Low Cost Design of High Performance Lift-Assist Pneumatic Manipulator

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Abstract— Lift assist pneumatic manipulators plays an important role in industrial. They are commonly used to lift, transport goods or help in crafting process. Therefore, a control system for high performance, quick respond lift assist pneumatic manipulator is proposed. This whole system is an integration of a mechanical system (manipulator), electric components (microcontroller, load sensor, amplifier) and pneumatic actuators (cylinder, pressure valve). Any changes of load can be detected by the loadcell, the signal is then amplified and fed back to the controller. The controller is designed to calculate the balance pressure based on the received data and sends the control signal to the regulate pressure valve via RS232 protocol. The performance is tested experimentally. It is found that the manipulator equipped this control system is easier to operate since it has no buttons and has a far better effectiveness at about 99,5% in comparison with 85-90% of the others. The main difference is the developed controller in this paper try to compensate the effects of various uncertainties like: friction in mechanical structure, pressure drop in pneumatic system, ...without using a complex model while the others ignore them.

Keywords— buttonless manipulator, handing aid devices, lift- assist manipulator, manipulator controller, pneumatic load manipulator

I. INTRODUCTION

Manipulation (lifting/installing) of heavy loads is one of the most important part of any work in manufacture system. It is the main cause of musculoskeletal problems in workers and number of accidents especially in small and medium enterprises. These loads can sometime be light enough for them to lift but if they do it on a frequently basis it can lead to exhaust, fatigue or even injury. It is estimated that 30% of European worker suffer low-back disorder cause by lifting and handling load (OSHA, 2009) [1]. It not only increases the costs sustained by industries but also has a severe impact of the worker's life quality. As a result, safety and ergonomics guidelines for industry [2-4] set the maximum allowed for compressive spinal compression at 6400N, which is approximately equivalent to lifting a load of 40 kg. To follow these safety recommendations are the reasons for the necessary of using

supporting tools or lift assist manipulators when the load exceeded the limitation.

There are many devices, tools or manipulators which are designed commercially to solve this problem.

The first approach is to use collaborative robot – “cobot” in-short is studied in robotic community. A cobot uses software-defined “virtual surfaces” to constrain and guide motion of the load so that the workers can provide forces in directions which are the most comfortable. The disadvantage is they still have to apply the most of force required. [5, 6].

The second approach suggested operator wearing an exoskeleton type device with kinds of actuators to support them in work. In fact, these types of device are used in many aspects such as: agriculture [7], rehabilitation [8], or in heavy industry [9, 10]. Generally, these types of device are heavy and complex.

The third approach is to have the manipulators generate a load which is equal to object's mass and keep it floating in the air. The operators then manipulate it by applying a very small force [11]. The design proposed in this paper follows this approach. The general principle of these type of device is using a gravity- compensator system or a load counter-weighting system which is usually adjusted by a pneumatic controller. This is a low cost, high performance controller but still has some disadvantages. First, it is not flexible - it means that the mass of the object which is needed to manipulate must be known before it can be lifted. Therefore, the number of weight stage which can be managed is limited since it is depend on the complication of the pneumatic control circuit. There are no more than 3 weights stage that this kind of manipulator can lift. Second, it is difficult for workers to operate as it used many buttons therefore it can lead to time consuming or even mis-operating. The proposed control system is used to improve these characteristics and help manipulator to reach the better effectiveness.

This paper presents a performance-based control strategy which determines the relation among air pressure in the cylinder, weight of the load and uncertainty dynamic properties of pneumatic system.

II. CONTROL STRATEGY

Figure 1: Principle of lifting object using cylinder

Mechanical system is presented in Figure 1. It consists of a double-acting cylinder with a fixed end, an object mounted with the piston rod via a stainless-steel cable. Whenever there is a pressure in the right chamber of cylinder, it will generate a force which can lift the object.

The steady state equation can be written as:

$$F_{\text{lift-assist}} = P_{\text{load}} \pm F_{\text{friction}}$$

Where

- $F_{\text{lift-assist}} = \frac{p\pi(D^2 - d^2)}{4}$ (N) - force generated by cylinder (lift-assist force)
- $P_{\text{load}} = mg$ (N) - object's mass
- F_{friction} - the force of friction acts in the opposite direction of object's motion
- $P_{\text{load}} \pm F_{\text{friction}}$ - absolute balance force

The total friction force includes 5 main components

- Pressure drop caused by effectiveness of regulate pressure valve
- Pressure drop along pipe length
- Pressure drop due to area change
- Friction between piston rod and wall of cylinder
- Friction between guide roller and cable

It can be seen that the components which cause loss in the system are too difficult to be measured exactly but they still have great impacts on effectiveness of lift-assist manipulator. Therefore, this paper presents an experiment-based method to calculate this lift-assist force.

The purpose of the controller is to adjust the cylinder's pressure in order to minimize the difference between lift-assist force and absolute balance force. The smaller this difference is the better the effectiveness is. It also means that the workers just have to apply a small force to move the object. The difficult is that the absolute balance force changes continuously when the object's mass changes from 0 to 50kg so that current controllers usually focus on balancing the object's mass and ignore the friction force which has significant impact on system's effectiveness.

Figure 2: The controller configuration

Therefore, it is necessary to create a function describe the relation between the cylinder's pressure and absolute balance force while the object's mass changes continuously from 0 to 50kg. During the system's waiting statement, the controller does not recognize the mass which is needed to lift. Whenever operator applies a force, the system's waiting statement will be break (Figure 2). There is pressure inside the cylinder, and it starts to generate a lift-assist force stretching the cable. The value sending from the loadcell and the pressure in the cylinder increase so the object is lifted gradually. When it is totally lifted off the ground, the value sending from the loadcell is stable, balancing process is completed.

Figure 3: Control flow diagram

Whenever there is start signal, a continuous signal from load sensor is sampled by the controller every 50ms (sample time) and reproduced from discrete-time value by a filter. The data then goes through a validity check. If it does not pass the check, the break will activate and the whole system will stop. Otherwise, the controller will calculate the value of cylinder pressure which follows a developed algorithm and send it to the regulate pressure valve through RS232 protocol.

III. EXPERIMENTAL SETUP

The system is built in this experiment with popular components and low cost, includes (Figure 4):

- Microcontroller unit: Atmega328P
- Load sensor: Loadcell Keli PT100 kg
- Differential amplifier: JY-S60 0-5V/0-10V/4-20mA sensitive 2.0mV/V
- Regulate pressure valve: ITV 2050 SMC
- Double-acting cylinder: CDM2HC40-100-A93 from SMC with bore size D=40mm, and rod size d=14mm,

- Air supply: $p = 6,8\text{bar}$

The system to collect data is presented in block diagram and picture below.

Figure 4: System block diagram

Figure 5: The experimental schematic apparatus of tested controller

Step 1: Hanging the object with variety of mass within permitted limitation (0-50kg) using hook

Step 2: Increasing the pressure inside the cylinder till the object is totally lifted off the ground and in a stable statement.

Step 3: Increasing the pressure gradually without breaking the stable statement, using dynamometer to test whether the force needed to move the object up is smaller than 0,5% of the object 's mass. If yes, the cylinder 's pressure value is logged.

Step 4: Decreasing the pressure gradually without breaking the stable statement, using dynamometer to test whether the force needed to move the object down is smaller than 0,5% of the object 's mass. If yes, the cylinder 's pressure value is logged. The more samples it has, the better the result will be.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

With the object's mass is 5, 10, 15, ..., 50kg, we did some experiments. The mass and pressure value were recorded respectively. Using the least square method to create the control function that minimizes error of pressure in output's controller. A polynomial:

$$p(x) = p_1 x^n + p_2 x^{(n-1)} + \dots + p_n x + p_n \quad (1)$$

of degree n , the coefficient in $p(x)$ is calculated by pseudo-invert matrix of data. The 3th-degree polynomial is used because the maximum error of pressure is the best in experimental results.

$$F_{up} = 2,2497 \cdot 10^{-7} x^3 - 9,8937 \cdot 10^{-5} x^2 + 0,9770x + 35,8607 \quad (2)$$

$$F_{down} = 6,3847 \cdot 10^{-8} x^3 - 4,3547 \cdot 10^{-5} x^2 + 0,9686x + 0,4967 \quad (3)$$

$$F_{stable} = -4,2769 \cdot 10^{-8} x^3 + 4,8645 \cdot 10^{-5} x^2 + 0,9611x + 17,2146 \quad (4)$$

Graphs of these function are presented below (Figure 6)

Figure 6: Characteristics curves of lift-assist force

Theoretical error of controller:

$$\frac{p \cdot e_{max}}{2^{10} - 1} \cdot \frac{\pi(D-d)^2}{4} = \frac{6,8.5,45}{1023} \cdot \frac{\pi(4-1,2)^2}{4} = 0,223(kg)$$

Lift-assist effectiveness can reach 99,5%

Figure 7: System response when lifting objects

The figures present the relation between object's mass and the system's respond. It can be seen from the result that the controller works properly with any load within the permitted limitation. The settling time is around 6,5s. The overshoot is about 10% and settle-state error is small (Figure 7).

V. CONCLUSION

In this paper, the control system for high performance lift-assist pneumatic manipulator is designed and developed based on experimental calculation. The absolute balance force calculated does not only compensate for the gravity but also for the various uncertainties. Therefore, the effectiveness of this kind of pneumatic manipulator can reach to 99,5%- much better than 85-90% and the complication of operation is reduced dramatically since this manipulator is buttonless. Furthermore, it can work properly with any load within the permitted limitation.

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