Auto-calibration Frequency and the Coarse Error Elimination

Dragan Denic, Goran Miljkovic, Jelena Lukic, Miodrag Arsic and Milan Simic
Faculty of Electronic Engineering
University of Niš, Aleksandra Medvedeva 14, 18000 Niš
Serbia
{dragan.denic@elfak.ni.ac.rs}
{goran.miljkovic@elfak.ni.ac.rs}
{miodrag.arsic@elfak.ni.ac.rs}
{milan.simic@elfak.ni.ac.rs}
{jelenalukicpk@gmail.com}

ABSTRACT: *WHAT IS THE PROPOSAL FOR THE POSITION METERING TECHNIQUE? The position measurement method is performed with a hybrid pseudo encoder deactivated by combining the pseudo encoder with the incremental code track. The combination of the two code tracks improves the measurement resolution. The proposed hybrid pseudo encoder includes the detector for the pseudo-code reading errors. This helps to decrease the autocalibration frequency and eliminates the coarse error. TECHNIQUE TESTING OF THE PROPOSED ENCODER ELECTRONIC BLOCK IN THE PRESENTED CODER AND CODER TRACK CONDITION.*

Keywords: Position Measurement, Hybrid Pseudorandom Encoder, Automatically Guided Vehicles (AGV)

Received: 4 June 2023, Revised 10 August 2023, Accepted 19 August 2023

DOI: 10.6025/isej/2023/10/2/38-44

1. Introduction

The high accuracy measurement of the lengths and the angles is often requested in modern industrial production processes. The accuracy of 0.1 μm is no rare and it is more often requested. Such a request is a result of the high level of production automation and strict requirements regarding the positioning of the movable parts of the manufacturing units. At the same time, the requirements for the position measuring of the automatically guided vehicles (AGV), which move independently on the factory floor as a production platforms or transport units, are stricter. These vehicles have the increasing tendency towards the flexible movable systems which represent the combination of vehicles and robots [1]. These automatically guided vehicles can often be in the interaction with the other production units, such as robots, machine tools, charging and discharging units and etc. Therefore, the precise and highly reliable information about the position is necessary. For this reason the utilization of the classical absolute measuring systems is unacceptable for economic reasons, because of the large number of code tracks. Today, most of the systems rely on the incremental methods for the position determination, which in turn have the known drawback of error accumulation. There were attempts to compensate these drawbacks by using the optical calibration methods or special code marking of the specified locations [2]. Unfortunately, the usage of these solutions is limited with the number of reference points, i.e. for economic reasons.

The result of the latest research in the field of digital position transducers for AGVs is the pseudorandom coding method, which, for the absolute position determination, requires only one bit per quantization step, [3], [4]. The longitudinal coding method was developed with the help of an useful pseudorandom code property that the first n-l digits of a pseudorandom code word are identical with the last n-l digits of a previous pseudorandom code word. Therefore, unlike transverse coding technique, which requires that for each coding device sector a digital code is written in the transverse direction, this technique allows the absolute position measurement with the use of just one code track. It is based on the "window property" [3] of the pseudorandom binary sequences (PRBS) $\{S(p)/p = 0, 1,...,2^n - 2\}$. Accordingly, any $n$bit long code word $\{S(p + n - k)/k = n, ..., 1\}$ provided by the scanning of the PRBS with the window of width n, $\{x(k)/k=n,...,1\}$, is unique and may fully identify the absolute position of the window p with regard to the sequence start.

In the case when the high resolution of the measurement is required, the PRBS of the greater length need to be applied because the operating range of the AGV can be 300-400 m. Therefore, due to the code conversion problem [4], for a given maximum velocity of the AGV, the overall measurement resolution is limited. Even if there is no such a problem, the code reading uncertainty limits the overall measurement resolution of the pseudorandom position encoder. However, the convenience of the pseudorandom coding application can be utilized for the case when the high precision of positioning is required. The basic idea, which will be presented in this paper, was derived from the fact that the pseudorandom coding is very suitable for use with incremental position measurement methods. PRBS-s can be used for encoding of the reference markers used for the measuring system autocalibration. This approach leads to the realization of the hybrid measuring system. The aim of this paper is to emphasize the great advantage of the hybrid method for the measuring of the AGV position.

From the measurement and the position determination points of view, the hybrid measuring system uses a measurement method that combines the absolute and the incremental methods. The hybrid measuring method includes the functional elements of both methods. The intention is to retain the good qualities of these methods, and to eliminate their disadvantages. In 1983, Whitwell proposed [5] that the track with conventional markers (measurement grid) needs to be placed along the several code tracks of some absolute scale. Using n code tracks for each sector of the width d the digital code is written. At the same time, the conventional incremental encoder with minimum two detectors is applied. Two signals phase shifted for $\pi/2$ are needed for the AGV motion direction determination.

Whenever the determination of the absolute position is carried out (by direct reading of the digital code in the transverse direction) the accumulated encoder errors are automatically eliminated. Further incremental position determining is performed with respect to the absolute value of the determined position.

Any error in the absolute value of the determined position would represent a systematic error which can be eliminated only during the next absolute position determination process. However, this systematic error would be enormously large in relation to the accuracy and resolution of the applied incremental encoder. Except this drawback, the disadvantage of a large number of code tracks also remains. For the case of movable systems with a wide range of movement, even at relatively low resolution of the absolute position determination the number of code tracks is so large, that the proposed hybrid system becomes economically unacceptable for the implementation.

2. The Hybrid Pseudorandom Encoder

The main drawback of the previously described "classical" hybrid position encoder is that it has a high number of code tracks applied for writing the digital code in the transverse direction. This drawback can be eliminated with pseudorandom position encoder employment for determination of the AGV absolute position. The benefit of combining pseudorandom and incremental coding methods was indicated in [3]. This is done in the terms of resolution increase by introducing a greater number of sensor heads arranged according to the "vernier" method. This opened the possibility for measuring system functioning according to the incremental method. However, in this measuring system are not included the main advantages of the incremental method, such as: simplicity, small number of connecting wires and the high density of measurement range partitioning. As noted above, the hybrid encoder represents the direct combination of the absolute and the incremental encoder [6]. The solution proposed in this paper is shown in the Figure 1. Along the synchronization and the code track the measurement grid with the conventional markers is added. The whole electronic block, required for obtaining the information on the relative position of the AGV in binary code, is included. It may be noted that the pseudorandom position encoder is simply extended by adding a complete two-phase incremental encoder. The number of pulses is quadrupled by combining A and B signals using the EXOR circuit and with edge detection of thus obtained signal. To determine the direction of movement one of the solutions described in [7] can be applied. Otherwise, depending on the detection technique and specific detectors applied, the distance between $y(1)$ and $y(2)$ can be $r = (e + 1/4)\, d/g = (e+1/4)q$, where e can take an arbitrary value from the set {0, 1, 2, 3,...}, and g is the number of markers per one sector width d. In general, if the resolution increase for m bits is needed, the requirement for $g = 2^m$ should be fulfilled. For the case when the number of pulses is quadrupled, as it is proposed here, the number of markers (or reflecting areas, in the case when an optical reflection method is applied) in one sector, for the absolute position determination, is $g = 2^{m-2}$. The $(n + m)$-bit UP/DOWN counter is applied and thus the reached output resolution is $(n + m)$-bits. The code reading uncertainty problem is solved by using the external synchronization method. Along the code track an additional synchronization track is placed. The code reading is done at the moment when the sensor head AUT detects the transition between two adjacent sectors, [3], [4].

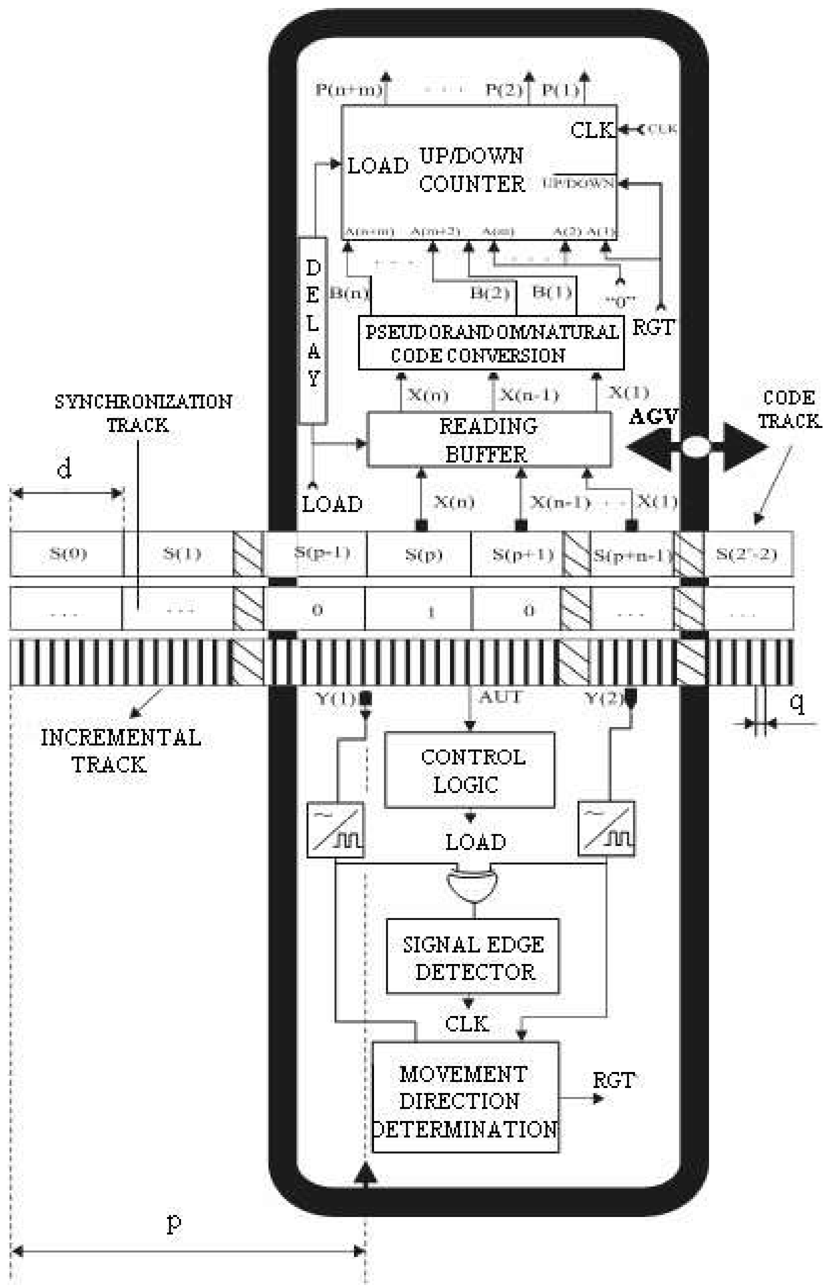

Figure 1. The hybrid pseudorandom position encoder

Otherwise, the hybrid position encoder from Figure 1, does not need the additional VER head, which is used at pseudorandom encoders for determining of the movable system movement direction, [3]. The AGV movement direction is now determined with the applied incremental encoder. The marker, in relation to which the position is determined, is placed opposite the detector $y(1)$. The n-bit adder is no more needed as the correction element [3]. The difference in the position of the AGV on the same transition, depending on the AGV movement direction, is now $q/4$. This correction for the least significant bit is automatically performed during the measuring system autocalibration.

The proposed measuring system operates according to the incremental method. At the moment when the synchronization head AUT detects the transition between two sectors, of width d, the pseudorandom code reading is done. In this case, the control logic for LOAD signal obtaining is very simple and can be realized by using the Schmitt circuit (or the comparator) and edge detector. Converting of the read code into the natural code gives the absolute position of the AGV. At the same time a pulse is obtained at the output of the delay circuit and the absolute position is loaded as a new state of the counter. These n bits of the AGV current position are respectively entered in the first n inputs of the UP/DOWN counter starting from the input of the greatest weight. In the next m-1 counter stages the logic zeros are entered. At the least significant input logic one or logic zero is fed depending on the AGV movement direction, Figure 1. In this way the measuring system autocalibration is performed. It continues to work according to the incremental method and in relation to the new counter state.

This increase of this solution complexity in relation to the pseudorandom position encoder complexity is insignificant comparing to the quality obtained. The proposed hybrid position encoder is a cost-effective solution even for movable systems with the highest requirements. It can be applied in systems with the wide range of movement, which require high precision and high resolution of the position measuring because of the mutual influence with the other production units.

However, the act of autocalibration represents a critical moment in the functioning of the hybrid position encoder. That is the reason why the hybrid position encoder has not found its application in practice until today. The word "calibration" implies the existence of a reference against which the correction is made. The question is whether the measured absolute position satisfies the criteria of one reference. At first instant it does. The code is written on a physical track and it can be read only at precisely determined locations. Such information can be accepted as a reference, but it is necessary to ensure the conditions that will guarantee that no errors will happen during the code reading procedure. Unfortunately, no one can claim that in real industrial conditions such terms will be provided. Approaching to these ideal conditions can be very expensive, but it does not solve the problem. Therefore, in this paper we started with a new approach. The additional information is introduced for indicating the presence of an error, with the probability of one, in the pseudorandom code reading. For the realization of the hybrid position encoder the detector of the pseudorandom code reading errors is required. It confirms that the obtained pseudorandom code word corresponds to a certain physical reference, with which the current AGV position coincides. Only in this case the measuring system autocalibration is done. Otherwise, if such confirmation does not exist, the obtained pseudorandom code word will not be accepted as the reference and the measuring system autocalibration will not occur. In this way the autocalibration frequency becomes lower, but the possibility of the course error is eliminated.

3. Experimental Results

The development of an experimental system can be of great importance for the research of various solutions of position encoders. The realization of different encoder solutions requires the code tracks manufacturing, which can be expensive and impractical because the obtained solutions need the application of different code reading methods. Therefore, the simulation of the system movement and the testing of the proposed encoder electronic block should be performed with the computer and the corresponding hardware application.

In order to test the electronic block of the position encoder, an experimental system consisted of the computer, the parallel I/O card and the microprocessor development system based on the Intel 8031, is built (Figure 2.). So, in this experimental system configuration the electronic block of the pseudorandom position encoder is realized by using the microprocessor development system based on the Intel 8031, while the computer is used for the simulation of the movable system movement. By starting the program for the simulation of the movable system movement at the corresponding parallel outputs of the I/O card the signals, equal to those which would be obtained at the output of sensor heads for the given movement route, are generated. These signals are fed to the port 1 of the Intel 8031microprocessor. After the testing is finished, by using the tabular or graphical presentations the given series of positions and the obtained series of positions can be compared. The tabular view provides the continuous information about the measuring system working regime. Since all the real situations can be simulated, including damaged or contaminated measuring tracks, there is no reason to expect a different behavior of the measuring system in its concrete application. In other words, the test results fully and realistically characterize the proposed position encoder.

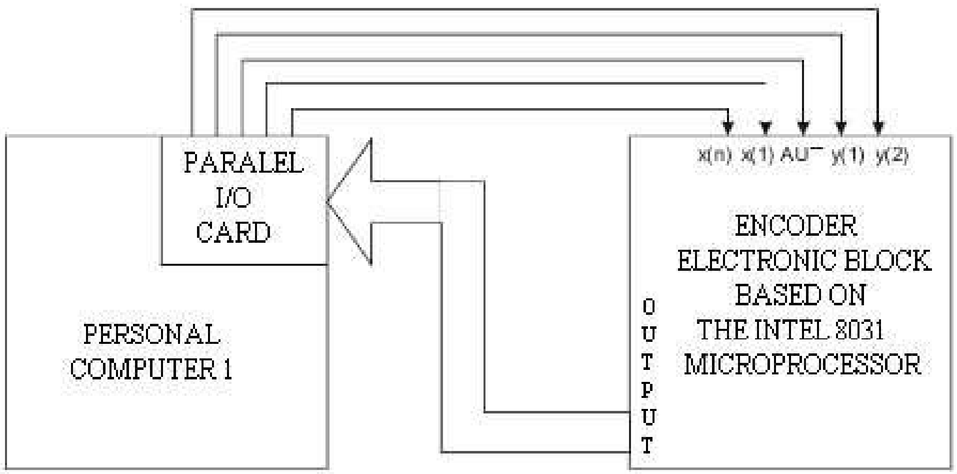

Figure 2. Testing of the position encoder electronic block

The electronic block has been tested during a period of several months and for over a thousand randomly selected AGV movement routes. After the measuring system entered into the normal working regime, for the ideal measuring tracks located in an ideal environment case, there is no typical AGV movement which would lead to an error in the position determination or which would take the measuring system out of its normal working regime.

The simulation of incremental and code track contamination can be done with the program that has been already developed for the simulation of the movable system movement. The contamination level is specified in percentage. As a consequence of the code track contamination the frequency of the measuring system autocalibration decreases. Fig. 3 gives the graphical representation of the 16-bit hybrid encoder test results when the incremental track contamination level is 9.4% and an additional code track contamination level is 3%. Obviously, the position measurement error considerably increases with wrong pseudorandom code bit readings. In the best case, the maximal measurement error is about ten times higher. The error is even higher when the code reading synchronization is lost, which often happens. As it is noted above, instead of 64 quantization steps, the next measuring system autocalibration, in the worst case, does not occur until 1280 quantization steps are ran over in the same AGV movement direction. Specifically, in the case of the performed testing, Fig. 3, there was the code reading synchronization loss. The next measuring system autocalibration was performed after 16 absolute quantization steps *d* of the AGV movement. As it can be seen from the error graphic, i.e. from the graphic of real and determined position difference, the previous condition caused the maximal error of one hundred increments. Normally, at the moment when the error is detected, the measuring system provides the information that it switched to the incremental working mode. The measuring system continues to function as a classical two-phase incremental position encoder until the next autocalibration of the measuring system is performed. It should be mentioned again that the adopted contamination level of the incremental track is much higher than it is usually reported in the practice, and that the considered case represents the worst possible case. It is important to say that during the long testing period of the encoder electronic block, each simulated code reading error was detected.

4. Conclusion

The proposed hybrid pseudorandom position encoder solution represents a new approach in the field of position measurements. The hybrid pseudorandom encoder, which combines the good properties of the incremental and the absolute position measuring methods, is applicable in practice due to the presence of the code reading error detector. For the first time, the reliability of the obtained position information is considered and the reliable detection of the possible errors is provided. The results obtained so far indicate the fully functionality of the proposed encoder. The software realization of the encoder electronic block is also possible by using the microprocessor. The realized encoder electronic block has been tested by using an experimental system developed for the AGV movement simulation, even in the presence of damage or contamination of the measuring tracks. After testing it was shown that the maximal error is one hundred increments when the incremental track contamination level is 9.4%, when the code track contamination level is 3%and in the presence of the code reading synchronization loss.

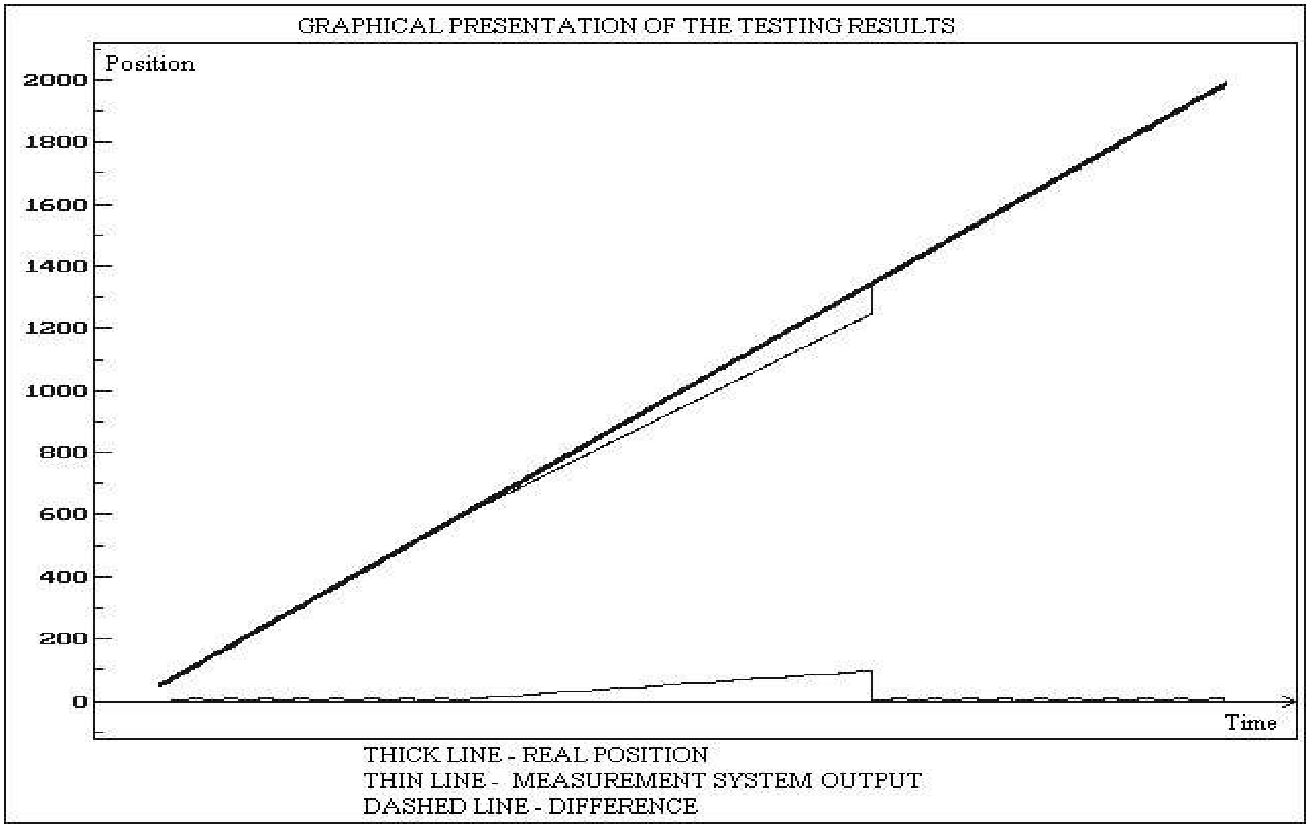

Figure 3. Testing results of the encoder electronic block when the incremental track contamination level is 9.4% and the code track contamination level is 3%

Of course, it should be noted that the adopted incremental track contamination level during testing was much higher than it has been reported in practice.

Acknowledgement

Research activities presented in this paper, are supported by funds of the Ministry of Education and Science of the Republic of Serbia, having the reference project number TR32045.

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