Method of Mobile Robots Active External Environment Organization in Automated Production

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Abstract: Proposed an original method of mobile robot active environment forming with various configurations of Π-shaped loops of current carrying cable and multicoil inductive sensor capable information of mobile robot on-board control system as about its lateral deviation from the current-carrying cable, determining trajectory of the robot movement and its track side position, that is information about docks, branches, corners. Here is considered problems of encoding and decoding characteristic track points and specified ways to improve accuracy of sensor.

Key words: Inductive sensor · Mobile robot · Encoding · Decoding · External environment · Configuration · track · Control system

INTRODUCTION

Controlled mobile vehicles (electric vehicles, stacker cranes, loader cranes and so on) related to a class of mobile robots are major link in automation of storage-retrieval terminal operations in production [1, 2]. Mobile robots of this type move within its environment using wheels activated by actuator-driven onboard system, the structure of which includes a sensor system representing with interface between robot and its operation environment, that is external environment.

The task of positioning movement consists of sequential robot delivery to a specified sequence of target positions representing with a set of process equipment in the workshop, lots of tool storage cells, blank or finished products [3, 4]. Here arises the problem of track planning, which in case of intellectual class mobile robot creation uses approach, known as cell decomposition and skeleting [5] when free space of robot represented by less measurements, that is some skeleton of the configuration space. These approaches require advanced software [6, 7], which provides solution of recognition tasks and filtering associated with definition of robot location and orientation in space, which in turn requires onboard control system equipping with such sensors as cameras or radars, laser range finders, gyros,

accelerometers and also requires a powerful on-board microcontroller [8]. This significantly increases the cost of logistics automation control systems and makes application of such systems economically inexpedient in production. More efficient is application of systems that use fixed configurations of active external environment with the ability of it flexibly change during functioning. Authors propose an original method of active external environment forming for mobile vehicles as part of automated warehouses with multicoil inductive sensor as means of route tracking in the workshop work area or automated warehouse with possibility of locating places of road branching, along which mobile robot moves and codes assigned to transport robot service places of automated production area or warehouse positions [9]. Feature consists of applying the docking places original coding, branches and corners with Π-shaped loops of the current cable itself [10].

Main Part: One of key elements of flexible automated production is controlled mobile transport system, which includes within its structure active external environment, defining the movement trajectory with docking system and mobile robot with on-board control system based on microcontroller. Under dustiness or high humidity conditions of production, which is typical for building

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materials industry, it is appropriate to create an active external environment as setpoint device of movement track using a cable fitted into the floor, powered by alternator. In this case, induction sensors may be used as robot lateral deviation sensor from kinematic trajectory, but to determine positioning place it is required additional sensors, which complicates and increases the cost of system. In this article we propose an original method for constructing an active external environment that uses classical principle of electromagnetic induction with a combination of data measurement and encoding systems [9, 10], through usage of multicoil induction sensor, performing functions of measuring decoder and Π-shaped loops of current carrying cable, through which provides encoding of characteristic track points.

Multicoil inductive sensor (IS), which is the assembly of even number of plane (disk) coils mounted coaxially in a next to each other line, fixed on mobile robot (Fig. 1, *a*). Pair of plane coils are differentially connected and their magnetic centers M_m, M_{m+1},...,M_{m+6} (Fig. 1, *b*) arranged transversely with respect to the trace of current-carrying cables with a step P determines resolution of sensor in measurement of robot deviations from the desired trajectory movement.

In the initial state inductive sensor installed above current carrying wire at a height h equal to several centimeters, so that coil planes perpendicular to laying surface of current-carrying wire and longitudinal axis of IS perpendicular to current-carrying wire. To each pair of differentially connected coils induce EMF, which amplitude E_i depends on magnetic center displacement of this pair of coils relative to the trace (Fig. 2, *a*). This figure shows static characteristics of induction sensor: *a*) for *i*-th pair of differentially connected planar coils and *b*) for 6th and 9th pairs of coils.

Since the inductive sensor designed so that magnetic centers of coils pairs are arranged one behind the other, then set of EMF values induced in pairs of coils at any time reproduces static characteristic of taken separately pair of coils. This property used as the basis for determining mobile robot deviation from desired movement trajectory. Since robot deviation from track can occur in different directions from a current-carrying wire, then magnetic center of inductive sensor is expedient to choose as a reference. In the case when it is located directly above current-carrying wire or offset with respect thereto at a distance not exceeding deadband $P/2$, deviation considered as zero (Fig. 2, b). This state detected by condition $E_z < E_i$, $i = 0,1,...,k – 1$ Where E_z –

EMF value induced in pair of coils, magnetic center of which taken as a reference; E_i – EMF value induced in i-th pair of coils. If under the influence of perturbations mobile robot displaced to the right relatively to the track, then relation $E_l < E_i$, $i = 0,1,...,k – 1$, $i \neq l$ is valid.

Value E_l characterizes EMF value induced in a pair of coils with magnetic center located above current-carrying wire or offset from it at less than $R/2$. Mobile robot deviation from specified trajectory calculated by formula:

$$S = \{|N_z - N_l|P + P/2\} \text{sign}(N_z - N_l), \qquad (1)$$

where N_z – coils pair number, magnetic center of which taken as a reference; N_l – plane coils pairs number with a minimum EMF.

It follows from (1) that static error of definition value S depends on step of magnetic center set P, which in its turn determined by thickness B of plane coil.

Since the first follows from the fact that P cannot be less than value B due to the sensor embodiment and as sensitivity threshold U_0 of analog-digital converter is a finite value, then digital representation of EMF values induced in coils adjacent to the reference may be distinguishable only for variant {2} (Fig. 3).

In this regard, static characteristic slope of adjacent coils pairs should be selected the condition

$$tga = \frac{U_0}{P} \qquad (2)$$

Providing specified slope (2) of static characteristic performed by selecting electrical and geometric parameters of coils in accordance with expression:

$$k = \frac{0.4\pi\mu_0 SWI}{d} \cdot 10^{-8}, \qquad (3)$$

where k – induction sensor conversion ratio; $[mu]_0$ – environment magnetic permeability; S – coil sectional area; d – air gap value; W – number of turns; I – value of coil current strength. Measurement range D of induction sensor depends on the distance x between coils in differentially connected pair (Fig. 4).

If value of transport robot deviation from track will be more than range D, then due to sensitivity threshold finiteness U_0, it cannot be determined the number of pair, for which the EMF value is minimal, because there will be several such pairs. From dependence $D(x)$, the graph of which is shown in Fig. 4, follows that induction sensor measuring range increases with distance increasing between coils in differentially connected pair.
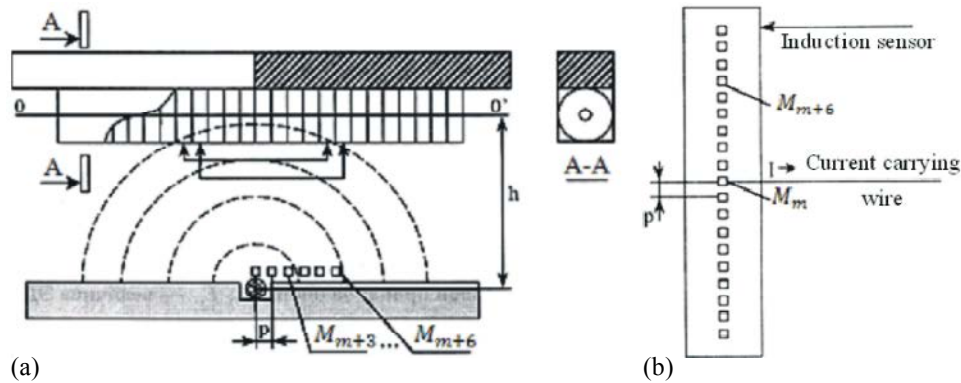
(a)   (b)

Fig. 1: Interaction scheme of current-carrying sensor with current-carrying wire (*a*) and position of magnetic centers of differentially connected coils of induction sensor (*b*)
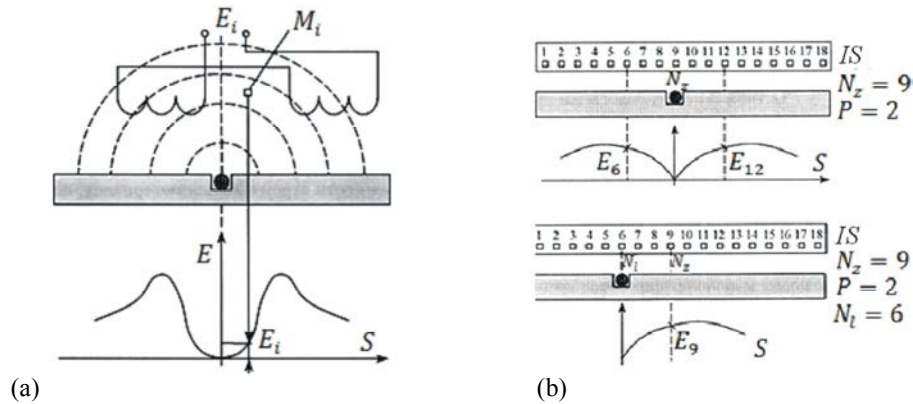

(a)   (b)

Fig. 2: Magnetic center arrangement of differentially connected induction sensor coils and their static characteristics (a) and variant of induction sensor arrangement above current-carrying wire (b)
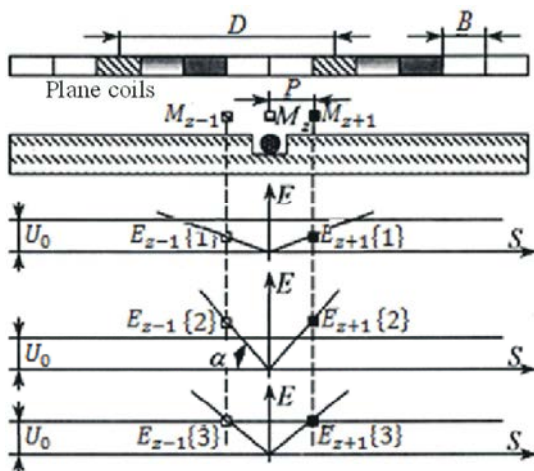

Fig. 3: Static characteristic slope dependence for adjacent coils pairs of the distance between them

This property must be used in manufacturing of sensor with a lot of number of differentially connected coils. As can be seen, induction sensor is a discrete type sensor, as it directly performs quantization of measured parameter by level.

Information about deviation $e(t)$ used to form control action applied to servodrive according to taken control law implemented by microcontroller. Technological equipment decoding can be realized simultaneously with induction sensor. For this purpose, Π-shaped loops of gain-phase setting device sequentially encoding two digit of dock code in *J*-based numeral system are laid in opposite directions from each other through the robot movement track, that is in places of its positioning relatively to precise stop point located at the intersection of precision positioning axis and current-carrying wire (Fig. 5).

Selection of numerical system for encoding equipment, serviced by robot, determines by number of differentially connected coils pairs. If magnetic center of central pair denoted by zero and others enumerated in
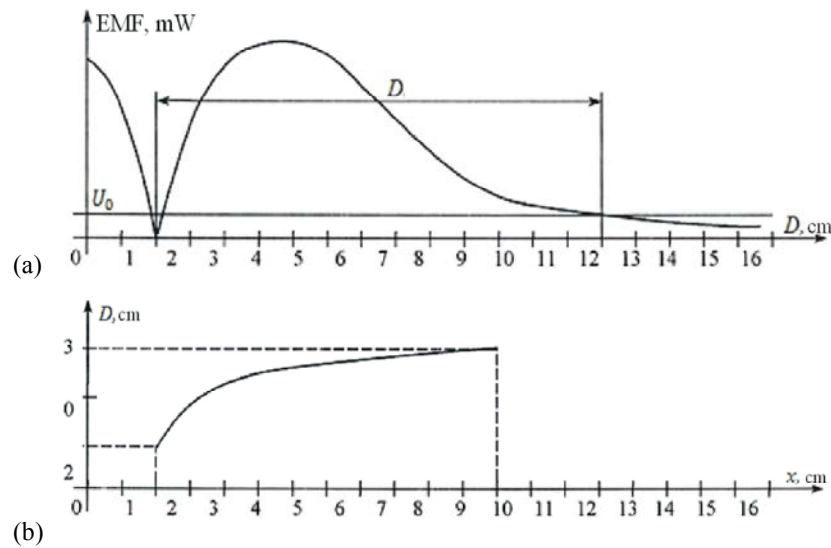
Fig. 4: Total induction sensor EMF including sensitivity threshold (*a*) and inductive sensor measuring range dependence of the distance between coils (*b*)
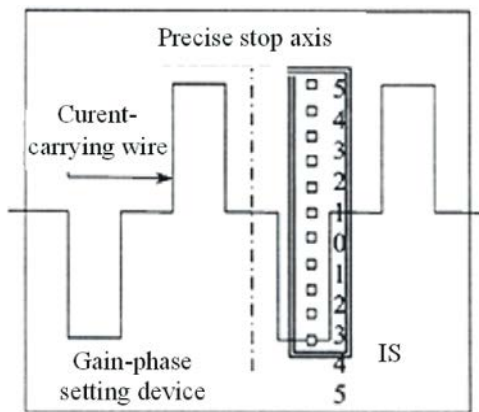

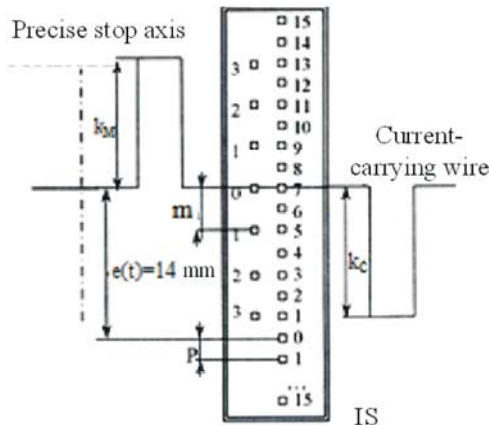Fig. 5: Robot positioning location encoding by Π-shaped loops in the *J*-based numeral system

Fig. 6: Illustration of information reading reliability increasing by consolidation of digit rate

both directions and assume that deviation from the track near the dock is small while robot moves along current-carrying wire that follows from technological requirements and magnetic center of central pair coincides with robot trajectory motion, then, in this case, at sequential read information from inductive sensor at the time when it is located at first above one Π-shaped loop encoding significant bit and then above another Π-shaped loop encoding lowest digit of dock or track branch code, can be determined dock code encoded by Π-shaped loops of gain-phase setpoint device. While construction of setpoint device, proposed in Fig. 5, dock code can be obtained, if Π-shaped loop encoding significant bit dock code covers 5 magnetic centers, excluding central and Π-shaped loop coding lowest digit of dock code, the same number of magnet centers located in opposite side of center. Then dock code can be calculated by formula:

$$n = k_C J^1 + k_M J^0 \tag{4}$$

or for considered case n = 5·6¹+5·6⁰ = 35 where $k_C = 5$ – value of significant bit of dock code; $k_M = 5$ – value of lowest digit of dock code; $J = 6$ - the radix.

While the number of magnetic centers, sequentially covered by loops encoding maximal dock code taking into account central magnetic center, determines the radix *J*, in which dock code will be determined and the number of magnetic centers excluding central magnetic center respectively determines high and low code digits.

Obviously, when servicing more equipment by vehicle, it is necessary to change the construction of induction sensor that will automatically cause changing of radix, by which the dock code will be determined. To ensure the accurate of deviation determination from current-carrying wire with an accuracy of 1 mm, IS must structurally be performed so that magnetic centers of differentially connected coils pairs separated from each other by 2 mm.

Having set with a maximum deviation of a mobile robot from the track, for example, equal to 15 mm, number of differentially connected coils pairs in the IS can be determined. In this case, inductive sensor must contain such quantity of magnetic coils centers that extremes magnetic induction sensor coil centers are above Π-shaped loops of gain-phase setpoint device of maximum maintained equipment code with a maximum deviation of robot from the track in docks encoding places in J-based numerical system. With this construction, the IS with maximum deviation can defined any dock code of a plurality of 1, 2,..., n at robot movement along the track.

To determine the maximum deviation equal to 15 mm with an accuracy of 1 mm IS must contains 30 pairs of differentially connected coils and it means that, according to proposed coding scheme, can be encoded 63 equipment units $n = 7 \cdot 8^1 + 7 \cdot 8^0 = 63$ serviced by robot considering maximum deviation.

When the number of maintained equipment is small, accuracy of information reading can be increased by consolidation of digit rate, combining m magnetic coils centers of ISs and taking them as a unit, then the amount of such units covered by Π-shaped loops of gain-phase setpoint device will determine dock code. In this case, the number n for considered example on condition that $m = 2$, will be equal to $15 (n = 3 \cdot 4^1 + 3 \cdot 4^0 = 15)$ (Fig. 6).

Application of proposed approach to organization of active external environment using original construction sensor greatly simplifies the structure of mobile robot onboard system.

Summary: Proposed method can be used to construction of active external environment and on-board control system of mobile vehicle used in automated production process. Also can be improved technical characteristics of obtaining information tool for mobile vehicle, if use not differentially connected coils, but magnetically sensitive resistive bridges, which are also differentially connected, as sensing elements in inductive sensor [8, 12].

CONCLUSIONS

Proposed method of characteristic points positioning of active external environment and their decoding through multicoil inductive sensor, acting as a measure of deviation from the track with issuing of information in digital form simultaneously with decoding location of the mobile robot, can simplify the onboard control system due to number of equipment.

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