DESIGN OF A MANIPULATOR FOR TELE-OPERATION APPLICATIONS

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ABSTRACT: A manipulator for remote duplication of an operator's arm motion is presented. The focus of design is on the economic efficiency with limited payload, speed and accuracy ranges for a given application. The arm has eight degrees of freedom with upper arm, elbow, lower arm, wrist and end effector. The actuators employ screw–nut combination for maximum payload and self-locking feature with low cost geared motors. The end effector has three degrees of freedom for wrist and one degree of freedom for fingers. The three fingers are coupled by a triangular joint that offers approximately equal grasping forces among them and are operated by one actuator. The mechanism, which is composed of the combination of screw-nut-timing pulley, was designed for an upper arm. The motion range of the manipulator had been analyzed by a forward kinematics. The performance of the manipulator based on video motion capture of an operator had been verified by experiments.

Keywords: *Manipulator, Tele-operation, Robot Arm, Performance Evaluation, Motion Tracking*

1. INTRODUCTION

Since the late twentieth century, robots have contributed to improve the productivity of various industries [1]. In the early 1980s, many types of construction robots have been developed and applied to help a worker in construction site. Most of them are single-task robots such as painting, assembly, cleaning, inspection, etc. [2][3]. Among the potential robot applications in building construction, tele-operated manipulators for material handling and assistance to works attract a lot of interest because of the difficulties of using of elevators and cranes in limited environments [4].

This work presents the design of a tele-operated manipulator that can be applied to various tasks such as assistance, maintenance, repetitive work. It includes a novel design for the economic efficiency.

This paper is organized as follows. Section 2 describes the design of a manipulator and characteristics. Section 3 provides a kinematic analysis of the manipulator. A verification test is represented in section 4, and Section 5 concludes this paper.

2. DESIGN OF A MANIPULATOR

A serial manipulator with eight DOFs, which is based on the screw-nut mechanism, has been developed. It is shown in Fig. 1. The specifications are described in Table 1.

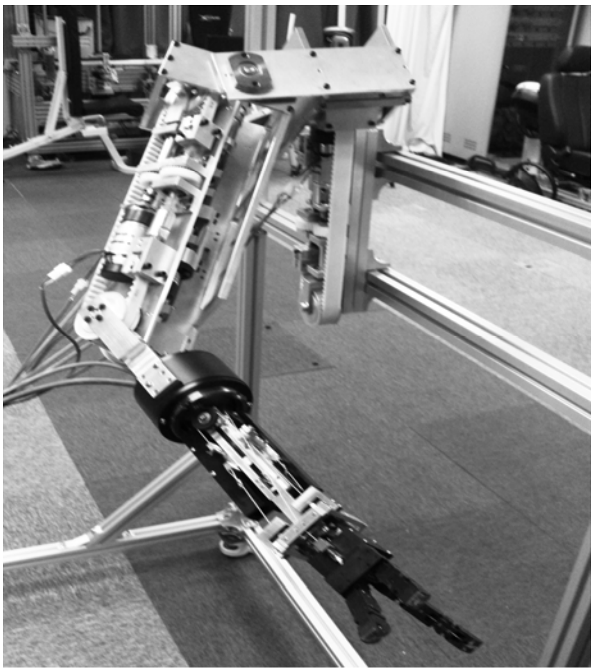


Fig. 1 The developed manipulator

Table 1 Specifications of the developed manipulator

Weight	8 Kg
Actuator type	DC Geared motor with encoder
Actuator capacity	30W (un upper arm) & 6W (a lower arm)
Voltage	24V
Payload	4 Kg (Max)

2.1 END-EFFECOR DESIGN

As shown in Fig. 2, the end-effector has been composed of three modules mimicking the human finger. It can rotate on three axes corresponding to rotation axes of the human wrist. A module has three rotational joints like the finger. Three modules are operated together by one actuator. It has compliance for various shaped objects due to the mechanism that makes the deflection of each module adjusted along the shape of grasping objects [5]. Grasping force is generated by the driving wire pulled by compressed springs [6]. The detailed description related to above mentioned mechanism was represented in the previous work [7].

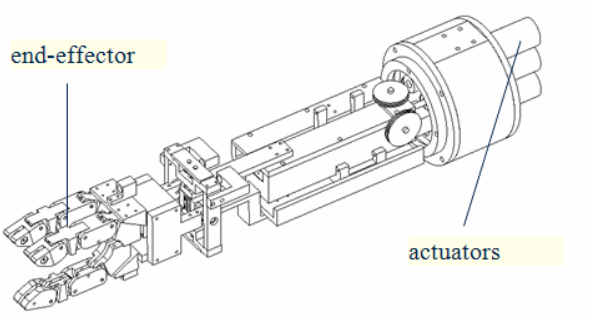


Fig. 2 Lower Arm

2.2 MECHANISM OF AN UPPER ARM

The rotational mechanism of the upper arm has been developed based on the screw-nut mechanism. It is shown in Fig. 3. The nut, which is inserted in gear2, is rotated by the actuator. Along the rotation of the nut, the screw moves linearly. Timing-belt, which is connected to each end of the screw, moves linearly with screw, and this motion makes a joint fixed to the timing-pulley rotated [8]. As using the screw-nut mechanism, high torque about the joint can be achieved with low cost geared motors. Moreover, a posture

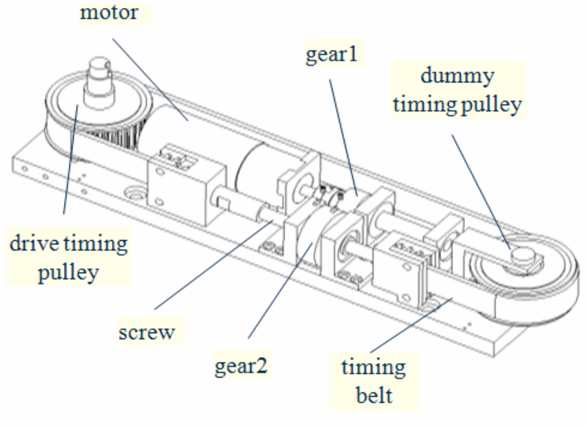


Fig. 3 Rotational mechanism of the upper arm

can be maintained without power due to the self-locking feature of the screw-nut mechanism. The control of joint rotation is relatively easy and stable because the rotation error of actuator hardly affects to the rotation error of joint due to overall high reduction ratio between actuator and joint.

3. KINEMATICS

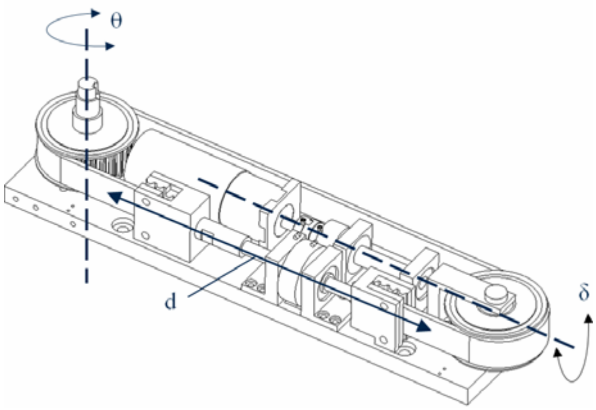


Fig. 4 Kinematic analysis of the mechanism

The relation between the rotation of joint (θ) and the rotation of actuator (δ) in Fig.4 is equal to Eq. (1).

$$\theta = \frac{2d}{D_p} = \frac{LD_{g1}}{\pi D_{g2} D_p}\delta \tag{1}$$

D_{g1}, D_{g2} *and* D_p denote respectively the pitch circle diameter of gear1, gear2 and timing pulley. L and d represent the lead of screw and the displacement of screw, respectively.

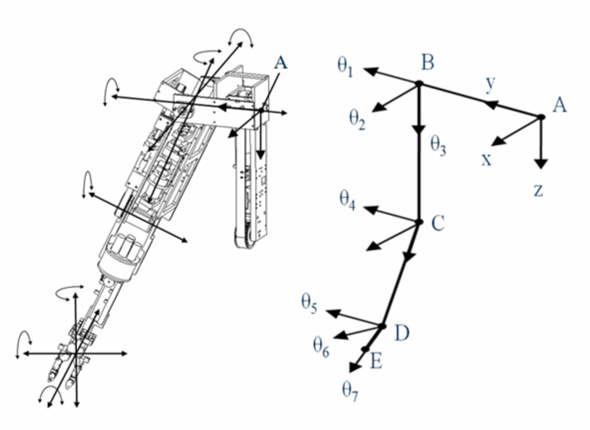


Fig. 5 Coordinates of each joint for a forward kinematics

The position vector of the end-effector along the rotation of each joint can be obtained from a forward kinematics [9]. Coordinates of each joint related to a forward kinematics is shown in Fig. 5. Coordinate 'A' represents the origin of the manipulator. Coordinate 'B, C, D' are located in the rotation center of each joint. 'E' represents the mid-point among three modules. The rotation matrix (${}^fR_m$) of each coordinate using the x-y-z Euler angle is expressed as Eq. (2).

$$
\begin{aligned}
{}^f R_m &= R(x)R(y)R(z) \\
&= \begin{bmatrix} c_y c_z & -c_y s_z & s_y \\ s_x s_y c_z + c_x s_z & -s_x s_y c_z + c_x c_z & -s_x c_y \\ -c_x s_y c_z + s_x s_z & c_x s_y s_z + s_x c_z & c_x c_y \end{bmatrix}
\end{aligned} \tag{2}
$$

The translation matrix (${}^fd_m$) is determined as the distance between each coordinate. The transformation matrix is composed as

$$
{}^f T_m = \begin{bmatrix} {}^f R_m & {}^f d_m \\ \bar{0} & 1 \end{bmatrix} \tag{3}
$$

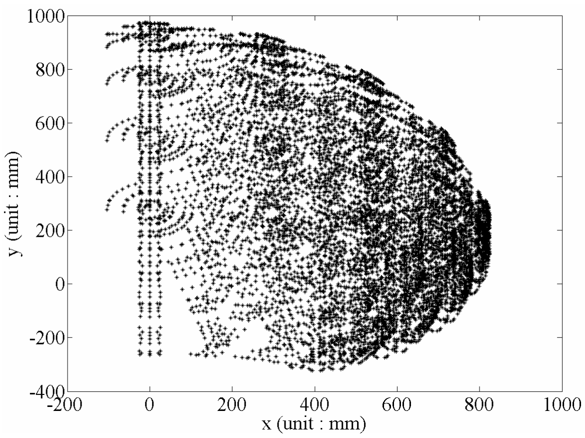
where f and m denote a fixed frame and a moving frame, respectively. The position vector of the end-effector from the origin A can be expressed as Eq. (4).

$$
{}^A P_E = {}^A T_B {}^B T_C {}^C T_D {}^D P_E \tag{4}
$$

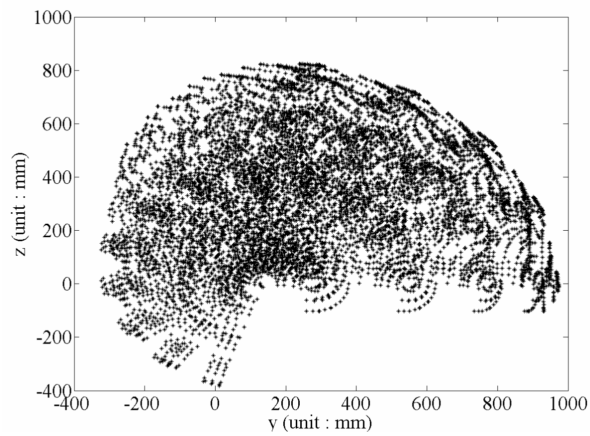
Through the combination of Eq.(1), Eq. (3) and Eq. (4), the position vector of the end-effector is expressed as the function of the actuator rotation of each actuator (δ_i).

$$
{}^A P_E(\delta_i) = {}^A R_B {}^B R_C ({}^C R_D {}^D_E P + {}^C d_D) + {}^A R_B {}^B d_C + {}^A d_B \tag{5}
$$

The workspace of the manipulator is determined by substituting the motion range of each joint into Eq. (5). Fig.6 shows the results for analysis of the workspace.



(a) Workspace (XY Plane)



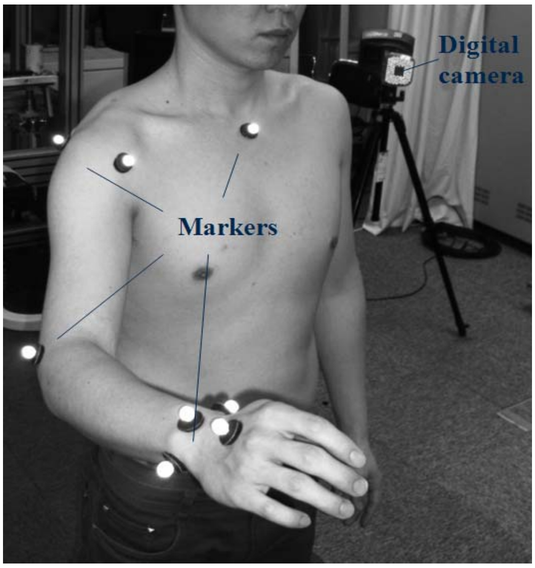
(b) Workspace (YZ Plane)

Fig. 6 Workspace of the developed manipulator

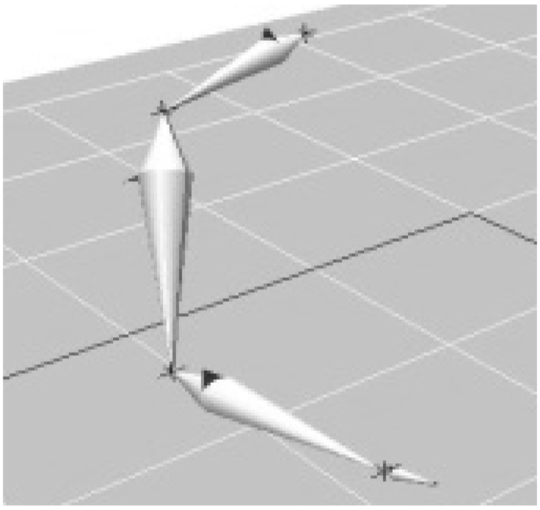
4. PERFORMANCE EVALUATION

The performance of the manipulator based on motion analysis of an operator is verified by experiments. The hardware for motion analysis has been composed of eight optical devices (HAWK, Motion Analysis). SKB(Skeleton Builder) and EVART is employed as software for motion analysis [10].

Considering the center of joint rotation, ten-markers are attached to the arm of an operator. The imaginary bone, which is corresponding to the bone of the human arm, is created based on markers by SKB. The imaginary bone is rotated based on the position data of markers which is obtained by digital cameras. The joint angles of SKB model are corresponding to joint angles of the arm. The motion data has been collected with 120Hz. Fig.7 shows the position of markers and the imaginary bone.



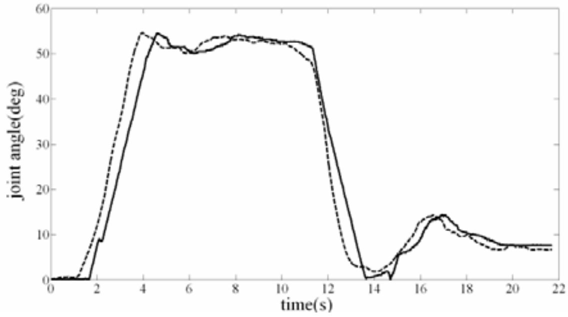
(a) Marker set for motion analysis



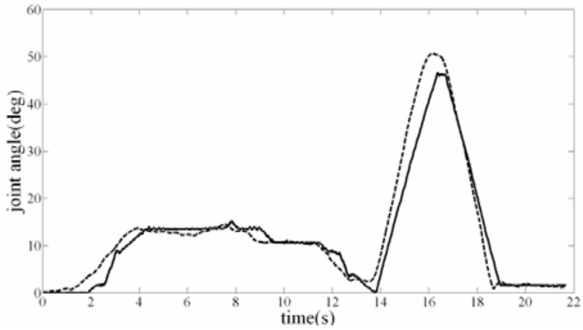
(b) SKB model

Fig. 7 Motion analysis of the operator

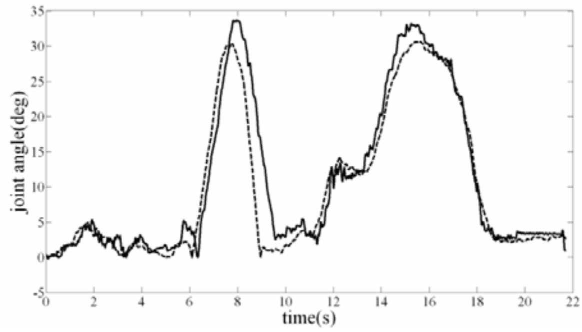
The number of rotation of actuators to track the action of the operator is decided by Eq. (1). The control logic based on the PID control is made up of using Labview, and DAQ (PCI6601, National Instruments Co.) is used to collect the rotation data of the actuator' encoder and to send command to the actuator.



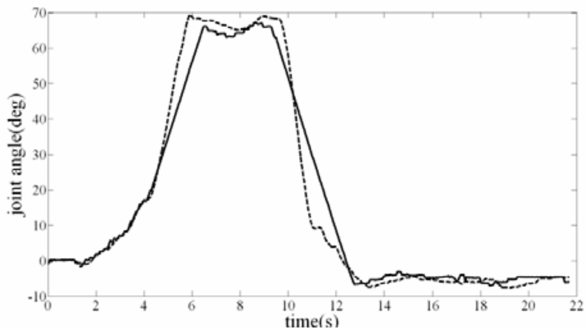
(a) θ_1 (— : operator motion , - - : manipulator motion)



(b) θ_2 (— : operator motion , - - : manipulator motion)



(c) θ_3 (— : operator motion , - - : manipulator motion)



(d) θ_4 (— : operator motion , - - : manipulator motion)

Fig. 8 Test results

To validate tracking performance, the motion of the manipulator had been analyzed. The comparison between joint angles of the manipulator and joint angles of an operator had been shown in Fig.8

5. Conclusion

A serial manipulator with 8DOFs, which can perform various tasks in remote site by tracking of operator action, had been developed in this paper. The mechanism had been design based on screw-nut mechanism. Using this mechanism, it can have the economic efficiency with limited payload, speed and accuracy ranges for a given application. The work space had been analyzed through a forward kinematics. Through the comparison between motion analysis data of the manipulator and it of an operator, tracking performance had been validated.

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REFERENCES

[1] J.E. Colgate, M.A. Peshkin, S.H. Klostermeyer, “Intelligent Assist Devices in Industrial Applications: a review”, *IEEE/RSJ Intl. Conference on Intelligent Robots and Systems*, Las Vegas, Nevada, 2003.

[2] S.K. Woo, D.H. Hong, W.C. Lee, J.H. Chung, T.H. Kim, “A Robotic System for Road Lane Painting”, *Automation in Construction*, Vol. 17(2), pp122-129, 2008.

[3] L. Cousineau, N. Miura, “Construction Robots: The Search for New Building Technology in Japan”, *ASCE Press*, 1998.

[4] P. Gonzalez de Santos, J. Estremera, E. Garcia, A. Armada, “Power Assist Devices for Installing Plaster Panels in Construction”*, Automation in Construction*, Vol. 17(4), pp459-466, 2008.

[5] K.H. Kim, H.K Ko, C.H. Cho, “Grasping Structure for Robots”, *Korean Patent Application*, 10-2009-0057033, 2009.

[6] K.H. Kim, H.K Ko, C.H. Cho, “Rotational Device for Robots and a Robot Arm Using the Same”, *Korean Patent Application*, 10-2009-0057027, 2009.

[7] H.K. Ko, K.H. Kim, C.H. Cho, “Design of an Economic Service Robot Hand Based on Biomimetics and TRIZ”, *J of KSME A*, Vol. 34(11), pp.1741-1747, 2010.

[8] H.K. Ko, K.H. Kim, C.H. Cho, “Rotational device for robot and robot arm using the same”, *Korean Patent Application*, 10-2011-0009594 (2011).

[9] H.S. Choi, T.H. Kim, W. J. Moon, L.R. Paul, “Study on a Ultra-light Dual Revolute Manipulator with High Joint Torque”, *International journal of precision engineering and manufacturing*, Vol.10,(4), pp49-56, 2009.

[10] http://www.motionanalysis.com/index.html