Velocity Estimation For Haptic Applications

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Abstract—**This paper presents a detailed approach and the main results of real-time velocity estimation based on the dynamic model of a DC motor. The key contribution of velocity estimation here is to reduce noise behaviors of encoder-based measurement. In particular, the estimated signal can be useful for many applications such as haptic devices, industrial applications as well as robotics. The proposed method is simple to implement. Therefore, encoders or tachometers can be replaced with current sensors which are cheaper, and more compact. This solution was investigated with experimental results. The results indicated that, estimation velocity could reduce noise significantly compared to encoder-based measurement. And, with the same experimental parameters and hardware, the proposed velocity estimated signal is exactly the same as the result of encoder-based measurement.**

Keywords-velocity estimation; haptic application; velocity estimation for energy calculation;

I. INTRODUCTION

Recently, haptic technology has been developed for several impressive applications such as haptic phones [1], virtual training systems [2], 3D games with haptic feedback, steer-by-wire systems [4]. Bejczy and Salisbury [5] introduce a six degree-of-freedom hand controller for use in space telerobotics.

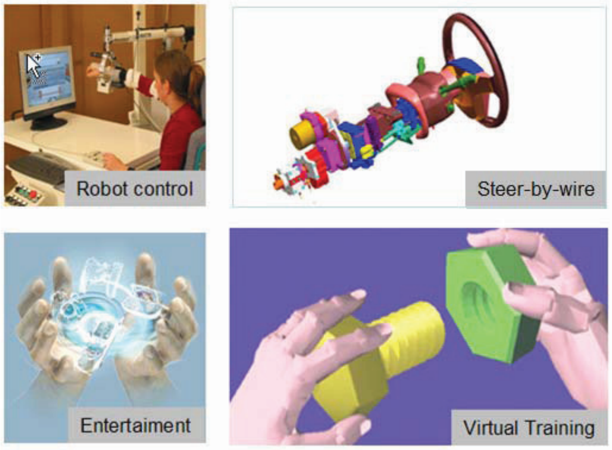

Fig 1. Applications of haptic technology

One of the most common position sensors in haptic systems is the optical encoder because it is easy to interface, and is extremely linear and free of dynamics. Unfortunately, the output of an encoder is quantized, and it was well-known that the quantization may lead to limiting cycles in digital control systems [6], [7]. Previous methods for real-time velocity estimation included: finite difference and inverse-time methods, filtered derivative, and Kalman filtering. All these methods share fundamental tradeoffs between: noise reduction and control delay; accuracy of the estimate and its reliability; as well as regarding the computational load. They also all might need complex tuning technique [8]. Moreover, in low frequency systems such as steer-by-wire system, haptic interfaces, the encoder signal may cause heavy noise effect. To solve this issue, a nonlinear spring model combining the linear spring model with a square-root spring model, was presented to suppress the noisy behavior of position-sensor quantization while the velocity was low [9]. In reference [10], Yoon Sang Kim, and Hannaford, B. introduced velocity threshold to reduce the noise in velocity measurements. The experimental results have verified that the velocity threshold makes the PC freer from the noise effect at low velocity.

Recently, the current sensors have been used for realistic haptic feedback presented in [11]. From this success, this research demonstrate and compare two different schemes of real-time velocity estimation based on the model of a DC motor and direct current measurement from a Hall current sensor. The result shows that the estimation velocity can be suitable for haptic applications as well as general systems in which the encoders are used.

II. PROPOSED METHOD FOR VELOCITY ESIMATION

A. DC Motor Dynamics

Basically, a direct current motor can be described by the following Kirchhoff's voltage equation:

$$L\frac{di}{dt}+R.i=V-K_t.\dot{\theta} \qquad (1)$$

where:

L : Motor inductance
i : Rotor current
R : Motor resistance
V : Supply voltage
K_t : Motor constant
θ : Rotor angle

According to this equation, the rotor angle θ of the motor can be easily abstained if other parameters and the rotor current are known. Since, motor inductance, motor resistance, and motor constant are fixed and given by the motor manufactures. And the rotor current can be directly acquired from motor driver using a compact Hall current sensor. In addition, supply voltage for the motor is measured from the motor by implementing an analog digital converter.

B. *Velocity Estimation*

Based on the equation (1), rotor velocity or rotor position might be calculated based on two approaches.

Method 1:

The direct way to estimate rotor velocity is to measure voltage and current from motor and motor's driver respectively. Then, by taking derivation of current signal, angular velocity of rotor will be obtained from equation (2).

$$\dot{\theta} = \frac{1}{K_t}\left[V - \left(L\frac{di}{dt} + R.i\right)\right] \qquad (2)$$

Method 2:

The second method is to take integral manipulation of both sides of equation (1). And then, by taking derivation of rotor's position calculated in equation (3), the rotor's velocity can be obtained. This method is quite interesting due to its repeated mathematic manipulation of signals. Let's consider the results of these two methods in section 4.

$$\theta = \int_{t1}^{t2}\dot{\theta} = \frac{1}{K_t}\left[\int_{t1}^{t2} V - \left(Li + R\int_{t1}^{t2} i\right)\right] \qquad (3)$$

III. EXPERIMENT RESULT

A. *Experimental Setup*

The overview of the experimental setup used for investigating the proposed method is illustrated as the Fig. 2. The power was provided to a Maxon DC motor through a motor driver and power supply. The motor's armature current was measured by a Hall current sensor. The measured current signal was acquired by a NI PCI 7356 board with the UMI 7764 connecter. Finally, the current signal was applied to velocity estimation algorithm programmed in the computer. In addition, an encoder with the revolution of 4096 pulse/rev was connected directly to DC motor shaft to measured DC motor velocity. In the experimental computer, a graphical user interface (GUI) based on LabVIEW environment was developed to allow user to observe experimental process and results. The GUI not only included two velocity estimation algorithms described in section 2.2 but also had analog converter, PWM generator module, and so on.

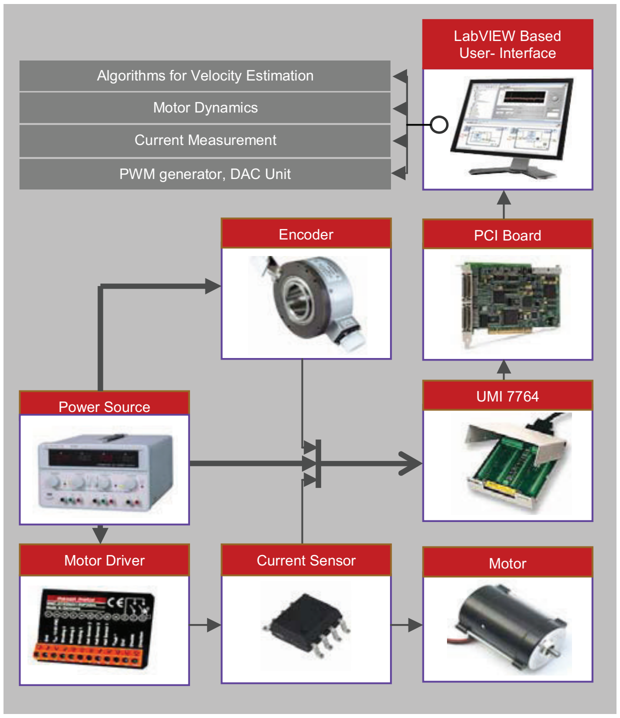

Fig 2. Experimental setup for investigating the proposed methods of velocity estimation

B. *Experimental Result*

The experiment is conducted to find the effect factors which have significant influences on the estimated signal quality.

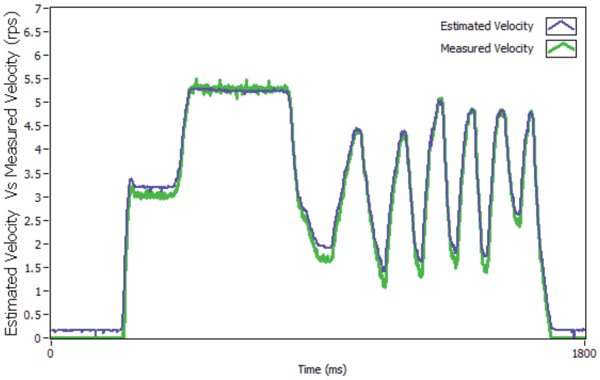

Fig. 3. Estimated velocity verse measured velocity based on method 1

For the first case, results of two methods as mentioned in section 3 are examined. The results of method 1 display better estimated signal compared to method 2. The Fig. 3, and 4 are the estimated velocity verse measured velocity based on method 1. Fig. 5 and 6 are the estimated velocity verse measured velocity based on method 2. Both methods can provide estimated velocity signal with 2-5% of error. However, the Fig. 4 shows that there is less noise estimated signal compared to Fig. 6.

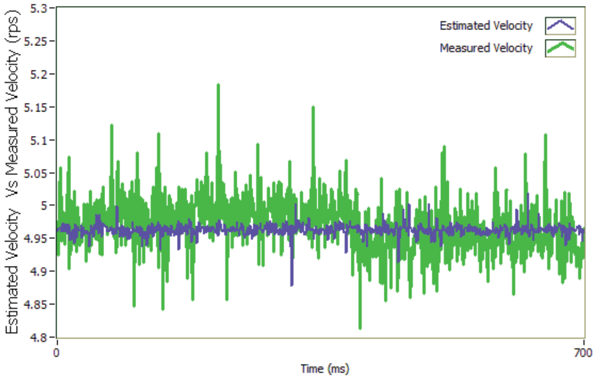

Fig. 4. Noise behavior of the estimated velocity based on method 1

However, there is constant error at very low velocity. The lowest velocity which can be estimated is 0.2revolution per second which is equal to 0.8pulse/ms. This limitation may be improved in our future work.

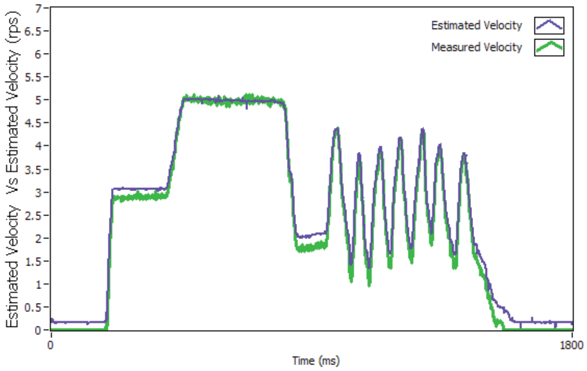

Fig 5. Estimated velocity verse measured velocity based on method 2

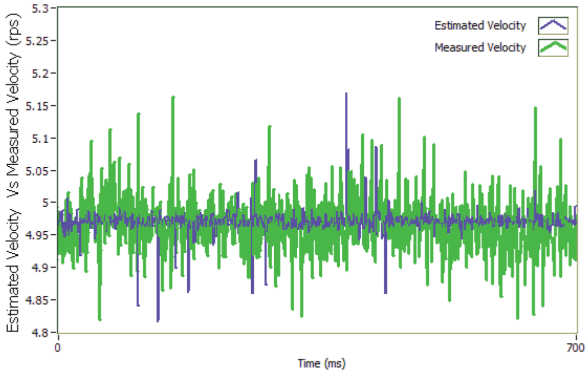

Fig. 6. Noise behavior of the estimated velocity based on method 2

In the second case, the signal quality of measured velocity with two different methods of calculation is tested. The first method is to take derivation of the encoder signal. And in the second method, the measured velocity is acquired from available "Read Velocity" function. This value of velocity is filtered by LabVIEW embedded functions. Fig. 7 shows that taking derivation of position signal causes huge noise behaviors in measured signal. With the embedded filter in LabVIEW the velocity can be improved as shown in Fig. 8.

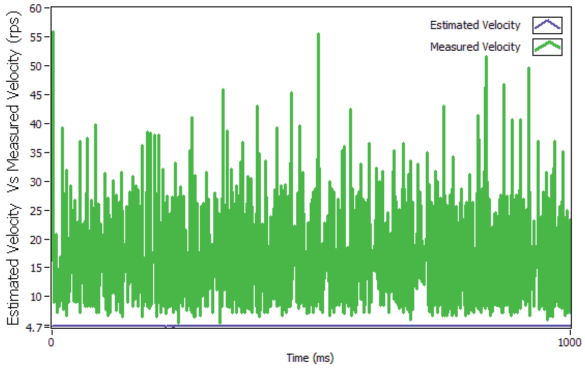

Fig. 7. Noise behaviors of the measured velocity calculated by taking derivation from encoder signal

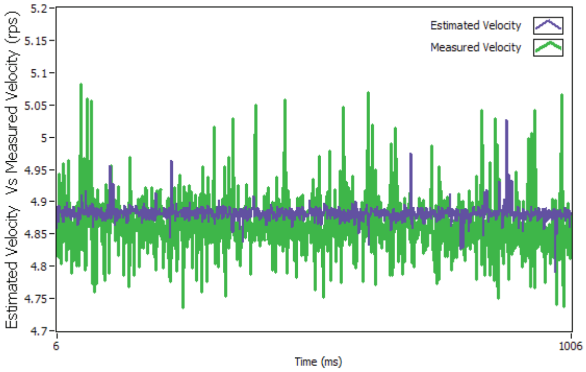

Fig. 8. Noise behaviors of the measured velocity is reduced by using a filter

At high frequency of input command from motor driver, a real-time signal of both estimated velocity and measured velocity were tracking and matching well as shown in Fig. 9.

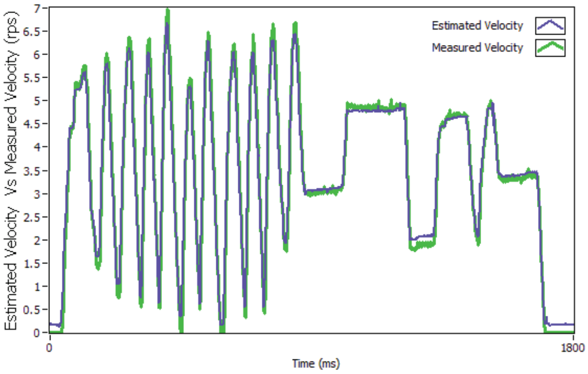

Fig. 9. A real-time signal of both estimated velocity and measured velocity were tracking and matching well

IV. CONCLUSION

First, the result of this research has shown that the estimated velocity always reduced noise behaviors compared to encoder-based measurement. Therefore, the estimated velocity at low speed can be used in haptic applications for with compact current sensors. Since the estimated signal has smaller noise, the force feedback may be smoother and stable during contact.

Second, this is less noise behaviors compared to measured velocity can be used for observing the system energy which is noteworthy in stabilization of the haptic systems [12].

Moreover, this also can be applied in other industrial applications in which encoders or tachometers are presented.

For future work, this study should be completed and investigated with an electronic circuit and its own embedded software which can be operated without any desktop computers.

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