CONSTRUCTIONS OF HUMANOID ROBOT ARM, CONTROLLING AND LEARNING THE MOVEMENTS OF THEIR JOINTS

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Abstract: The kinematic systems fairly determine the trajectories and their derivatives of the joints/articulations. Thus if a trajectory and its derivatives are given generally, an inverse dynamic task has to be solved. This lecture deals with the construction of 2-6 DOF and 3-4 links robot arms. So between the links 1 or more DOF are operated by the flexor-extensor antagonistic pairs of PAM elements changing the angles arising at the artificial articulations. By developing a humanoid robot arm one has to simplify the structures of muscles/articulations and the human brain functionalities in order to guide and learn the movements.

Keywords: Humanoid robot arm, Pneumatic Artificial Muscle (PAM), Degree Of Freedom (DOF), kinematic constructions, cerebellar folium

INTRODUCTION

The authors' previous publications dealt with the construction of a 2 DOF and 2 links humanoid robot arm (upper-lower arms, shoulder-elbow-wrist punctiform articulations) with operating it by pairs of PAM elements from starting to a target point in a plane (Endrődy et al., 2009). It presented some adaptive/learning algorithms guiding the modification of the angles between the shoulder-upper arm (α_{u0}) at the shoulder and between the upper-lower arms (β_{f0}) at elbow. It is well-known that at the humanoid robots any link to the next link/arm at an articulation of the kinematic systems can possess more than 1 DOF. But at the industrial robot generally every link has only 1 DOF. Thus at the shoulder we can realise 1, 2 or 3 DOF, at elbow 1 DOF, at wrist 1 or 2 DOF, finally at the end of the hand there is a holder by the thumb and the fingers. From these DOFs at the shoulder one generally realise 1 twist DOF around the axe of the upper arm and at the wrist 1 other twist DOF around the "radius's axe" can be realized: the lower arm and the hand moving together. These twist DOFs can be operated and analysed separately from the other flexing DOFs at the shoulder, elbow and wrist. For us the most interesting case is when the arm has equally 1-1 flexing DOF at these articulations together with 3 DOF.

The artificial shoulder articulation can be modellized by a spherical joint or 2 cylindrical flexing joints and 1 joint with twisted axe, which are "near enough" to the shoulder. The elbow can be modellized by 1 cylindrical flexing joint. Finally the artificial wrist can realise virtually by 1 cylindrical flexing joint and 1 other joint with twisted axe (for the lower arm and hand together). In the case of 3 flexing DOF - around parallel directions - the robot arm loses the unambiguous solution for the moving transformation of its hand's holder point (from starting to target point). Keeping the notations for the artificial articulations' angles at shoulder (α) and at elbow (β), we can choose at wrist (γ) for the angle between the axes of the hand and lower arm. Thus, at the beginning of the movements to guard the unambiguous solution, we can transform the arm's holder point by ($\Delta\gamma = 0$), that is the lower arm and the hand will move together.

This lecture deals with 2 or more DOF kinematic systems, humanoid robot arms, their virtual models and their guiding/learning movements. Our basic motivation was that we should define several kinds of kinematic (mechanical) constructions without building up them but their virtual model could be operated for the given tasks and could be tested (Balara and Petík, 2004, Sárosi et al., 2009; Tomán et al., 2008). Having designed mechanically and kinematically these robot arm constructions (and all of their parts) we gave the adequate constraints in every artificial articulations in order to be able to assemble the whole robot arms afterwards. Thus every motion type, controlling and/or learning their typical movements should be studied/analysed without building up all of our constructions to spare a lot of time, money and materials.

ROBOT ARM CONSTRUCTIONS

One can move the Inventor-made virtual robot arm models directly and also by VBA Macro program. So, this lecture deals with guiding and controlling movement-strategies of high priority in the following cases:

- guiding the wrist point (or the holder point) of the robot arm from a starting to a target point,
- controlling the wrist point movements via given trajectory and its first and second order derivatives, too.

There are some moving/controlling strategies but all of them can be characterised by a kind of inverse dynamic controlling process. The Fig. 1. shows a 6 DOF robot arm which was analysed by object oriented VBA Macro programs, too. We tested its movements step by step at some trajectories given. In this robot arm we wanted to modellize1-1 flexing DOF by cylindrical joints at the shoulder, elbow and wrist artificial articulations.

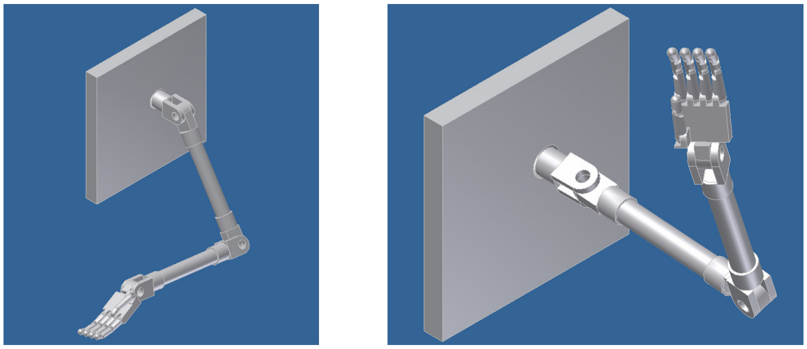

Fig. 1. A 6 DOF humanoid robot arm in two characteristic states

```
Sub Move()    Dim AssemblyDocument As AssemblyDocument
              Dim Angle1Param, Angle2Param As Parameter
              Dim AssCompDef As AssemblyComponentDefinition
              Dim CY1 As Integer
              Set AssemblyDocument = ThisApplication.ActiveDocument
              Set AssCompDef = AssemblyDocument.ComponentDefinition
              Set Angle1Param = AssCompDef.Parameters.Item("Angle1")
              Set Angle2Param = AssCompDef.Parameters.Item("Angle2")
For CY1 = 1 To 45
              Angle1Param.Value = 90 / 180 * 3.14 – 2* CY1 / 180 * 3.14
              AssemblyDocument.Update
              Angle2Param.Value = 45 / 180 * 3.14 + 2 * CY1 / 180 * 3.14
              AssemblyDocument.Update           Next        End Sub
```

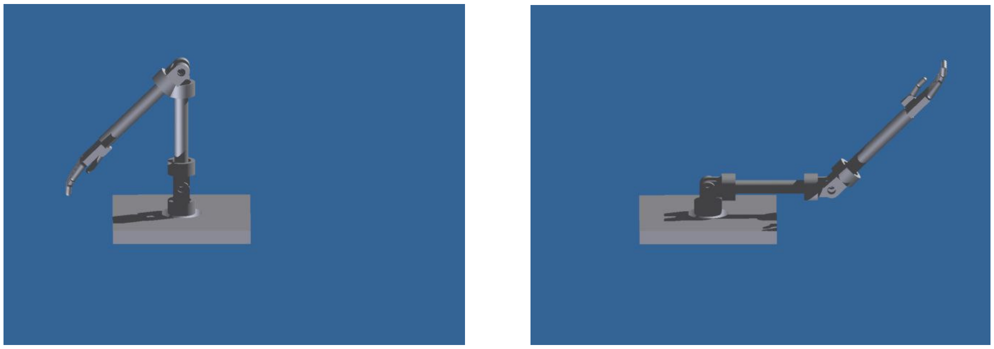

Fig. 2. The VBA Macro program can control this (5 DOF) robot arm by the Angle1 and Angle2 [°] parameters at the shoulder and elbow articulations

The Fig. 2. shows how could be controlled the I.1. (constraint) = Angle1 and II.1. (constraint) = Angle2 parameters of a 5 DOF robot arm by the VBA macro program. We can see the results only for the Angle1 and Angle2 parameters. We also mention that only 2 flexing DOF out of the 3 must be used. In the 6 DOF case the 3rd one at the wrist, e. g. the III.1. (flexing constraint) has to be fixed at the first motion step. At the shoulder and wrist articulations can be realised 1-1 twisting DOF (I.2. and II.2.constraints) around the axes of the links (actual pieces of the arm), the twisting angles are addable sum. At the shoulder we can apply another flexing DOF by a cylindrical joint (I.3. constraint) to realise the 3rd DOF at the shoulder.

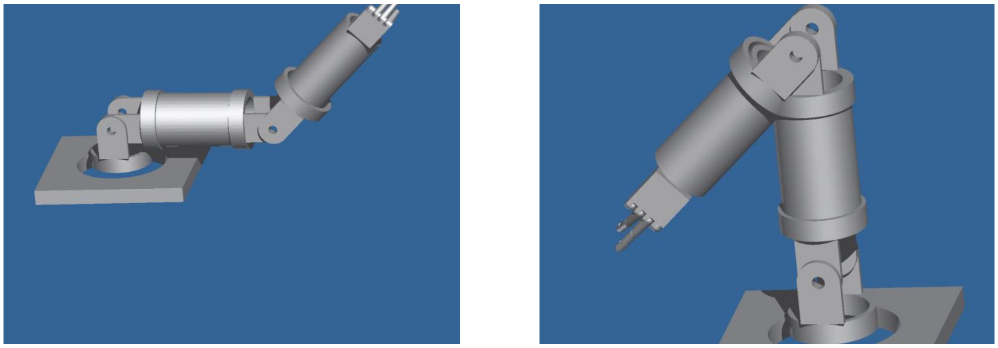

Fig. 3. A kind of Reha-robot arm (5 DOF) also can controlled by a VBA Macro program

There are some other applications of the robot arms: the Fig. 3. shows a virtual kinematic model (Reha-robot arm) for rehabilitating movements for somebody who has arm, muscles, tendons, articulations, but after a stroke or spinal/cerebral injury needs motion-rehabilitation by a kind of robot control. This model was also tested with some VBA macro programs by circular moving steps for any planar target points.

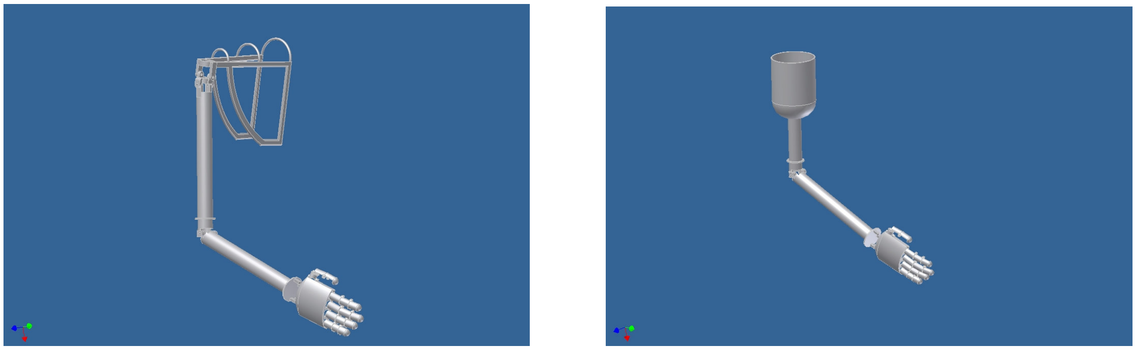

Fig. 4. There are a 4 DOF and another 3 DOF prosthesis analysed

The Fig. 4. shows two experimental arm-prosthesis constructions: 4 DOF prosthesis for replacing the upper and lower arm and other one with 3 DOF for a person who partially lost the upper arm, too.

MOVING-STRATEGIES FOR 2-6 DOF ROBOT ARM

The authors would like to expound some fundamental robot arm moving-strategies which can solve inverse dynamic controlling programming task but we analysed only the unambiguous flexing DOF cases:

- 1st possibility: One can determine the inverse transformation (more generally inverse Jakobi) $T_{j\,i} = T_{ij}^{-1}$ matrix which is simple enough to apply, but only in the 2 DOF cases and besides when only the starting and the target point are given for the robot arm holding point. If the trajectory is also given, we must apply the inverse transformation matrix for $P_i(x_i, y_i, z_i)$ points backward from the target point up to the starting point-densely enough (n-times) along the trajectory. But first we can choose the 2 DOFs (articulations/links) which are most important in the task to solve. In this method we can get a lot of difficulties even in the 2 DOF cases also if we have to solve the task with given 1st and 2nd derivatives of the trajectories and/or the robot arm possesses not only (parallel) flexing DOFs. To solve this task, e. g. the object oriented Inventor VBA Macro programming system is suitable for this aim: writing the controlling program.

- 2nd possibility: We can use the Inventor CAD system itself to produce the inverse dynamic programs to control movement-steps: by defining the "trajectory-rail/track" (for the robot arm holder point) as a continuous polyline which consists of any number of lines, arcs, etc. with tangent constraint; otherwise we can use the so called transitional constraint between the cylindrical/spherical holder (virtually) and a series of surface-pairs producing the trajectory. One can store data in a table at n places of the trajectory before the robot arm has to go along the $P_i(x_i, y_i, z_i)$ points, the angles (α_i, β_i) of the shoulder and the elbow articulations for these places. That is the angles (α_i, β_i) will be needed in the expected applications to control the robot arm along the given trajectory from the starting to the target point.
- 3rd possibility: We can design/make also an adaptive control program considering the given trajectory and the errors in every i-th steps between the starting and the target point. This adaptive control algorithm can be added with a kind of heuristic learning and/or remembering possibilities. In every controlled step the errors between the expected and the actual arrived i-th point of the trajectory can be corrected for the following experiences. For this aim we have to analyse the actual difference and the predicted deviation of the holder position of the robot arm to produce better and better controlling program.
- 4th possibility: The best controlling system for humanoid robot arm (upper-lower arms-hand) could mime the human brain neuronal networks' controlling process for the muscles, tendons and bones of the human limbs (Ahn and Anh, 2009). According to our present knowledge the required limbs' conscious movements are controlled first of all by motor cortex' nuclei given commands via the spinal cords' efferent neuronal networks (see Fig. 5.).

The eyes and visual cortex' neuronal networks watch the movements of the arm's articulations along a wanted trajectory. The visual system generates error-series along the trajectory between the actual and required positions, velocity, accelerate, force, torque and state-parameters of the muscles, tendons, bones. The cerebellum has homogenous folium-structures and deep nuclei for connecting other parts of the brain. The folium-networks have special "inverse neuronal structures", as Prof. J. Szentágothai said: it is similar to an organist who presses all the keys except the one which gives the sounds (Szentágothai, 1977). Thus every folium can control the antagonistically and synergically operated muscles in an autonomic way because as well-known, they need inverse dynamic control for the limbs of the arm. Besides the cerebellar folium-neuronal-structures can learn from the sensed and predicted positions, parameters of the limbs for the sophisticated movements. The "output" Purkinje neurons of folium bring inhibiting distributed commands via the cerebellar deep nuclei for spinal cord and via thalamus nuclei for cortex, so the folium-structures have very effective fluencies in controlling and learning the sophisticated movements of the arm.

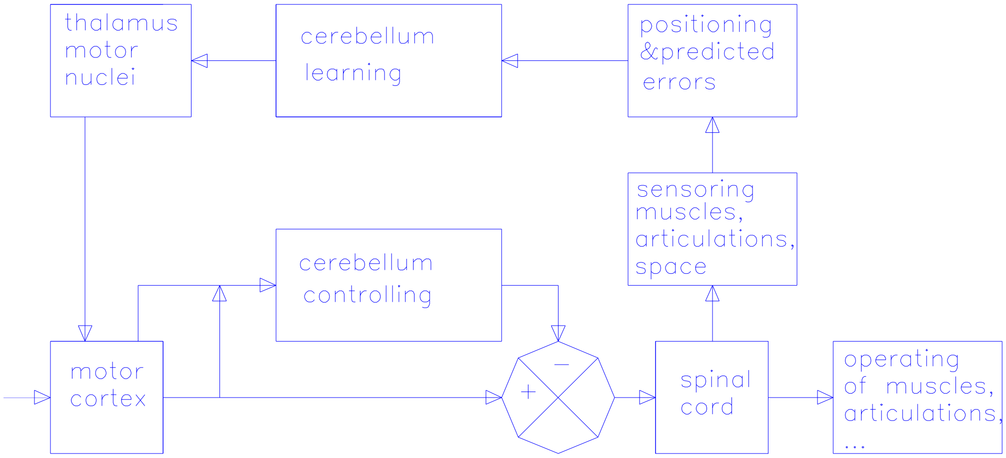

Fig. 5. Motor cortex and cerebellum folium paths for controlling the human limbs' motion

The best controlling and learning strategies for the movements of the human robot arm, to try modelling the folium's structure: defining a neural network, a folium model controlling and learning the robot arm movements (Fagg et al., 1997, Smagt, 1997, Hikaridai, 1997, Smagt, 1998).

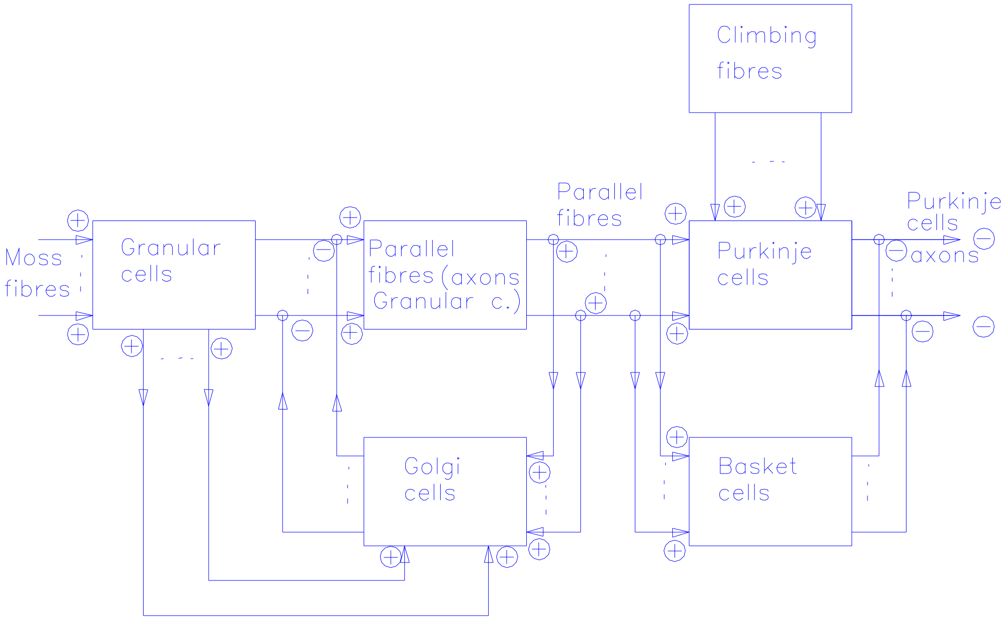

Fig. 6. The neural model of the folium with feed-back and feed-forward control possibilities

We developed a new controlling/learning neural system flowchart (see Fig. 6.) which hopefully can go further a bit (Smagt, 1998, Ahn and Anh, 2009).

CONTROLLING THE ROBOT ARM'S CIRCULAR STEPS BY PAM ELEMENTS

Till now we have not analysed how the robot arm-links can be moved along an arc separately/one-by-one and together along a kind of boved trajectory in the case of 2 flexing DOF arm by the PAM elements. These PAM elements can contract linearly in different extent. The PAMs operate only in one direction (pulling) so it must be used together with its antagonistic pair, similarly to the muscles in the human body (Sárosi et al., 2009). Last year we made a few test-bed constructions to analyse its highly nonlinear character (e. g. F [N], Δl [mm] and p [bar, Pa]), its other important parameters: its exact longitudinal (± 0.01mm) sliding control process and defined maximal contractions (e. g. ± 10 %). After fixing the angle domain (e. g. 0-90°) at every flexing articulation for moving a link of the robot arm, one can define (for the rotational torque) the measures of the actual arm [mm] and the point of application of the force and the direction line of the force, that is the fixing places of the artificial muscle elements. One of the main problem at any 2 DOF robot arm-controlling process is how the given trajectory function of the holder point can be interpolated by little arcs from the starting point up to the target point (Endrődy et al., 2008). First we have to find better and better interpolating by arcs („in second order" for α_i and β_i at the elbow and the shoulder articulations). Then at any movement strategies controlling algorithms mentioned, it is simpler to map the α_i, β_i [°] angles to the controlled contractions of the antagonistic pairs of PAM elements at the shoulder and elbow artificial articulations.

CONCLUSIONS

The earlier cerebellar models demonstrated the possibilities of the role of the folium in solving the inverse dynamic control tasks of the robot arm movements. The main possibility came by the Purkinje cells generated inhibitory output.

Taking into consideration that the new light-weight artificial muscles (PAM elements) changed the traditional robot control methods. Recently large contradictions came between the earlier cerebellum models and understanding its role in the motor cortex-cerebellum-spinal cord neuronal networks for the controlling and learning processes of the human limbs' movements. It seems more important to define inverse and forward models, too. We ought to modellize not only the motor apparatus, sensory organs but also the external world from which the actual movement controlling tasks come. The mimesis of the cerebellum could get more attention in the present-day research.

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