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Force Measurement Using Magnetic Potentiometer

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Abstract: An actuator is a device that accomplishes the actuation, which is defined as the process of converting some form of energy into mechanical force and motion. To control the actuator, it is important to use sensor technology to get positioning or force information. This paper is focused on an approach to measure the force for a class of compliant actuators. The proposed approach uses a potentiometer and Hooke's law to calculate output force. Since the noise is found in potentiometer sensor, a low-pass filter is proposed to overcome this problem. The advantage of the proposed force estimation approach is that it is based on the cheap potentiometer, and it does not require the force sensor. Experimental test is given to verify the effectiveness of the proposed approach.

Keywords: Compliant actuator, Displacement, Force, Measurement, Potentiometer.

1. Introduction

In industrial applications, actuators are always required to be as stiff as possible to make high-precision motion control. The transmission mechanisms are also rigid and non-back-drivable [1]. However, over the past decade many applications are oriented towards to life science and biomedical fields such as exoskeletons and rehabilitation service. The challenging issue in these applications is how to integrate with the muscle that has a neuro-motor system which has compliant and zero-force functions. This requires the actuator which can achieve force control, impedance control and back-derivability [2, 3]. The traditional stiff actuators (dc motor or servo motor) cannot meet these demands. In recent years, compilant actuators have been developed for safe and human-friendly robotics applications. It is expected that the actuators might improve control and work in cooperation with human. In such kind of actuators, output force plays an active role for feedback loop and impedance control. Therefore, in a practical application, it is quite important to know force so that the controller can drive the actuator to reach the desired target force. To measure force, various methods have been reported. In [4], the authors propose to use a laser Raman spectrophotometer with single crystal silicon and a strain gauge for the measurement and calibration of the force applied to the micro object. In [5], it is described that forces over the entire hand can be measured by using thin-film sensors. In [6], MEMS force sensor is used to measure small force. In [7], the authors design a tip force sensor to assist a surgery operation. In [8], the authors develop a vision-based force measurement system. Other types of force sensors can be found in [9, 10]. These force sensors are suitable only for small force range such as micro-Newton or less than several Newtons of force. For measuring a large force, references in [11] uses a spring scale to obtain the force. However, the resolution of spring scale is very low. In [12], the encoder is proposed for use of measuring the large force based on Hooke's law. However, the encoder needs to have a complex circuit to convert signal into digital code and is more expensive than potentiometer. In [13], the resistance potentiometer is suggested for use in the force measurement of actuators. However, the resistance potentiometer is very easy to be damaged for it depends on friction.

In this paper, we present a magnetic potentiometer to measure the force for a class of compliant actuators. The magnetic potentiometer is capable of tracking motion in a contactless manner. This is different from traditional potentiometer. The basic idea of the proposed method is to employ Hooke's law to obtain the force information indirectly using linear displacement which is measured by the magnetic potentiometer. Since the signal noise is observed over a very wide frequency range, a low-pass filter is designed to solve this issue in the paper. The effectiveness of the proposed method is illustrated by a test which controls the actuator to the desired output force.

This paper is organized as follows. Background and a compliant actuator are described in Section 2. The magnetic potentiometer features and specifications are described in Section 3. The force measurement system, filter design are shown in Section 4. The Proportional-Derivative control uses force feedback information and experimental results are shown in Section 5. Finally, some concluding remarks are given in Section 6.

2. Background and Compliant Actuator

Gait disorders in the elderly are common and in most cases cannot be treated medically or surgically. Therefore, treatment often relies on rehabilitation service. Rehabilitation robotics has shown promise in providing patients with intensive therapy leading to functional gains. This involves the use of a robot exoskeleton device or end-effector device to help the patient retrain motor coordination by performing gait movement. Here, we develop a new exoskeleton (see Fig. 1) for rehabilitation. The core component is compliant actuator.

Our compliant actuator consists of a servomotor, two springs (passive elastic elements), a ball screw and an output link. A torsional spring is placed in series between the servomotor and the ball screw. The ball screw nut is attached to the output link in series through another translational spring. When the nut moves, a deflection is produced in the spring, which is measured by a linear encoder. The output force is calculated based on the spring constant and the linear deflection following Hooke's law, which is

$$F = -kx ,$$

where k is the spring constant and x is the displacement. Fig. 2 shows the schematic diagram, the exploded view of the prototype actuator design. The objective of the compliant actuator is to achieve the output force control. To this end, we have to measure the displacement, for the spring constant can be obtained accurately.

Fig. 1. Exoskeleton with actuator.

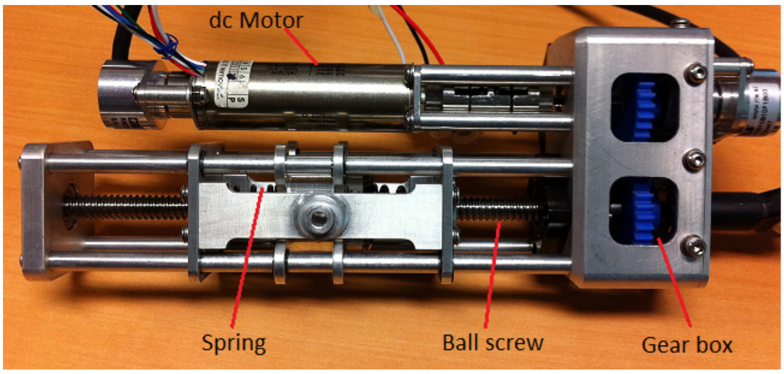

Fig. 2. Structure of compliant actuator.

3. Magnetic Potentiometer

The potentiometer used in this paper is a MagnetoPot sensor which is made by Spectra Symbol as shown in Fig. 3. It is able to track motion in a contactless manner. It functions as a voltage divider. Such function is implemented by a magnet on the opposing side of a motion device which guides the built-in magnetics of the MagnetoPot for linear displacement through a potentiometric output. The datasheet [14] is shown in Table 1. Since the potentiometer is variable voltage divider with a magnet, the electrical output is obtained. This changes the relative "closeness" of that pin to 5 volts and ground, giving us a different analog input. An electrical schematic is shown in Fig. 4.

Fig. 3. MagnetoPot potentiometer.

Table 1. MagnetoPot Specifications.

Life Cycle	>1 million
Height	≤ 3.50 mm (0.138″)
Actuation Force:	18 grams pull force from exterior magnet or ferromagnet
Resistance – Standard:	10 kOhm (lengths >300 mm = 20 kOhm)
Resistance Tolerance:	±20 %
Effective Electrical Travel:	8 to 1200 mm
Resolution:	Depends on the exterior magnet strength and distance to the MagnetoPot
Independent Linearity:	± 5 % (± 1 % available)

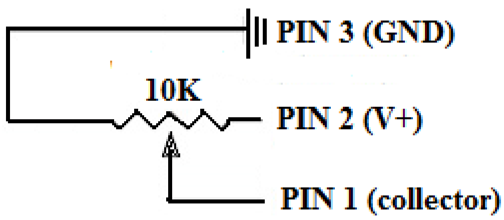

Fig. 4. Electrical schematic.

4. Force Measurement and Output Force Control

The force measurement system is shown in Fig. 5, where we connect three wires of the potentiometer to the dSPACE system: the first goes to ground from PIN 3 of the potentiometer; the second goes from 5 volts; the third goes from analog input PIN 1 to the dSPACE control card. The dSPACE control development and rapid prototyping system, in particular, the DS1104 board, is used, which integrates the whole development cycle seamlessly into a single environment. MATLAB/Simulink can be directly used in the dSPACE real-time control system. The sampling period for our test is chosen as 0.0005s.

Noise Filter: During the force measurement, it is found that noise is introduced due to the potentiometer sensor, and circuit. To analyze the signal noise, a fast Fourier transform (FFT) algorithm is used. It is a popular off-line approach widely used to realize the frequency distribution over time domain. Fig. 6 shows the spectrum of the potentiometer signal. It is observed that the noise exists over a wide range with large amplitude and most of the frequencies are high frequency. Since working range in our project is within low frequency, it is proposed to remove the noise by using a low-pass filter $\dfrac{1}{0.05s+1}$. Fig. 7 shows the whole system with low-pass filter. Figs. 8-9 show the filter performance compared with the signal without filter. It is observed from the figures that the noise is rejected by the designed filter and the estimated output force approaches the actual one closely.

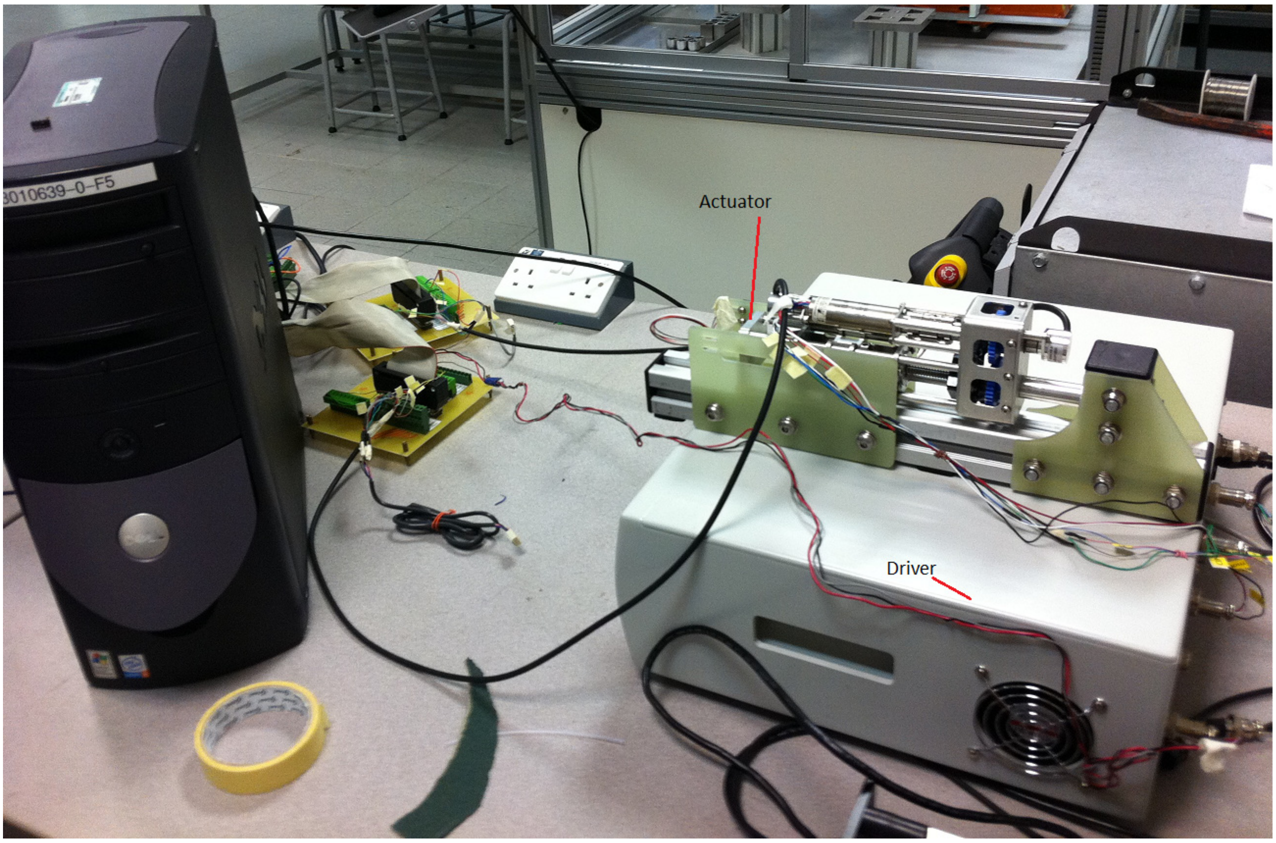

Fig. 5. Force measurement system.

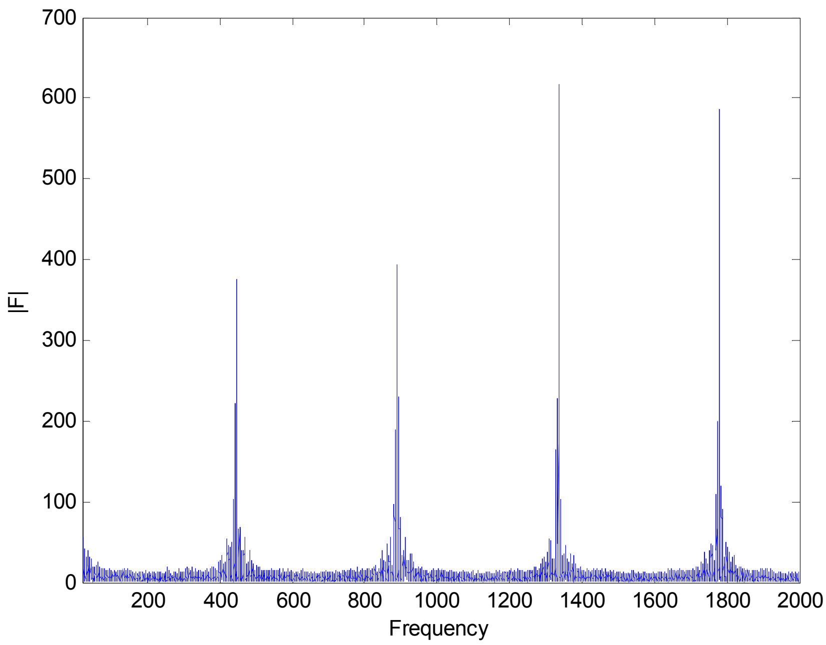

Fig. 6. Spectrum of the potentiometer signal.

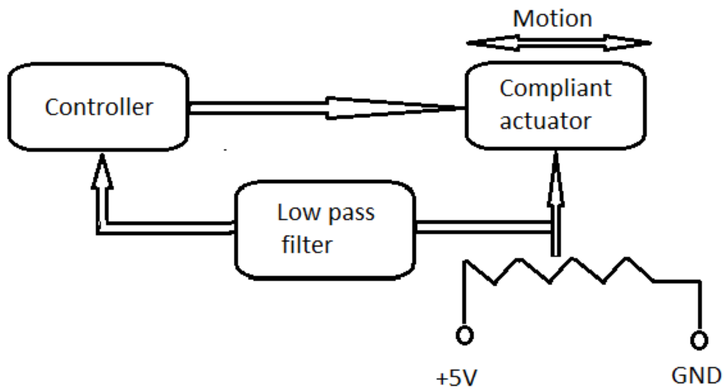

Fig. 7. Measurement system with filter design.

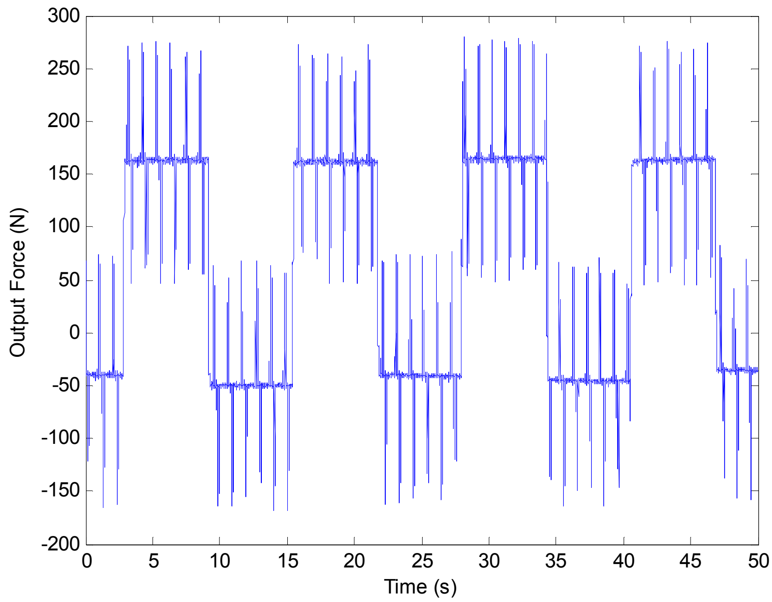

Fig. 8. Output force measurement without filter.

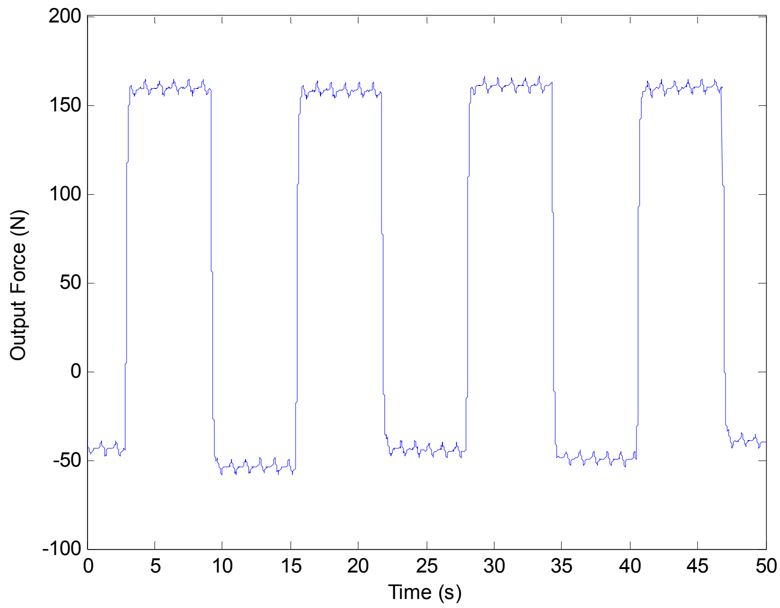

Fig. 9. Output force measurement with a low-pass filter

5. Force Feedback Control

Output Force Control: The compliant actuator performance at output end is to produce a linear output force. As stated above, the potentiometer is used to calculate output force which is fed back to the controller. Here, a Proportional-Derivative (PD) controller is employed to minimize the error between the measured and desired forces by adjusting the control inputs (Fig. 10).

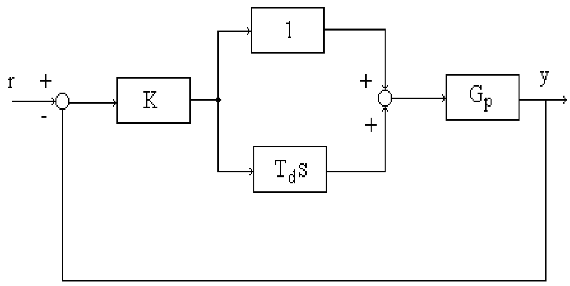

Fig. 10. PD control structure.

Fig. 11 shows the schematic diagram of the overall model with a PD controller. The output force control is shown in Fig. 12, where the dotted line represents the desired output forces, while the solid line represents actual output forces. It is observed that the controller is able to drive the actuator to follow the desired output force trajectory.

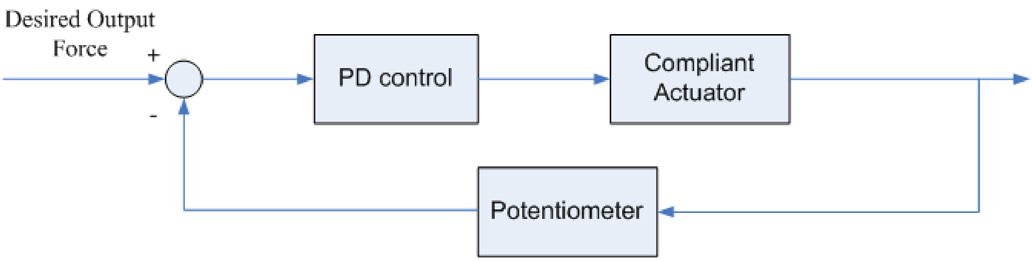

Fig. 11. The overall structure of PD control.

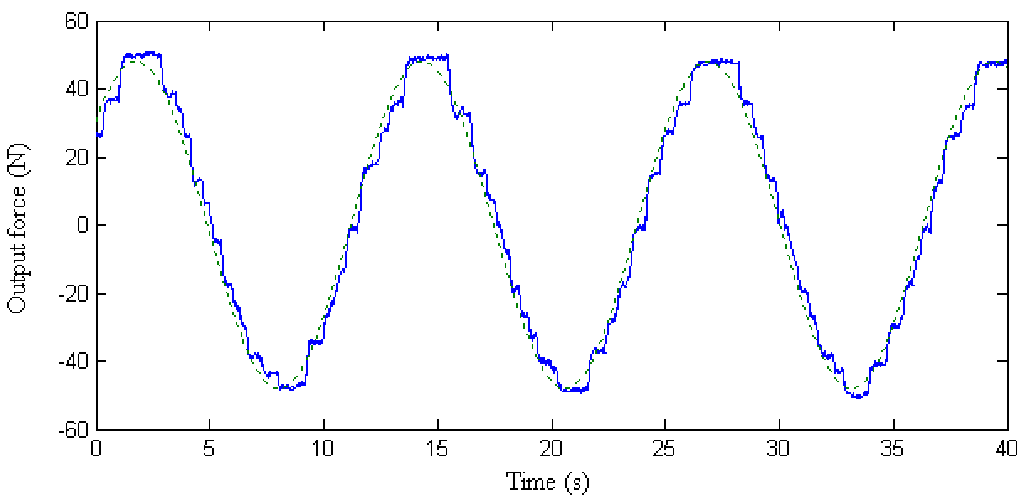

Fig. 12. Output force control: desired vs. actual ones.

6. Conclusions

A new technique for measuring output force has been presented in this work. Instead of using force sensor, we exploited here the magnetic potentiometer technique to estimate the force on-line. This technique allows us to use cheap magnetic potentiometer and mount sensor easily. The low-pass filter has been proposed for removing the noise found in the signal. The experimental results have shown that the proposed technique is significantly efficient for calculating force in a compliant actuator.

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Guide for Contributors

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Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

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- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
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- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
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