Dimension Computing of Rigid Group of Organism in Unknown Environment and Robot's Perception of the Physical World Structure

Blagoj Ristevski[1], Violeta Manevska[2], Elena Vlahu–Georgievska[3], Nikola Rendevski[4]

Abstract – **In this paper we present the obtaining of sensor outputs, if the motor commands and the parameters which describe the organism's environment are known. The organism is composed of an arm that is fixed to a basis. The arm is composed of four joints where there are some proprioceptive sensors. The arm has two fingers; each has an eye with photosensors. We perform a simulation to obtain the dimensions when the body changes, the environment changes and both change.**

Keywords: **cognitive robotics, sensorimotor system, sensorimotor dependencies, dimension computing,**

I. Introduction

In the robotics, a steady challenge is the objects position in the 3D space. A main problem is how the robot understands the space, what it happens in robot's "brain", what is the position and orientation of its parts (joints). Also, it is necessary to know how its joints should move and rotate to particular space position. The parts of a manipulator, joints or tools with which it works, as well as the other objects in its environment, are described with two attributes: position and orientation.

In order to describe the position and the orientation of some body in the space, a coordinate system is added to that body. Afterwards, the position and the orientation of that coordinate system are described in regard to some referent coordinate system. Each joint can be observed as a rigid body in relation to the referent system. The position and the rotation are defined for each joint. A rotation matrix is used to describe the orientation of each robot's eye.

In the second section we describe the problem of inverse kinematics, i.e. how the controllable coordinates of each joint are obtained. In the following section, we depict the robot's sensorimotor system. The fourth section describes the robot's organism and its environment. The results of the experiment, obtained by using MATLAB, are depicted in the Section 5. Finally, in the last section we provide concluding remarks about dimensionality computing when the robot's body changes, the environment changes and both change .

[1]Blagoj Ristevski is with the Faculty of Administration and Information Systems Management, Partizanska b.b. (kompleks kasarni), 7000 Bitola, Macedonia
e-mail: blagoj.ristevski@uklo.edu.mk

[2]Violeta Manevska, [3]Elena Vlahu–Georgievska, [4]Nikola Rendevski are with the Faculty of Administration and Information Systems Management, Partizanska b.b. (kompleks kasarni), 7000 Bitola, Macedonia

II. Inverse Kinematics

To move the manipulator from one to another location, it is necessary to move every joint for particular distance in particular time. Most frequently, every joint starts and ends the movement simultaneously, so the manipulator's movement seems coordinated. The method for computing of these movement functions is known as the trajectory generation. This problem of inverse kinematics can have one or more solutions or no solution at all. A system of transcendental equations should be solved. If controllable coordinates can be obtained with an algorithm, then the manipulator is solvable. As example, we will observe a robot's planar articulated arm with four joints, fixed to rigid base. Let l_1, l_2 and l_3 denote the joint lengths which are given. Let the last coordinate (x,y) and the angle value $\theta=\theta_1+\theta_2+\theta_3$ is given [4]. Then, we can write the following equations system Eq. 1:

$$\begin{aligned} x &= l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) \\ y &= l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3) \\ \theta &= \theta_1+\theta_2+\theta_3 \end{aligned} \tag{1}$$

The controllable coordinates of each joint should be found, i.e. the angles θ_1, θ_2 and θ_3 should be computed according to Eq. (1). But this is a mathematic approach.

The next step is to answer the question how one robot realizes the reality, especially the representation of the body, the environment, the space, the objects and their attributes. Also, what conclusion the robot should obtain about computing of input-output dependencies, and the minimal number of parameters, which are necessary to describe its inputs and outputs.

In this paper we show that there is a simple procedure which a robot can utilize to notice the differences between the body and the external environment. The robot can control its body, but its environment cannot. Also, it is shown that the "brain" of robot can infer the dimensionality of external physical space and the additional nonspace parameters necessary for describing objects attributes or entities, without any prior knowledge.

For that purpose it is observed one simply organism which consists of an articulated arm, fixed on a base. At the end of each finger, there is a composite eye with many photosensors. Also, the organism has proprioceptive devices, which signal the position of the different arm parts. The environment is consisting of a set of lights. Signal transmission is provided from the sensors to the brain, which controls the effectors, which move the arm.

The space environment can be divided into two parts. The organism has a total control over the first part (organism body). The organism has partial control over the second part which is called organism environment. There are two types of inputs. The first ones are called proprioceptive, and the second ones are exteroceptive. The body is stationery when the proprioceptive is constant, and the environment is stationery when the exteroceptive is constant.

III. Mathematical Model of Sensorimotor System

An environment whose sets of state E is a manifold $\mathcal{E}$ with dimension e is considered [1] [2] [5] [6]. The set of all observed sensor inputs S is a manifold $\mathcal{S}$ with dimension s and the set of all possible outputs M is a manifold $\mathcal{M}$ with dimension m. Their dependences are given by Eq. 2:

$$\begin{aligned} S &= \psi(M, E) \\ \mathcal{S} &= \psi(\mathcal{M} \times \mathcal{E}) \end{aligned} \tag{2}$$

According to standard mathematical tools with manifolds, the tangent space $\{dS\}$ of $\mathcal{S}$ is considered in a particular point $S_0 = \psi(M_0, E_0)$.

In the $\{dS\}$ two natural subspaces are identified:

- a vector subspace $\{dS\}_{dE=0}$ of sensor input changes, determined only by the motor command changes and
- a vector subspace $\{dS\}_{dM=0}$ of sensor input changes, determined only by the environment changes.

The aforementioned can be described with Eqs. 3 and 4:

$$dS = \left.\frac{\partial \psi}{\partial M}\right|_{(M_0,E_0)} dM + \left.\frac{\partial \psi}{\partial E}\right|_{(M_0,E_0)} dE \tag{3}$$

or

$$\{dS\} = \{dS\}_{dM=0} + \{dS\}_{dE=0} \tag{4}$$

Their intersection is a manifold, too.

In order to find the dependencies of defined entities' dimensions, the term compensability is defined. The compensability defines a class of body movements with particular structure. When the body makes such movement, then its movement to return back to its original position is called compensating movement. If the body makes two consecutive compensating movements, then the global result movement is compensating, too. This class of movement has a mathematical structure of group with identity element - stationarity. One element from this group is a compensating transformation of the exteroceptive body. In the same way a group of compensating transformation of the body-environment system can be defined. The compensability implies that there is something common between particular body movement and particular environment movement. It could be stated that the body and the environment are incorporated in one entity called space. An approximation to space concept is made by sensorimotor approach [3]. Let

$$T = \{dS\}_{dM=0} \cap \{dS\}_{dE=0} \tag{5}$$

$dS_{dM=0}$ is compensating if

$$\begin{aligned} &\exists dS_{dE=0} \big| dS_{dM=0} + dS_{dE=0} = 0 \Leftrightarrow dS_{dM=0} = -dS_{dE=0} \Leftrightarrow \\ &\Leftrightarrow dS_{dM=0} \in T \end{aligned} \tag{6}$$

According to Eqs (5) and (6), the space of compensated movement has the dimension of T. The following equation applies to the dimension of these spaces:

$$\begin{aligned} &\dim\{S_{dM=0} + dS_{dE=0}\} = \dim\{dS\}_{dM=0} + \\ &+ \dim\{dS\}_{dE=0} - \dim\{dS_{dM=0} \cap dS_{dE=0}\} \end{aligned} \tag{7}$$

To put it in a different way: $d=p+e-b$, where $d=\dim\{dS\}$ and $b=\dim T=\dim\psi(M_0,E_0)$.

IV. Robot's Body and Environment

A case, when the organism is composed of an articulated arm fixed to a base, is considered. The arm consists of four joints. Each of the joints has five proprioceptive sensors. The arm has two fingers, and on each finger there is one eye. Each eye is composed of composite "retina" with 20 omnidirection photosensors. The environment consists of three lights (Fig. 1).

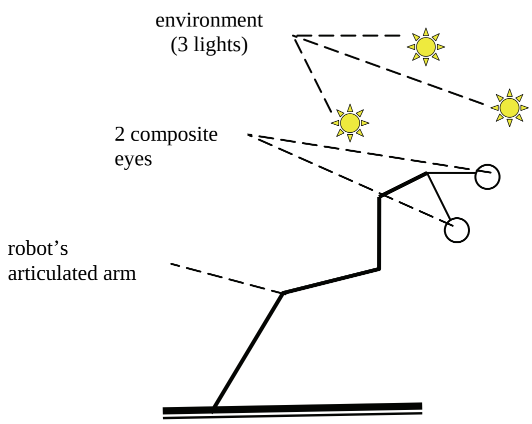

Fig. 1 Robot's articulated arm with 2 fingers and 2 eyes in an environment of 3 lights .

The motor command that moves the organisms is 40 dimensional vector. A 9-dimensional vector is jointed to the environment (the space position of the three lights). The values of sensor inputs (for exteroceptive and proprioceptive sensors) are obtained by using matrices and vectors by chance. The results of these accounts are made by using MATLAB [7]. The motor commands are simulated in the following way [6]:

$$
\begin{aligned}
&(Q,P,\alpha)=\sigma(W_1\sigma(W_2\cdot M-\mu_2)-\mu_1)\\
&L=\sigma(V_1\sigma(V_2\cdot E-\nu_2)-\nu_1)\\
&S^e_{i,k}=d_i\sum_j\frac{\theta_j}{\left\|P_i+Rot(\alpha_i^\theta,\alpha_i^\varphi,\alpha_i^\psi)\cdot C_{i,k}-L_j\right\|^2}\\
&S^p_i=\sigma(U_1\sigma(U_2\cdot M-\tau_2)-\tau_1)
\end{aligned}
\tag{8}
$$

where W_1, W_2, V_1, V_2, U_1, U_2 are matrices obtained from uniform distribution between -1 and 1, by chance, also and vectors μ_1, μ_2, ν_1, ν_2, τ_1, τ_2 .σ is arbitrary nonlinearity, in this case a hyperbolic tangent function. $C_{i,k}$ are obtained by central normal distribution, whose variance could be conceived as the retina size, so the sensor changes are results from the eye rotation, which is from the same order as translation changes of the eye. In Eq. (8) the matrix Q contains the position of the joints, matrix P – position of the two eyes, $(\alpha_i^\theta,\alpha_i^\varphi,\alpha_i^\psi)$ - the euler angles of i-th eye orientation, Rot – rotation matrix of i-th eye, $C_{i,k}$ – the relative position of k-th photosensor with respect to i-th eye, d – diaphragm blends of both eyes, L- the space positions of the three lights, θ - their illumination. $S_{i,k}{}^e$ presents sensor input of k-th exteroceptive sensor of i-th eye, $S_i{}^p$ – sensor input of i-th proprioceptive. M and E present the motor commands and control vector of environment, respectively.

V. Results

The 40 eigenvalues λ_i are obtained from covariance matrix of the 40 exteroceptive inputs, for 50 performed measurements. Then, the ratios between eigenvalue i to eigenvalue i+1 λ_i/λ_{i+1} are calculated, where i is eigenvalue index. The maximum one of these ratios is found, which indicates the biggest change in the eigenvalue magnitude (Fig.2 - Fig. 4). The dimensions of the tangent spaces from this maximum ratio are obtained. From the Fig. 2, the obtained dimension b=4, in case when both the environment and the body change.

Similarly, the maximum ratio of eigenvalues is found, in case only body changes, but the environment is stationary (Fig. 3). The last case is shown at Fig. 4 (only environment changes).

From previous numerical accounts and from the graphic presentations of Fig. 2- Fig. 4, the dimensions are estimated: the body dimension (p), the environment dimension (e) and both (e). A relation between the dimensions of all defined entities should be found. It is shown that the dimension of compensated movements space is the same with the dimension of the space of the compensating movements (Eqs. (5) and (6)). For that reason the space of compensated movement has the dimension of T. The derived dimension of the rigid group (d) could be calculated in the following way: d=p+e-b=4+4-4 (the obtained dimensions depend on the motor command vector M and the environment vector E, which in our case are generated by chance). It could be concluded that the obtained dimension of tangent spaces is the same as the significant non-zero values. The maximal ratio between the i-th and the i+1-th eigenvalue, indicates the biggest change in the magnitude of the eigenvalues.

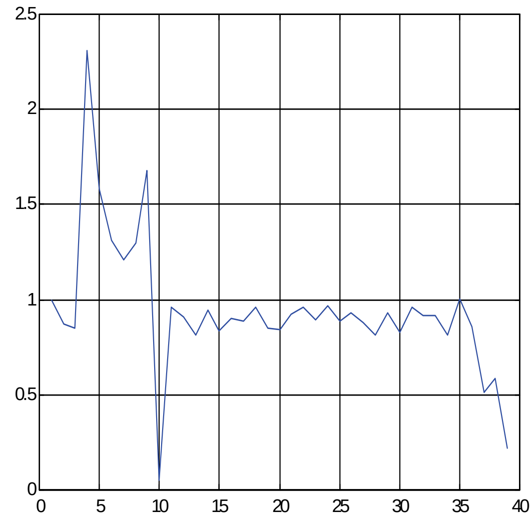

Fig. 2. Graphic presentation of the ratios λ_i/λ_{i+1} when both, environment and body change. The dimension b=4.

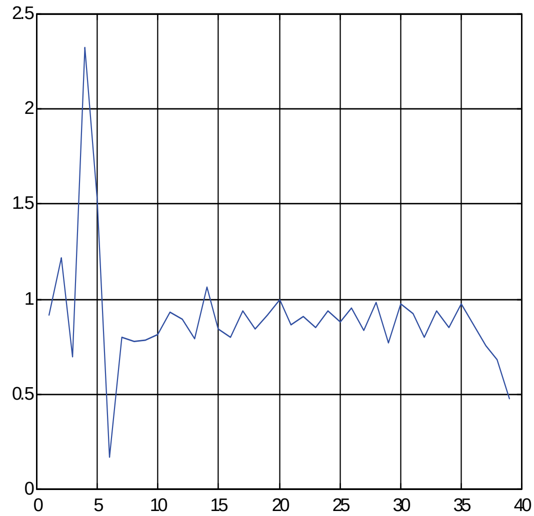

Fig. 3. Graphic presentation of the ratios λ_i/λ_{i+1} when the body changes. The dimension p=4.

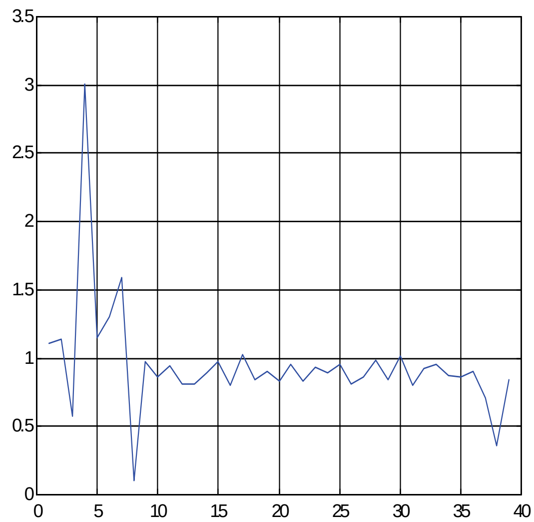

Fig. 4. Graphic presentation of the ratios λ_i/λ_{i+1} when the environment changes. The obtained dimension e=4.

VI. Conclusion

In this article, we demonstrated a way of inferring the dependency between input and output of a robot, and a way of dimension computing, too. We have computed the dimension -the number of variables necessary to describe the environment (in our case it contained 3 lights). We made the dimension accounts for 3 cases: when the body changes, when the environment changes, and when both change.

References

[1] A. Howard, G. S. Sukhatme, M. J. Mataric, "Multi-Robot Mapping using Manifold Representation", IEEE International Conference on Robotics and Automation, pp. 4198-4203, New Orleans, Louisiana, April, 2004.

[2] M. Gretzer, H. I. Christensen, "Should your robot do Lie Bracket Estimation?", October, 2006.

[3] R. A. Peters II, O. C. Jenkins, "Uncovering Manifold Structures in Robonaut's Sensory-Data State Space", IEEE-RAS International Conference on Humanoid Robots, IEEE, 2005.

[4] V. Kumar, "Introduction to Robot Geometry and Kinematics".

[5] D. Philipona, J. K. O'Regan, J.-P. Nadal, O. J.-M. D. Coenen, "Perception of the structure of the physical world using unknown multimodal sensors and effectors".

[6] D. Philipona, J.K.O'Regan, J.-P. Nadal, "Is there something out there? Inferring space sensorimotor dependencies", Neural Computation, 15(9), 2003.

[7] www.mathworks.com