# Enhancing Three-dimensional Movement Control System for Assemblies of Machine-Building Facilities

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**Abstract.** Aspects of enhancing three-dimensional movement control system are given in the paper. Such system is to be used while controlling assemblies of machine-building facilities, which is a relevant issue. The base of the system known is three-dimensional movement control device with optical principle of action. The device consists of multi point light emitter and light receiver matrix. The processing of signals is enhanced to increase accuracy of measurements by switching from discrete to analog signals. Light receiver matrix is divided into four areas, and the output value of each light emitter in each matrix area is proportional to its luminance level. Thus, determing output electric signal value of each light emitter in corresponding area leads to determing position of multipoint light emitter and position of object tracked. This is done by using Case-based reasoning method, the precedent in which is described as integral signal value of each matrix area, coordinates of light receivers, which luminance level is high, and decision to be made in this situation.

## 1. Introduction

Applying automation systems in machine-building industry results in increasing accuracy, efficiency and reliability of engineering facilities, decreasing labor cost to implementing operations and enhancing quality of a final product.

Machine-building facilities, constructive elements of which perform three-dimensional displacements, are highly spread in the industry. There is a need to track these displacements, measure bank and tilt angles of assemblies etc. Parallel kinematic machines are examples of such facilities.

Automation systems characterized by low response time, high accuracy and reliability are used for tracking three-dimensional movement of machinery. Systems based on contactless measurements are especially relevant in this case.

One of such systems known is three-dimensional movement control system based on device with optical principle of action shown at Fig. 1. The device consists of multi point light emitter 4, which includes a set number of light emitters 5, firmly attached to object tracked 1 at connection point 3 by a hinge 2 and light receiver matrix 6 located at a set radius around light emitter.

When all light emitters are on and object tracked is in a certain point in space, beams of light emitters cover a group of light receivers, which make up a matrix. When object tracked changes its location in space, tilts at some angle or rotates around its axis, the direction of light beam of each emitter changes, and each light beam covers another group of light receivers. Thus, actuation of certain group of light receivers is influenced by three-dimensional location of object tracked.

System previously elaborated uses Case-based reasoning (CBR) method to determine three-dimensional location of object. This method is based on searching a precedent in Case base (CB). Output discrete signal of each light receiver in matrix flows to microcontroller. The value of the signal defines if light receiver is covered by light beam. A group of light receivers covered by light beams is identified, based on which three-dimensional location is determined by applying CBR method.
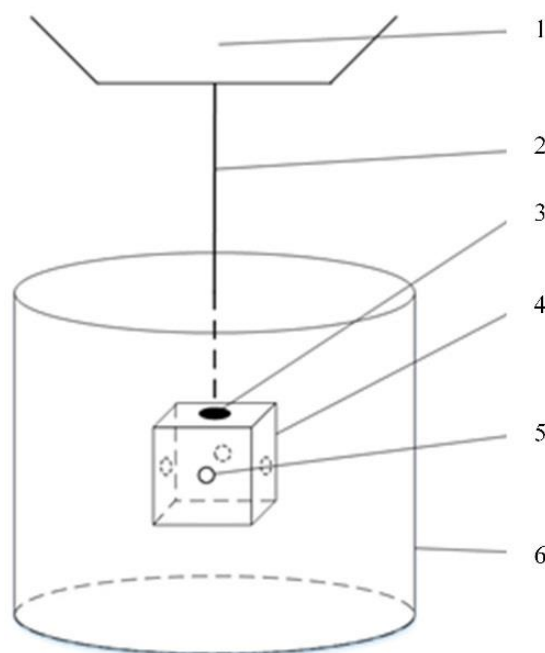
Fig. 1. Optical device for tracking three-dimensional movement

However, the algorithm for processing signals of light receivers described does not provide with high accuracy. This is because the output signal of each light receiver is in discrete form, and the output value of light receiver, one quarter of which is covered by light beam (for instance), is equal to the output value of fully illuminated light receiver. Nevertheless, two these values of light receiver illumination respond to different directions of light beams and, consequently, different location of object tracked.

For this reason, the objective is to increase accuracy of three-dimensional movement control system by changing algorithm of processing output signals of light receivers.

## 2. Method

Whereas a disadvantage of signal processing principle described is a discrete form of signals, it was decided to switch from discrete signals to analog signals. In this case, three-dimensional location of object tracked is defined not only by a group of light receivers actuated, but by a level of luminance of each light receiver in this group. It is considered that light receiver luminance is proportional to the value of its output signal.

In system elaborated each light receiver has an identifier and light receiver matrix is divided into four space areas (areas 1-4) which responds to number of laser light emitters. Each of four light emitters is oriented towards a certain area of light receivers.

A situation in which light beam of one light emitter covers the sensitive surfaces of a few light receivers is presented hereafter. In such situation, the output of each light receiver is an analog signal which value is proportional to the square of light receiver area, which is covered by light beam. Thus, the output values of light receiver areas 1-4 equal to the algebraic sum of electrical output signals of each light emitter covered by light beam and located in respective area:

$$U_{1-4} = \sum_{i=1}^{n} U_i \qquad\qquad\qquad (1)$$

where $U_1$, $U_2$, $U_3$, $U_4$ [V] are values of output signals of light emitter areas 1-4 respectively, 1..n are light emitters located at areas 1-4 of light receiver matrix (it is considered that number of light emitters located at areas 1-4 is equal), $U_i$ [V] is electrical output signal of light emitters 1..n located at light receiver areas 1-4 respectively.

Therefore, an electrical output signal which determines luminance level of whole light emitter matrix is calculated upon the formula:

$$U = U_1 + U_2 + U_3 + U_4 \tag{2}$$

and values $U_1$, $U_2$, $U_3$, $U_4$ indexed to certain light emitters, which are covered by a light beam from light emitters 1-4, determine tree-dimensional location of studied object. Three-dimensional coordinates x, y, z of studied object at this moment in time depend on electrical output signals of light emitter areas 1-4:

$$(x, y, z) = f(U_1, U_2, U_3, U_4) \tag{3}$$

## 3. Results and discussion
Functional structure of movement control system for studied object is presented at Fig. 2. The system includes microcontroller unit (MCU) as a base element.
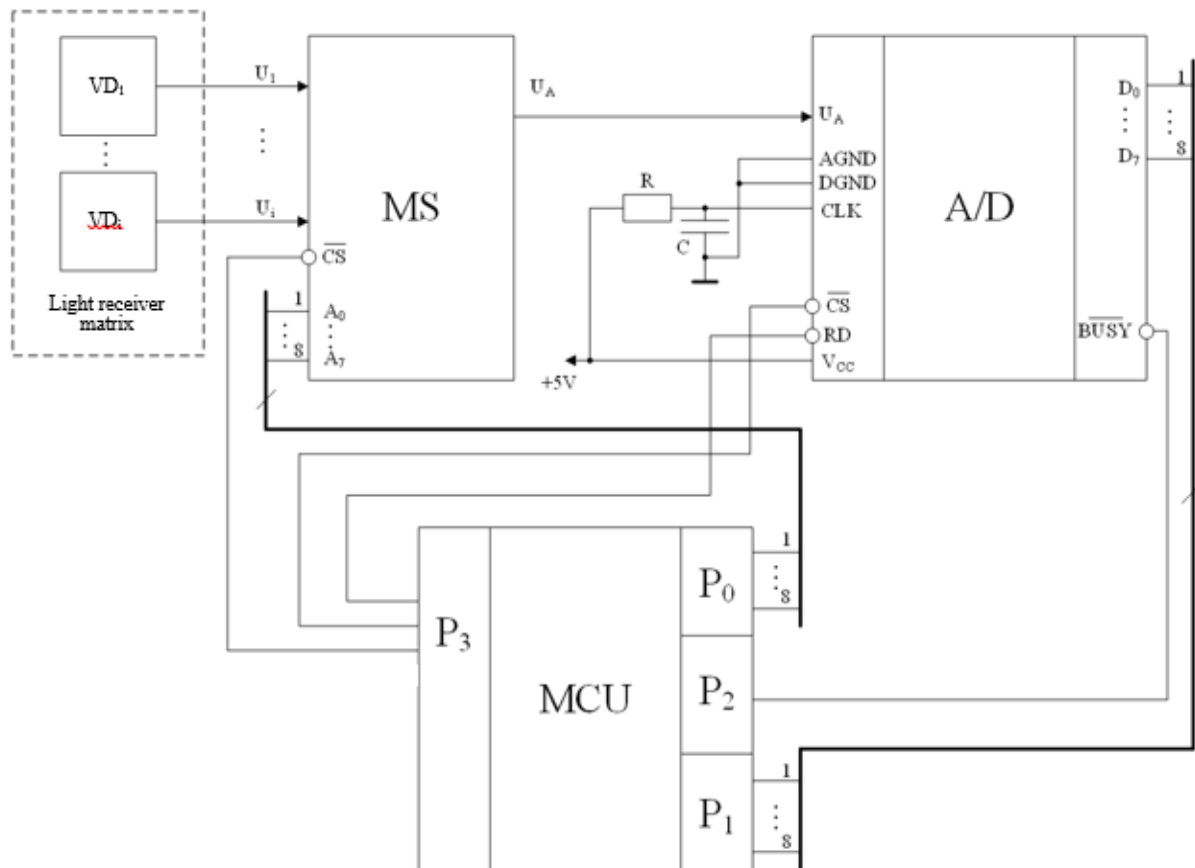


Fig. 2. System functional diagram

MCU controls light emitters scanning by using multiplexor if signals (MS) Analog-to-digital converter (A/D) consequently transforms input signals to digital code.

The value of output signal BUSY of A/D corresponds to the end of transformation. This signal flows to MCU port P2. After transformation is finished, the signal RD, which corresponds to reading, is sent

by line P3 of MCU. This signal value start the procedure of reading data from outputs D0-D7 of A/D and writing digital code to MCU internal memory.

After signals, which correspond to condition (luminance level) of all light receivers, are written to MCU internal memory in digital codes, a digital data processing is performed: obtaining the resulting signal for active (covered by light beam) light emitters located at areas 1-4, application of precedent method for determining a precise location of light emitter block in order to determine location of studied object.

The elaborated algorithm presented at Fig. 3 describes system performance.

Initialization includes setting microcontroller (setting reference values and constant values), preparing light emitter block (setting it to reference position and switching on) and light receivers (resetting their values).
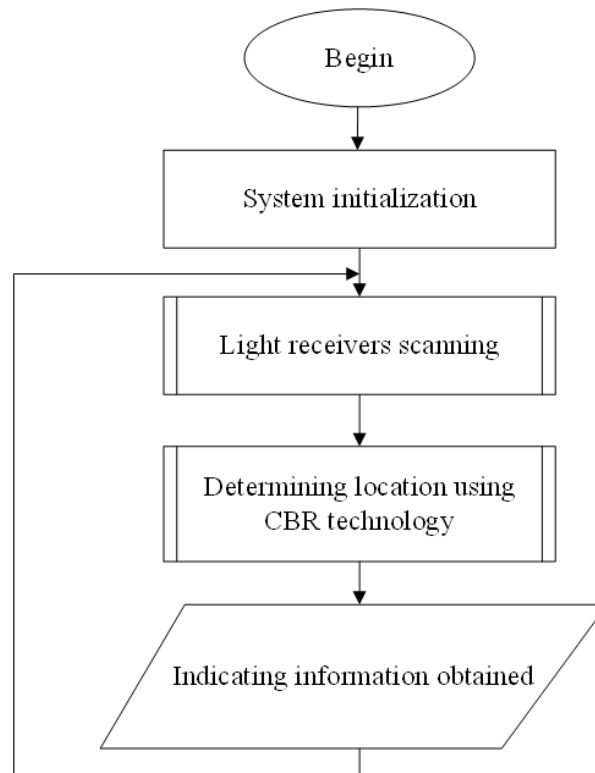


Fig. 3. System implementation algorithm

A consequent scanning of light receivers is performed thereafter. Scanning includes signal commutation (performed by MS), signal transformation from analog to digital form (performed by A/D) and uploading results to internal memory of MCU. After that data is processed in order to obtain information about three-dimensional location of studied object; information obtained is indicated in a previously set way. Data processing is performed with the use of precedent method.

System performance is cyclical, and all the procedures are implemented with preset periodicity.

Algorithm of forming decision based on precedent method also known as Case-based reasoning (CBR) technology [1-5] is given at Fig. 4.

A precedent in common case [6, 7] consists of information about current location of object tracked, associated decisions and other meaningful factors. A precedent is defined as follows:

$$\text{CASE} = \langle (\Sigma U_i,\ \Sigma(X,Y)_i), M \rangle \qquad (4)$$

where $\Sigma U_i$ are values of output signals of light emitter areas, $\Sigma(X,Y)_i$ are coordinates of light receivers which register signals from respective light emitters, *M* is a decision to be made according to information obtained.

In this instance, for four light receiver areas current situation is defined the following way:

$$CURRENT\_CASE = (U_1, U_2, U_3, U_4, (X, Y)_1, (X, Y)_2, (X, Y)_3, (X, Y)_4,) \ M \qquad (5)$$

where $U_1, U_2, U_3, U_4$ are values of output signals of light emitter areas 1-4 respectively, $(X, Y)_{1-4}$ are coordinates of light receivers which register signals from respective light emitters, M is a decision to de made according to information on signal values and coordinates of light receivers obtained.
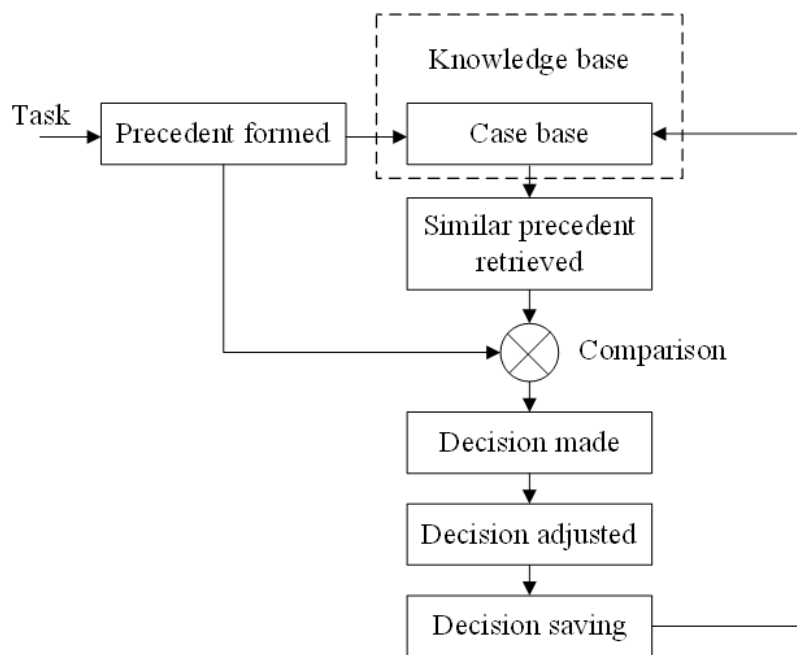


Fig. 4. CBR technology application algorithm

After that, a precedent mostly common to current case is searched in Case base (CB) [8-13], which is formed during system testing before commissioning. CB is also an element of a knowledge base. Meanwhile, a similarity degree parameter is taking into consideration. This parameter characterizes whether precedent from CB complies with current case and defines whether a decision, kept inside precedent from CB, is suitable for current case.

After similarity degree is determined for each precedent from CB, the precedent with higher similarity degree value is chosen for further processing.

A decision kept in precedent [14, 15] with higher similarity degree presents three-dimensional coordinates of studied object. After the decision is retrieved, it is adjusted and saved into CB. Thus, a result of CBR technology application to the system is a decision kept in this precedent.

## 4. Conclusion
Thus, a system enhanced performs three-dimensional movement control of assemblies of machine-building facilities. Accuracy of system previously developed was increased by switching from processing digital to analog signals, which is based on proportionality of luminance level and output signal value of each light receiver.

Signal processing is followed by application of CBR technology, coordinates of three-dimensional location of object tracked are the result of which.

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