



Biologically Inspired Object Localization for a Modular Mobile Robotic System

Zlatogor Minchev

Centre of Biomedical Engineering “Prof. Ivan Daskalov” – Bulgarian Academy of Sciences
105 Acad. G. Bonchev Str., 1113 Sofia, Bulgaria
E-mail: zminchev@clbme.bas.bg

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Abstract: The paper considers a general model of real biological creatures' antennae, which is practically implemented and tested, over a real element of a mobile modular robotic system - the robot MRI. The last could be utilized in solving of the most classical problem in Robotics – Object Localization. The functionality of the represented sensor system is described in a new and original manner by utilizing the tool of Generalized Nets - a new likelihood for description, modelling and simulation of different objects from the Artificial Intelligence area including Robotics.

Key words: Biologically inspired sensors, Modular robots, Object localization

Introduction

The object localization for mobile robots is an old task for which there have been proposed a lot of practical and theoretical solutions [4]. The present paper will consider a cybernetic approach, which permits to approximate the animated nature abilities for object localization by means of improvement the abilities of artificial systems and especially robots.

This idea is well known from the doom of cybernetics, when the main principles of organization and control of the animated nature have been an inspiration for creation and control of different artificial systems [43]. Nowadays, more than half a century later, these principles have already obsessed different areas of science ranging from planning in computer networks to autonomous or swarm robot navigation.

The last from the other hand is closely related to another problem of the modern Artificial Intelligence (AI) science – the autonomy [38].

This notion practically includes all the characteristics of living creatures, e.g. self-organization, self-existence, self-reproduction, self-control and even self-healing [26, 27]. However, creating an artificial system with all these characteristics is a very ambitious task, solving of which is still an open problem.

The achievements in the modern AI, from the other hand, are mainly based on these criteria satisfaction. They are basically founded in two main areas: autonomous robots and swarms of autonomous robots which some authors claim to reckon as intelligent systems. While the former satisfies only a few of the above mentioned conditions, the last are more powerful area by means of fulfilling the requirement of self-healing, stated for the first time by John von Newman in the form of self-reproducing cellular automata [34] that could be self-healed in case of any faults. This idea was further simplified in the form of Artificial Life but has the lack of practical implementation [21, 22].

The solution of this task was later given in the form of the first modular robotic system – CEBOT [9] and a whole kaleidoscope of its ancestors.

Nowadays they are divided into three main groups [42]:



lattice type systems;

chain (string) type systems;

mobile type systems.

The lattice type robots change their shape by moving into positions on a virtual grid or lattice. Like chain robots, all the modules remain attached to the robot. The lattice element possesses a spatial symmetry in accordance to its structure and it could be of 2D or 3D-type [37, 39, 41]. The chain type robotic systems create themselves by attaching and detaching chains of modules to and from themselves, with each chain always attached to the rest of the modules at one or more points. Nothing ever moves off on its own. Some practical implementation of these robots could be found in [7, 17, 32, 33, 35].

The mobile type of modular robots could change their shape by detaching and moving modules from their main body and linking up at a new location in order to form new configurations or simply to solve a common goal without links, but by utilizing an information exchange techniques. Here it should be noted that the mobility modus for this type of robots concerns not only the ground but also the air and the water, though in the literature could be found only a few ground solutions [5, 18, 19, 23, 29].

The present paper will consider a biologically inspired object localization sensor, which is built in a module from a mobile modular robotic system. This approach was chosen because the last is the most flexible and fast group of these robots and at the same time is easy for creation and practical experiments. The next paragraphs will reveal the idea of the author in detail, accentuating on its practical implementation in a real robot.

The robot

The utilized robot is based on the third type of swarm robots - mobile robots and its description could be found in [28]. Here MR1 (see Fig.1) will be briefly described because the main idea in this paper is to consider in detail its object localization sensors and their work.

MR1 is a mobile, non-holonomic robot that has two tactile and one laser beam-interruption sensor, positioned on a V-shaped plastic frame, rather similar to insects' antennae. As it is specially designed for experimental purposes, the movements he could perform are limited in the 2D plain. MR1 bi-directional movement is provided by one DC motor, connected to the backward robot's wheels through a mechanical cam-gear. His steering-wheel system consists of a couple of wheels, situated in front of its body and driven by a simple electromagnetic mechanism. The MR1 power supply is also implemented in his body. The robot's intelligence is hidden in a Generalized Nets based control system for personal computer (PC). The communication between the robot and the computer is carried out by wireless remote-control system (in 27 Mhz frequency band for less external environment influence in rough terrain conditions) that is connected to the PC's parallel port.

This solution is chosen mainly for simplicity and flexibility, because the PC gives a opportunity for easier, faster and cheaper further changes in the MR1 control (including enlarging his perceptive abilities, implementation of new control techniques and participation in robots swarms) with minimal efforts. It also gives an opportunity to connect MR1 with LAN or WAN network architectures and even GPS systems. This greatly enlarges the MR1 abilities for integration and remote control and allows integrating it into an intelligent robotic swarm of heterogeneous or homogeneous type.

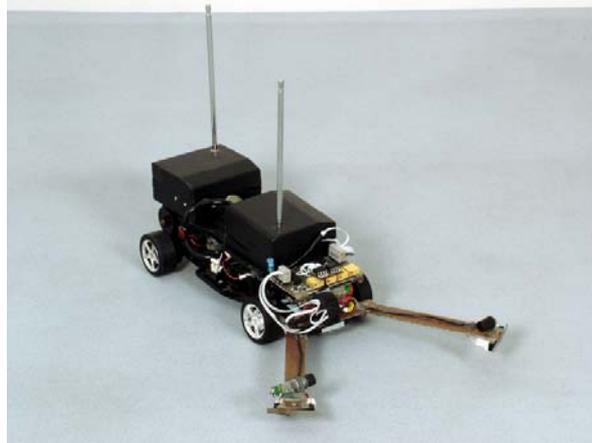


Fig.1 The picture of the utilized mobile robot MR1

Biological foundations

The biological foundations of the revealed sensor for object localization is based on the idea for object detection in the animated nature and especially in the way of localizing objects of insects, and some other special species of mammalia and crustaceous [10]. This approach was chosen because previous attempts of the author for creating different type of sensors based on the Object-Reflection paradigm of Infra Red light [30] requires more power and sensors compared to this one. Above all it also depends on the colour and reflecting abilities of the localized object and even in its improved implementation is ineffective by means of distance/power ratio [4].

The biological examples of this type could also be found in the literature [10, 20] but in a more different manner, so the author could claim here for originality.

Some examples of this biological approach are depicted in Fig. 2.



Fig. 2 Some biological examples of antennae sensors for different animals

As a result of Fig.2 observation, it could be concluded that the repetitive elements in all these examples are the antenna's sensors. So they could be practically implemented with some modifications in the artificial creatures like robots.

The object localizing sensor

The construction of the sensor is based on the idea for interruption of concentrated light beam together with the idea of its standing on to artificial antennae. This approach is further supplemented by four micro switches (one for each edge of the frame) for the antennae edges, where the former solution practically fails. The real implementation of this idea is shown on Fig. 3.

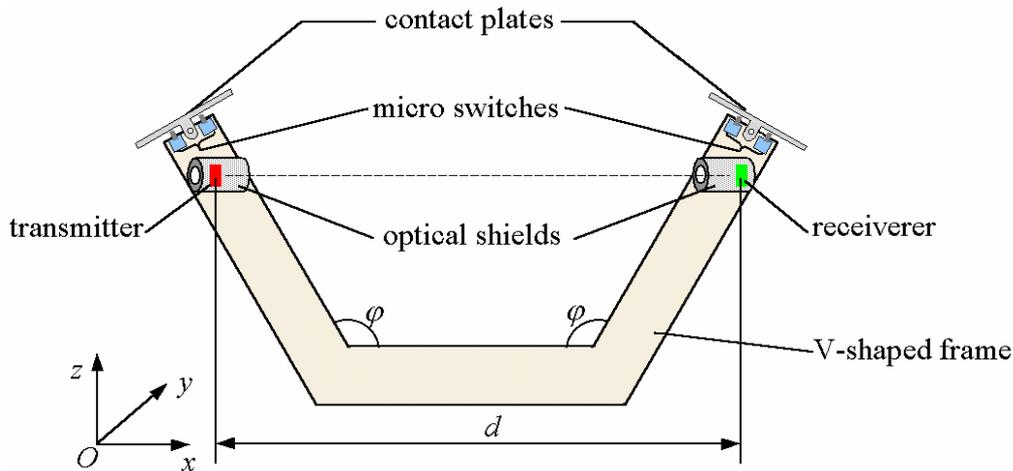


Fig. 3 The artificial antennae general structure

As it is clear from Fig.3 the system consists of an optical beam interrupter and four tactile switches.

The optical beam interrupter is built of two optical devices – one optical transmitter and one optical receiver, which here are denoted with a red and a green rectangle. In order to reduce the ambient light influence of sunrays and other strong artificial light sources like halogen or mercury lamps over these optical devices, a couple of tubular plastic shields is used (see the hatched grey cylinders). Here it should be noted that as an optical transmitter could be used either a laser semiconductor diode or an Infra Red (IR) light emitting diode - LED (e.g. those of *Vishay Telefunken* - TSAL 6100 [15] or the *OPTEK* company - OP 240, OP 295 and BN 301) or even IR couples like OP 740 [11]. All the emitters however are driven by one and the same input constant voltage U_{in} , that is just the supply DC voltage. In the present solution the laser one is more suitable because its light is stronger, coherent, monochromatic, has a narrow range of wavelengths compared to the infrared one (see Fig. 4) that allows more efficient propagation of light by reducing the environment dispersion [12]. Above all these devices are usually with an internally built in focussing system (like those of Roithener Laser Technik - LM-01, LM-02, LM-03, and LM-04 [14]), which reduces the power consumption and size of the optical shield. The receiver could be a phototransistor, diode, resistor or PIN diode, which acts like an electronic key. In the present solution the author has chosen the phototransistor IF - D92 but IF - D93 or another phototransistor could also be used [13]. The resulting voltage U_{out} should be further inverted in order to be able to obtain an electric voltage only if any non-transparent obstacle interrupts the optical beam (denoted with a dotted line). The reason for this is the low power consumption of this schematic solution (see Fig. 5), cheap practical realization, commercial application, good sensitivity and simple further processing of the output signal compared to the other two possibilities (a photodiode or a photoresistor) that require an additional amplifier implementation [16].

The distance between the optical transmitter and receiver is denoted with the latin letter d and depends on the detectable obstacle size, transmitter power and the receiver sensitivity.

The base of the sensor system is a plastic frame (see the white frame), which is also biologically influenced by means of its shape – half of a hexagon or modified latin V. A shape, which is very stiff one and not foreign to the animated nature [40]. So, the internal angle φ between the two antennae in this case is 120° . The size of the frame is also strongly dependent on the distance d and the building material thickness and strength. In the present solution the author has chosen a plastic material approach because of its easy practical implementation, good fleetness, strength and mostly for the experimental nature of the sensor

system implementation – robotics. As this artificial sensors' system is only a homotety of the real animals' antennae it is not so sensitive and in order to provide at least front object detection the application of lonely optical beam interrupter is not sufficient. So, to remove these dead points in the antennae edges, additional elements' application is required. These additional elements could be implemented by means of four micro switches (see the blue rectangles) fixed on the modified V-shape plastic frame and involved in practical edge tactile sensors implementation. These switches together with a couple of thin metallic plates mounted on this frame (see the grey thick lines) with the ability for bounded rotary motion around the Y-axis. They are forming the whole edge detectors that in combination with the optical beam interrupter is completing the artificial antennae sensors' set.

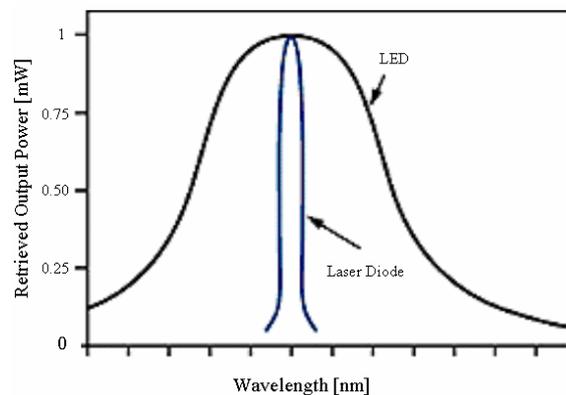


Fig. 4 A comparative representation of Retrieved Output Power / Wavelength ratio for a usual LED (the black curve) and a laser one (the blue curve)

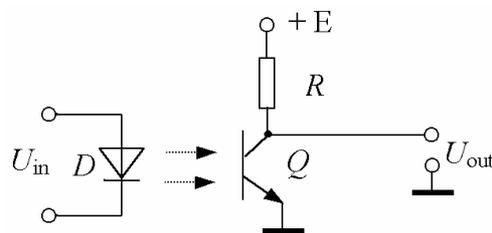


Fig. 5 An electronic equivalent of the optical beam interrupter. The letter D marks the LED and Q marks the receiving phototransistor mounted in a common emitter solution; R denotes the load of the transistor. U_{in} and U_{out} are the input and output voltages of the circuit. They are dependent on the definite utilized semiconductural devices and the power supply voltage – E .

Methodology, symbols and signatures

As the utilized tool for sensors' work description may be to some extent new and unfamiliar or even unknown to the broad scientific audience, here will be given a brief description of its structure and abilities. Above all the application of this tool allows understanding in a holistic manner the author's idea for modelling and control of modular robots and especially its application in the unknown environment investigation [25, 27, 28, 31].

Generalized Nets (GN) [2] are a new, flexible and convenient tool for description, modelling and simulation of different areas of our everyday life, including Artificial Intelligence (AI) and especially Robotics [3]. They are based on the well-known Petri Nets Theory [36], which is also implemented in the robotics area description, modelling and simulation [1, 24]. However, GNs are more suitable than Petri Nets by means of deadlock situation overcoming

and knowledge representation. One of the basic reasons for this is that GNs are based on the Entity-Relationship (E-R) paradigm [6] while Petri Nets are hierarchically organized. Their basic building elements are: transitions, places, tokens and predicate matrices. The full family of symbols and signatures utilized in GN theory could be found in [2]. In this paper are utilized reduced GNs, so the model uses three main symbolic notations: the Latin letter Z (denotes a transition) followed by an Arabic number, that indexes this transition, (e.g. Z_1 or $Z_{1,i}$ for the first or for the i^{th} transition in the GN, where: i is a natural number, i.e. $i \in \mathbb{N}$), the Latin letter l (denotes an input or output place in accordance with its position: left - input place, right - output place), also followed by an index (e.g. l_i for the the i^{th} place in the GN, $i \in \mathbb{N}$) and the indexed Latin letter r (e.g. r_i for the i^{th} matrix in the GN, $i \in \mathbb{N}$), which denotes the predicate matrix of a transition. The links between the transitions are based on the notion that input places of one transition could be output places of another or vice versa. The main idea of the GNs is to move virtual tokens among the net (from input to output places or sometimes vice versa), satisfying the conditions of the predicate matrices of the included in the net transitions.

Description of the model

In this section will be described the model of artificial antennae sensors' system work in terms of GNs.

The model consists of seven transitions and twenty-three places that consider the work of the biologically inspired artificial antennae sensors' system in general. Here it should be noted that everywhere in the text the reader meets "*rectangular pulse*" notion, the author has meant this in general, overlooking any definite parameters of the pulse like amplitude or duration.

The first stage of the described system presents the physical sensors' system, i.e. one optical beam interrupter (l_1) and two couples of tactile sensors (l_2 and l_3), which have two possible states – opened and closed by means of physical existence and non-existence of a localized object. While these places represent only the physical side of the above mentioned sensors, the rest of this transition elements – places l_4 , l_5 , l_6 and l_7 are representing the results of their work and the supply circuit of this first stage of the system.

The second stage is a logical OR circuit united with an electronic gate [16], i.e. a decision that allows the resulting electrical signal from the previous stage to proceed if there is a logical unit on some of its inputs and the gate is opened. This practically means that some of the sensors' set is localized an obstacle. This circuit is represented by the transition Z_2 and places: l_4 , l_5 , l_6 , l_{20} (as inputs) and: l_8 , l_9 , l_{10} and l_{11} (as outputs). Here it should be noted that while the loop at place l_{11} is representing the supply circuit of this stage, the other loop (place l_{10}) is responsible for the state of the electronic gate.

The third stage represents a single pulse generator that works in the following way: if an input driving signal appears from the previous stage, the present stage generates a short rectangular pulse. The reason for implementing this stage is the necessity of producing a short signal in case of localization of an obstacle. The last is a requisite condition that emerges from two basic facts – one for the freedom of the utilized communicational channel and one for the localization strategy.

Here it should be noted that while the first condition considers the communication channel ability to transmit and receive information in close frequency bands, which sometimes could produce a cross-talk problem in the very robot [16], the second problem is much more dangerous. The reason for this is hidden in the fact that while the first condition could be surmounted by utilizing different types of modulation or serial communication for the receiver and transmitter circuits of the robot, the second problem is insurmountable, by means of simple mechanical Newton's laws [8] and the size of the detectable object. The last

sometimes could be too small and in case of object detection it may happen that as soon as the robot stops (in order to report the situation of object localization), there is already no such an obstacle. This practically produces spurious results.

So in order to solve these two problems a single pulse generator followed by a time delay circuit and automatic electronic gate have been accomplished. The gate should be closed until an object is detected and opened until the robot receives remote instructions from the GN control system for obstacle avoidance.

Here the single pulse generator is presented by the transition Z_3 and the places: l_8, l_{12}, l_{13} . Similar to the previous two transitions, the last loop – place l_{13} , represents the supply circuit of this stage.

The fourth stage is represented by the transition Z_4 and places: l_{12}, l_{14}, l_{15} and l_{16} . It is a model of a delay circuit that produces two short output rectangular pulses that have the time shift depicted in Fig.5. Here it should be noted that the red signal (with duration t_2) is for the place l_{15} , while the blue one (with duration t_1) is for the place l_{14} and $t_2 < t_1$. The place l_{16} , represents the power supply circuit of this stage. The reason for this time delay distribution of the signals is the necessity of simultaneous stopping of the robot and transmission of the exact information for a localized object by means of activated sensor (s) index (indexes).

The fifth stage of the represented model corresponds to the generalized robot's movement controller. This model is accomplished by the transition Z_5 and places: l_{14}, l_{18}, l_{17} . While place l_{18} presents the supply circuit of this stage, the rest places supercede the input (l_{14}) and output (l_{17}) of this controller.

The sixth stage of the system represented by the transition Z_6 and places: l_{15} (driving input), l_{21} (supply circuit), l_{19} (driving output for the transition Z_7), l_{20} (driving output for the transition Z_2). This unit supercedes the internal robot controller, responsible for the electronic gate resetting (see transition Z_2 above description) and transmission of the information for the activated sensors (see transition Z_1 above description).

Finally, the last stage of the present model is the transition Z_7 and places: l_{19}, l_{22}, l_{23} , which present transmitter system of the robot MR1.

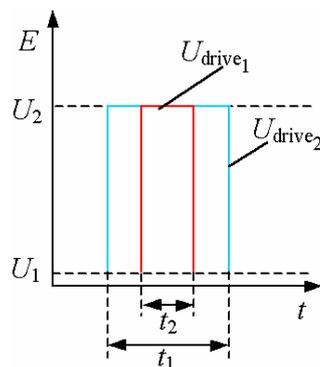


Fig. 6 The time delay digram of the resulting driving pulses - U_{drive_1} and U_{drive_2} of transition Z_4

The whole GN model of the artificial antennae sensors' system work is depicted in Fig.7. Here it should be noted that the labeled circles mark the input and output places, while the transitions are marked with a small labeled equilateral triangle, turned with his base top to the ground and followed by a simple solid line. The different links (including the internal and external loops) between the transitions are marked with solid pointing arrows, which show their direction. The indexes in to the labels are relative because as it was mentioned above,

GNs are based on the E-R concept, so generally, they are utilized here only for simplicity in the explanation of the established model work description.

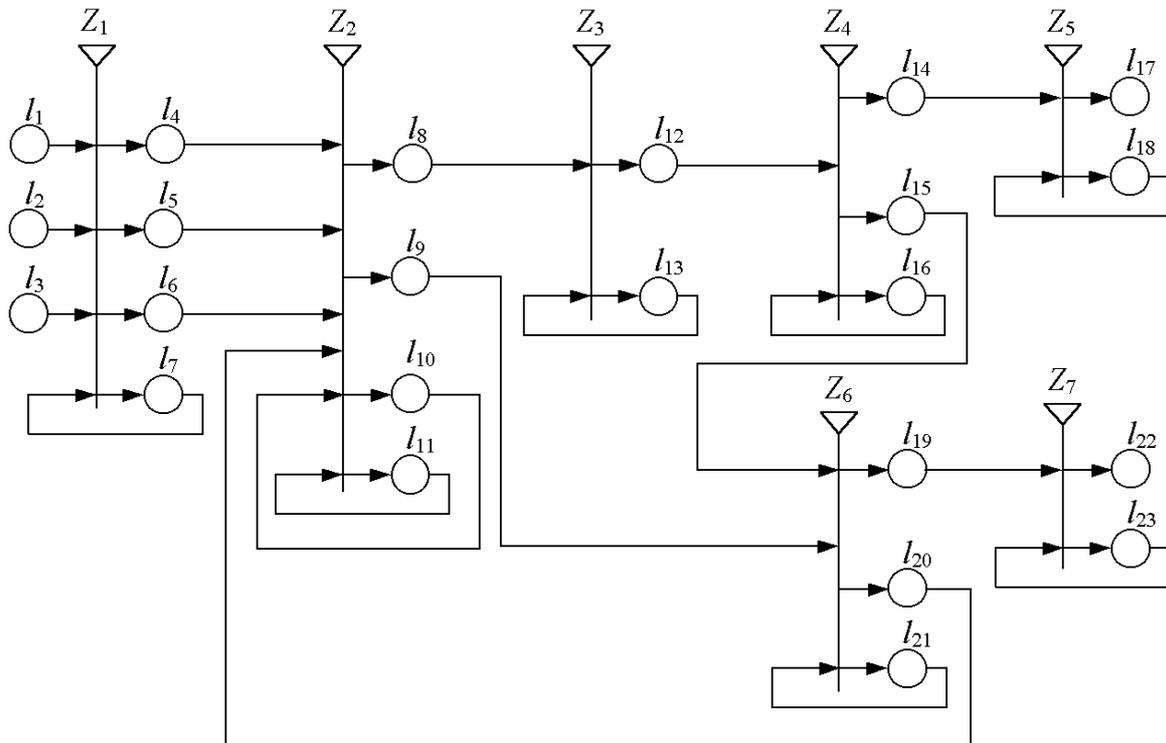


Fig. 7 The Generalized Nets Model of the artificial antennae sensors' system work

Model structure

Transition Z_1 has the following structure:

$$Z_1 = \langle \{l_1, l_2, l_3, l_7\}, \{l_4, l_5, l_6, l_7\}, r_1 \rangle,$$

where:

$r_1 =$	l_4	l_5	l_6	l_7
l_1	<i>true</i>	<i>false</i>	<i>false</i>	<i>false</i>
l_2	<i>false</i>	<i>true</i>	<i>false</i>	<i>false</i>
l_3	<i>false</i>	<i>false</i>	<i>true</i>	<i>false</i>
l_7	<i>false</i>	<i>false</i>	<i>false</i>	<i>true</i>

Transition Z_2 has the following structure:

$$Z_2 = \langle \{l_4, l_5, l_6, l_{10}, l_{11}, l_{20}\}, \{l_8, l_9, l_{10}, l_{11}\}, r_2 \rangle,$$

where:



$r_2 =$	l_8	l_9	l_{10}	l_{11}
l_4	$W_{4,8}$	<i>false</i>	$W_{4,10}$	<i>false</i>
l_5	$W_{5,8}$	<i>false</i>	$W_{5,10}$	<i>false</i>
l_6	$W_{6,8}$	<i>false</i>	$W_{6,10}$	<i>false</i>
l_{10}	<i>false</i>	$W_{10,9}$	<i>true</i>	<i>false</i>
l_{11}	<i>false</i>	<i>false</i>	<i>false</i>	<i>true</i>
l_{20}	<i>false</i>	<i>false</i>	$W_{20,10}$	<i>false</i>

and:

$W_{4,8}$ = “token α_1 is in place l_4 and optical beam interrupter acts as a closed switch”;
 $W_{5,8}$ = “token α_2 is in place l_5 and first couple of tactile sensors acts as a closed switch”;
 $W_{6,8}$ = “token α_3 is in place l_6 and second couple of tactile sensors acts as a closed switch”;
 $W_{4,10}$ = “token α_1 is in place l_4 and optical beam interrupter acts as a closed switch”;
 $W_{5,10}$ = “token α_2 is in place l_5 and first couple of tactile sensors acts as a closed switch”;
 $W_{6,10}$ = “token α_3 is in place l_6 and second couple of tactile sensors acts as a closed switch”;
 $W_{10,9}$ = “token γ is in place l_{10} ”;
 $W_{20,10}$ = “token β is in place l_{20} ”.

Transition Z_3 has the following structure:

$$Z_3 = \langle \{l_4, l_{13}\}, \{l_{12}, l_{13}\}, r_3 \rangle,$$

where:

$r_3 =$	l_{12}	l_{13}
l_8	$W_{8,12}$	<i>false</i>
l_{13}	<i>false</i>	<i>true</i>

and: $W_{8,12}$ = “token β is in place l_8 ”;

Transition Z_4 has the following structure:

$$Z_4 = \langle \{l_{12}, l_{16}\}, \{l_{14}, l_{15}, l_{16}\}, r_4 \rangle,$$

where:

$r_4 =$	l_{14}	l_{15}	l_{16}
l_{12}	$W_{12,14}$	$W_{12,15}$	<i>false</i>
l_{16}	<i>false</i>	<i>false</i>	<i>true</i>

and: $W_{12,14}$ = “token β is in place l_{12} ”;

$W_{12,15}$ = “token β is in place l_{12} ”;

Transition Z_5 has the following structure:



$$Z_5 = \langle \{l_{14}, l_{18}\}, \{l_{17}, l_{18}\}, r_5 \rangle,$$

where:

$$r_5 = \begin{array}{c|cc} & l_{17} & l_{18} \\ \hline l_{14} & W_{14,17} & false \\ l_{18} & false & true \end{array}$$

and: $W_{14,17}$ = “token β is in place l_{14} ”;

Transition Z_6 has the following structure:

$$Z_6 = \langle \{l_9, l_{15}, l_{21}\}, \{l_{19}, l_{20}, l_{21}\}, r_6 \rangle,$$

where:

$$r_6 = \begin{array}{c|ccc} & l_{19} & l_{20} & l_{21} \\ \hline l_9 & W_{9,19} & false & false \\ l_{15} & false & W_{15,20} & false \\ l_{21} & false & false & true \end{array}$$

and: $W_{9,19}$ = “token γ is in place l_9 ”;

$W_{15,20}$ = “token β_1 is in place l_{15} ”.

Transition Z_7 has the following structure:

$$Z_7 = \langle \{l_{19}, l_{23}\}, \{l_{22}, l_{23}\}, r_7 \rangle,$$

where:

$$r_7 = \begin{array}{c|cc} & l_{22} & l_{23} \\ \hline l_{19} & W_{19,22} & false \\ l_{23} & false & true \end{array}$$

and: $W_{19,22}$ = “token γ is in place l_{19} ”;

Model work

The model work will be described in ten steps that consider one cycle of its modelling time. After finishing the cycle, these steps are repeated from the beginning in a new cycle. An assumption for localized object from the sensor and preliminary start of the robot MR1 is made in the model.

Step I: Tokens $\alpha_1, \alpha_2, \alpha_3, \delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6, \delta_7$ and ε enter places $l_1, l_2, l_3, l_7, l_{11}, l_{13}, l_{16}, l_{18}, l_{21}, l_{23}$ and l_{10} of the transitions $Z_1, Z_2, Z_3, Z_4, Z_5, Z_6$ and Z_7 with the following initial characteristics:

$X_0^{\alpha_1}$ = “current physical state of the optical beam interrupter switch”;

$X_0^{\alpha_2}$ = “current physical state of the first couple of tactile sensor switch”;



$X_0^{\alpha_3}$ = “current physical state of the second couple of tactile sensor switch”;

$X_0^{\delta_i}$ = “supply voltage of the i^{th} module of the system”, $i = 1, 2, \dots, 6$;

X_0^ε = “ $S_{\text{gate}} = \text{“opened”}$ ”, $S_{\text{gate}} \in \{\text{opened}, \text{closed}\}$, i.e. the current state of the electronic gate, which initially should be opened (see below).

Step II: Tokens α_1 , α_2 and α_3 enter places l_4 , l_5 and l_6 of the transitions’ couple $Z_1 - Z_2$. They obtain the following new characteristics:

$X_1^{\alpha_1}$ = “current electrical state of the optical beam interrupter switch”;

$X_1^{\alpha_2}$ = “current electrical state of the first couple of tactile sensor switch”;

$X_1^{\alpha_3}$ = “current electrical state of the second couple of tactile sensor switch”.

Step III: Tokens α_1 , α_2 and α_3 are divided in two new groups of tokens: $\alpha_i - \alpha_i'$, $i \in \{1, 2, 3\}$. The first group of these tokens - α_1 , α_2 and α_3 , enter place l_8 of transitions couple $Z_2 - Z_3$, where they unite into one new token - β . The second group of these tokens - α_1' , α_2' and α_3' , enter place l_{10} , where they are also united with the ε token from *Step I* into one new token - γ . This is conceivable if predicates: $W_{4,8}$ = “token α_1 is in place l_4 and optical beam interrupter acts as a closed switch”, $W_{5,8}$ = “token α_2 is in place l_5 and first couple of tactile sensors acts as a closed switch”, $W_{6,8}$ = “token α_3 is in place l_6 and second couple of tactile sensors acts as a closed switch”, $W_{4,10}$ = “token α_1' is in place l_4 and optical beam interrupter acts as a closed switch”, $W_{5,10}$ = “token α_2' is in place l_5 and first couple of tactile sensors acts as a closed switch” and $W_{6,10}$ = “token α_3' is in place l_6 and second couple of tactile sensors acts as a closed switch” are *true*.

Here it should be noted that if some of these predicates’ value is *false*, the tokens from the corresponding places stay there until the next cycle when they are united with the new tokens and obtain their new characteristics.

Tokens β and γ obtain the following new characteristics:

X_0^β = “single pulse generator driving voltage relevant to logical unit”;

X_0^γ = “index (indexes) of the closed electrical switches - optical beam interrupter or (and) tactile sensor switches and $S_{\text{gate}} = \text{“opened”}$ ”.

Step IV: Token β enters place l_{12} of transitions couple $Z_3 - Z_4$ if predicate $W_{8,12}$ = “token β is in place l_8 ” is *true*. It obtains the following new characteristic:

X_1^β = “single pulse driving voltage”;

Step V: Token β is divided into two new tokens – β and β' . The first one - β , enters place l_{14} of transitions’ couple $Z_4 - Z_5$ and the second one - β' , enters place l_{15} of transitions’ couple $Z_4 - Z_6$. This is conceivable if predicates: $W_{12,14}$ = “token β is in place l_{12} ” and $W_{12,15}$ = “token β' is in place l_{12} ” are *true*. They obtain the following new characteristics:

X_2^β = “ U_{drive_2} ”;

$X_0^{\beta'}$ = “ U_{drive_1} ”.



Step VI: Token β enters place l_{17} of transition Z_5 and token β' , enters place l_{20} of transitions' couple $Z_2 - Z_6$. This is conceivable if predicates: $W_{14,17} =$ "token β is in place l_{14} " and $W_{15,20} =$ "token β' is in place l_{15} " are *true*. They obtain the following new characteristics:

$$X_3^\beta = "U_{\text{drive-motors}}";$$
$$X_1^{\beta'} = "S_{\text{gate}} = \textit{closed}";$$

Step VII: Token β' enters place l_{10} of transition Z_2 where it unites with token γ from *Step 3* into a new token - γ_1 . This is conceivable if predicate: $W_{20,10} =$ "token β' is in place l_{20} " is *true*. Token γ_1 obtains the following new characteristic:

$$X_0^{\gamma_1} = X_0^\gamma = \textit{"index (indexes) of the closed electrical switches - optical beam interrupter or (and) tactile sensor switches and } S_{\text{gate}} = \textit{closed}";$$

Step VIII: Token γ_1 is divided into two new tokens - γ_1 and γ_1' . The first one - γ_1 stays at place l_{10} of transition Z_2 and the second one - γ_1' enters place l_9 of transitions' couple $Z_2 - Z_6$.

This is conceivable if predicate: $W_{10,9} =$ "token γ_1' is in place l_{10} " is *true*.

It obtains the following new characteristic:

$$X_0^{\gamma_1'} = \textit{"index (indexes) of the closed electrical switches - optical beam interrupter or (and) tactile sensor switches and } S_{\text{gate}} = \textit{closed}";$$

Step IX: Token γ_1' enters place l_{19} of transitions' couple $Z_6 - Z_7$ if predicate: $W_{9,19} =$ "token γ_1' is in place l_9 " is *true*. It obtains the following new characteristic:

$$X_1^{\gamma_1'} = \textit{"index (indexes) of the closed electrical switches - optical beam interrupter or (and) tactile sensor switches}";$$

Step X: Token γ_1' enters place l_{22} of transition Z_7 if predicate: $W_{19,22} =$ "token γ_1' is in place l_{19} " is *true*. It obtains the following new characteristic:

$$X_2^{\gamma_1'} = "U_{\text{transmitter}_i}, i = 1, 2, \dots, n, n \in \mathbf{N}, \text{ where } n \text{ denotes the number of possible codes for the transmitting voltage. Here } n = 3, \text{ because only three groups of sensors are implemented in the artificial antennae system – two tactile couples and one optical beam interruption circuit.}$$

With this step, one full cycle of the represented model work was established, however it should be noted that the represented model work considers only the situation when there is an object detected by some of the sensors implemented in the artificial antennae. Otherwise as it was noted in the *Step II* description, the circuit waits the above-mentioned event.

Conclusion

The revealed artificial model of real biological antennae sensors' system gives a possibility for practical implementation of the animated nature principles in the new technologies development. Above all this system is practically tested in a real environment by means of the robot MR1. This solution makes the present considerations more valuable by means of their ability to be implemented elsewhere in robotics. Here it should be noted that except a simple solution the present paper could be considered as a small research in the biologically inspired



robotics sensors. The reason for this is hidden in the fact that except just a single solution the author has also tested the object-reflection approach and marked the pros and cons of the both solutions.

As for the established tool for modelling in this paper – the Generalized Nets it should be noted that they give a possibility to understand the presented model in a holistic and general way by means of the author attempts for creating a common and comprehensive theoretical approach for modular robots description, modelling and simulation from one hand and from another to utilize the tool of GNs in their real-time control. The last shows the great flexibility of the GNs as a broad spectrum modelling theory. However it should be noted that as far as the represented solution is just a model of the real biological antennae their practical abilities are functionally limited but fortunately practically effective or at least applicable.

Refereces

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