Automation in Construction 17 (2008) 907–914

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

# Remote control of backhoe at construction site with a pneumatic robot system

Takahiro Sasaki *, Kenji Kawashima

*Tokyo Institute of Technology, Precision and Intelligence Laboratory, 4259, Nagatuta, Midori-ku, R2-46,Yokohama, 226-8503, Japan*

ARTICLE INFO

*Article history:*
Accepted 12 February 2008

*Keywords:*
Remote control
Construction machines
Pneumatic artificial rubber muscle
Disaster
Robot arm

ABSTRACT

In this paper, remote control of backhoes is achieved at construction sites with a pneumatic robotic system we have developed. The system mainly consists of pneumatic robot arms actuated by pneumatic rubber muscles (PARM), CCD cameras and a control box containing power source, PC and wireless LAN boards. The remote control system was applied to two types of backhoe, one small with bucket size of 0.025 [$m^3$] and another medium-sized bucket with 0.28 [$m^3$]. Field tests were conducted at local construction sites to confirm the effectiveness of the system. The remote control operations were achieved with the working efficiency of more than 50% compared with that of the direct operation. The effectiveness of the system has been determined.


## 1. Introduction

In disaster sites, the remote control of construction machines is essential in order to minimize the injuries and loss of life. There is a substantial literature dealing with the development of remote control systems for manipulating the functional tasks of construction machines in disaster sites [1–6]. However, the ordinary systems are large and heavy so that the transportation takes time and is troublesome. The installation of robot to ordinary construction machinery is more effective for practical use in the opinion of transportation and quickness of the activity.

A pneumatic system has a high weight–power ratio and compliance and clean energy to drive. Therefore, pneumatic robot systems that consist of pneumatic actuators were applied to the remote control of construction machinery [7]. We have developed a remote control system using pneumatic rubber muscle (PARM) as the actuator of the robot system [8,9]. The effectiveness of the system was demonstrated with a small backhoe. However, there are demands to make the system more compact to install more ordinary machines.

In this research, we have newly developed a 6-DOF (degree of freedom) pneumatic module arm which consists of three 2-DOF modules. The modules make the system simpler and more portable. In addition, we also newly developed a control box to make the system compact for easy installation to the operation room of middle type backhoes.

Two CCD cameras are installed on the pneumatic robot system in order to monitor the synchronized activities of the pneumatic robot system and backhoe machines from different perspective positions [10,11]. Images from the cameras are transported into the master side through a wireless LAN, and then display on a Laptop PC. The wireless LAN and PC boards, and the power source are built in the control box. The entire weight of the pneumatic robot system is only 40 kg.

The system was installed on a small type backhoe whose bucket size is 0.025 [$m^3$] and a middle type that of 0.28 [$m^3$]. The effectiveness of the system was confirmed by some field tests at construction sites.

## 2. 6-DOF pneumatic module arm

### 2.1. Pneumatic artificial rubber muscle

Pneumatic artificial rubber muscle is a noble actuator that has a high weight–power ratio [12–17]. As shown in Fig. 1, PARM is composed of rubber tube and fibers bladed around it.

Driving system of single joint using PARMs is shown in Fig. 2. Two PARMs are connected to a link in parallel. A 5-port servo valve (MYPE-

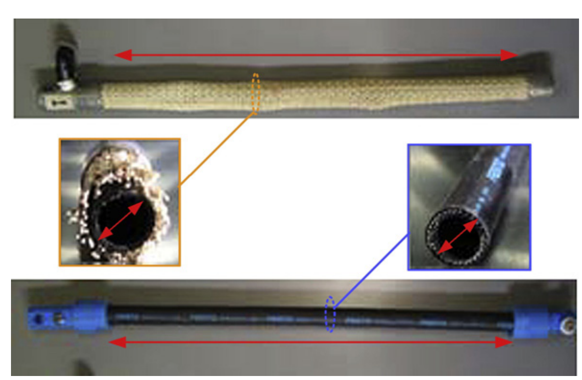

**Fig. 1.** Pneumatic artificial rubber muscles (PARM) (Upper side: McKibben type, Lower side: fiber knitted type).

* Corresponding author.
*E-mail address:* sasaki-takahiro@c.metro-u.ac.jp (T. Sasaki).

0926-5805/$ – see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.autcon.2008.02.004

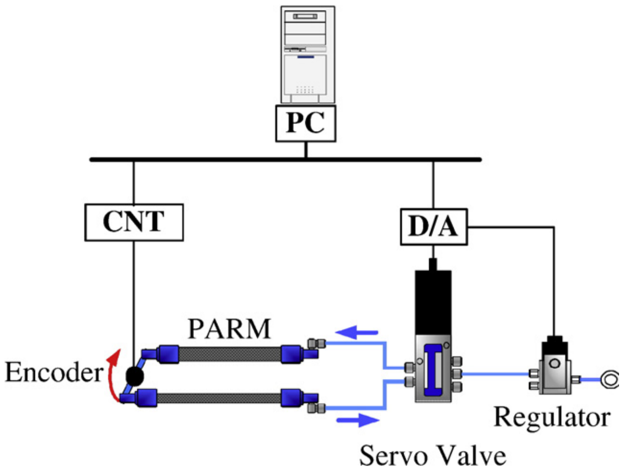


**Fig. 2.** Joint driving system.

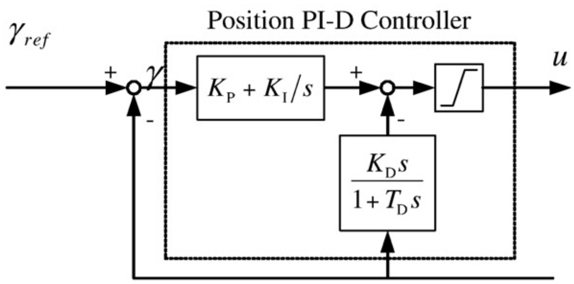


**Fig. 3.** Single position PI-D feedback control block diagram.

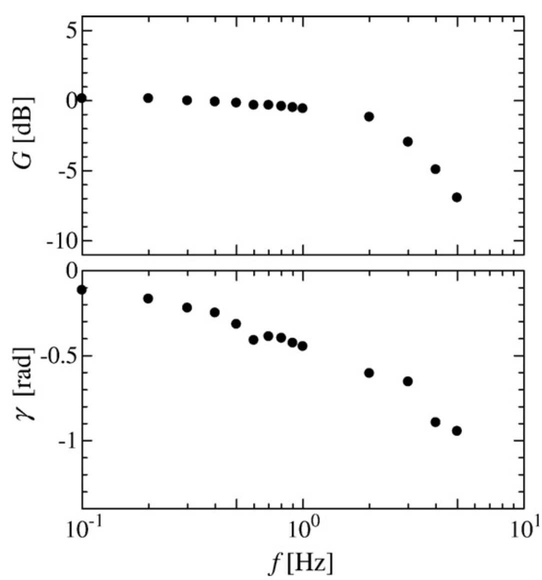


**Fig. 4.** Bode diagram of single position control of PARM.

5-M5-010B: FESTO) controls supply and exhaust air to PARMs. Then, the difference of contraction quantities of two PARMs creates joint torque that is called BMDS (Bi-Muscular Driving System). A rotary encoder was set to each joint and the rotation angle was measured and controlled.

1-DOF position control experiment was conducted using single loop position control as shown in Fig. 3. For experimental condition,

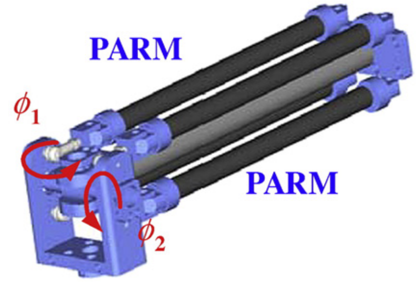


**Fig. 5.** 2-DOF module (CAD Image).

the amplitude is 10 [°] and each feedback gains are $K_P$=35 [V/rad], $K_I$=20 [V·s/rad], $K_P$=0.2 [V/(s·rad)] and $T_D$=0.02 [s]. The frequency responses were obtained by experimental results and were summarized in a bode diagram as shown in Fig. 4. As the delay cannot be observed at the frequency of 1 [Hz], it is enough for operating the lever of backhoes.

### 2.2. 2-DOF arm module

We have developed 2-DOF module using pneumatic artificial rubber muscles. Fig. 5 shows the CAD image of the module and Fig. 6 is photograph of the developed module. The operating range of each angle is 20 [°] and 40 [°] as shown in Table 1. The weight of the module is only about 1 [kg]. It can be seen from Fig. 6 that the driving part of the module is connected by ball joints with four PARMs. Fig. 7 shows the movement of 2-DOF arm module. Two pairs of BMDS realize 2-DOF motions.

Experimental results of joint driving at 1 [Hz] are shown in Fig. 8. Controlled joint $\phi_1$, $\phi_2$ is smoothly driven. Even there is a delay about 0.1 [s], both of joints were well controlled.

### 2.3. 6-DOF pneumatic robot arm

Pneumatic robot arms coupled three 2-DOF modules are shown in Fig. 9. The size of upper arm and forearm are 490 [mm] and 400 [mm], respectively. The weight of the arm is only about 3 [kg] and 20 [N] force can be generated at the tip position. As each module is controlled two 5-port servo valves, the arm is controlled with six servo valves. Rotary encoders were set to each joint and the rotation angles were measured.

## 3. Remote control system

### 3.1. Control box

A control box was developed for the pneumatic robot systems as shown in Fig. 10. The control box is divided into three small units,

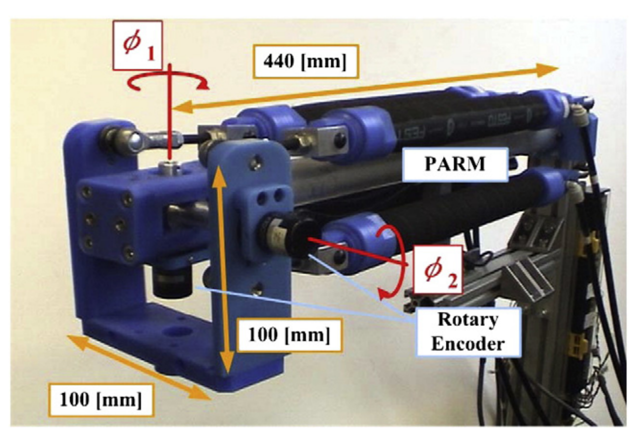


**Fig. 6.** Photograph of 2-DOF module.