Modelling of anthropomorphic robots

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Abstract – **The paper presents some aspects of anthropomorphic robots modeling. Thus, considering biomechanical criteria related to the human superior limb a topological synthesis was made. Also, for a parallel anthropomorphic mechanism, the direct and inverse kinematics and dynamics were developed. Both, kinematics and dynamics were developed in a modular manner, in order to increase reconfigurability of the mathematical model of the robotic system.**

I. INTRODUCTION

Anthropomorphic robots are directly related with the human wish to self-outrun. Anthropomorphic mechanisms constitute the mechanical architecture of those robots. Most of the anthropomorphic robots prototypes are basically models of the human arm bone system. That means a serial topology, with rotational joints as actuators. Usually, this type of robots has industrial tasks such as mechanical operations (fitting, drilling, punching, screw fastening, boring, reaming). Also, they can be used in human prosthetics or for other biomedical tasks (Gosselin, C.M., et al., 1996, Merlet, J., 1997). There are also few prototypes of anthropomorphic robots which have parallel mechanisms as mechanical structure (Charoenseang, S. Et al., 1998, Northrup, S., et al, 2001).

The main goal of this work is to develop a modular mathematical model for kinematics and dynamics of the parallel anthropomorphic robots.

II. TOPOLOGY

Anthropomorphic mechanisms are defined as functional and structural models of the human superior limb (HSL). Biomechanical studies related to HSL are praised that there are three main joints in its structure (Fig.1): shoulder, elbow and wrist joint respectively.

There are also, considered three elementary mouvements which can describe, from kinematic point of view the behaviour of an arbitrary human joint. These mouvements are: flexion – extension (F-E), adduction – abduction (Ad-Ab) and pronation – supination or internal rotation – external rotation (P-S or IR-ER).

The shoulder joint is usually modeled as a spherical joint. There are few interpretation related to the movement which can be performed on the level of the elbow and wrist joint respectively.

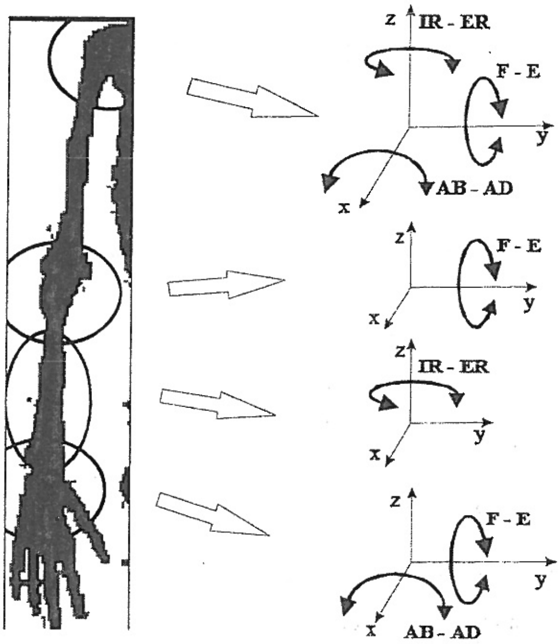


Fig. 1. Degrees of freedom of Human Superior Limb

One of these interpretations considers that at the level of the elbow joint can be performed two movements (F-E) and (P-S). Of course, in this case also only two movements ((F-E) and (P-S)) can be performed at the level of wrist joint. This type of distribution of the degrees of freedom will be note with 3-2-2.

If only the bone – joint system is take into consideration a serial topology for the HSL (with 3-2-2 distribution of dof and named SAM322) it results (Fig.1a).

Based on the parallel elementary mechanisms with three (Fig.2b), two (Fig.2c) and one (Fig.2d) dof, a corresponding model of the muscle-bone-joint system of HSL can be also developed.

Figure 3a presents the graph of the parallel anthropomorphic mechanism (with 3-2-2 dof distribution and named PAM322), which results as a serial connection of the elementary mechanisms. Biomechanics of the HSL praised also that there are muscles, which act at the level of more then one joint. Thus, more then 30 % of the human muscles are two-articular muscles (they acting at the level of two joints). Figure 3b presents the graph of the same mechanism (named PAMB322) if the two-articular muscles are takes into consideration.

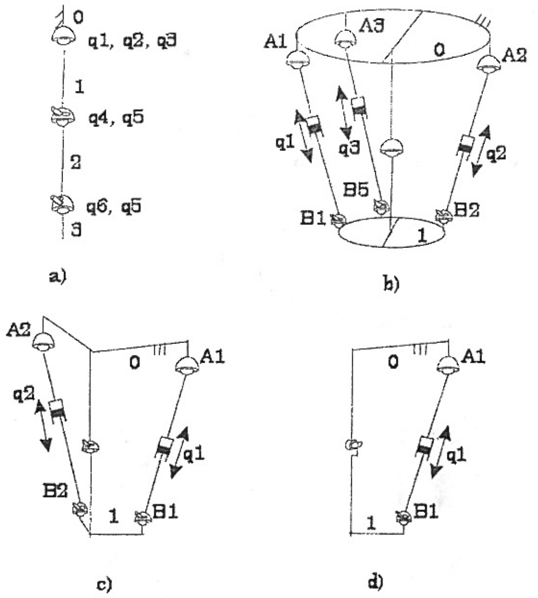


Fig. 2. Anthropomorphic mechanisms

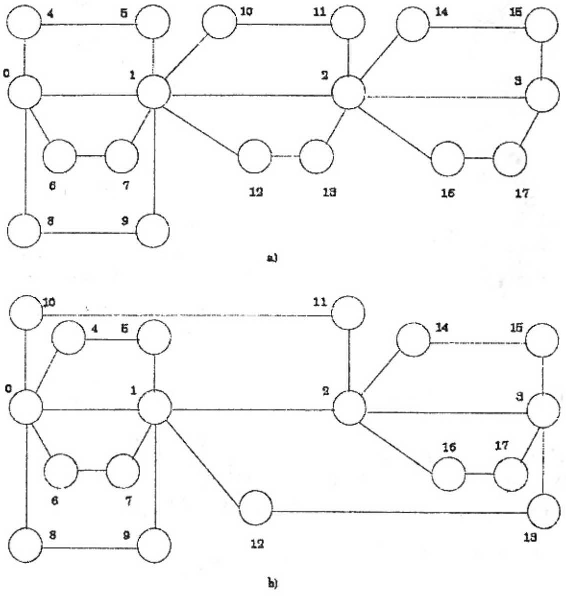


Fig.3.. Graph of the PAM322
and PAMB322 mechanisms

III. KINEMATICS AND DYNAMICS OF ELEMENTARY MECHANISMS

First, kinematics and dynamics of the elementary mechanisms will be presented. Generally, the pose of the mobile platform (position and orientation) is given by (Fig.4):

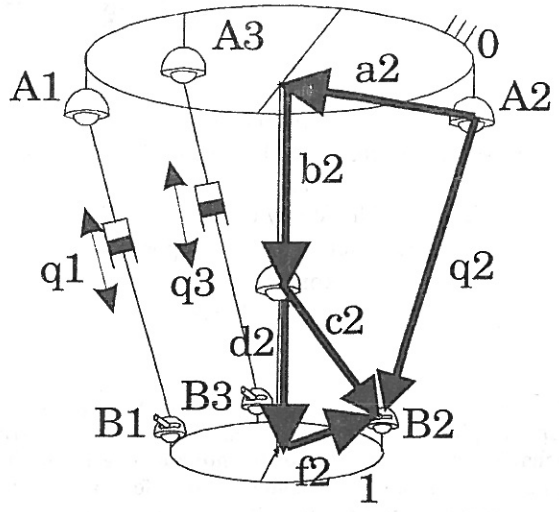


Fig. 4. Kinematics of elementary mechanism with 3 dof

$$\begin{gathered}\|\mathbf{a_i}+\mathbf{b_i}+\mathbf{c_i}\| = \|\mathbf{q_i}\| \\ \|\mathbf{d_i}+\mathbf{f_i}\| = \|\mathbf{c_i}\| \\ |\mathbf{B_iB_j}| = \mathbf{l_{ij}}\end{gathered} \qquad (1)$$

here $\mathbf{l_{ij}}$ is the lenght of the vector $\mathbf{B_iB_j}$. Equations (1) can be used for both forward and inverse kinematics. In the case of forward kinematics, equations (1) is solved using numerical methods. For inverse kinematics it is enough to use first relation of the equations (1).

A line of the inverse Jacobian matrix rows is given by:

$$\mathbf{J}^{-1}{}_{\mathbf{i}} = \left[\frac{\mathbf{c_i}\times(\mathbf{a_i}+\mathbf{b_i})}{\mathbf{q_i}}\right] \qquad (2)$$

The dynamic equations of movement for the elementary mechanisms can be relatively easily developed if the algorithm presented by (Merlet 2000) is respected.

Thus, for the mechanism with 3 dof (Fig. 5), it results:

$$\tau = \mathbf{J}^{*}(\mathbf{T_1}-\mathbf{V_1})\dot{\mathbf{W}}+\mathbf{J}^{*}(\mathbf{T_2}-\mathbf{V_2}) \qquad (3)$$

where all components of the relation (3) are defined by (Merlet, 2000).

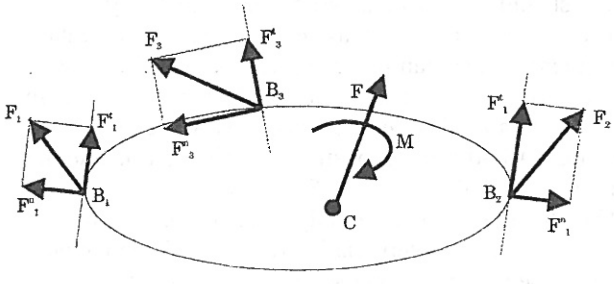


Fig. 5. Forces on the mobile platform

IV. KINEMATICS AND DYNAMICS OF PAM322

Kinematics of the PAM322 (Fig.6) can be developed in modular manner.

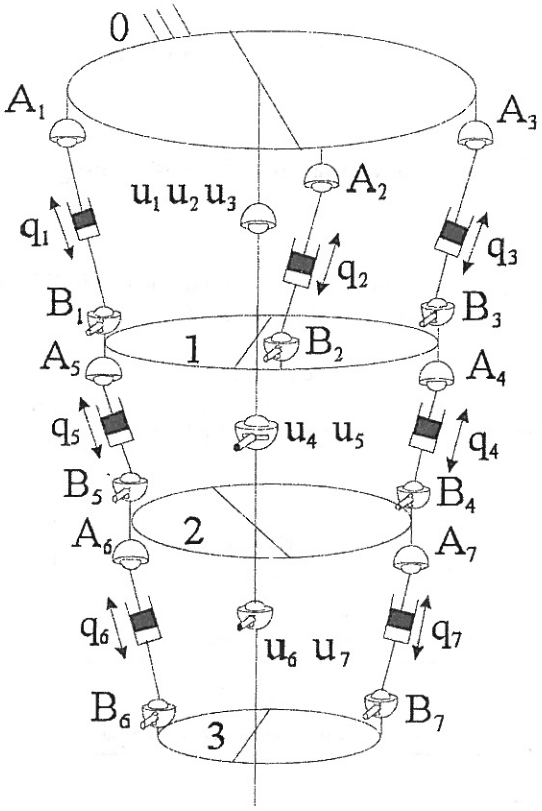


Fig. 6. General representation of PAM322

Thus, if the system (1) is solved, the angles u_I are determinate. The 4 x 4 transformation matrix, which describes the relative movement between mobile platform and fixed platform respectively, is given by:

$$\mathbf{H_i} = \mathbf{H_i}(\mathbf{q_i}, \mathbf{l_i}) = \prod_{i=1}^{3} \mathbf{A}_i(u_i) \tag{4}$$

It results that, for forward kinematics, the solution is given by:

$$\mathbf{H_{03}} = \prod_{j=1}^{3} \mathbf{H_j} \tag{5}$$

The algorithm for the forward kinematics is presented by figure 7.

For inverse kinematics, the absolute position and orientation of the last mobile platform is known. Also, a corresponding open loop (Fig. 8) is considered.

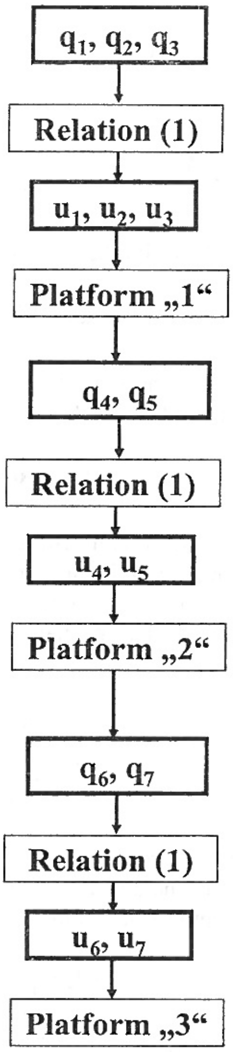


Fig. 7 Algorithm of forward kinematics

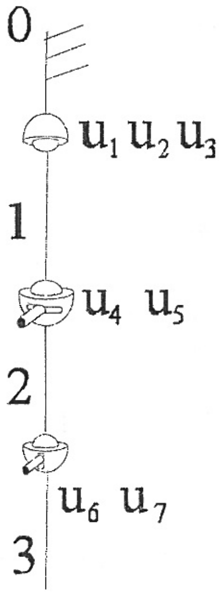


Fig. 8 Inverse kinematics open loop

Using the relations:

$$\prod_{i=j}^{1} A_i^{-1} H_{03} = \prod_{i=j+1}^{7} A_i \,, j = 1,6 \tag{6}$$

it is possible to find the functions:

$$u_i = f_i(u_1) \tag{7}$$

It results that the coordinates of the points A_i and B_i could be expressed as functions of the angle u_1 and:

$$q_i = q_i(u_1) \tag{8}$$

In the case of human arm a criterion for optimization could be the minimization of the mechanical work performed by muscular system.

For PAM322 the mechanical work of the actuated joints is given by:

$$L = \sum_{i=1}^{7} F_i \, q_{ij} \tag{9}$$

where F_i are the forces performed at the level of prismatic joints and q_{ij} are the displacements.

Using (8) and (9) it results:

$$L = L(u_1) \tag{10}$$

From relation (2) is possible to find the value u^*_1 which corresponds to L_{min}:

$$L_{min} = L(u^*_1) \tag{11}$$

The algorithm of the inverse kinematics is presented by figure 3.

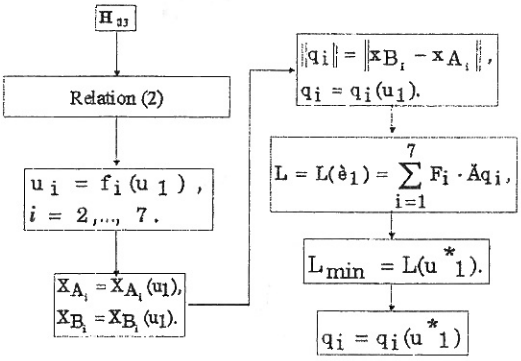


Fig. 9 Algorithm of inverse kinematics

Dynamics of PAM322 can be developed similarly, in a modular manner. Thus, let presume that dynamics of the mobile platform (1) related to the platform (0) is known. Also, the relative dynamics of the platform (2) related to the platform (1) is known.

With these assumtions the impulse and the absolute kinetic momentum of the platform (2) related to the origine of the fixed coordinate system are given by (Brisan, 2003):

$$m\left\{\omega^2{}_{20} + \frac{d\omega_{20}}{dt}\right\} r_{C2} = \sum f_i + m\, a_{O2}$$

$$J_{O2}\frac{d\Xi_{20}}{dt} + \omega_{20} J_{O2} \Xi_{20} = \sum r_{i2} f_i - m r_{C2} a_{O2} \tag{12}$$

where J_{O2} is the inertial matrix related to the origin O2. and all other elements of the relation (12) are kinematic parameters.

The same algorithm can be applied for absolute dynamics of the platform (3). The algorithm of the dynamics for PAM322 is presented by figure 10.

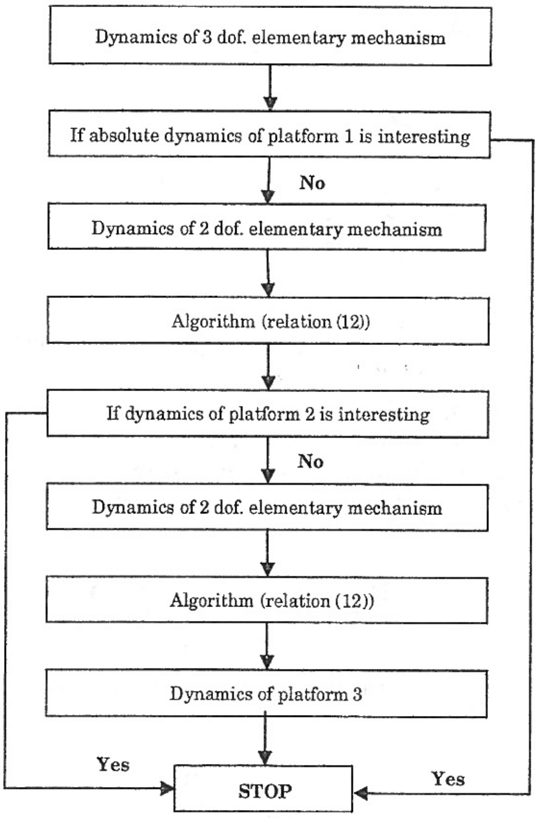


Fig. 10 Algorithm of the dynamics of PAM322

V. NUMERICAL RESULTS AND SIMULATION

In order to simulate different types of movements, a virtual model of PAM322 was created using MOBILE software package (Fig.11). The relative geometrical dimensions of this virtual model were close to those of a human upper arm.

Also, for adopted displacements of the actuators, the absolute position and orientation of the last mobile platform of PAM322 under numerical form were obtained (Fig.12).

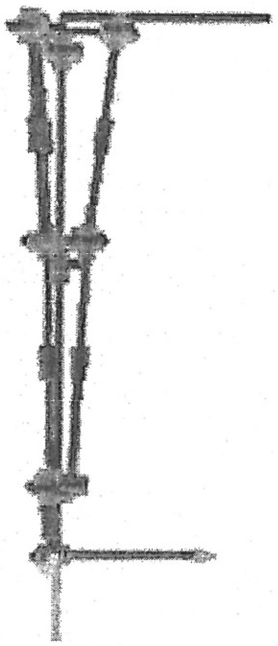
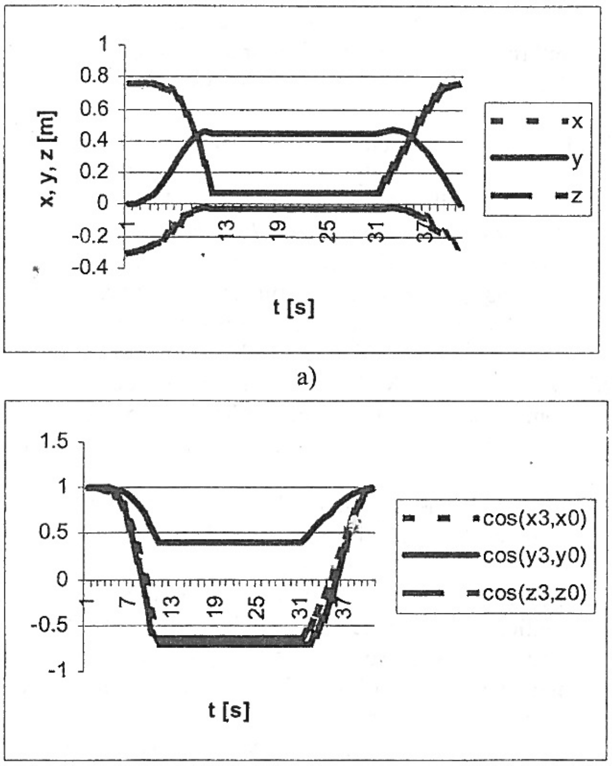


Fig.11 Virtual model of PAM322



a)

b)

Fig. 12. Absolute position (a) and absolute orientation (b) of the platform "3" of PAM322

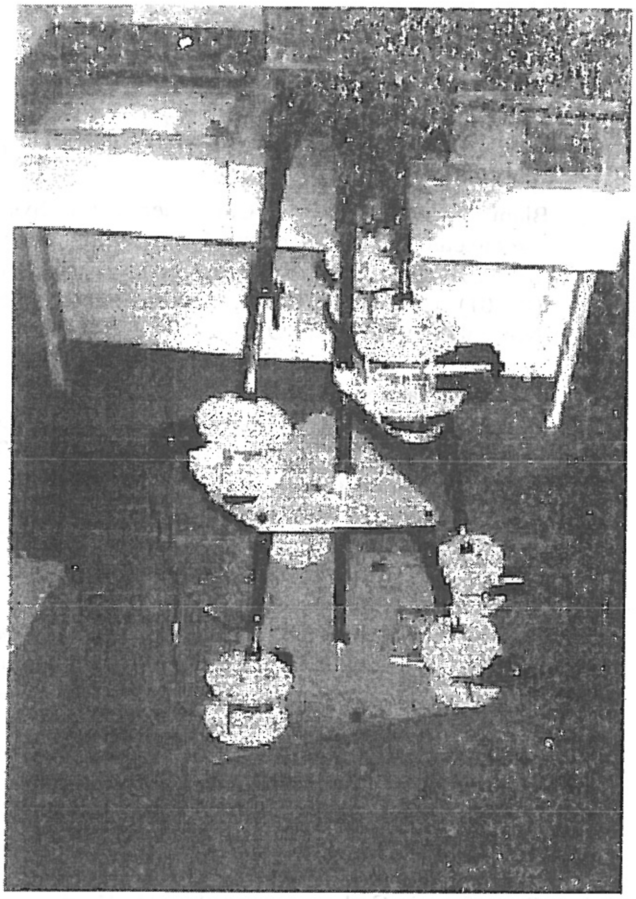


Fig.13 Prototype of PAM322

V. CONCLUSIONS

The human superior arm can be modelled by anthropomorphic mechanisms with parallel topology. Using biomechanical criteria it is possible to find different types of anthropomorphic mechanisms. Both, kinematics and dynamics of PAM can be design in modular manner. This is useful for control model development.

V. ACKNOWLEDGMENTS

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