FPGA Based Quadrature Decoder/Counter with I²C Bus Interface for Motor Control

Manu T S[1] *B. Thilagavathi*[2] *AnithaMary. X*[3]

Abstract

This paper presents a new solution for processing the pulses from an optical encoder attached to a motor shaft, and deriving the rotational speed information The measurement accuracy at low speeds using the proposed method is improved, compared to currently known methods. Another significant advantage of using the proposed circuit is that it can be implemented in specific hardware, thus, reserving the full computational power of the controlling micro controllers for high-level control tasks and for future software expansions.

Keywords : Field Programmable Gate Array, Position Control, Quadrature Encoder/Decoder

1. Introduction

This paper describes the design of a high- performance circuit that performs both position and velocity measurements. A new solution for processing the pulses from the encoder and deriving the speed information is proposed. This is an adaptive technique allowing the evaluation of the speed with very good accuracy, even at very low rotational speeds. The main advantage of implementing the position and speed measurement circuitry in dedicated hardware is that the Microcontroller reserves its entire computational time for high-level control tasks. The proposed circuit is an interface between the microcontroller and the shaft quadrature encoder. Simulation and experimental results from the designed and constructed chip are given.

All high-accuracy position control applications typically use an incremental or an absolute optical encoder mounted on the motor's shaft. The output of the encoder usually provides quadrature pulses. These pulses are used to derive both position and angular velocity of the motor's shaft. An ordinary incremental encoder does not give the absolute position but provides finer resolution. Many of the incremental encoders utilize quadrature sinusoidal scaling signals, which are generated by optical slits, for example. Typically, the rotating angle is measured by counting the number of sinusoidal waves or rectangular pulses, using a pulse counter.

The purpose of a quadrature decoder/counter is to take some of the real-time computational load off the microprocessor. When the processor reads the output signals of the position encoder, every change in state must be detected. This means that for an encoder of 250 pulses per channel per revolution turning at a modest 6000 rpm, the processor must detect and decode 100,000 state changes per second. This is difficult for most microcontrollers, and many systems use higher speeds and/or even denser encoders.

[1]P.G scholar, Department of Electronics and Instrumentation Engineering, Karunya University, Coimbatore. Email:manuts@karunya.edu.in.

[2]Lecturer,Department of Electronics and Instrumentation Engineering,Karunya University, Coimbatore. Email:deepanasri@rediffmail.com.

[3]Asst Professor, Department of Electronics and Instumentation Engineering, Karunya University Coimbatore Email : anithajohnson 2003 @gmail.com.

The solution to this difficulty is a circuit that will detect each of these state changes and send them to a counter. Each time a state change is detected in the positive direction, the decoder will increment the counter; a change in the other direction causes the counter to be decremented. Thus the counter will keep a running count of how far the encoder has moved, until it overflows. Now the microprocessor can read the number in the counter and compare that number to a previous reading in order to measure the distance traveled. Since the counter stores the position changes, a system using an 8-bit counter can measure the position from signals whose frequency is about 127 times higher than that of the fastest signals that can be measured by a software-only system. In a similar way, the 4-bit counter can read signals approximately 8 times faster than those read only by software. The typical application block diagram is show in figure 1.

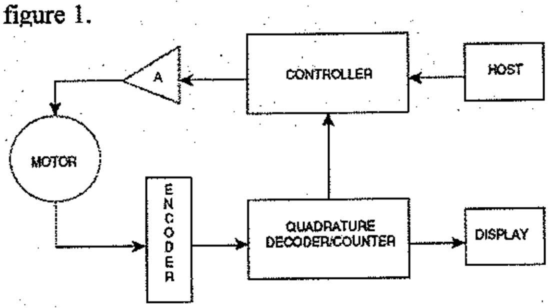
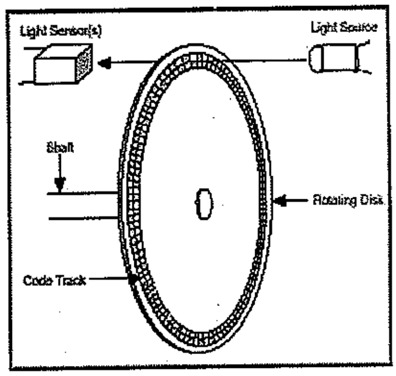


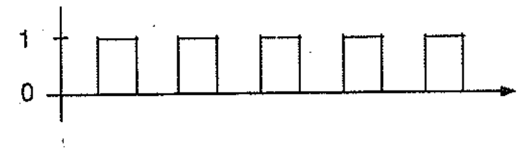
Figure 1 : Typical Application Block Diagram

2. Optical Encoder / Decoder

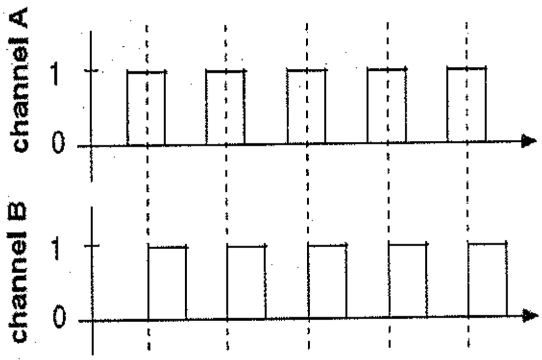
Often used for digital position and velocity measurement Two types - 1) absolute encoders: gives actual position 2) incremental encoders: gives change in position. Usually encoders' measure angular displacement - can be used to measure rectilinear position - computer mouse (2-dimensional position) Incremental Encoder: a wheel with little windows (front and side views): as shown below



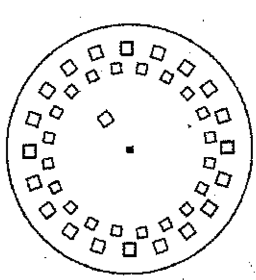
As wheel rotates, the photocell generates a digital signal as shown below figure .



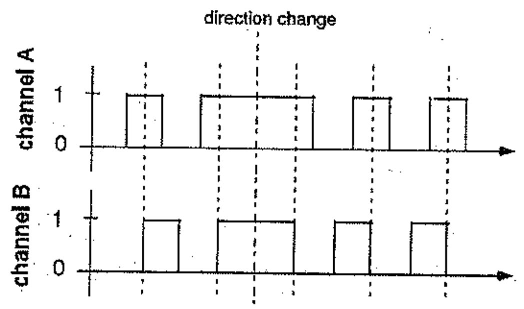
If windows and dividers are of equal width, then the "on" and "off" times are of equal duration for constant rotation rate. Encoders actually generate a quadrature signal, consisting of two square waves that are 90 degree out of phase as shown below.



This may be done using a one track encoder with two light sensors placed side by side Or a two track encoder as shown below.



Direction of rotation is determined by the phase difference between the two signals • For example, if Channel A leads Channel B, then the encoder is rotating (say) Clock wise direction (CW) If Channel B leads Channel A, then the direction of rotation is Counter clock wise direction (CCW) the direction of rotation can be find out by detecting the change of direction. The direction changing can be explained by using the signals below



3. The Micro controller for Motor control

The classical approach of using a digital signal processor in position control is illustrated in Fig. 1a. This configuration consists of a position control loop that includes an inner speed control loop.

The angular rotor position is sampled and compared to the reference value. The position error is then processed by the position controller to provide the speed reference for the speed control loop. In the speed control loop, the motor speed is sampled and compared to the imposed reference value. Speed error is processed by the speed controller to provide an appropriate control signal for the motor drive.

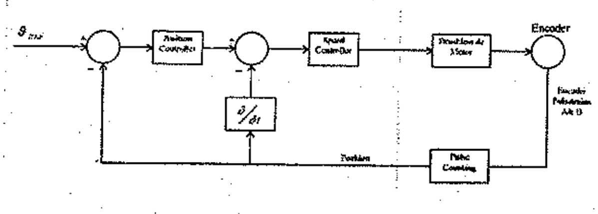


FIgure 1a : Classical Approach Of Position Control Loop

In the commonly used configuration shown in Fig. 1(a), the microcontroller calculates the actual speed by making repeated arithmetic differentiation of the position information. In proposed system [Fig. 1b], the micro controller reads the actual position and velocity of the motor shaft directly from the proposed interface circuit, compares it with the desired position and speed, executes the control algorithm, and drives the motor

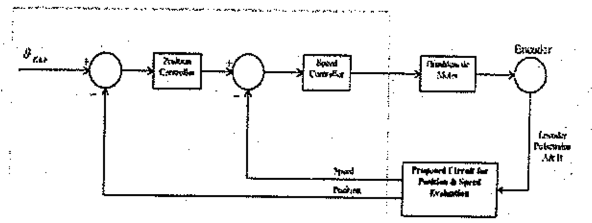


Figure 1b : The Proposed Circuit Producing Actual Position And Speed Information.

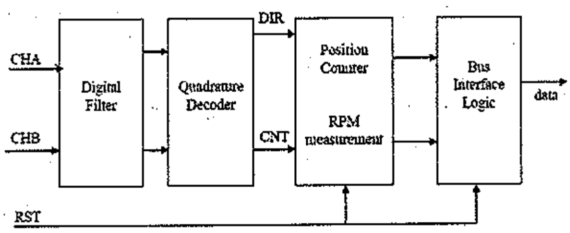
4. Position Measurement

A dominant factor that limits the positioning accuracy of a servo controller is the angle resolution of an encoder attached to the motor shaft. The angle resolution of a conventional incremental encoder, available at reasonable cost, is 0.09.This resolution is sufficient for most applications and the movement in high-speed positioning is also smooth. In low speed operation, however, the intermittent movement due to the digital control becomes appreciable and the angle resolution of the encoder must be increased. Several methods for improving the resolution and accuracy of rotary encoders have been proposed in the literature. Among them, is an interpolation method the ways to improve the resolution of the available encoders, instead of using one having more precise scale, are: the multiply-by-four method, where 1/4 of the scale pitch resolution is obtained using a simple pulse technique; the interpolation of the scale interval of the currently used encoder the incremental encoder used in our application provides 1024 pulses/rotation. This limits the position encoding accuracy to 360/1024=0.3520. In order to improve the angle resolution, the multiply-by-four technique is used. The multiply-by-four technique provides, in this case 360/4096=0.0870, angle resolution without additional cost to the application.

5. Velocity Measurement

It is based on counting encoder pulses in a specific time interval, and the corresponding time is measured by counting the clock pulses of a high-frequency clock with period Tc .The integer number of encoder pulses in a specific time interval. Both the pulse counter and the TC (time counter) are started at a rising edge of the encoder pulse. The counters are stopped by the first rising edge of the encoder pulse occurring after the interval Tc The content of the pulse counter (Cp) is then the number of encoder pulses measured, and the content of the TC is the number of time clocks (Ct) measured. The values of Cp and Ct are used to calculate the rotational speed of the motor since is the angular position difference and is the accurate sampling time of each measurement

6. Functional Description



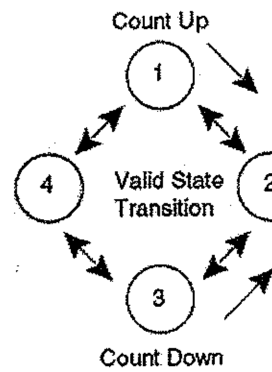
A. Digital Filter

The digital filter is responsible for rejecting noise on the incoming quadrature signals. This is achieved by combining Schmitt triggered inputs and three clock-cycle delay filters. This combination rejects low level noise and large, short duration noise spikes that typically occur in motor system applications. The signals on each channel are sampled on rising clock edges. A time history of the signals is stored in the four-bit shift register. Any change on the input is tested for a stable level being present for three consecutive rising clock edges. Therefore, the filtered output waveforms can change only after an input level has the same value for three consecutive rising clock edges. By this method the short noise spikes between rising clock edges are ignored and pulses shorter than two-clock period are rejected.

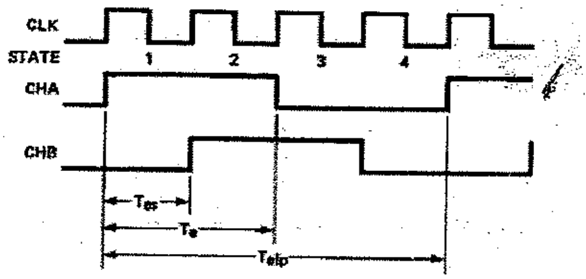
B.Decoder Logic

The decoder logic decodes the incoming filtered signals into count information. The decoder samples the outputs of channels A and B. Based on the past binary state of the two signals and the present state, it outputs a count signal (CNT) and direction signal (UP_DN) to the position counter, see state transition diagram below. Channel A leading Channel B results in counting up. Channel B leading channel A results in counting down.

Counter State Transition Diagram



Based on the states of the motor rotor position and quadrature signal came from the encoder the direction of the rotation of the motor is find out by the decoder logic the signal and states of each rotor position is as shown in the signal diagram f and logic for each state change is shown in the table below



C. Position Counter

Table 1 : Direction Decoding

Channel A	Channel B	Up/Down
1	0	1(UP)
–	1	0(Down)

Table 2 : States of Motor

CH A	CH B	STATE
1	0	S1
1	1	S2
0	1	S3
0	0	S4

The binary up/down counters counts on rising clock edge. Channel A leading channel B results in counting up. Channel B leading Channel A results in count down.

D. Position Data Latch

The position data latch captures the position counter output data on each rising clock edge, except when its inputs are disabled by the inhibit logic during two-byte operation. The inhibit logic samples the OE and SEL control signals and does the conditional inhibit of the position data;-register.

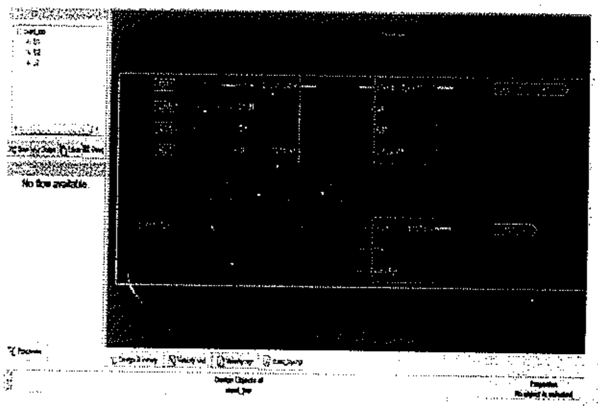
E. Bus I/F Logic

Consists of multiplexers and tri-state output buffer. This allows the independent access to the low and high bytes of the position data latch.

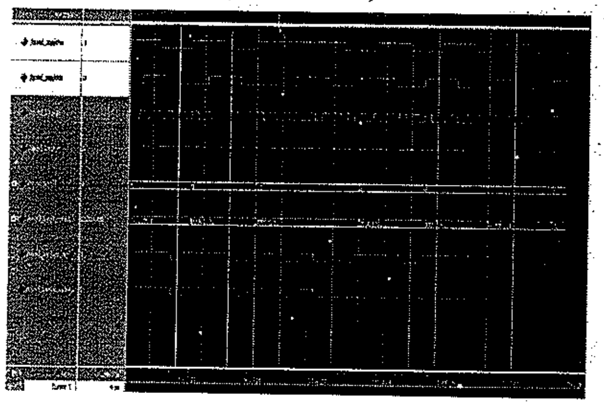
7. Testing And Experimental Results

The simulation result of the quadrature decoder /counter is shown below the simulation is done by using ModelSim Simulator.

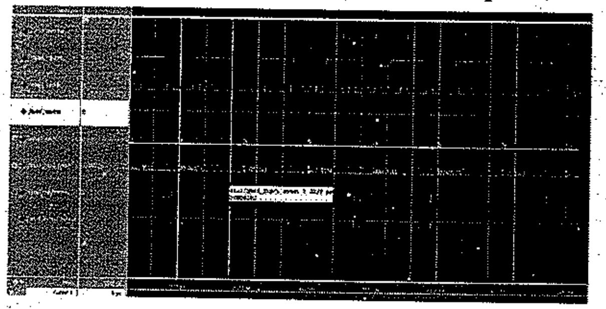
Results (Schematic block)



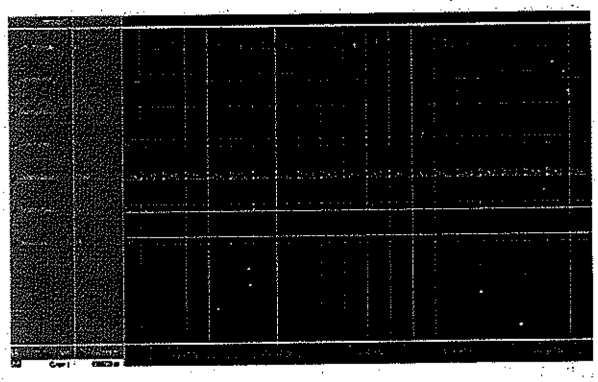
Simulation Result : Motor CCW Rotation (Down Count)



Simulation Result : Motor CW Rotation Up Count



Simulation Result : RPM Measurement



8. Conclusion

In this paper, an incremental encoder based position and velocity measurement FPGA with SPI interface has been described. It is based on two techniques: counting pulses from a clock between successive pulses of the encoder for low speed application and counting the number of pulses from the encoder in a known time for medium and high speeds. The combined techniques enable the chip to deliver high accuracy for a wide speed range without degradation in dynamic behavior. With on-chip velocity estimate, it reduces computational complexity imposed on the supervisory microcontroller.

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Author's Biography

Anitha Mary.X completed Bachelor of Engineering in Electronics and Instrumentation in Karunya Institute of Technology, Coimbatore and Master of Engineering in Anna University, Coimbatore. Currently pursuing Ph.D in Control System in Karunya University. She awarded Bharathiar University 7 th Rank in U.G. and currently guiding many U.G. and P.G. Area of Interest is Control system, FPGA.

Manu is a P.G. Scholar from Karunya University, coimbatore.

Thilagavathy is working as lecturer in Karunya University