Absolute Position Measurement Using the Method of Pseudorandom Code Parallel Reading

Dragan B. Denić[1], Ivana S. Randjelović[2] and Miodrag Z. Arsić[3]

Abstract – **Possibilities for digital measurement of absolute position using only one code track are considered in this paper. It is provided using an especial code technique based on pseudorandom binary sequences. Problems in the field of micropositioning are considered and a concrete solution is proposed. A method for parallel reading of pseudorandom code using linear photodetector array is applied.**

Keywords – **Position measurement, pseudorandom encoder, pseudorandom sequence.**

I. Introduction

One good alternative to the classical absolute encoder is the absolute encoder that uses the longitudinal code technique. The absolute position is coded by applying one code track with a pseudorandom binary sequence so that each group of n successive bits represents a unique code word. Two successive code words are overlapping and they differ only in one bit. Summary of basic problems in realization of pseudorandom encoders is given in [5]. Basic dilemma is about the application of the parallel code reading method or the method of serial pseudorandom code reading, Fig. 1. In the reference [6], a solution of parallel code reading is given in case of an application of the pseudorandom encoder with large measurement scale and with a relatively low measurement resolution. Application of n sensor heads for reading of n bit code words is problematic when dealing with high measurement resolution. In that case we use a linear integrated photodetector array [1] or CCD cameras. Disadvantage of such an approach is a significant time of signal processing at the output of these complex detection circuits and that is why these solutions are unacceptable for commercial encoders of high resolutions. Serial pseudorandom code reading [8,9] simplifies pseudorandom encoder and enables greater measurement resolution, but at the same time owns a disadvantage. Pseudorandom encoder with a serial code reading requires small initial movement for the first determination of the position after the power is turned on. For many applications and also for the commercial optical encoders this is not a problem, but this solution still does not represent a real absolute encoder. It owns all good features of an absolute encoder, it is almost as simple as an incremental encoder, very reliable and it has recently appeared on the market and represents a real hit. It is called a virtual absolute encoder because of the induced disadvantage above. However, there are applications where requiring of an initial movement after power is turned on is not desirable for determining the first absolute position. There are some special applications where it is impossible to demand such initial movement, such as systems for level measurement by using digital position converters. Thus it is very interesting to consider the possibilities of realization of the real high-resolution absolute pseudorandom encoder using a method of parallel code reading. Because of a great need for such a solution, in this paper, a possibility of algorithm solution acceleration using linear integrated photodetector array for parallel pseudorandom code reading, will be considered.

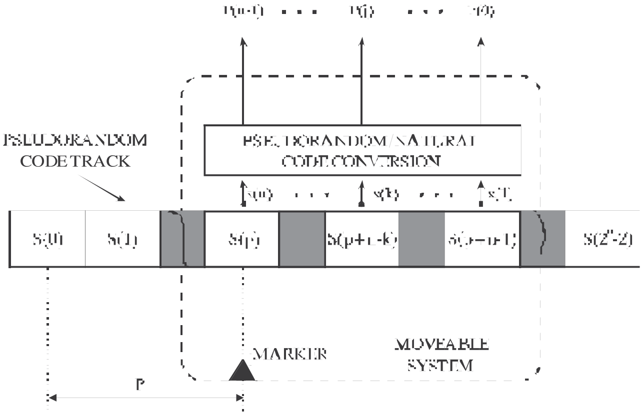

Fig. 1. Absolute position p is entirely identified by the pseudorandom code word $x(k)/k = n, ..., 1$

II. Pseudorandom Code and Its Usage in Encoders

The method of pseudorandom encoding, which for absolute position determining requires only one code track, represents an attractive alternative to the classic measurement method. Its advantages are significant in case of high-resolution position encoders and linear position encoders with very long code tracks. A coding is based on the "window property" of $\mathrm{PRBS_s}$ $\{S(p)/p = 0, 1, ..., 2^n - 2\}$. According to this, any n - bit code word $\{S(p + n - k)/k = n, ..., 1\}$ provided by a window $\{x(k)/k = n, ..., 1\}$, of width n scanning the $\mathrm{PSBS_s}$, is unique and may fully identify windows absolute

[1]Dragan B. Denić is with the Faculty of Electronic Engineering, University of Niš, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mail: ddenic@elfak.ni.ac.yu

[2]Ivana S. Randjelović is with the Faculty of Electronic Engineering, University of Niš, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mail: rivana@elfak.ni.ac.yu

[3]Miodrag Z. Arsić is with the Faculty of Electronic Engineering, University of Niš, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mail: marsic@elfak.ni.ac.yu

position p relative to the beginning of sequence, Fig. 1.

As shown on Fig. 1, code words are now arraying linearly or longitudinally (but not transversely like in case of classic coding), and they overlap. The first $(n-1)$ bits of such code word are identical to the last $(n-1)$ ones of the previous code word. Therefore, in contrast to transverse coding technique, which requires writing of a definite digital code in the transverse direction for each sector of code device, this method enables coding with one bit per sector.

III. Solutions Based of the Linear Photodetector Array

Commercial integrated photodetector arrays are available on the market with different intervals between photodetectors. Those intervals are 13 μm, 10 μm, 7 μm and smaller. Number of photodetectors can be few thousands, thus few tenths of sensors are used for one bit reading. Because of a exactly defined interval between two detectors, it is possible to use large number of photodetectors in order to increase a precision of absolute position measurement. A solution presenting basic principles of so far known solutions for parallel reading using linear photodetectors array is shown in references [1], [11]. A code track of transparent type is applied, so that there is a light source at one side and at other side is an integrated circuit, which consists of a linear photodetector array. This integrated circuit often offers a possibility of serial reading of photodetectors output signal. In case of using circuits with k photodetectors, after k tact pulses a read state is put into a shift register. Let us read $(n+c)$ bits and let nominal value of photodetectors number per one code bit be m. n is a number of bits needed for detecting the absolute position. Usually, at least one additional bit is read, and generally c additional bits. This way system redundancy is increased and use of some methods for code reading error detection is enabled. A condition $k \geq (n+c)m$ is always accomplished. Read code word is in the following form $\{00000111...110000111...1100....\}$.

A transition is detected at the border of two elements. In the ideal case, a number of consecutive "1" or "0" per one bit equals m. But, a deviation may occur due to not ideal drift of code elements on code track. After the reading of total output code, its conversion into natural code is done. A generator of used $PSBS_s$ starts from the code word that corresponds to initial "0" position, on the code track. Generator core is a shift register with appropriate feedback. With each tact that conduces generating of next PSBS byte, m tact from the shift register are performed. A code identical to the one that would be read in case of continuous MS movement from the position "0", is obtained that way. In an ideal case, after a certain number of register shifts, a code word identical to the read one would be obtained. That correspondence could be simply detected by digital comparator circuit. A number of steps counted by a counter until the moment of correspondence represents output position information in the natural code. Unfortunately, as said before, an error would often occur in practice, and it is enough that one bit is read from $(m+1)$ detectors and the $PSBS_s$ generator will not generate such code word, thus, a correspondence will not be detected. This is why a digital correlator is used, although it is a much complex solution, but it solves the problem. Accuracy of the detected code is increased introducing a greater value for c. Accuracy of correlator output does not depend much on the accuracy of defining boundary locations of code elements.

In the reference [11], a possible realization is discussed. A classic pseudorandom/natural code conversion is done using a simple digital comparator. Additional fine position could be defined based on the detected, defined transitions. Using this procedure, measurement time would be reduced, which is still not good enough for general-purpose encoders. Further in the paper, this idea will be elaborated and with some additional modifications, we will attempt to realize a solution where rough position for each new code reading is not defined.

IV. Complete Solution Algorithm without Using Permanent Code Reading During the MS Movement

A realization of the electronic encoder block using discrete electronic circuits is shown in Fig. 2. Of course, the same function can be done using microprocessors and the appropriate software. Also, a realization using one of modern programmable logical circuits is possible. An example of a possible realization algorithm of a new solution proposed here is shown in Fig. 3. The basic idea is to exclude the digital correlator, separately from all the elements connected for the purpose of achieving any correlation function. Although digital correlators are well known and commercially available, in this case, they lead to a more complex system. In reference [11] it is pointed to a fact that with software realiza-

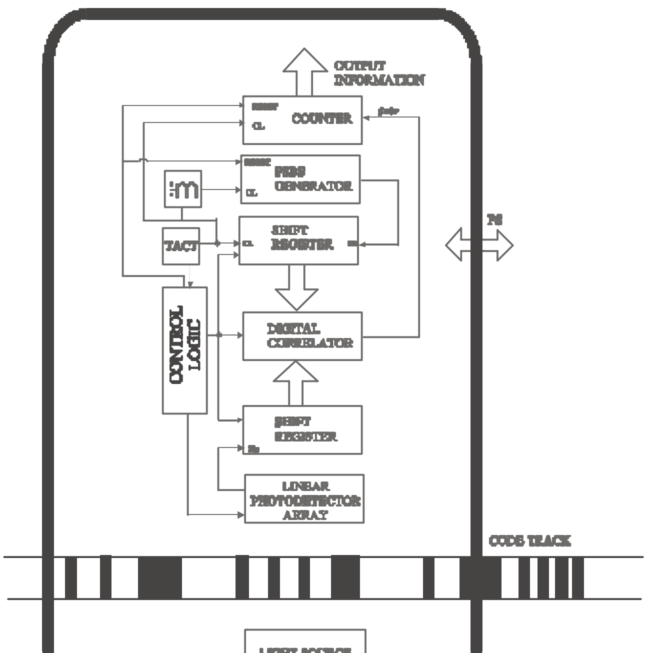

Fig. 2. High-resolution pseudorandom encoder with applied method of parallel code reading

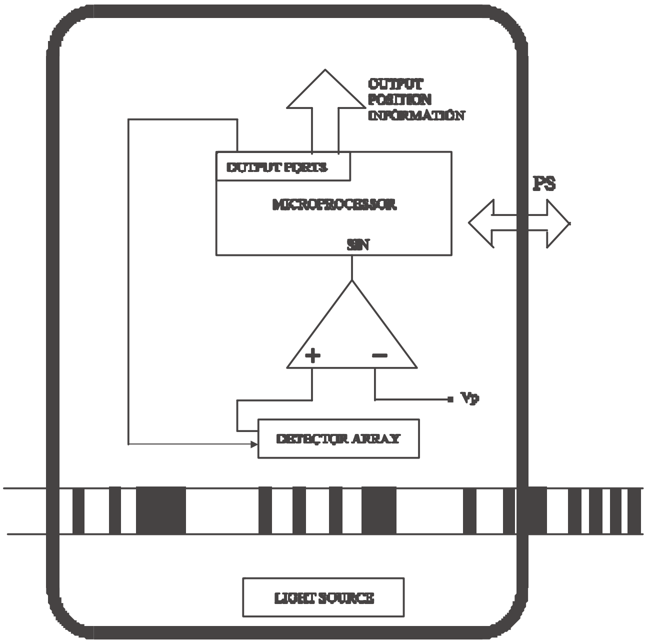

Fig. 3. An example of an encoder realization using a microprocessor

tion, simpler techniques can be used rather than the accurate and precise mathematical correlative ones. Our goal is to achieve shorter time for PSBS reconstruction read from the track, and then use of the well-known algorithm of pseudorandom/natural code conversion. The other idea is not to determine the rough position constantly, but only for certain values of the fine position. The fine position is defined by a number of rightmost photodetectors that read a bit that is not entirely included by the used circuit of photodetectors. This way, without using any arithmetical operations, a momentary position of the movable system is directly obtained with a fine position resolution defined by the distance of two consecutive photodetectors in the photodetector array circuit. For example, for the used 10 - bit PSBS and for m=64 (64 photodetectors per one bit), 16 - bit output position information is obtained by means of direct linking of 10 - bit code conversion result and 6 bits of smaller weight that define a number of photodetectors which detect next, not quite visible bit.

As it is shown in Fig. 3, a microprocessor defines the operation of photodetector array circuit using control signals. A reading of recorded PSBS sequence is done in a way that series of voltage levels, which indicate a light intensity on the corresponding elements of photodetector array, is lead to the input of a comparator. That way, with a defined voltage level Vp, this series of voltage levels is converted to a series of logical ”0” and ”1” at the comparator output, that is then lead to a serial microprocessor port. Afterwards, the microprocessor does the functions according to the software whose algorithm is shown in Fig. 4.

This way obtained bits are memorized and then analyzed. Memorized binary code word is in the form of $\{...000111...1111000...\}$, considering that m consecutive detectors are used for reading of one bit. However, as it is previously mentioned, it is possible that some deviations oc-

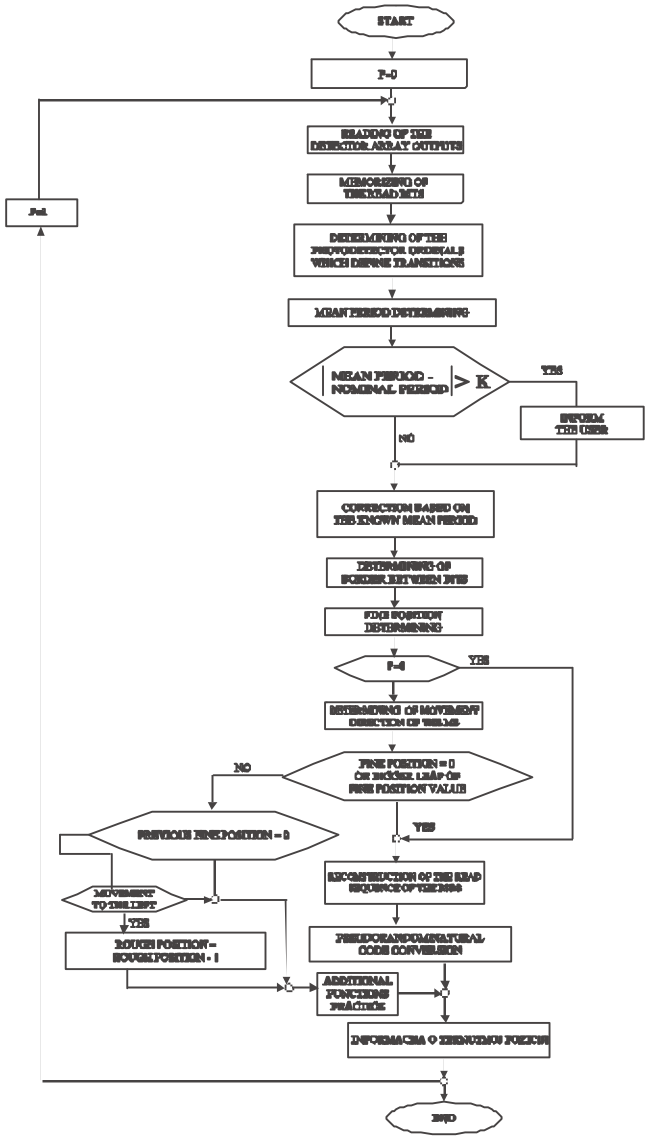

Fig. 4. Algorithm of the proposed solution

cur - $\{...0001011...1101000...\}$. Detector ordinals are then determined. Since nominal period (a number of detectors per one bit) is known, a difference of two consecutive detector ordinals is approximately dm, $d = \{1, 2, ..., n\}$. All deviations greater then this one can be updated, but the periods between the transitions will be different afterwards. There are other reasons why they will be different from nominal period, but those deviations must not be great.

In any case, a calculation of period mean value is proposed here. In the ideal case, obtained mean period (meaning the integer part of the mean value) will be equal to the nominal period. In reality, there will be deviations, and if they are greater than the proposed value k, the user should be informed. The system can track down those deviations and perform diagnostics in part of additional functions. Based on the estimated mean period, certain corrections are eventually performed and the detector ordinals are determined. Fine position is now simply evaluated as a number of detectors that are outside of the last determined transition. The MS movement direction is determined based of the previous value of the fine position. When the boundary between bits is known, it is easy to perform the reconstruction of the read part of PSBS and then the pseudorandom/natural code conversion. The value of the rough position is that way determined. Since the rough position has the same values for a great number of simultaneous code readings, there is no need for permanent performing of this, according to the necessary time, the most important part of the algorithm. It is being performed only when fine position equals ”0”, or when higher fine position value leap is detected. The latter ensures working in case of leap of the output position whose fine position equals 0. According to a well - know problem of necessary position correction in case of parallel pseudorandom code reading [6], rough position value is decreased by one in case of moving to the left.

All the additional functions, such as error detection, error diagnosing, code track status recording (location and size of dirt), are performed permanently, except in case when new rough position value is determined. Also, with the first passing through the algorithm after the turn on (parameter p equals ”0”), the rough position is immediately determined regardless to the fine position value. In the case of already considered example n=17, m=10 and the overall resolution of 1 μm, required time for execution is now at least 10 times less. In case of m taking considerably higher values respected to the pseudorandom code longitude (for instance, n=10, m=64), that acceleration is substantially higher.

V. Conclusion

The presented solution considerably decreases the basic problem, which is a substantial time needed for the execution of the position measuring. The process of determining the fine and rough position is being divided based on the recorded pseudorandom code, and now, all known pseudorandom/natural code conversions can be directly applied, which results in 10 times higher acceleration in relation to the already known solutions and methods in this field. What is proposed here is occasional determining of the rough position, which gives space for realization of many additional functions without increasing the maximal time for the execution of the algorithm.

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