

# Design of Linear Motion Controller for Incremental Optical Encoder

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**ABSTRACT:** In Optical electronics for light wave experiments where light waves are reflected from object under study, mirror/Lens used to focus such reflected light from object to image detector screens. Accurate Processing of such images will be greatly influenced by knowledge of focal lengths of lenses and precise positioning of lens. Such positioning achieved by Micro motors, used to rotate the lens and also feedback the position information. These DC motorized actuators translates linear and rotary stages optical mounts and fiber positioners. Having an optical encoder that generates pulse when it moves, acts as a feedback element. Encoder mike send quadrature pulses to the controller indicating direction of travel and distance moved. The controller decodes pulse to display position while regulating speed.

**KEYWORDS:** Encoder Mike, Quadrature Pulses, Incremental Optical Encoder.

## I. INTRODUCTION

Angular position and velocity information is often required in motion control systems design of mechanical machines, because control is applied by using an angular measurement of the position or velocity. Nowadays, incremental optical encoders, also known as shaft encoders, are widely used for this purpose since the majority of precision motion devices are driven by rotary motors. The maximum accuracy of the controlled system is limited by the measurement accuracy. When measuring position by using incremental optical encoders with limited resolution, the occurrence of quantization errors is inevitable. Differentiating encoder measurements to obtain velocity information results in an amplification of the quantization errors.[2].The performance can be increased by improving the measurement accuracy, i.e. using a higher resolution encoder. However, this is an expensive option. A possible solution is the concept of time stamping with extrapolation. It improves the accuracy of the position and velocity estimation, using only the encoder measurements. The controller has an encoder time stamp register, which stores counter values of the quadrature signal produced by the encoder and the time instant at which the corresponding transition has occurred. The combination of a time instant and a counter value is called a time stamp. Time stamps from previous transitions can be used to achieve a more accurate position estimation than the position measurement of the encoder by fitting a polynomial through these points. Furthermore, it is possible to prevent time stamps from entering the register. This can be done by skipping a number of transitions of the quadrature signal or by introducing a delay.

## II. INCREMENTAL ENCODER

The incremental optical encoder [6] consists of three basic components: a slotted disk, a light source and a dual light-detector. As shown in Fig. 2.1. The light source shines on a disk which is covered with a regularly-spaced radial pattern of transmissivity and reflective/absorptive elements called encoder increments. Low resolution encoders use a disk with radially-cut slots to vary optical transmissivity of the disk. High resolution encoders typically use a radial pattern of chromium lines evaporated onto clear glass. A dual light detector on the opposite side of the disk detects varying intensities of light as the disk rotates due to the pattern on the disk. The output of the light detectors are two signals, (a, b) in Fig. 2.2, which are correlated with the intensity of the light striking each of the two detectors. Ideally, the signals

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are sinusoidal waveforms. The two signals are in quadrature, i.e. 90° phase shift with respect to each other. This makes it possible to determine the direction of motion by detecting the leading signal. In digital encoders, the two detector outputs are converted into digital quadrature signals using thresholding circuits. Due to the quadrature phase between the two signals, position changes of 0.25 of a line can be converted into a pulse train signal. A digital counter counts "up" and "down" changes and uses this counter value as an estimate of the encoder position.

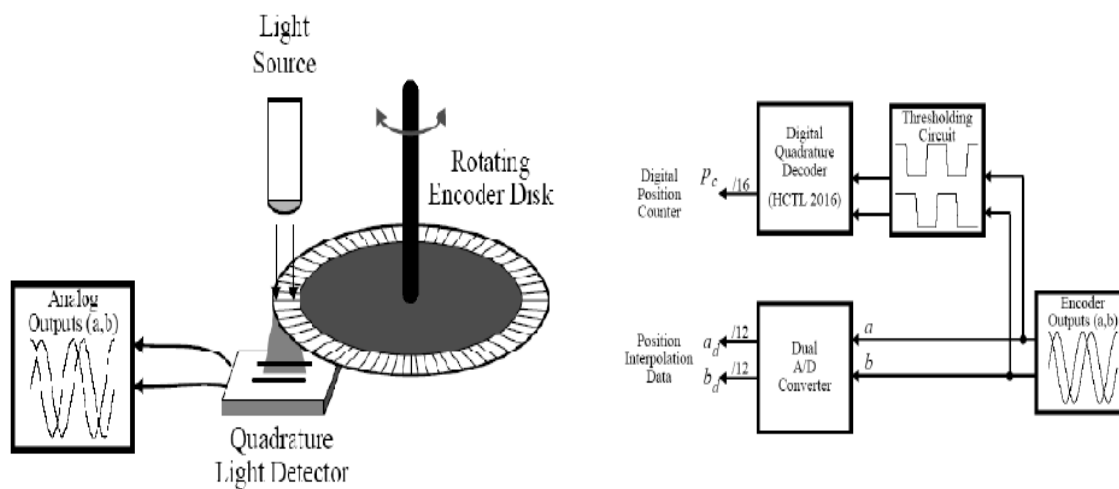


Fig 2.1: Principle of optic encoder

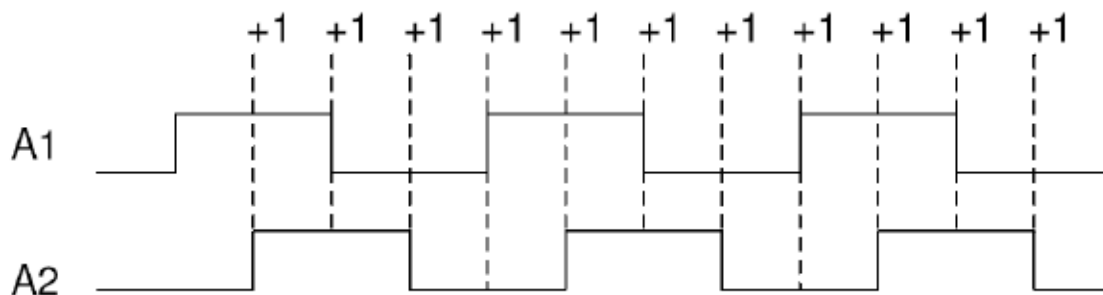


Fig 2.2: Encoder quadrature output pulse trains

## 2.1 :Concept of time stamping

To control an electrical motor, information of its position and/or velocity is needed to obtain a good tracking performance. The common way to determine the position is to read out the encoder counter value at a certain sampling frequency of the controller. The number of encoder increments registered by the counter is a measure for the distance the motor has travelled. The measured signal is quantized because of the finite resolution of the encoder. Therefore, a quantization error on the position, with a maximum value of half an encoder step, is introduced. To obtain the angular velocity, the quantized position signal can be differentiated. However, the discontinuities in the position signal will result in spikes in the velocity signal. Time stamping is also known as the event detection method. An event refers to the transition of one encoder increment to the next. At such step, the position  $x_i$  is exactly known, namely halfway the two encoder steps (See Fig. 2.3).

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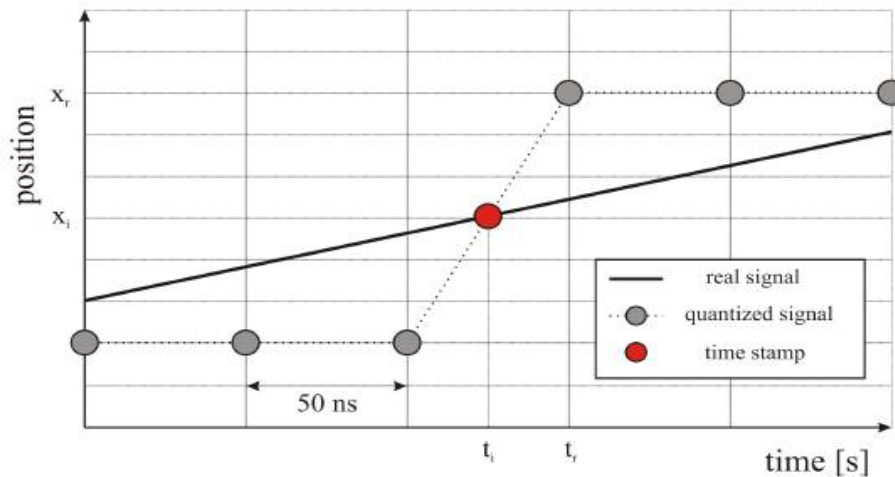


Fig 2.3: Concept of time stamping

It is possible to detect the time instant  $t_i$  at which such a quadrature event takes place. The combination  $(x_i, t_i)$  of a time instant  $t_i$  and the matching position  $x_i$  is called a time stamp. The accuracy by which quadrature events can be detected is dependent on the clock frequency  $f_c = 1/T_c$ . When encoder imperfections are neglected, the position therefore can be corrected to  $x_i$ . The time stamp resolution of 50 ns is assumed small enough to neglect the difference between  $t_i$  and  $t_d$ . Finally, a time stamp consists of the pair  $(x_i, t_d)$ . By using the time stamps of a certain amount of previous events, position estimation can be obtained by fitting a polynomial through these points. This fit can be extrapolated to have a very accurate prediction of the position at the time instant determined by the sampling frequency of the controller.

## 2.2 Extrapolation

In the concept of time stamping, extrapolation plays a significant role. The order of polynomial fitting and the number of time stamps that are used to calculate the fit are important parameters. There are several methods to fit a polynomial through a discrete set of points. One of the most computationally convenient ways is the method of least squares, which can be presented as solving a set of linear equations:

Parameters:

n- number of time stamps

m- order of the polynomial fit

$c_i$ - polynomial coefficients, with  $i = 1, \dots, m$

$t_j$ - time instants, with  $j = 0, \dots, n$

Assuming  $A$  is an  $m \times n$  matrix with  $m > n$ ,  $b$  is a  $n \times 1$  vector and  $x$  is a  $m \times 1$  vector.

The solution to this over determined system then can be formulated as follows:

$$x = (A^T A)^{-1} A^T b \tag{2.1}$$

To solve this equation for  $x$  and minimize the computational costs, LU decomposition is used.

The matrix  $ATA$  is decomposed into a product of a lower triangular matrix,  $L$ , and an upper triangular matrix,  $U$ . The linear system  $A^T Ax = A^T b$  can be written as  $LUx = A^T b$  and hence can be solved by first solving the lower triangular system  $Ly = b$  by forward substitution, followed by the upper triangular system  $Ux = y$  by back-substitution. Now the coefficients of the polynomial are known and an estimation of the position on a certain time instant can be determined with this polynomial,

$$x(f) = c(m)t(m) + c(m-1)t(m-1) + \dots + c(0). \tag{2.2}$$

From Fig. 3.2 it can be seen that the estimated position  $x_f$  is a better approximation to the real position than the quantized measurement  $x_q$ .

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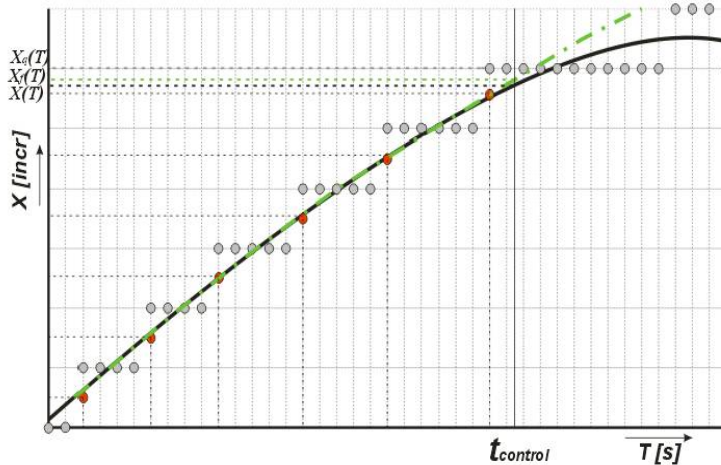


Fig 2.4: polynomial fitting over quantized pulse trains

### 2.3 Oriel encoder :

The Oriel Motormike is DC motorized actuators translate linear and rotary stages, optical mounts and fiber positioners. They have an optical encoder that generates pulses when the actuator moves.

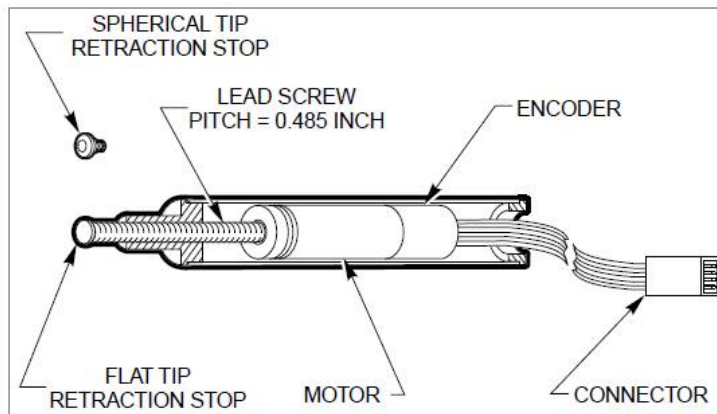


Fig 2.5: Cut away view of an Oriel Encoder Mike™.

#### Specifications:

Travel length: 0.5, 1 or 2 inches  
(12.7, 25.4, or 50.8 mm)

Temperature range: 32° to 150 °F (0 to 65 °C)

Vacuum compatibility: To 10<sup>-6</sup> torr

Motor supply voltage: 12 V

Maximum axial load: 22 lbf (10 kgf)

Maximum linear speed: 300 μm/s

Minimum linear speed: 0.5 μm/s

Backlash (load dependent): <8 μm; reproducible to 0.5 μm at constant load

Resolution: 0.1 μm

Unidirectional repeatability: <2 μm

Cables: Each actuator includes a 6.5 ft. (2 m) long cable to connect to Oriel Controllers

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### 2.4 Proposed block diagram:

Controller designed to have following features:

1) Driver unit:

Includes PWM signals to change voltage to motor and H bridge includes to change direction Of motor either clockwise or anticlockwise

2) Quadrature Decoder unit:

It includes decoding of quadrature output pulses to sense position and give direction information.

3) Position counter unit:

Includes counting the pulse trains to give readout of positions

4) Controlling signals:

This consists of memory storage of position counter. This is required to initialize the motor position during power off/on. User can also give a preset position value for motor. The controller uses polynomial fitting lookup time stamp to give more accurate positioning by calculating error of quantized pulses .

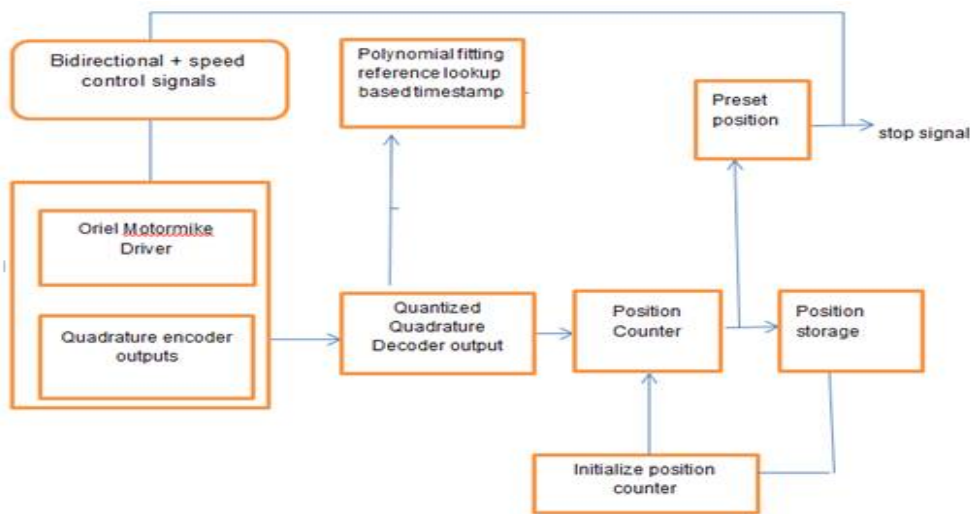


Fig 2.6: Proposed block diagram of controller

Following design of layout developed for implementation of proposed block diagram as follows:

Whenever Motormike runs it starts giving quadrature decoder pulses which are fed to decoder unit for which resolution option available ,we have chosen \*1 resolution so that the position information and direction information fed to counter section which stores and acts as position controller to achieve desired positions. BCD i/o are used as communication signals for position data.

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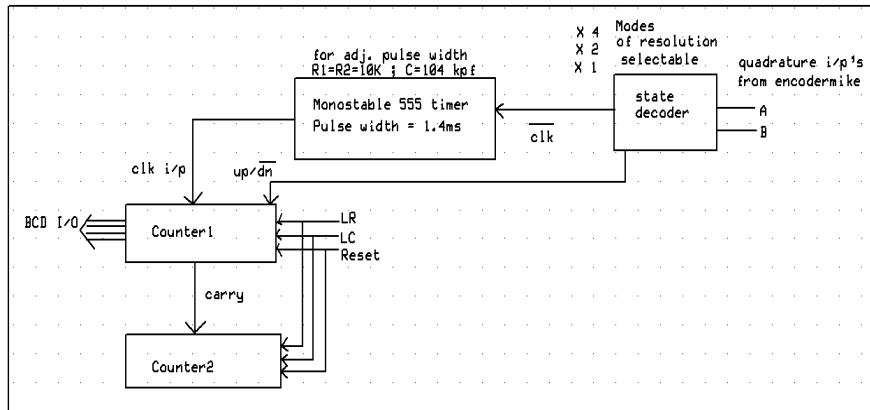


Fig 2.7: Layout Of Design

### III.RESULT AND ANALYSIS

The observation of recording speed of motor changing proportionally with applied PWM voltage. .

time(s)	voltage(v)	speed (microm/s)
	0	0
	0.9	0
361.24	1	13.8412136
218.11	1.5	22.92421255
124.86	2	40.04485023
112.5	2.5	44.44444444
92.82	3	53.86770093
71.42	3.5	70.00840101
59.84	4	83.55614973
53.3	4.5	93.80863039
49.32	5	101.378751

Table 3.1 speed vs. voltage observation table for Motormike

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The speed profile curve has been plotted from above data as follows:

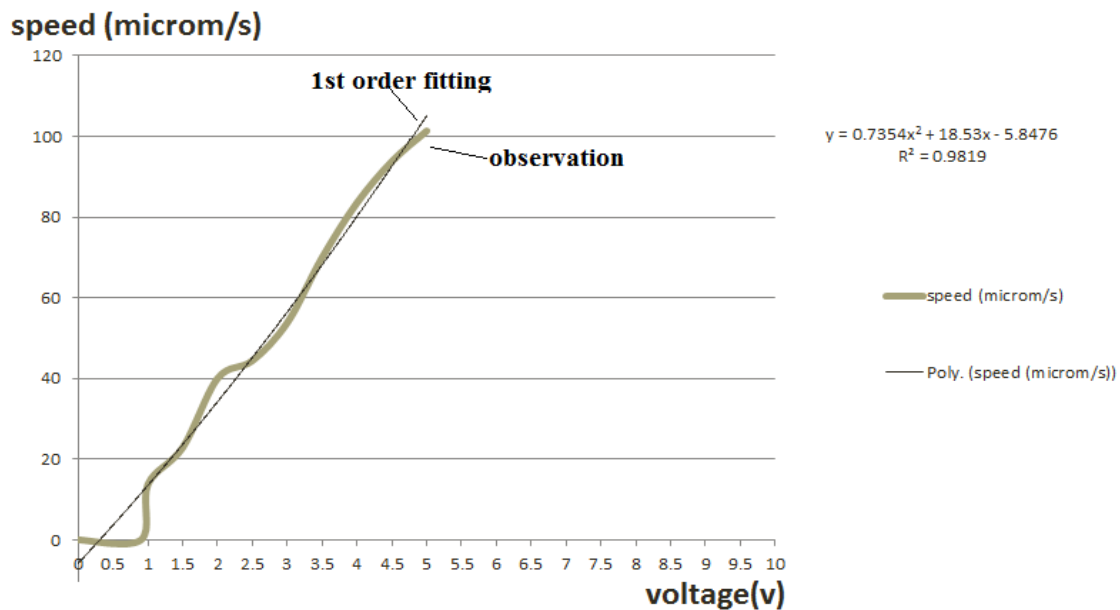


Fig 3.2: Speed vs. Voltage Characteristic Curve Fitting

The graph reveals 2<sup>nd</sup> order quadratic equation which can be approximated to 1<sup>st</sup> order linear curve with 98.19% of Linearity.

## IV. CONCLUSION

The paper focuses on importance of optical encoder for motion application with the development of motion controller block diagram and simplicity of design through the linear results obtained. The fit algorithms need to be optimized for relative high velocities and such designing of linear motor controller are necessary for development of “optical lever” in optical laboratories i.e. a precise angular deflection produced by rotating lenses in collimated beam chambers .

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