Inference on results obtained by experimenting to control speed and precise extension of a pneumatic cylinder in a cost-effective manner

Sarvagya Tripathi¹, Pankaj Kumar ¹*, Uma Maheswari ²

¹Department of Mechanical Engineering, SRM Institute of Science and Technology, India.
3Department of Electronics and Instrumentation Engineering SRM university
*Corresponding Author

*Corresponding Author: pankajkumar.r@ktr.srmuniv.ac.in

Abstract: The paper investigates the viability and cost effectiveness of a stepper/servo motors to operate a ball valve in sync with an infrared/laser displacement sensor to obtain precise location of the air piston under varying and static load. The experiment conducted in reference making a viable Exo-Skeleton it was found out that pneumatic system had an edge over hydraulics due to its lightweight design, speed, and its being operational even after loss of pressure. But the key area of hindrance remained the cost and effectiveness of pneumatic cylinder present in the market with precise displacement control owing to dynamically variable loads applicable on the cylinder. A custom valve (ball valve/pin valve) was built, controlled with servo motors and a displacement sensor to track the exact position of the piston rod. With respect to the linear motion of its piston rod. The system is divided into two parts firstly being the servo operated ball valves which h are formed by mounting a servo on the operating handle of the ball valve, and a displacement sensor tracking the movement of piston rod

Keywords: PID control, Machine Learning, Dynamic Load, Air recirculation.

1. Introduction

Pneumatic system just like hydraulic systems use a compressed working medium fed into a closed cylinder with a linearly moving piston to lift load or to provide motion to the mechanism it is attached to. But unlike hydraulic systems it is mostly desirable since it is easily maintained, light weight, quicker and mess free. But for years the main problem for pneumatics systems have been to control its positioning and speed [1,2] which was tried to solve using different approach like using a solenoid/servo valve [3-6] and fuzzy logic Proportional-Integral-Derivative(P.I.D.) controls [7,8].

The paper proposes use of Machine learning and servo-controlled ball valve to control the volume of air entering the pneumatic system and to recompress the used air using two-cylinder setup to recirculate the used air, saving energy.
2. Experimental Setup

The setup was made using Janatics A12 cylinders and off the shelf servo HK15298 and ball valves. The algorithm was on a i5 Lenovo laptop and Arduino Uno was used to control the system with a switching frequency of 8Mhz load cell used was HX711 Weight Sensor, two pressure sensor SPX3058D was used to measure the pressure on the two side of the piston chamber and a mass/ gyro as well as accelerometer was used on same chip MPU-6050.

Figure 1. Piston design.

Figure 2. Circuit Diagram.
The force exerted by a single acting pneumatic cylinder can be expressed as

\[ \text{Force} = \text{Pressure} \times \text{Area} \]

\[ \text{Mass} \times \text{Acceleration due to gravity} \times \text{height} = (\text{Pressure} \times 3.14 \times \text{Diameter}^2)^4. \]

The minimum pressure required to lift a load in pneumatic system given by,

\[ \text{Pressure} = \frac{(4 \times \text{mass} \times \text{acceleration due to gravity} \times h)}{(\text{diameter}^2 \times 3.14)} \]

It was also found that at low pressure friction is applied hysteresis curve is obtained and as the velocity of the piston increases we found a linear behavior as indicated in [9].

Using this information, a machine learning and PID algorithm was built which dynamically calculated the force required each time by measuring the mass of the object to be lifted by interfacing Load Cell and HX711 Weight Sensor and Arduino Uno. The system also consisted of a feedback loop which improved the correctness of measurement and pressure provided by measuring the velocity given to the load according to the application being made and gradually the algorithm created a data set and could calculate the volume of air required more efficiently, which provide a jerk free smooth movement with required velocity.

The algorithm also enabled the system for partial lifting i.e. holding up a load at a distance less than full stroke of the piston by pressure lock on the pressurized side of the air chamber.
The system uses two tanks namely T1 and T2 for the circulation of the pressurized gas initially T1 is pressurized to the required pressure and gas is transferred from T1 to the cylinder via a check valve and a solenoid valve to move the piston on the other way round when the piston is retracted it is transferred to T2 which is at a lower pressure that T1 and the process continues till pressure in T1 becomes equal to T2 then T1 or T2 is pressurized back to a higher pressure and system continues and depending upon the number of pistons in the cylinder either T1 or T2 can be used to pressurize the piston (decided by the system algorithm) and a total of 30% of the gas could be reused reducing the energy requirement of the system.

Figure 4. Theoretical pressure with angle.

Figure 5. Change in required pressure with mass and angle.
It was found out that piston’s pressure at outlet port was not proportionate hence different piston with different volume gave unique back pressure. It was found that back pressure was affected by the air cushion and the orifice of port hence it significantly varied from piston of comparable volume.

![Graph showing Volume vs Pressure on outlet port.](image)

**Figure 6.** Volume vs Pressure on outlet port.

Key: -

T1 = tank 1
T2 = tank 2
S1 = servo operated ball valve 1
S2 = servo operated ball valve 2
S3 = servo operated ball valve 3
S4 = servo operated ball valve 4
C1 = check valve 1
C2 = check valve 2
C3 = check valve 3
C4 = check valve 4

The pressure in tank T1 and T2 is compared via the algorithm and whichever is greater gas is released from that valve on expansion side. The gas on the other side of the inlet is compressed into the tank with lower pressure and the valve connected to lower pressure tanks are in on state. The accelerometer and gyro sensor keep a check on the jerky movement of the load and the valve is opened in a very controlled manner via the servo until the required pressure is obtained in the chamber.
The system uses a servo-controlled ball valve which is controlled via the algorithms to deliver exact volume of air to the system.

**Table 1. Valve State during Extension.**

| Valve | State | Valve | State |
|-------|-------|-------|-------|
| S1    | OFF   | S1    | ON    |
| S2    | ON    | S2    | OFF   |
| S3    | ON    | S3    | OFF   |
| S4    | OFF   | S4    | ON    |

**Table 2. Valve State during Retraction.**

| Valve | State | Valve | State |
|-------|-------|-------|-------|
| S1    | ON    | S1    | OFF   |
| S2    | OFF   | S2    | ON    |
| S3    | OFF   | S3    | ON    |
| S4    | ON    | S4    | OFF   |

3. ALGORITHM

Algorithm for choosing the volume of air flow depends on Pressure.

Step:1 The input independent variables are mass(x1), diameter(x2), height(x3) of the training data and its corresponding dependent variable (y) volume of air flow.

Step:2 from an input and output relationship between and variable x1 x2 & x3 using a function f(x).

\[ f(x_1, x_2, x_3) = y. \]

Step:3 Since the dependent variable x is continues and not finite, it is regression problem. So, for a model or function (f) for the variables. (polynomial regression etc.)

Step:4 Predict the volume of air flow (y*) for the new independent variable (x1*, x2*, x3*) using the model created in step 3.

4. Conclusion

In this paper possibility of increasing efficiency of a pneumatic system [10] is explored using a machine learning and Proportional-Integral-Derivative algorithms. It was found out experimentally that not all loads need full lifting power of a pneumatic system hence these algorithms can calculate exactly the amount of air required by the system to lift a load at different heights and angles; as load at different angles and heights required different force to be lifted. The paper also investigates a low-cost servo
operated valve which can efficiently modulate pressure within a pneumatic system and could save a lot of upfront investment.

The two-tank setup was found to be helpful as a lot of compressed air could be harnessed as the exhaust port pressure is much lowered in the recovery tank owing to the equation \( P_1V_1 = P_2V_2 \). Hence a greater volume of compressed air is stored into the tank which can be pressurized higher or used as it is into lower power requirement systems.

It was also found that pistons of comparable or same volume dint have equal exhaust pressure owing to variation in construction of air cushion and clearances in the pistons of different manufacturer.

5. References

[1] R.B. Van Varseveld, G.M. 2002 Bone Accurate position control of a pneumatic actuator using on/off solenoid valves (IEEE) 195-204.

[2] A. Gentile, N.I. Giannoccaro, G. Reina 2003 Experimental tests on position control of a pneumatic actuator using on/off solenoid valves (IEEE)

[3] T. Nguyen, J. Leavitt, F. Jabbari, J. E. Bobrow 2007 Accurate Sliding-Mode Control of Pneumatic Systems Using Low-Cost Solenoid Valves (IEEE) 216,219.

[4] Takashi Miyajima, Toshinori Fujita, Kazutoshi Sakakic, Kenji Kawashimad, ToshiharuKagawad. 2007 Development of a digital control system for high-performance pneumatic servo valve Precision Engineering, (ELSEVIER) 156-161.

[5] M.Taghizadehab, A.Ghaffaria, F.Najafia, 2009 Mechatronics Modeling and identification of a solenoid valve for PWM control applications, Comptes Rendus Mécanique, (ELSEVIER) 131-140.

[6] N. Ye, S. Scavarda, M. Betemps and A. Jutard 1992 Models of a Pneumatic PWM Solenoid Valve for Engineering Application. Dynamic Systems, Measurement, and Control (ASME) 680-688.

[7] Manukid Parnichkun, Charoen Ngaecharoenkul, 2001 Kinematics control of a pneumatic system by hybrid fuzzy (PID Mechatronics ELSEVIER) 1001,1023.

[8] JihongWang, JunshengPuPhilipMoore. 1999 A practical control strategy for servo-pneumatic actuator systems (Control Engineering Practice ELSEVIER) 1483,1488.

[9] Xuan Bo Tran1, Hideki Yanada 2013 Dynamic Friction Behaviors of Pneumatic Cylinders (ICA) 180,190