Anthropomorphic Criterial Technique to Control a Robotic Prosthesis

A. P. Gusev[1], A. M. Andreev[2]
Bauman Moscow State Technical University
Moscow, Russia
[1]xitren@ya.ru, [2]arkandreev@gmail.com

***Abstract*— Advances in the field of rehabilitation medicine require creation of more advanced prostheses and performance improvement of mechatronic devices characteristics. This will drive a soft rehabilitation cycle. There are many studies that attempt to recreate a dynamic control model that is similar in quality to the human nervous system. In this study, we will shortly analyze modern methods of controlling mechatronic devices and derive formal properties of anthropomorphy. This will give us the effectiveness of prosthesis control during walking and become a basis for synthesis of control programs for anthropomorphic biomechanical prostheses.**

Keywords—* *control method; robotic prosthesis; anthropomorphy; mathematical criteria; sign; synthesis; control

I. Introduction

The behavior term "anthropomorphism" literally means "like a human". In many ways modern research in the field of robotics is designed to level out major properties of machines control logic. Make them a worthy collaboration with man. This approach will solve a large number of issues related to medicine. With the proper level of technology, we will be able to completely and indistinguishably replace person lost functionality. [4]

Robotic complexes will solve huge number of socials and economics set of problems. First, the quality of people's lives will increase significantly. Secondly, the state's spending on social benefits will decrease and people will return to their workplaces.

However, the term anthropomorphic [9], from the engineering design point of view remains "state-of-art". At the moment, there is no precise quantitative qualification concept in this field of science. Our goal is interpreted from the three classical optimization problems point of view:

- minimization of pressure in the place of prosthesis – person connection;
- minimization of the amount of energy consumed by the robotic system;
- similarization with a visual kinetic behavior of the human foot (cosmetic principle).

Modern developed methodologies for managing a lower limb prosthesis can be divided into several conditional classes: controls based on PID (proportional integral derivative controller) and having a behavior of a simple state machine [8] which is designed to switch the phases of the step; predicative model, which is based on the physical model of the prosthesis and analyzing the kinematic correspondence of the real gait of the embedded model; Adaptive techniques that use statistical data to find the best solutions.

The third class is our object of interest. It is this type of control algorithm that allows solving the following types of tasks: using observations to interpret a situation; choosing an appropriate intervening action; adapting to changing environments; learning from experience.

It is these tasks that we can find in real prosthetic and rehabilitation work experience. Using technologies should be adaptive because each person has his own unique physique, gait, changing external environment (not only the type of movement and type of terrain, like the sand, asphalt, but also the weather and seasons). It is impossible to put enough rules into the system so that it can react to absolutely any conditions. It is impossible because of their huge number of combinations.

II. Background and Related Work

The main scientific basis for this research was the results of research and development program named "3.1-EXOMODULE". Within this program was developed and tested basic exoprostheses and controlling electronics models.

In the work of this research was created a set of research services which obtained a knowledge base was developed on the dependence of the final results (the biomechanical deviation from the norm) on the parameters of the solution.

Also, within the framework of this project, conclusions were drawn on the need to actively manage the bionic leg prosthesis to increase the speed of movement over uneven surfaces and increase the working time of the battery [7].

III. Proposed Technique

In this paper, we propose to use a semantic Bayesian networks as a dynamic control system. Described dynamic system represents an artificial intelligence model. Such a concept will help us to reach satisfaction of evaluation parameters [13] which described in section E. This will also solve the set of problems described in introduction.

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A. *Input parameters*

Any of the signals listed in Table 1, can be used as an input parameters of the system. The list is quite complete, because covers a different range of tasks. Of course, for the most effective management, you did like to have as much information about the processes as possible. But this is not possible outside the laboratory.

TABLE I. DATA TYPES, USED AS INPUT PARAMETERS

Parameter type	Signal source	K	Chan.	Freq.
Functional	Electroencephalography	1	8	250 Hz
	Electrocardiogram	1	1	250 Hz
	Electromyogram	1	4	4 kHz
Kinematic	Knee angle sensor	1	1	3 kHz
	Thigh angle sensor	1	1	3 kHz
Dynamic	Transverse force in the prosthesis	1	1	3 kHz
	Longitudinal force in the prosthesis	1	1	3 kHz
	Sagittal momentum	1	1	3 kHz
Environment	External environment image	2	2	30 Hz
	Eye-tracker pupil image	2	1	200 Hz

Electro-biological signals are used to improve the quality of user physiology interface. They realize proportional speed control in the prosthesis of the lower and upper limb.

Angle, force and moment sensors are the main ways to obtain information about the mechanical limitations. These limitations connected to quality of the prosthesis itself and also the parameters of the gait cycle, shown in Fig. 1.

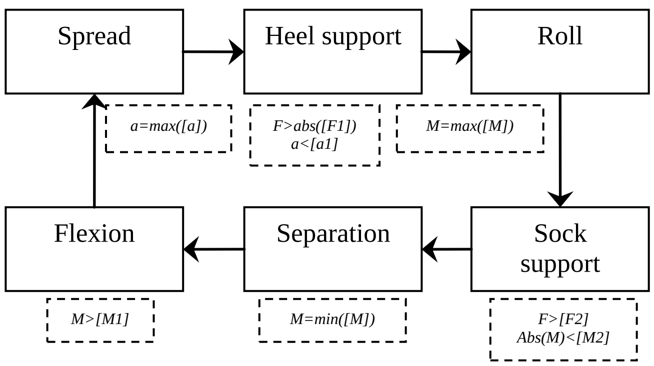


Fig. 1. Gait biodynamics with division on functional cycles, where α1 – knee angle to start heel support; α2 – knee angle for a sitting mode; F1 – force in the prosthesis to start hell support; F2 – force in the prosthesis to start flexion; M1 – moment in the prosthesis to start flexion; M2 – moment in the prosthesis to start separation

External space images give as determination of the direction of viewpoint in spatial coordinates [1]. Images can be used to automatically switch between obstacles overcoming modes (for example, switching to climbing stairs mode).

B. *Dynamic control system architecture*

The system architecture management [14] (shown in Figure 2) establishes several separate procedural blocks: the data preparation unit (for statistical analysis); semantic net constructor; dynamic network structure optimizer; block of probability distribution.

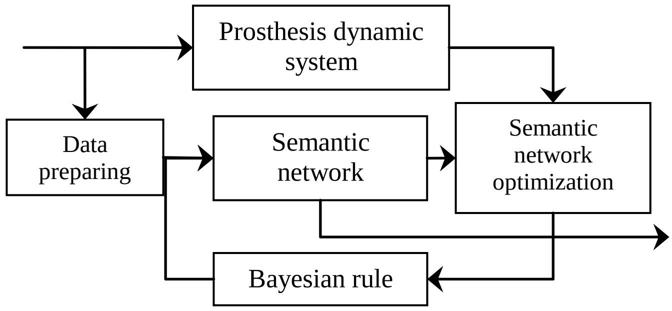


Fig. 2. Architecture of intellectual dynamic control system

C. *Data representation*

In general, each dataset is added to the semantic network as a network fragment. Each network fragment is a homogeneous data class. The data instance representation for the semantic network should be built in the form of a directed acyclic graph (DAG), shown in Fig. 3.

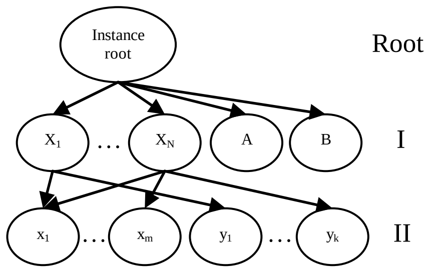


Fig. 3. Generic view on the data instance

A sampled signal unit was extracted from signal flow in the form of a window [11] and used as an input data. For this types of signal use only a single-level network.

For biological signals, the window size was set to 500 milliseconds [3]. For example, in the case of an electroencephalogram, the value of such a window was 128 samples.

Images and multidimensional signals use two levels network for representation. On the first level we describe verticals and parameters. Whereas in the second level described the relationship between the elements of a structure and its dimensions. More details can be found in [10].

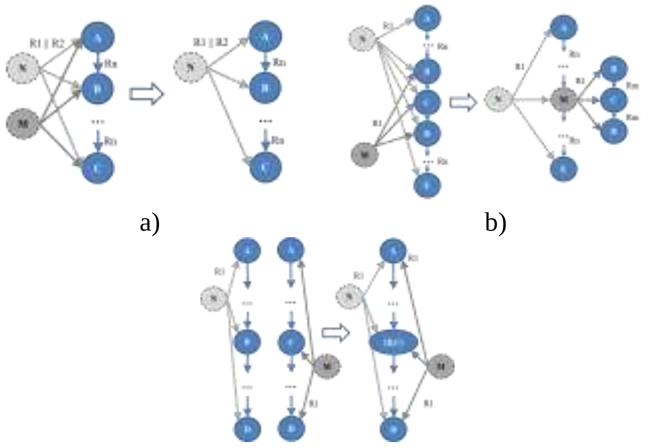
D. *Network optimization rules*

The Bayes net is a set of variables Y, and a set of directed edges C between variables. Each variable has a finite set of mutually exclusive states. The variables together with the directed edges form an acyclic directed graph (DAG). The optimizer of the semantic network monitors compliance with these requirements [6].

Adding new vertices to the graph, we must be convinced of the absence of overlapping structures. This rule is called the equals exclusion rule (Fig. 4a) and is designed solely to optimize the size of the semantic network.

Another rule order the need to determine when one process is part of another process. This rule is called the rule of instantiation (Fig. 4b).

The last rule is aimed at distinguishing finite states of a variable. This rule is called the rule of abstraction (Fig. 4c).



a) b) c)

Fig. 4. Data structure optimization rules

E. Functional procedures

The resulting semantic structure now needs to be recombined to a junction tree [2], for this we perform several simple actions:

1. Inserting conditional distributions in the DAG.

$$p(Y) = \prod_i p(Y_i \mid Y_{pa(i)}) = \prod_i f_i(Y_{C_i})$$

где, $C_i = i \cup pa(i)$ и $f_i(Y_{C_i}) = p(Y_i \mid Y_{pa(i)})$

2. Inferring posterior distributions given observed evidence by adding factors with just one adjacent node (for example, D – pattern n100, C – pattern p300).

$$f_D(D) = \begin{cases} 1 & if\,(D) = n100 \\ 0 & otherwise \end{cases} \quad f_C(C) = \begin{cases} 1 & if\,(C) = p300 \\ 0 & otherwise \end{cases}$$

3. Transforming DAG in undirected moralized graph by simply “marry” all parents of each node by adding edges connecting them, then drop all arrows on edges.

$$p(Y) = \frac{1}{Z} \prod_i f_i(Y_{C_i})$$

4. Triangulate graph by add edges to the graph so that every loop of size > 4 has at least one chord. Note recursive nature: adding edges often creates new loops; we need to make sure new loops of length > 4 have chords too. This needed to prevent this overconfident and oscillatory behavior, we need to make sure that different channels of communication coordinate with each other to prevent double counting.

5. Now translate triangulated graph to junction tree. Junction tree is a tree is a tree where nodes and edges are labelled with sets of variables. Variable sets on nodes are called cliques, and variable sets on edges are separators. A junction tree has two properties: cliques contain all adjacent separators; running intersection property: if two cliques contain variable Y, all cliques and separators on the path between the two cliques contain Y.

In the described above junction tree, probabilities can propagate through messages where the message can be recursively calculated using the following formula:

$$M_{i \to j}(Y_j) = \sum_{Y_i} f_{(ij)}(Y_i, Y_j) \prod_{k \in ne(i) \setminus j} M_{k \to i}(Y_i)$$

IV. Simulation Results

To approbate the developed algorithm we built a high-level class model on the Java language. Also, methods for optimizing the semantic structure were implemented, as phases (1 – concretization, 2 – abstractions, 3 – equivalents). The data of the obtained experiments are presented in Fig. 5 and 6.

The input signal was EEG recording and the recording of the step dynamics, while the results within the parameters evaluated were mostly identical.

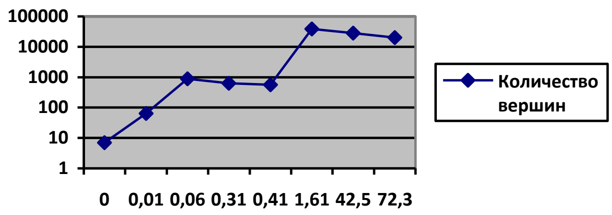


Fig. 5. Number of verticals by time in the simulation of learning process

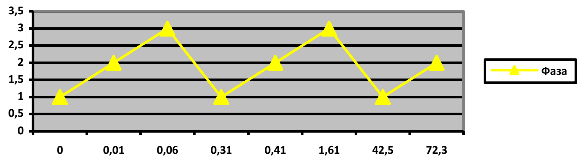


Fig. 6. Changing a phase during the time in the simulation of learning process

V. Conclusion and Future Work

Bayesian networks have effective decision mechanisms with competitive theoretical parameters which makes them very popular for developing dynamic system controls [13]. Nevertheless, classical Bayesian networks have many limitations arising development of the knowledge base. The proposed model allows to simplify the organization and increase the applicability. The introduction of the evaluation also helps to formalize the quality of the adaptation. This is extremely important in order to understand limitations of the constructed algorithm implemented to the problem posed.

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