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Controller design and simulation of a one-degree-of-freedom power assist system for lifting objects

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Abstract

This paper presents a controller design and simulation of a one-degree-of-freedom power assist robot for lifting objects. The research is conducted through a simulation of the control system of power assist devices, without determining friction of the system, but allowing for time delay at 150 µs. To this end, a force sensor-less method, a calculation of the disturbance torque from the actual weight of an object which can be estimated from a disturbance observer in place of a force sensor is employed. The disturbance torque obtained is then converted to force signal and reference motion to control the power assist system. Both, force signal and reference motion are generated by the PID controller, which is designed for the power assist system to maintain its stability. From the simulation, the controller enables the robot to efficiently lift an object with ease of use; the operator perceives a load applied 10 times lighter than the actual weight (assist ratio, α = 10). In practice, however, there might be other limitations to be taken into account: for example, strength of the power assist robot's structure which has to be suitable for a certain task.

Keywords: Power assist robot, Force sensor less, Disturbance observer, Feedback control

1. Introduction

As the working-age population is shifting towards aging society, more and more people are prone to direct impacts on health, especially those working in factories and hospitals, as well as other industries where tasks require lifting heavy objects [1-3]. As a result, in the past 15 years medical robots have been developed [4] in order to facilitate operations and prevent serious injury. Power assist robots for lifting heavy objects are another technology which has been created. Nevertheless, their system and mechanism still need further research and development for commercial purposes. This research therefore presents a simulation and an analysis of a one-degree-of-freedom power assist robot for lifting objects, and identifies the extent to which the system can be utilized.

2. Materials and methods

2.1 Mathematical model

This research, drawn upon a concept of the power assist system, as shown in Fig.1, examines the system of the one-degree-of-freedom power assist robot for lifting objects using a mathematical model of the power assist robot mechanism with the same parameters as the previous works [1-2], but allows for time delay at 150 µs. The equation (1) can be expressed in transfer function of the system (motor angle vs. torque command) as below.

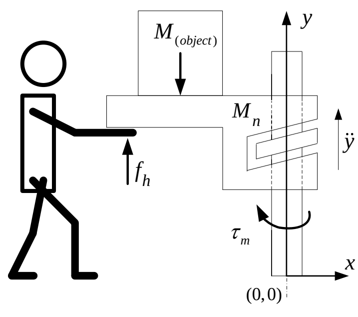

Figure 1 Concept of power assist system

$$G(s) = \frac{3.553\times10^{6}}{1.18\times10^{-5}s^{4} + (0.03559)s^{3} + 41.93s^{2}} e^{(-0.00015s)} \quad (1)$$

From the concept of the power assists system, shown in Fig.1, the equation (2) of motion of the system can be expressed as:

$$\tau_m\left(\frac{1}{N}\right) + f_h - Mg = (M)\ddot{y} \quad ; M = M_{(object)} + M_n \quad (2)$$

Where, τ_m; motor torque command of actuator, f_h; operation force from

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human, M ; total weight of a load (object + moving part), y ; position of the lift, and g; acceleration of gravity.

For controlling functions of the actuator of the power assist system, the position controller (C_p) is designed as function of position. The control law can be expressed as the equation (3).

$$\tau_m = C_p(y^* - y) \quad (3)$$

Further, in this research, a force controller (C_f) is devised in order to enable the operator to perceive load force 10 times lighter than the actual weight (assist ratio, α = 10). The control law can be expressed as the equation (4).

$$y^* = C_f(f_h - \frac{1}{\alpha} f_{\hat{d}}) \quad (4)$$

2.2 Force observers

In order to utilize the force observer instead of the force sensor, the study begins with analyzing the disturbance observer structure since the reaction force observer is dependent on the disturbance observer techniques [1-3, 5], as shown in Fig. 2. Therefore, disturbance can be computed as follows with force or torque units as shown in this equation.

$$d_0(s) = \tau_m(s) - G_n^{-1}(s)\{\theta(s) - v(s)\}$$

$\therefore$ the simplify formulated as

$$d_0(s) = \tau_m - J_m s^2 \theta \quad (5)$$

and $$P(s) = \frac{\omega_0^2}{s^2 + 2\xi_0\omega_0 s + \omega_0^2} \quad (6)$$

When;

τ_m	is motor torque command input signal
θ	is the output signal
v	is noise of the system
d	is the incident disturbances
J_m	is inertial of the mechanism
G(s)	is the model of the actuator or plant of the system
$G_n(s)$	is the nominal model of the actuator
P(s)	is a low-pass filter ω_0 is cut-off angular frequency (ω_0= 600π rad/s or 300 Hz)
ξ_0	is damping coefficient (ξ_0 = 1)
$\hat{d}_{(s)}$	is the estimation disturbance
N	is gear ratio (0.177 mm/rad)

As for simulation conditions for control of the power assist system, this research employs the parameters of a simple mechanism with 1 DOF power assist devices for lifting objects, but specifically determines control speed of the power assist robot under low speed, or under the frictionless system (τ_f = 0).

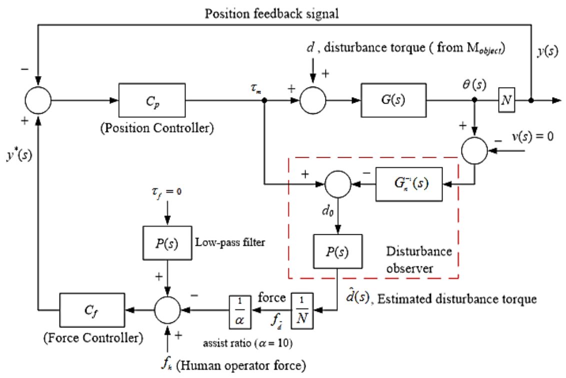


Figure 2 Block diagram of power assist system based on disturbance observer technique

2.3 Controller design

2.3.1 Position controller

The position feedback controller C_p, shown in Fig.2, is devised with the design that allows the system to move freely without receiving load force from lifting an object (d = 0), thereby resulting in the unit-step response with 20 % Maximum Overshoot and Setting Time at 40 ms. This thus makes the system stable and output tracks the reference motion, generated by the PID controller. In this research PID controller {C_p = 1.05 + 0.01/s + 0.015s} is employed to control the power assist system.

2.3.2 Force controller

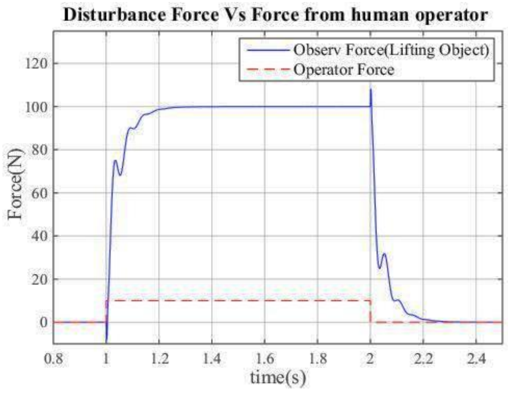
The force feedback controller C_f, show in Fig.2, is devised with the design that allows the system to receive load force from lifting an object. The force here is determined to have a relation with the motion position, resembling the force generated by elasticity of a spring (d = (K_e)y), whereby stiffness constant K_e = 10 N/mm. The designed controller enables the human operator to perceive load force 10 times lighter than the actual weight applied. Also, the system results in the unit-step response with no overshoot and setting time at 0.2 s. This thus makes the system stable and output track the reference force, generated by the PID controller. For this research PID controller {C_f = 0.1 + 25/s + 0.00001s} is used to control the power assist system.

3. Simulation results of the system stability

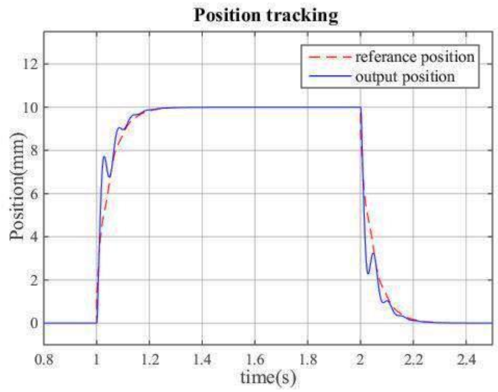
From the simulation, when the power assist system operated through the designed controller is applied with a load force of 100 N, the operator use the force of only 10 N to lift the object. This demonstrates good position tracking of the system by which it enables desired maneuverability of the operator. The results are shown in Fig.3.

4. Discussion and conclusion

This research is conducted to controller design and simulation of a one-degree-of-freedom power assist devices for lifting objects. In doing this, the mathematical model of the power assist robot mechanism is determined, with the same parameters used in the previous works [1-2]. Also, in controlling the system, a force sensor-less method, a calculation of the disturbance torque from the actual weight of an object which can be estimated from a disturbance



(a)



(b)

Figure 3 (a) force tracking signal with assist ratio = 10 (b) position tracking signal

observer in place of a force sensor is employed. The disturbance torque obtained is then converted to force signal and reference motion. These are generated by the PID controller, which is designed to further stabilize the power assist system. According to the simulation, the controller designed for the power assist system enables the robot to efficiently lift an object and enhances its operability, maneuverability and ease of use; the operator perceives load force 10 times lighter than its actual weight. In practice, however, there might be other limitations: for example, strength of the structure designed for development of a power assist robot may not be able to support load force applied. This will in turn damage its structure. It is precisely a design of a power assist robot's structure that needs to be analyzed, among other things in terms of capacity to support applied load force, in order to ensure proper operability for certain task and also a particular type of material.

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6. References

[1] Ishihara M, Ito K, Inuzuka K. Force Sensorless Power Assist Control using Operation Force Observer for Nursing Lift. 2015 IEEE International Conference on Mechatronics (ICM); 2015 March 6-8; Nagoya, Japan. IEEE; 2015. p. 216-221.

[2] Ito K, Ishihara M, Inuzuka K. Force Sensorless Power Assist Controller Design of Transferring Assist Robot. World Automation Congress; 2014 Aug 3-7; Hawaii: USA. New Jersey: IEEE; 2014. p. 1-6.

[3] Oh S, Kong K, Hori Y. Design and Analysis of Force-Sensor-Less Power-Assist Control. IEEE Transaction on Industrial Electronics 2014;61(2):985-993.

[4] Nagai K, Nakanishi I. Power Assist Control of Robotic Orthoses Considering Human Characteristics on Assist Motions. Proceedings of the IEEE International Workshop on Robot and Human interaction; 1999 September; Pisa, Italy. IEEE; 1999. p. 1-6.

[5] Khalil I, Sabanovic A. Sensorless Torque/Force Control. In: Ahmad M, editor. Advances in Motor Torque Control. Croatia; InTech; 2011. p.49-68.