Chapter 2
An Improved Variable M/T Method Based on Speed Estimation for Optical Incremental Encoders

Hui Wang and Jian-tao Pu

Abstract Optical incremental encoders are widely used for the speed measurements in motor servo systems due to low cost and high performance. But it is difficult to use the encoders when wide speed range, high accuracy and extremely short responding time are required at the same time in high performance servo systems. In this paper, an improved variable M/T method is introduced. In this method, both encoder pulse and high frequency clock pulse are counted in a variable interval which ensures the high measurement accuracy in both high speed and low speed. By speed estimation algorithm, the rapid response can be obtained even at very low speed.

Keywords Optical incremental encoder • Motor servo system • Speed measurement • Variable M/T method

Introduction

Optical incremental encoders are widely used as speed sensors on closed-loop speed control systems. With high noise immunity, low maintenance, and low cost, they are the preferred method for obtaining motor velocity information and are generally considered to be superior to direct current tachometers (Ekekwe et al. 2008). Optical incremental encoders produce two sequences of pulses with a 90° phase shift, which are called quadrature encoded pulses. As the motor rotating, the direction can be determined by detecting which of the two sequences is the leading sequence and the

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speed can be determined by the pulse frequency. The speed accuracy is limited by the quantized speed measurement of the encoder, i.e. it is limited by the number of slits on the encoder disk (Merry et al. 2010). But higher resolution is limited by the manufacturing capacity and cost. Therefore a quadrupler is usually used to improve the encoder resolution which generates a decoded clock with four times frequency of each input sequence.

Counting the decoded clock during a constant sampling period can get the pulse frequency. However this method is not applicable at low speed since the pulses are not frequently produced and no pulse will be detected in some sampling periods (Lilit Kovudhikulrungsri and Takafumi Koseki 2006; Takafumi Koseki et al. 2010). An alternative way is to measure the time interval between two consecutive pulses (Lilit Kovudhikulrungsri and Takafumi Koseki 2006). The approach has high resolution at low speed but low resolution at high speed. Combination of these methods is proposed by Ohmae et al. in (1982). This method combines the advantages of each method with high accuracy in wide speed range. But it still can't solve the problem of long time delay at low speed even though the resolution at low speed is raised. In reference (Bonert 1983, 1989), the constant elapsed time (CET) method is proposed which measures the elapsed time between k successive pulses, and dynamically adjusts the value of k to obtain a near constant response time. E. Galvan et al. improve the aforementioned method by several adaptive techniques to maintain the accuracy of the results while preserving the short system response time (Hagiwara et al. 1992; Galvan et al. 1994, 1996; Bhatti and Hannaford 1997). In literature, kinds of microcontroller and ASIC are used to implement these techniques (Rull et al. 1999; Lygouras 2000; Sisinni et al. 2002; Tsai and Chen 2002). But the CET method uses a variable sampling interval so as to adapt accordingly to the motor speed each time which brings new problems in the design of the closed-loop controllers.

In this paper, a new approach of speed measurement is proposed for high accuracy in wide speed range. This approach is based on a speed estimation which takes account of the speed reference change during the speed measurement period. Therefore the accuracy maintains high in wide speed range with rapid response at the same time. It is particularly suitable for the advanced numerical control system or servo system in industry robots which have strictly rapid response and wide speed range requirements.

This paper is organized as follows: speed measurement techniques are introduced in section "Introduction". A new speed measurement approach is presented in details in section "Speed Measurement Techniques". Section "An Improved Variable M/T Method" shows the discussions, while section "Conclusion" gives the final conclusions.

Speed Measurement Techniques

The types of speed measurement techniques basically fall into four categories: M method counting with fixed sampling interval (clock-driven); T method counting in time between two consecutive encoder decoded clock pulses (encoder driven); M/T

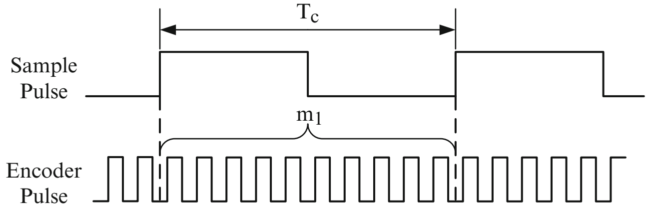

Fig. 2.1 Scheme of M method

method which is the combination of the two methods with fixed sampling interval; variable M/T method with a variable counting interval.

M Method

This method, shown in Fig. 2.1, is implemented by counting the encoder pulses m_1 produced in a fixed counting period – Tc (usually the system sampling period) and dividing by the counting period.

Setting the number of encoder pulse as Z per revolution, the motor speed is given by

$$n = \frac{60m_1}{ZT_c}. \tag{2.1}$$

As Z and Tc are constant, the motor speed n is proportional to the value of m_1, so called as M method. Obviously the maximum error will be one encoder pulse. The relative error is defined as the division of the absolute error by the true value and can be written as

$$\delta_{\max} = \frac{1}{m_1} \times 100\,\%. \tag{2.2}$$

Encoder pulse frequency is proportional to the motor speed, thus bigger value of m_1, i.e. lower relative error, will be gotten at high speed during a certain sampling period. So the M method is more applicable at medium and high speeds rather than at low speed, where the encoder pulses cannot be detected at every control period, as a result the accuracy will remarkably decline.

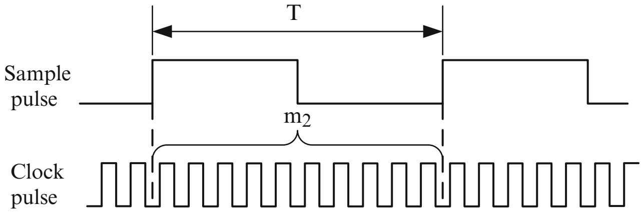

Fig. 2.2 Scheme of T method

T Method

Motor speed can be obtained by measure the time interval of the encoder cycle. That is to count pulses of a high-frequency clock between successive pulses of the encoder as shown in Fig. 2.2. This method involves measuring the encoder cycle T, so called as T method.

If f_0 is clock frequency, Z has the same significance as in M method and counter final value is m_2 as denoted in Fig. 2.2, the velocity can be expressed as

$$n = \frac{60 f_0}{Z m_2}. \tag{2.3}$$

Higher count value m_2 means longer T of encoder cycle, i.e. lower motor speed. The maximum error will be one clock pulse, so the relative error is given by

$$\delta_{\max} = \frac{1}{m_2 - 1} \times 100\,\%. \tag{2.4}$$

Equation (2.4) indicates that the bigger m_2, the lower error. The motor speed is inversely proportional to m_2. Therefore T method is preferred at low speed, but has unacceptable error at high speed.

M/T Method

Obviously in wide speed range neither M method nor T method is suitable, that is why M/T method is proposed. This method maintains the resolution by combining the advantages of each method. It measures not only encoder pulse but also the clock pulse in fixed sampling periods, as shown in Fig. 2.3.

Substituting $Tc = m_2/f_0$ for Tc in Eq. (2.1) gives the motor speed

$$n = \frac{60 f_0 m_1}{Z m_2}. \tag{2.5}$$

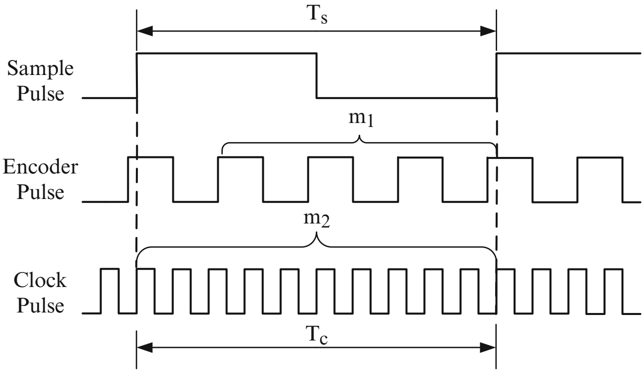

Fig. 2.3 Scheme of M/T method

M/T method greatly improves the accuracy at low speed and can be easily implemented by QEP unit of DSP. However it still can't deal with the problem of low encoder pulse frequency at very low speed and the system performance will deteriorate by intermittent speed feedback. To overcome this shortcoming, the variable M/T method comes into being.

Variable M/T Method

The difference between M/T method and variable M/T method lies in the counting time. For variable M/T method, counting time begins at the first rising edge of the encoder pulse in sampling period and finishes at the end of a whole encoder cycle in the current sampling period, as shown in Fig. 2.4.

In this method, the motor speed is given by the same equation as Eq. (2.5) of the M/T method. Attention to the trigger time of counting time Tc delaying the sampling time Ts at the rising edge of the encoder pulse following the current sampling period. This can bring two advantages. First, the number m_2 is counted in the period of m_1 complete encoder cycles. The error will be one clock pulse which is much shorter than encoder pulse. It can decrease the counting error effectively. Second, it unifies M method and T method in one method. At high speed shown in Fig. 2.4a, encoder frequency is larger than sampling frequency, Tc approximates Ts. In this case, variable M/T method has the same effect with M/T method and the relative error is nearly the same. As speed decreasing to a very low value that encoder cycle is much longer than sampling period, variable M/T method turns to be T method when m_1 equals to one. At that time variable M/T method has the same relative error with T method. Concisely variable M/T method can gain a high accuracy in quite wide speed range.

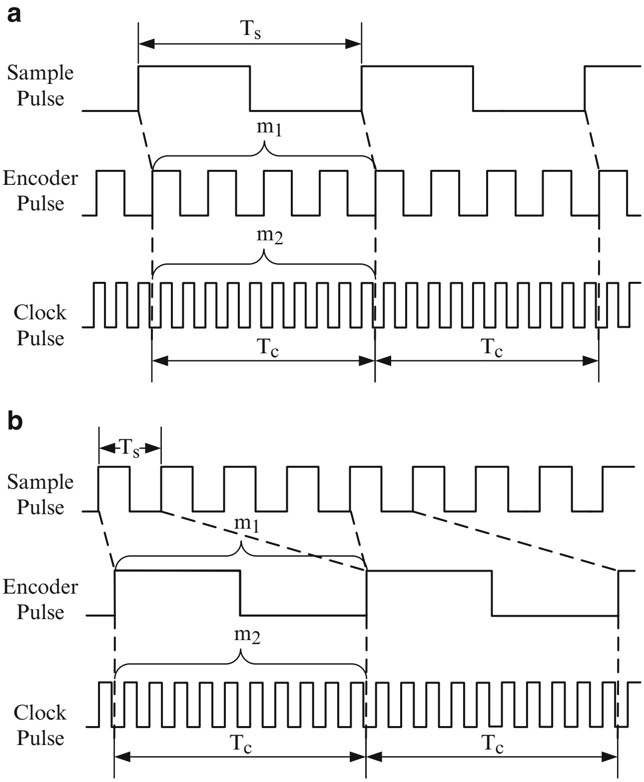

Fig. 2.4 Scheme of variable M/T method (**a**) At high speed (**b**) At low speed

An Improved Variable M/T Method

As T method, time delay is unavoidable in variable M/T method at low speed, since the counting time is much longer than sampling period and the calculated speed is the average value of the previous interval. There is not any information about speed during the counting interval. Using a zero-order holder or one-order holder is an easy solution to the problem. Bu it is not suitable for the applications with rapid changing references such as advanced numerical control machines and industry robots, since this speed measurement value of the previous counting interval has no information about the change of the speed reference during the current sampling period. The delay of the speed feedback will be unacceptable and will cause the system vibration.

An improved variable M/T method based on speed estimation will bring good performance which takes account of the speed reference change during the speed measurement period. The speed control loop scheme is shown in Fig. 2.5. Speed

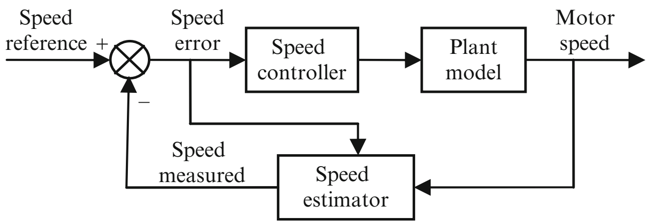

Fig. 2.5 Speed measurement using speed estimator

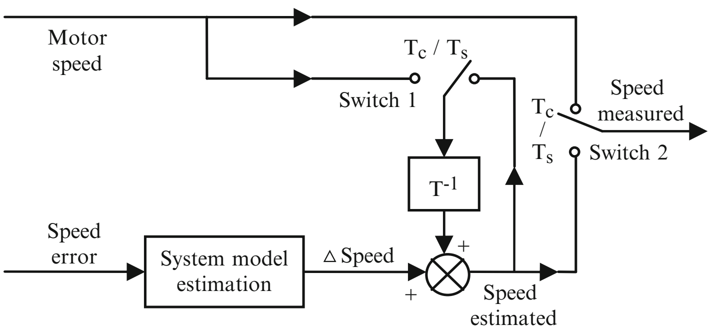

Fig. 2.6 Speed estimator framework

feedback comes form speed estimator which has two inputs, motor speed and speed error. The structure of speed estimator is shown in Fig. 2.6. If the counting period Tc just ends in the current sampling period, the counting Motor speed will be sent immediately to the estimator output with switch 2 connected up. At the same time switch 1 turns left to store the newest motor speed. Otherwise switch 2 connects down and the estimator output is speed estimated signal which is the sum of delta speed from the system model estimation and the previous motor speed by switch 1 turns to right. By this way the speed estimation will get to the controller during every sampling period between the counting periods. Therefore the accuracy maintains high in wide speed range with rapid response at the same time.

Conclusion

In this paper, an incremental encoder-based motor speed measurement has been described. It is based on variable M/T method which provides an alternative counting period between the system sampling period at high speed and encoder cycle at low speed, so that it can gain high accuracy for a wide speed range. At low speed it can obtain a higher accuracy, but the long counting time brings the sluggish system response. While the improved method with speed estimator can give the more accurate speed feedback and improve the performance at very low speed. For the advanced numerical control system or servo system in industry robots which have strictly rapid response and wide speed range requirements, improved variable M/T method is particularly suitable.

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