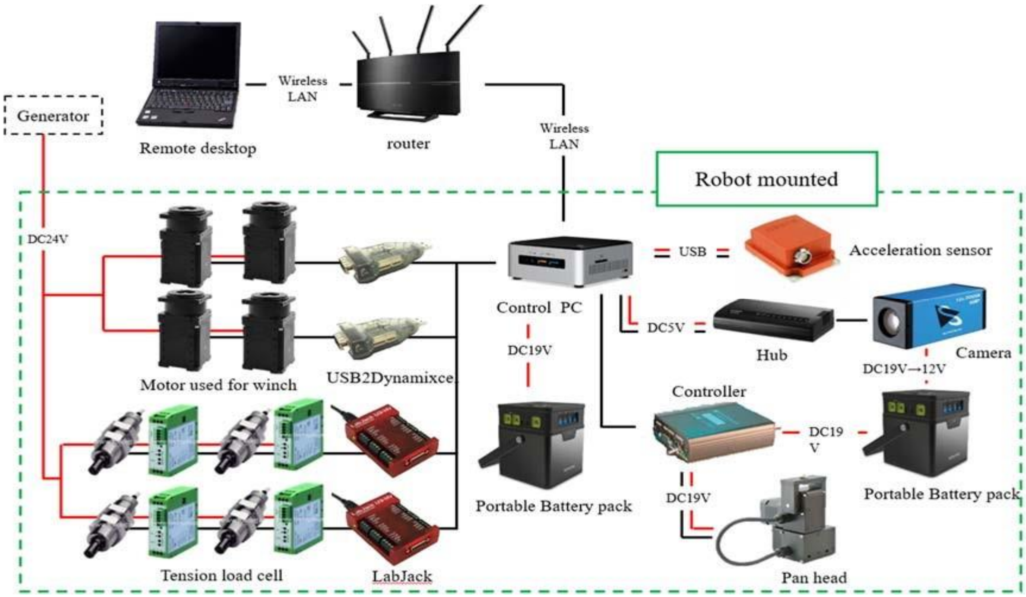

Figure 2: Connection of devices

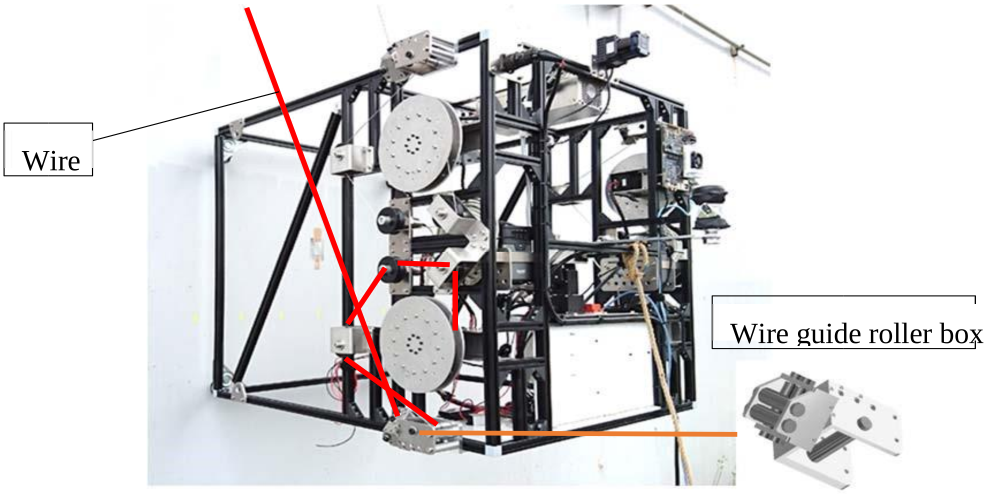

Figure 3: The developed wire-suspended robot

Table 1. The specifications of robot

Mass	60kg
Size	Vertical:840mm Side:1000mm Height:840mm
Moving velocity	25cm/s
Power supply	Motor:AC100V Wire feeding Control PC:DC20V

3 Inspection Experiment On An Actual Bridge

In order to confirm the effectiveness of the developed robot, the inspection experiment was performed in an actual bridge. In this experiment, it is confirmed whether the movement of the pier surface, and the imaging of the crack are possible by the developed robot system.

3.1 Target bridge and inspection method

The experiment was conducted at Hachinohe

Ohashi in Hachinohe City, Aomori Prefecture, Japan (Figure 4). The bridge pier used in this experiment is 25.5 m height and 20 m width at most. In order to carry out this experiment, jigs for attaching the wire to the bridge pier was attached before the experiment. The inspection procedure is shown in Figure 5.

a). Attachment of the wires to the jigs: Wire attachment to the jigs was performed using a crane car. There are two fixed jigs at the positions shown in Figure 4, and are attached to the left and right of the bridge pier. Two wires are attached at the one jig, and a total of four wires were attached.

b). Installation of robot: Place the robot on the surface of the bridge pier while winding up the wires one by one.

c). Bridge inspection work: The inspector performed a photographing inspection of the crack of the bridge pier using the controller and GUI.

The robot was moved along the path shown by the red line in Figure 4, and photographing was performed in a time interval automaticaly.

d). Collection of the robot: We worked in the slimlar way as installing the robot and attaching the wire, and we took the robot away from the pier and carried out the collection of the robot.

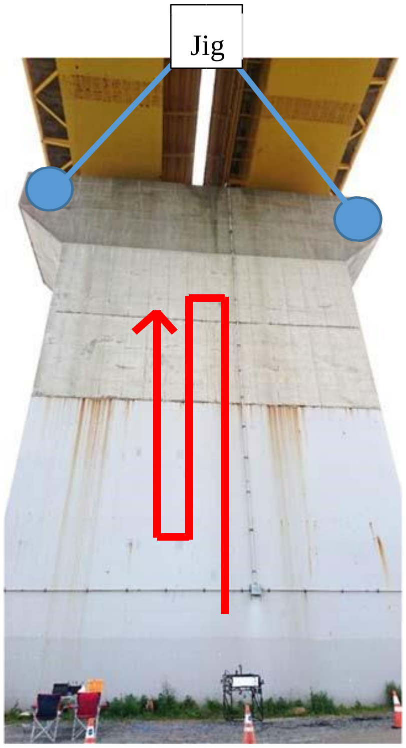

Figure 4: Bridge pier for the inspection experiment

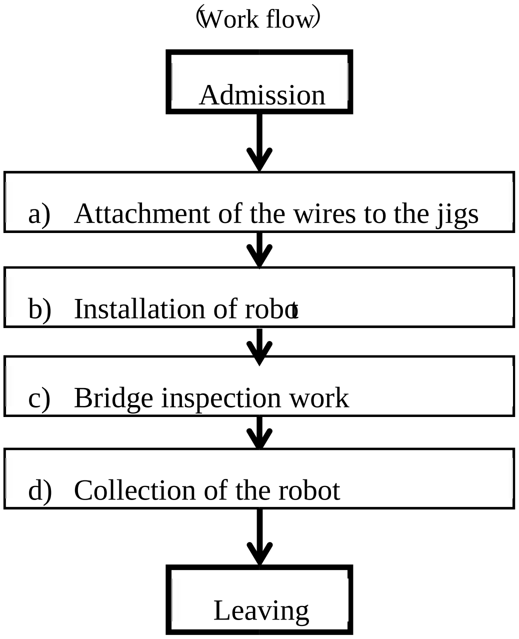

Figure 5: Inspection procedure

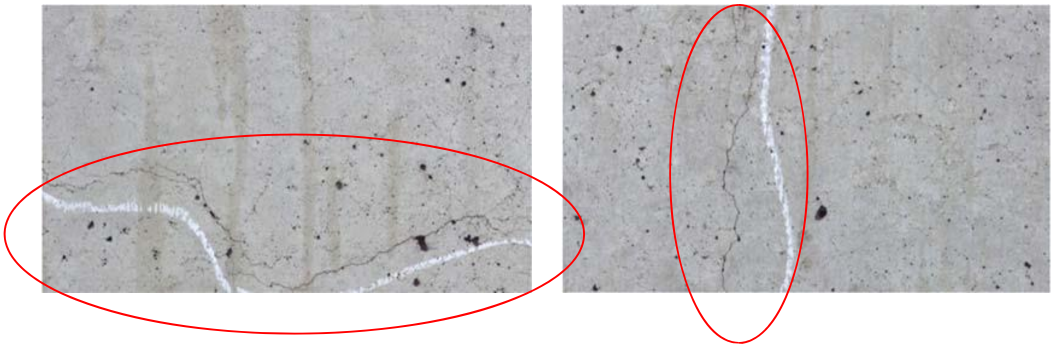

Figure 6: Images taken by robot camera

3.2 Experimental result and consideration

As a result of the experiment, we describe the movement of the robot by wire and the shooting of the crack.

a). Movement of robot by wire: It was confirmed that the robot could be moved vertically and horizontally by wire driving. The bridge pier had a level difference of about several centimeters in the center, and it was necessary to attach a rope to the back of the robot, and pull it to get over the step. During the work, the wire could fall off the pulley. It is necessary to review the diameter of the caster according to the height of the step which must be overcome, and to make it possible to get over the step. In addition, when the wire is long, there is a problem that the attitude control becomes unstable. When the wire length is long, since the wire elongation cannot be ignored, a control system should consider the wire elongation.

b). Photographing the crack: The images taken by a robot camera are shown in Figure 6. The crack could be clearly photographed as indicated by the red circle in Figure 6. In addition, after bridge testing, we try to develop a crack identification system using image recognition.

4 Conclusions

In this paper, we proposed a bridge inspection robot system that enables stable inspection by wire drive. In the real bridge operation experiment conducted at Hachinohe Ohashi, the developed robot was operated and it was possible to photograph a crack that existed on the pier surface. The concern in terms of movement was revealed that I could not get over the place where there was a small step on the bridge pier. Therefore, it is considered necessary to review the diameters of the guide roller and the caster. In the future, we plan to create a crack map using LRF data acquired during the experiment. In addition, by installing a cleaning function and a tapping sound inspection function to inspect cracks inside the bridge pier that cannot be seen, and simple repair work.

References

Anirban Mazumdar, H. Harry Asada, Member, IEEE, Mag-Foot: A Steel Bridge Inspection Robot, The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems October 11-15, 2009 St. Louis, USA.

Nhan H. Pham, Hung M. La, Quang P.Ha, Sy N. Dang, Anh H. Vo, Quang H. Dinh, Visual and 3D Mapping for Steel Bridge Inspection Using a Climbing Robot, 33rd International Symposium on Automation and Robotics in Construction (ISARC 2016).

Junwon Seo, Luis Duque, and James P. Wacker,Field Application of UAS-Based Bridge Inspection, Transportation Research Record 1–10.

Prajwal Shanthakumar, Kevin Yu, Mandeep Singh, Jonah Orevillo, Eric Bianchi Matthew Hebdon, Pratap Tokekar, View Planning and Navigation Algorithms for Autonomous Bridge Inspection with UAVs, Authors Suppressed Due to Excessive Length.

Je-Keun Oh, Giho Jang, Semin Oh, Jeong Ho Lee, Byung-Ju Yi, Young Shik Moon, Jong Seh Lee, Youngjin Choi, Bridge inspection robot system with machine vision , Automation in Construction 18 (2009) 929–941. [6]. R. Fujisaw, K. Umemoto, M. Tanaka, N.

Sato, N. Nagaya, M. Katsuyama, DEVELOPMENT, BRIDGE INSPECTION AND OPERATION OF ARANEUS - WINCH WIRING ROBOT SYSTEM, Journal of Japan Society of Civil Engineering F4 (Construction Management), Vol. 73 No. 1, pp.26-37, 2017.