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POSITION TRANSDUCER WITH FREQUENT AUTOCALIBRATION CAPABILITY

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Abstract. The one–dimensional position measurement using pseudorandom encoding is discussed in this paper. An application in navigation of automated guided movable systems is described. Incremental encoders are simpler, cheaper and they can provide a high measurement resolution. However, they have well-known drawbacks of accumulating reading errors and the loss of position because of power interruption. We propose solution providing a frequent autocalibration of the measuring system in a simple manner, using the pseudorandom encoding. The applied method provides a reliable detection of errors and makes the system resistant on oscillations along the movement course. A position transducer with 12-bit output resolution has been realized.

1. Introduction

In the mechanical engineering, robotics, in the area of control and electronics, lengths and angles have to be measured with a high accuracy. It is achieved by means of incremental-type transducers, thanks to their simplified construction, small number of connection wires and to the high dividing density of measurement ranges. However, incremental technique has a great drawback because of the error accumulation. A lot of attempts have been made in order to compensate accumulated errors by using the method of optical calibration or the method of code labeling of specially assigned locations, [1]. Unfortunately, the application of those solutions is, for economical reasons, limited with a number of reference points.

A problem of accurate and reliable position determination is specially expressed in ever increasing application of flexible systems, representing a combination of automatically guided vehicles and robots. Those movable systems (MS) have a large movement range ($100m$ and more) and at the same time

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high measurement resolution is demanded. MS are frequently interacting with other manufacturing units (robots, machine tools, loading/unloading devices, etc.). This paper suggests a solution satisfying the mentioned high demands. A hybrid measurement system is used containing functional elements of both incremental and absolute techniques. The absolute technique provides a frequent autocalibration of the measurement system, while incremental technique ensures a high measurement resolution. A solution using pseudorandom binary sequences (PRBS) and only one code track has been used for determination of absolute position.

2. Pseudorandom encoding techniques

Requiring only a one-bit wide code track, the pseudorandom encoding may represent an attractive alternative to the implementation of absolute-type position encoders. It is based on the "window property" of PRBS $\{S(p)/p=0,1,\dots 2^n-2\}$, [5]. According to this, any n-tuple $\{S(p+n-k)$ $/k=n,\dots 1\}$ provided by a window $\{x(k)/k=n,\dots 1\}$ of width n scanning the PRBS, is unique and may fully identify window's absolute position p relative to the beginning of sequence. PRBS of the length 2^n-1, generated by n-bit shift register and the corresponding feedback [2], is entered on the code track (Fig. 1). Different solutions of the scanning problem are possible, [2],[3]. Position transducer, suggested here, uses an external synchronization track, located along the pseudorandom code track, Fig. 1. By means of control logic, sensor heads AUT and VER provide synchronization pulses and information about the movement direction (RGT-right). Code reading is always made when the head AUT detects transition between two consecutive quantization intervals.

The pseudorandom code can be read serially. The serial reading is based on the idea that it is possible to form n-tuple, that expressed position code, by using the bidirectional n-bit shift register and a single code reading head. A drawback of this solution is that position information is lost at every change of the movement direction. During the position transducer development proposed in this paper, a method has been developed which eliminates this drawback, eliminates systematic errors [2] and enables development of a reliable method for permanent checking of the code reading correctness.

The solution is based on the idea of using two code reading heads, instead of one, being at distance of $n \cdot q$. As it is shown in Fig. 1, by means of a simple logic, consisting of two AND and one OR gate, a selection of one of two reading heads is made. At the moving to the left the bits read out by the head $x(n)$ will be accepted, and at the movement to the right the bits read out by the head $x(0)$. In such way n-tuple, formed after the change of the movement direction, now respond to the current position of the movement system. The achieved continuity of the code word formation provides stability of information on the position and at possible oscillations of the movement system along the movement course, that may occur at low speed of the system movement. At the same time, unlike the previous solutions [2], there is no correction logic in the form of a parallel adder. Namely, thanks to the proposed arrangements of the reading heads, the systematic error is eliminated.

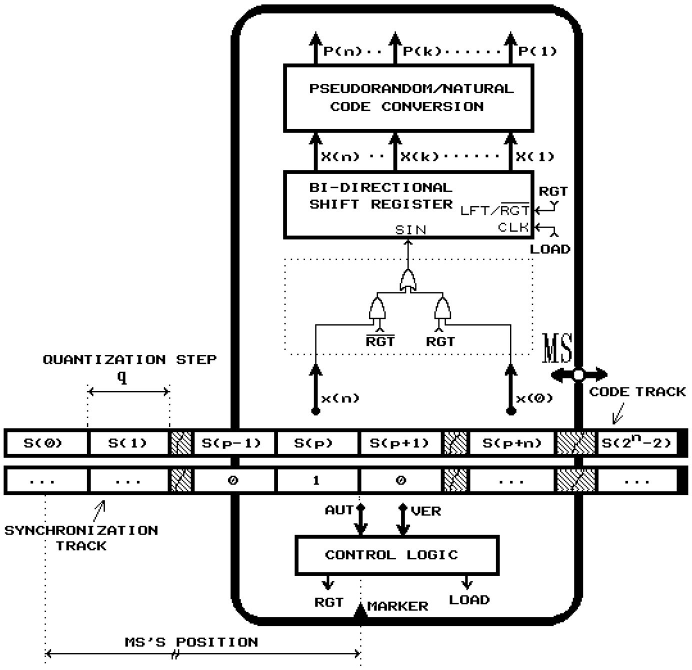

Figure 1. Linear pseudorandom position transducer.

3. Checking of pseudorandom code reading correctness

The constant distance between two code reading heads of $n \cdot q$ is a reference that enables checking of the code reading correctness, [4]. While one code reading head serves to form the main pseudorandom n-tuple (corresponding to the current position), the other one is used to form the control pseudorandom n-tuple. The way of loading the code bits into the main code assembly register X (bidirectional shift register for forming the main pseudorandom n-tuple) and into the control register Y, depending of the movable system moving direction, is shown in Fig. 2. Checking is made at every reading of the new bits. First, content of register Y is shifted n times to the left using direct feedback equation [2] (for moving of the MS to the right) or n times to the right using inverse feedback equation (for moving of MS to the left). Finally, the equality of the obtained n-tuple and the content of register X is examined.

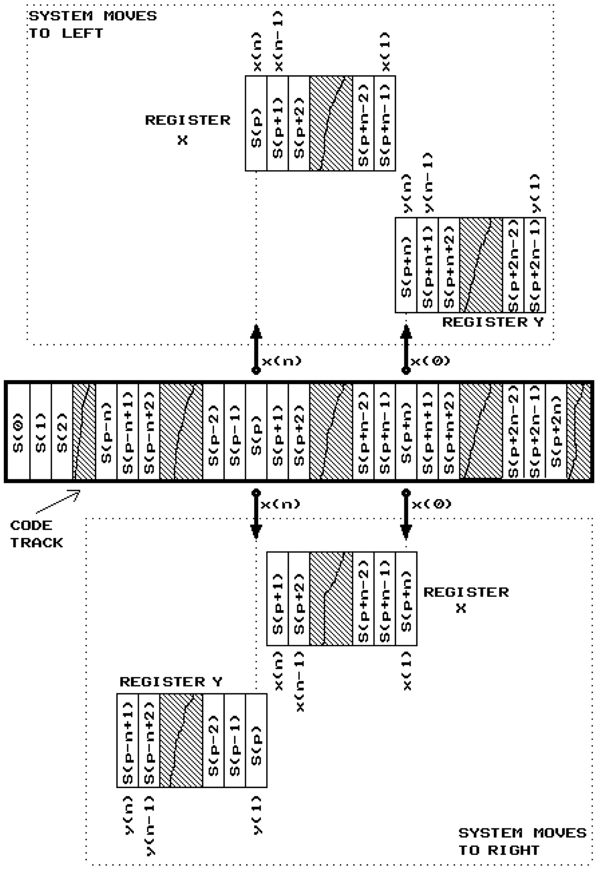

Figure 2. Forming of the main and control pseudorandom n-tuple, depending of the movable system moving direction.

This principle cannot be applied in the first n-quantization steps q after the MS moving direction changes, because, as it can be seen in Fig. 2, it comes to forming of the new control n-tuple. However, during this time bits that where loaded in register Y immediately before the MS moving direction changes, are read from code track and loaded to the main shift register X. On the basis of the proof on certain detection of possible errors [4] (that proof is valid in this method too, for constant MS movement in the same direction) and considering that error has not been detected, it follows that all bits, containing register Y, are correct. The basic idea is in their use for checking the code reading correctness after the change of the MS moving direction, to the moment of the repeated forming of the complete control n-tuple.

Let MS moves to the left, and let current code assembly register contents $\{X(k) = S(p-k+n)/k = n, \ldots, 1\}$ and $\{Y(k) = S(p-k+2n)/k = n, \ldots 1\}$, Fig. 1. After changing the MS moving direction new bits provided by the code reading heads $x(0) = S(p+n)$ and $x(n) = S(p)$ are loaded into $X(1)$ and $Y(1)$ stages of the code assembly registers X and Y, respectively. Obviously, at the moment of the new bit $S(p+n)$ loading into the register X its correct value is at the $Y(n)$ stage of the control register Y. At the same time previous register contents are shifted one time to the left. So, immediately before the loading of the next bit $S(p+n+1)$ into the main register X, its correct value will be, again, in $Y(n)$ stage of the register Y. With the similar consideration for the case of the direction change from MS moving to the right in movement to the left, it may be concluded that immediately before the new bit loading into the register X its correct value is always in $Y(1)$ stage of the control register Y. Although the formed pseudorandom code word is unique and fully identify the current position of the system, relative to the beginning of the track, it is necessary to make its conversion in to the natural binary code. Principles of the code conversion are described in details in [3, 8].

4. Realized measurement system

Absolute position measurement using the pseudorandom encoding is very suitable for combining with incremental method. Such an expanding would not demand an additional measurement scale, but the existing synchronization track could be used. The idea is based on the fact that it is possible to increase the resolution by adding to the synchronization head AUT m heads VER, located according to the vernier method, [6]. With such an approach a frequent system autocalibration is provided (at every reading of pseudorandom code), by which drawbacks of incremental method are eliminated. The suggested realization significantly simplifies the system and, at the same time, improves its performances.

A position transducer with 12 bit output resolution has been developed. In Table I are presented possible orientations from the standpoint of the realization of the hybrid position transducers. An option has been adopted under number 2 in accordance with the demand for more frequent autocalibration of measurement system. The method proposed here is used for reading of 10-bit pseudorandom code, that uses two heads for serial code reading ($x(10)$ and $x(0)$), as shown in Fig. 1.

Table 1. Options of the position transducers with 12 bit output resolution

Options	pseudorandom code length	number of heads VER
1	11	1
2	10	3
3	9	7
4	8	15
5	7	31

The head AUT and three additional heads VER are located at distance S in accordance to the vernier law, $S = (1+1/(m+1))\cdot q = (1+1/4)\cdot q = 5\cdot q/4$. The entire resolution is now $q/(m+1) = q/4$, which corresponds to the resolution that could be achieved by pseudorandom code of 12 bit length. However, now due to the decrease of the length of pseudorandom code word, maximum time, that is needed for the code conversion, is four times less, [2]. At the same time, the distance between two bits is four times larger. A conversion algorithm has been applied, that reduces maximum time of execution nearly two times, [8]. All in all it brings to the increment of the maximal movement speed approximately 30 times.

For software execution of other tasks (gathering of code bits, determination of movement direction, checking of code reading correctness etc.) negligible time is needed in relation to the maximum code conversion time. Therefore, now it is possible to realize the entire algorithm softwarewise. This solution, with regard to low microprocessor costs, is economically justified and make the measurement system flexible in relation to the concrete demands of its application. The basic functions achieved by the realized algorithm are: providing of the information on the relative position with regard to the starting position, up to the moment of pseudorandom code word formation (10 quantization steps q in the same direction), when the absolute position is determined and an information on system readiness is given; detection of the movement direction change; ensuring of the stability of information on the position for the case of system oscillation in the movement direction; permanent check of the code reading correctness; pseudorandom/natural code conversion; for the case of a detected error, continuation of the operation according to incremental method with regard to the last correct information on absolute position, up to the moment of an automatic restoration of the system; detection and alarm in case of code or synchronization track contamination.

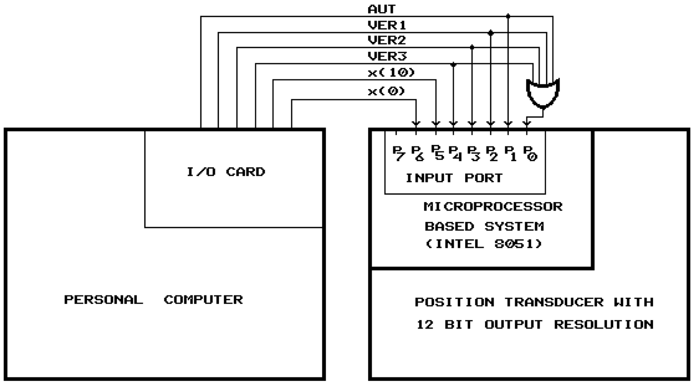

Figure 3. Experimental testing of the position transducer.

Structurally, algorithm consists of two parts. The first one is accomplished after switching on or at a possible error in reading of pseudorandom code. It determines the system position according to the incremental method, simultaneously forming the pseudorandom code words, using the incremental method up to the moment of their forming. The second part is that which would be executed continuously under the normal working conditions of the measurement system, and can be referred to as a working part of the algorithm. Such an approach is done only for the need of the working part of the algorithm to be as good as possible concerning the time needed for getting an information on the position. The algorithm is realized in machine language using the 12 MHz Intel microprocessor 8051.

For experimental purposes a program has been realized in programming language Pascal, which for arbitrary given movement path generates signals, corresponding to the outputs of the sensor heads. A personal computer, and I/O card have been used, as can be seen in Fig. 3. The obtained results have confirmed all expectations and have shown that the system does not lose the information on the position, not even in the case when 10% of the bits of pseudorandom code are incorrectly read.

5. Conclusion

The proposed pseudorandom encoding for position transducers has the notable advantage of reducing the manufacturing complexity (and cost) by reducing the number of the code tracks on the encoded device. In addition to that, the pseudorandom encoding technique is also appropriate for combining with incremental method. By using vernier method a measurement system has been developed, satisfying complex demands at the positioning of the system with large movement ranges. A position transducer has been realized with 12-bit output resolution and the same procedure is possible to be applied to transducers with some other arbitrary resolution. Some initial results, as well as design of the transducer, are already presented in [8]. However, this paper presents the most important methods that enabled the realization of the transducer with high performances. A new method for serial code reading has been applied and a reliable techniques has been developed for the control of the code reading correctness. The new method for checking of the code reading correctness, proposed here, provides permanent detection of the code reading errors without additional mechanical changes. This provides high reliability of the measurement system. Maximum movement speed of the moving system has been determined by frequency of measurement system autocalibration. But, even if the movement speed is exceeded the system does not lose the information on the position. In that case only the frequency of the measurement system autocalibration is proportionally decreased.

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