A software solution for displacement and angular speed measurement through virtual instrumentation

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Abstract: - This paper presents a software solution to implement a displacement and angular speed measurement for a mobile that is moving in a linear or circular direction. For this, is determined function to sensing the direction of movement and also the algorithm through which is make the measurement and these are implemented using a virtual instrument built in LabVIEW. Thus it is possible to use a data acquisition boards for general use, such as PCI-6024, which has no inputs for quadrature signals with a quadrature encoder, such as E6A2-CW5C or HEDS – 5500 that generates such signals.

Key-Words: - quadrature encoder, algorithm, measurement, virtual instrument, data acquisition board

1 Introduction

Movement is defined as a physical quantity of a mechanical change through is possible to provide information about position of a material point or mobile against a reference system. Quantities derived from this, which may be considered, are: position, distance or proximity. In many applications the displacement is considered as a vector so it is necessary to calculate both size and direction for this quantity.

Usual procedure for calculating the size of this quantity is to use incremental displacement sensor that generates a pulse train by counting of these pulses acquired from sensor.

Same incremental displacement sensor can be used to detect the direction of movement if it provides two trains of pulses shifted by one quarter of the period, in which case it is named quadrature encoder. A quadrature encoder can have up to three channels – channels A, B, and Z. There are data acquisition boards that accept at their counters signals provided by encoder quadrature signals such as the NI 622x, NI 625x, and NI 628x (M series devices) but there are also data acquisition boards that not accept such signals like the NI PCI-6024 (E series devices) [1]. In this case it is necessary to achieve a logical system to detect the direction of motion and also to increment or decrement a counting value depending of the direction of movement. Such a system can be achieved through hardware structure but also can be done by a software solution using digital inputs and counters on the data acquisition board.

2 Problem Formulation

To make a determination either linear or angular displacement is first necessary to determine its direction. After that, it can control the counting direction for the counter through which is determined the value of displacement by counting the train of pulses.

To measure angular displacement we use PCI-6024E, a data acquisition board from National Instruments that has 8 digital I/O (DIO0 … DIO7) lines (TTL/CMOS) and two 24-bit counter/timers without having the dedicated inputs to connect a quadrature encoder. Control the operation of the data acquisition boards is achieved through a program written in LabVIEW graphical programming language called virtual instrument.

To achieve the determination of displacement direction is needed in these conditions to be used two digital inputs to connect to the signals A and B carried over from the quadrature encoder. Displacement value is obtained by counting the pulses A or B, and its direction is determined by counting purposes, otherwise said, by increment or decrement the counter value [2]. The angular speed value is obtained by counting pulses during the prescribed time [3].

To realize the virtual instrument for displacement and angular speed measurement based on two trains of pulses shifted by one quarter of period is necessary to synthesize a control command for establish counting direction and an algorithm to control the counters and to extract the content of the counters in the prescribed time.
3 Problem Solution
The software solution of the problem consists in creating a virtual instrument which can be used to detect the direction of displacement and measure the angular speed and displacement values.

3.1. Identification of movement direction
As noted above, identification of the direction of movement is needed to control the direction of counting. For synthesizing the command control signal called Counting Selection is considered a chart signals that identify all the possibilities of combining the two pulse trains according to the direction of rotation. Based on this chart, 8 distinct states denoted by $S_i$ ($i = 0 \ldots 7$), can be identified and is constructed the states transition graph shown in Fig. 1[4].

Fig. 1. Transition graph of states

Based on the transition graph is built the primitive matrix (Fig.2.) that contain on the columns the correlation between combination of the input signals (Channel A and Channel B) and on the rows contains all possible transitions from one internal stable state. This is accompanied by full matrix of the output that contains the values of output variable during both states and transitions. Columns are cyclic coded using Gray code.

Fig. 2. Primitive matrix of states and output

To identify a minimal configuration of the sequentially system is built a reduced matrix of states. Technique used to reduce the number of states from primitive matrix, is based only on the equivalence from the theory of sequential automatic and reduction of state is through merging or annexation in compliance with specific rules [5].

To obtain the excitation functions of the sequentially system is required to encode the reduced matrix states. It notes the existence of 4 reduced states so that it would be necessary to encrypt them using two state variables i.e. $x_1$ and $x_2$. To take account of hazard that occurs due to simultaneous change of more than one input variable during transition between two states is used the Gray code.

To construct the excitation functions, represented by logic functions for states $x_1$ and $x_2$ is necessary to build matrices of transition for reduced states and their number must be equal to the number of state variables. These matrices are shown in Fig.3 in which notation X means states impossible during operation.

Fig. 3. State transition matrix

Applying the method of synthesis of logical functions based on Karnaugh diagrams it can identify the logical functions of the excitation variables (states) $x_1$, $x_2$ respectively for function of output signal Counting Selection as follows:

$$x_1 = x_1 \cdot x_2 + \overline{A} \cdot \overline{B} \cdot x_2 + B \cdot \overline{x_1} \cdot x_2 + A_1 \cdot x_1 \cdot x_2$$

$$x_2 = \overline{x_1} \cdot x_2 + A_1 \cdot \overline{x_1} + \overline{B} \cdot x_2$$

(1)

Counting Selection = $x_2$

From equations (1) can be seen that the output signal is identical to the state $x_2$ which simplifies implementation with logic gates for the scheme that generate the control signal for counting direction.

Based on logical functions (1) can create a logical diagram of the system through which make
selection for direction of counting and in Fig.4 is shown the software structure of this system built with logical functions in LabVIEW. Are used **Compound Arithmetic/Logic** functions through which can select basic arithmetic or logic operations with two or more variables.

![Software structure used to counting selection](image)

**Fig.4.** Software structure used to counting selection

This will be a sub-structure, SubVI called **SELECT**, in the main program used to determine the displacement and angular speed values.

### 3.2. Angular displacement and speed measurement

Determination of displacement is achieved by counting the pulses (increments of angular displacement) that correspond to the slots of incremental encoder. They are expressed in degrees and the value of an increment for angular displacement corresponds to the relation expressed by ratio between the angle at the center of the circle and the number of slots.

Angular speed measurement is based on counting of pulses during the prescribed time. The basic measuring process of pulse during a prescribed time method is shown in Fig.5. The duration of a measurement cycle is fixed and set a priori. The speed pulse counter and the timer are both started at a rising edge of the speed pulse. The pulse counter is stopped when the timer runs to the end of the prescribed time. The angular speed is then derived from the content of the pulse counter and the prescribed time.

![Pulse counting during prescribed time](image)

**Fig. 5.** Pulse counting during prescribed time.

This method can result in a loss of up to one speed pulse. As the duration of speed pulse increases with decreasing speed, this method has poor measurement accuracy at low speed.

The algorithm used to measurement the angular displacement and speed is shown in Fig.6. and its implementation by virtual instrumentation, called RPM. SubVI in the main program is shown in Fig.7.

![Angular displacement and speed measurement algorithm](image)

**Fig.6.** Angular displacement and speed measurement algorithm

![Algorithm implementation by virtual instrumentation](image)

**Fig.7.** Algorithm implementation by virtual instrumentation

Getting prescribed time necessary for calculating speed is achieved by using function **Tick Count** (ms) that returns the timer value, in milliseconds, between passages consecutive in the **While Loop**.

### 4. System Implementation with Virtual Instrument

A program developed in LabVIEW is called a virtual instrument (VI) and it has two components the block diagram that represent program itself and the front panel that is user interface. Through such a
virtual instrument can be controlled the operation of
the data acquisition board PCI-6024 whose digital
inputs DIO0 and DIO1 are used for acquisition of
Channel A and Channel B signals from incremental
sensor.

The main program algorithm is shown in Fig.8
and this includes SubVI's SELECT and RPM and
has a like basic structure **While Loop** that ensure the
continuous running of the program until the user
stop it through the STOP button. Based on this
algorithm is built the virtual instrument whose block
diagram is shown in Fig.9

Acquisition is executed in two sequences and the
program begins with reset of the local variable CTR
and timing setting that will be used for defining the
graphical representation of X-signal for the Channel
A respectively Channel B graphical indicators.

The input signals Channel A and Channel B are
taken from the incremental sensor by **line 1**
and **line 0** of the digital **port 0** port of the data acquisition
board PCI – 6024E using DAQ Assistant
function. This function creates, edits, and runs tasks using NI-DAQmx that is data acquisition driver. Reading
through this function is an array with eight boolean
components corresponding to the eight digital inputs
of the data acquisition board and through **Index
Array** function are selected components with index
0 and 1 that correspond to digital inputs DIO0
respectively DIO1. Thus the two components will be
the inputs Channel A and Channel B of the system
developed for determining the direction of
displacement, system that generates the output
signal Counting Selection [6].

Once direction is selected, this it will be
displayed on the front panel and the selection signal
is also used for selecting the direction of counting
(Count Up or Count Down) by applying it to the

![Fig.8. Main program algorithm](image)

![Fig.9. Diagram bloc of the virtual instrument](image)
selection of a terminal structure of the Case structure. Through this structure is also selected one of the counters ctr1 or ctr0 so that the counting upwards is performed by counter ctr0 and counting downwards is performed by counter ctr1.

For the two counters ctr1 and ctr0 counting values may be increasing (Count Up) when their value increases with each pulse applied to the entry CtriSource \((i = 0 \text{ or } 1)\) in domain \([0 ... 2^{24} = 16777216]\) or may be decreasing (Count Down) when its value decreases with each pulse applied to the entry CtriSource \((i = 0 \text{ or } 1)\) in domain \([2^{24} = 16777216 ... 0]\). So if it detects a number N higher than \(10^7\) is considered selected counter ctr0 and counting is carried downwards ever since the maximum counter value \(2^{24}\) which requires that the value of the number of pulses and hence calculation of displacement and angular speed values are obtained by difference between constant \(2^{24}\) and value of N representing the output of function DAQmx Read (Counter U32 1CH 1Samp)

Displacement in clockwise is considered that be displayed with positive sign and displacement in counterclockwise is considered that be displayed with negative sign. This convention require continuous tracking of the value of the two counters and this is achieved by using local variable CTR whose value is loaded into each of the two counters selected according counting sense through the input parameter initial count of the DAQmx Create Virtual Channel function.

Displaying number of pulses and calculating the displacement and angular speed, given the agreement between the direction of displacement and sign of these dimensions, is achieved through a Case structure.

Selection of the two cases is done through the comparison between the value N that represent the output of the function DAQmx Read and constant \(10^7\) (considered to be cover for measurements made under the following conditions: measurement time for one direction of displacement about 33 minutes, \(n = 200\) slots and maximum speed 1500 rev/min.)

Views of the front panel that is user interface, corresponding to the two directions of movement corresponding to two states of operation for the virtual instrument are presented in Fig.10

![Fig.10. User interface of the virtual instrument](image)

4 Conclusion
Using the virtual instrument in this form have a very high interest only for data acquisition systems that no accept at their counters signals provided by quadrature encoder, and these systems are use to measure displacements or angular velocities.

Function testing was done both for direction displayed and for measuring displacements or angular velocities. Tests were performed using quadrature encoders with 4, 200 (E6A2-CW5C) respectively 500 (HEDS – 5500) pulses/revolution for a wide range of speeds, connected to digital inputs of the PCI – 6024E data acquisition board, from which were used and the two counters ctr1 and ctr0.

References: