Three dimensional movement control system applying CBR-technology

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Abstract. In this paper the basic aspects of elaborating the three dimensional movement control device are presented. This device is used if the movement control of the suspended object is required. A multipoint light emitter is firmly attached to the controlled object. A set of light receivers registering the light emitters’ signals determines the object location. The aspects of elaborating the three dimensional movement control system structure are presented. The system is elaborated upon the movement control device. Case-Based Reasoning technology is used to determine the location of the controlled subject.

Key words – device, three dimensional movement, light emitter, light receiver, system, Case-Based Reasoning.

1. Introduction
Currently, movement parameters control of unstable objects represents a task. Exploiting automatic movement control systems provides with a solution for this task. Such systems are based on MEMS-accelerometers, MEMS-gyroscopes, inclinometers, etc. [1-3]. For example, a two dimensional tilt control device is elaborated [4]. However, the disability of such devices to measure three dimensional movements and their mechanical drawbacks constrain their functionality. Moreover, the quality of sensor values decreases because of vibrations and influence of external environment [5-9].

Thus, a problem of developing three dimensional movement control system marked by high sensibility and reliability and quick response is currently important. The main part of the system is to be a device measuring three dimensional movement of the object.

2. Methods
The device adequate to requirements mentioned was elaborated. Its structure is presented at figure 1. Elements of the device are multipoint light emitter (MLE) and signal receiver block (SRB). The MLE 4 is firmly attached to researched object 1 by bar-bell 2. Connecting point of bar-bell 2 and MLE 4 is marked as 3. MLE which is put into space confined by cylindrical hull 6 consists of four laser ray emitters 5. The hull includes SRB which is represented by light receiver matrix on its side. Sensitive side of each light receiver is directed inside the hull. Light receiver matrix on the side of the hull has a structure presented at figure 2. The side of the hull has a rectangular form, the vertical and horizontal distances between two next light emitter rows equal respectively \( l \) and \( h \) so that the side of the hull has a grid structure. Accuracy of the measurement is inversely proportional to the grid step (\( l \) and \( h \) values).
Figure 1. Structure diagram of three dimensional movement control device elaborated

The common light emitters number in the device depends on measurement accuracy demanded and is calculated upon the formula [10]:

\[ N = \frac{2\pi R \cdot H - 2h}{l} \cdot \frac{2}{h}, \]

where \( l \) is a horizontal distance value between light emitter rows, \( h \) is a vertical distance value between light emitter rows, \( R \) is a cylindrical hull radius value, \( H \) is a cylindrical hull height value.

Target function derived has a formula:

\[ F = \frac{MA \cdot NA}{P \cdot Z \cdot S} \rightarrow \text{max}. \]

Calculations undertaken of target function value show that optical principle of action of device elaborated is an advantage because it provides with lack of extra data filters. Meanwhile, using different measuring devices results in necessary application of such filters.

Figure 2. Light receiver matrix structure
A target function was created to justify selection of the device elaborated from a range of measurement devices. In common such function has a formula presented below:

\[ F = f(u_1, u_2, ..., u_n), \]

where \( u_i \) is a parameter analyzed.

The comparative analysis was undertaken for following cases: combined usage of accelerometer and gyroscope, usage of inclinometer and usage of device elaborated. The parameters analyzed were assumed to be market availability \( MA \) (on a scale of 1 to 5), price \( P \), zero drift \( Z \) and sensitivity drift \( S \) (temperature characteristics), number of measurement axis \( NA \).

Thus, device elaborated is an optical movement control device. Its principle of action is based on the usage of MLE (four laser ray emitters) attached firmly to object analyzed and SRB (light receiver matrix on the internal side of cylindrical hull). The device can be used while studying following parameters of object analyzed: tilt, three dimensional displacement, velocity, etc. Movement tendency research of the object can be carried out if its position dependence on time is identified.

The device can be a part of three dimensional movement control system, which consists of the following elements:
- three dimensional movement control device;
- two signal multiplexers;
- microcontroller.

3. Results and discussion

Functional diagram of the system is presented at figure 3. System executes as follows: after system run initialization is implemented, which considers setting reference values, downloading constants to microcontroller SMC, resetting light receivers’ values, switching on light emitters, setting reference position of object controlled.

![Figure 3. System functional diagram](image-url)
A continuous questioning of SRB takes place thereafter. Signals flow from light receivers \( VD_1 \ldots VD_N \) to current converting devices, each of them converts photocurrent from one light receiver to output voltage \( U_{\text{out}} \) and includes photodiode \( VD \), resistors \( R_1 \) and \( R_2 \) and operational amplifier DA. After that signals flow from current converting devices through channels \( 1..N \) (from horizontal matrix rows) and \( 1..M \) (from vertical matrix rows) to corresponding multiplexers \( MS_H \) and \( MS_V \). Signals from horizontal and vertical matrix rows are processed separately there and then flow to SMC. For instance, AVR by Atmel (8-bit device with RISC-architecture and speed of 16 MIPS) may serve as SMC.

Addresses of channels chosen for data transmission flow from SMC outputs 0 and 2 through address lines to the inputs \( A_1 \ldots A_K \) and \( A_1 \ldots A_L \) of \( MS_H \) and \( MS_V \) respectively. Signals from light receivers flow from \( MS_H \) and \( MS_V \) outputs marked as OUT to SMC inputs P1.0 and P1.1 through data lines and are stored in SMC RAM. Addresses of units chosen for rewriting data on current condition of the controlled object flow from SMC outputs P1.2-P1.6 through address lines to inputs \( A_0 \ldots A_4 \), whereas data exchange with SRAM is performed through SMC outputs P3.0-P3.7. Write-read managing output P1.7 of SMC is connected to corresponding input of WR/RD SRAM. Program stored in SMC Program Flash processes signals from light receiver matrix and establishes a set of light receivers, which are registering signals of light emitters at the moment.

It is suggested to use Case-Based Reasoning (CBR) method [11-13] to solve a task on adapting decision to experience related to solving similar tasks. The process of searching for information required is a subsequent implementation of following actions: obtaining (retrieving) a precedent, searching for the closest decision in Case Base (CB) considering similarity degree on criteria chosen, adjustment and saving, decision making. System structure considering application of CBR is given at figure 4. CBR algorithm respective to this is given at figure 5.

Figure 4. System structure diagram with Case-Based Reasoning applied

A precedent may be presented as follows:

\[
CASE = (VD_1, VD_2, VD_3, VD_4, R)
\]

where \( VD_1, VD_2, VD_3, VD_4 \) is a set of light receivers, which register signals from the first, second, third, fourth light emitters, which define current precedent, \( R \) corresponds to decisions (managing recommendations).
Meanwhile, $S(P, T)$ is a similarity degree, which is defined as follows:

$$S(P, T) = \frac{N_{PT}}{N},$$

where $N_{PT}$ is a number of matching features (signals) for precedent $P$ and situation $T$, $N$ is a common number of features.

CB is formed before system commissioning. Usage of exact system parameters (object controlled, length of bar-bell and location of connecting point of bar-bell and MLE (figure 1), MLE size and object controlled size) as will be used while exploiting system while forming CB is vitally important.

During system execution a similarity degree of current situation (a set of light receivers registering light emitters signals) to situations stored in CB is estimated. This is implemented with the use of Nearest method and failed decisions, related to incorrect system elements functioning, make up a special base of problematic conditions and are put into SMC SRAM.

In our view, for determining similarity degree of current situation it is more desirable to use a modified method. In this case, decision is to be chosen on the basis of a few closest neighbors (precedents), and it is required to take into account a possibility of changing $h$ parameter (distance between light receivers) in a set metric, which characterizes similarity degree.

It is obvious that when $h \rightarrow \min$, the number of light receivers in light receiver matrix $N \rightarrow \max$, and common number of combinations $R\Sigma$ of active light receivers, which register light signals from light emitters, increases.

Meanwhile, the number of these light receivers depends on the directional pattern of light emitters and may be minimized if laser ray is used. The location of nearby light receivers $VD$ relatively to basis point $i$ is given at figure 6. Horizontal and vertical distance values between light receivers nearby to $i$-th light receiver correspond to $h$.

The light receiver response condition is defined by boolean function:

$$B^n \rightarrow B,$$

where $B = \{0, 1\}$ is boolean set, $n$ is non-negative number (arity).

Boolean function for light receivers, which register light emitters signals, is defined as truth table given in table 1.
Table 1. Truth table for boolean function

| VD₁ | VD₂ | VD₃ | VD₄ | f(VD₁, …, VD₄) |
|-----|-----|-----|-----|----------------|
| 1   | 1   | 1   | 0   | f(1, 1, 1, 0)  |
| 1   | 1   | 0   | 1   | f(1, 1, 0, 1)  |
| 1   | 0   | 1   | 1   | f(1, 0, 1, 1)  |
| 0   | 1   | 1   | 1   | f(0, 1, 1, 1)  |
| 1   | 1   | 1   | 1   | f(1, 1, 1, 1)  |

Thus, a satisfactory condition of decision-making on choosing the nearest precedent is $M \geq 3$ considering weight coefficient $\lambda$. This value corresponds to reliable response of at least three light receivers in system with four light emitters.

**Conclusion**

It should be noted that two main components constitute a precedent structure: identifying (allows reuse) and tutoring (characterizes experience, includes proves for decisions and alternative and failed decisions). Object coordinates, its tilt, velocity and displacement value are determined if a decision is found with the use of CBR (considering parameters matching current situation).

As a result, system elaborated allows to determine the following parameters of object controlled unequivocally with accuracy demanded: object displacement value, tilt, velocity, acceleration, etc.

![Scheme of nearby photodetectors](image)

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