MODELING AND SIMULATION OF HUMAN ORIENTED ROBOTS

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Abstract: In present work a development of the passive approach is made to design of human - oriented robots. Model of robots with controllable compliance modules on the base and cable transmissions is developed that creates a natural security in the interaction with human. In the paper computer model of 4R robot is developed and simulated using Solid Dynamics 2004+ program software. Computer simulations of the robot compliance behavior are carried out. Influence of the compliance on the position control and on the motor torques is been evaluated when changing based mechanical characteristics. The results obtained from calculation of the mechanical parameters are also illustrated graphically. A model with animation of motion is obtained.

Key words: human, robot, safety, interaction, passive, compliance

INTRODUCTION

In the future, robots will take an active role not only in industry, but also in human life. Especially thriving is the development of robots for domestic services and entertainment.Investigations in this field find application as robotized systems for search and save in urban media as robots for personal catering, service robots, robots for domestic work (cleaning, trimming), medicine robots (in surgery and rehabilitation), robots for entertainment (toys, pets, guides and others).

These robots have to meet the safety requirements except the traditional requirements for performance. The manipulator safety depends on its mechanical, electrical and software characteristics. But even the most robust systems are not guaranteed of some unpredictable electrical, sensor or even software errors. That is why the mechanical characteristics of the robotized systems are the key factor for increasing the whole safety [1], [2], [3], [4], [5],[6].

It is important to produce manipulators possessing naturally low impedance in order to achieve natural safety in the mutual interaction “man-robot”. Two basic approaches are known – active and passive for the impedance modulation to secure levels. The active approach is based on the use of sensors and position and force feed backs by means of which a desired parametric proportion is balanced. This method is used with the industrial robots. It guarantees a wide range of stiffness variation, but it does not ensure high level of safety due to a low resolution or noise of the sensors, long calculation time and instability in the servo system.

The passive approach requires kinematics or actuation redundancy in the manipulation system. This approach is independent of the servo systems, but the range of the impedance parameter variation is limited. Passive approach is more convenient in the “man-robot” interaction.

The mechanical characteristics inertia, damping and stiffness are the key factor for increasing the whole safety during the interaction “human-robot”[7], [8].

During a collision with a robot arm the impulse force is determined from the speed of motion and the effective arm inertia.. Therefore the low arm inertia is determined for impact security. Human-oriented robots have to be with light bodies links and motors. In case of need of more powerful and heavier motors, they can be placed on the base using cables and other light transmissions [1], [5].

During a contact, the contact force depends of the manipulator stiffness. The human - centered robots have to be compliant for reduction of the contact force. The stiffness of the manipulation system must be specified to certain levels in order to increase the level of safety. It is possible to use devices with controlled passive joint compliance [2],[3] as it is shown on Fig.1. In each joint except an actuator for position control 5 is added an additional actuator 2 for stiffness variation of a passive compliant element 3.

The introduction of compliance enhances the level of safety but during an impact or immediately change of speed, the compliant arm is trended to oscillations. The presence of damping in joints decreases these oscillations. The human-centered compliant robots have to possess joint damping that can be achieved with passive friction devices. Here occur difficulties during ensuring of the effect of viscous damping..

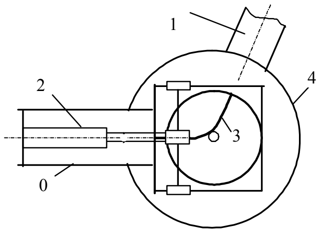


Fig.1. Passive compliance adjuster.

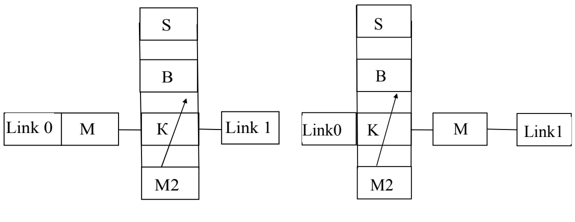
The objective of the work presented in this paper is development of the passive approach for creation of human-oriented robots, formulation of suitable model of the save arm and of the compliant joints implemented in it. To be created a computer model and to be performed simulation of a compliant arm.. The investigation results to be shown graphically.

MODEL OF A LIGHT ARM WITH CABLE TRANSMISSIONS AND COMPLIANT MODULES ON THE BASE

The building up of safety according to the selected passive approach requires creation of compliant modules for each joint, allowing stiffness and damping regulation in the joint according to the passive way. Each module should include a stiffness **K** and damping **B** regulator and a sensor **S** for deformation measurement.

In Fig.2 two variants of building up of a compliant joint are presented [9]. In this figure with **M** is marked a motor for position joint control and with M2 – second motor for stiffness control in the compliant element. In this figure with 0 is marked the basic limb, and with 1 – the operated limb. The difference between the two variants is in the sequence of location of the positioning element and the compliant element. In case a) the motor for position control **M** is located in the basic limb, while the compliant module is movable. The disadvantage of this variant is the bigger number of movable elements and the more difficult measurement of the deformations in the compliant element **K** at bigger stroke in the joint. This configuration is closest to the well known 'series elastic actuation"[4] the elastic element in which is with a constant stiffness. In the second case b) the compliant module is in the basic limb and the motor for the positional control is movable. This variant is more convenient for implementation of controllable joint compliance, because the components of the compliant module: **K, B, M2, S** are firmly linked with the base limb and the deformation of the compliant element is with limited dimensions.

The building up of a compliant joint according to the variant shown in Fig.2,b) allows position control in the free space and force control in the process of contact. Schemes for force control in the compliant joint are build [9].



a) b)

Fig.2. Block scheme of a compliant joint

Both schemes allow defining a desired joint stiffness $\mathbf{K_d}$ by means of the compliant module. The desired stiffness is achieved by means of a variation of one of the geometric parameters 1 of the elastic element, and its stiffness is a function of this parameter **K=f(l).**

For this purpose a special mechanism is designed similar to this one shown in Fig. 1, which is driven by an additional motor M2 (Fig.2) with position control along the axis of variation of the parameter 1.

The motors and the compliant modules must be located on the basis using light cable transmissions for creation of a light arm with low mass-inertia characteristics. In Fig. 3 is shown a kinematic scheme of an anthropomorphic arm with four degrees of freedom:

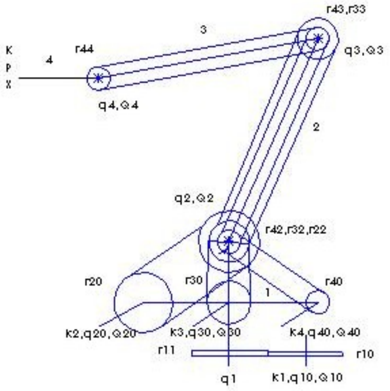


Fig. 3. Light arm with cable transmissions and compliant modules on the base.

The motion of the arm is given by the base motors and their relative rotation $\mathbf{q_{10};q_{20};q_{30};q_{40}}$. Base motion is transferred to the movable links 1,2,3,4 by means of the following transmissions - to 1: $\mathbf{r_{10}\text{-}r_{11}}$, to 2: $\mathbf{r_{20}\text{-}r_{22}}$, to 3 :$\mathbf{r_{30}\text{-}r_{32}\text{-}r_{33}}$, to 4: $\mathbf{r_{40}\text{-}r_{42}\text{-}r_{43}\text{-}r_{44}}$. The stiffness of the arm is determined by the compliant modules stiffness $\mathbf{k_1;k_2;k_3;k_4}$. The cable transmission causes linear influence on the arm stiffness. Computer simulations are made, using Solid Dynamics 2004+ program software. On the base of Fig.3 a virtual model is build, shown on Fig. 4. The experiments are made on the plane YZ where the robot's arm has three degrees of freedom.

The links of the manipulator are presented like light bodies with length l_2=0.2, l_3=0.2, l_4=0.1 [m] and mass m_2=0.434 [kg], m_3=0.434 [kg], m_4=0.588[kg]. The radii of all transmission wheels are r= 0.25 [m].

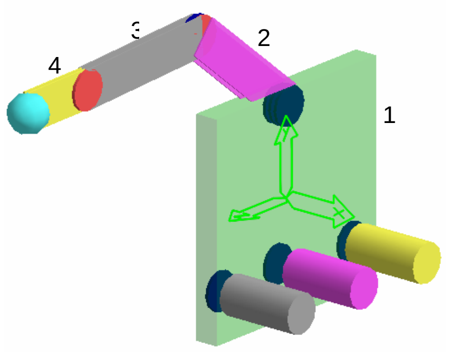


Fig.4. Solid Dynamics model of a compliant robot

COMPUTER SIMULATIONS OF THE ROBOT COMPLIANCE BEHAVIOR

3.1. Influence of the compliance on the position control.

The next simulation is carried out where the robot arm is leaded to the position shown on Fig. 4. A harmonic motion - $\mathbf{q_{20}}$ is set to the motor 2 with amplitude $\mathbf{A=20^0}$ and frequency **f=10 [Hz]** (Fig.5).

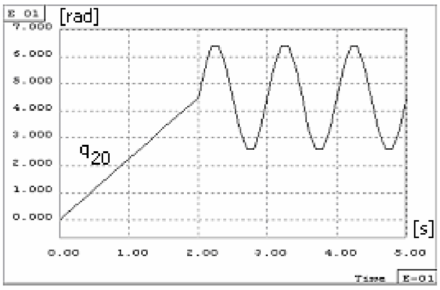
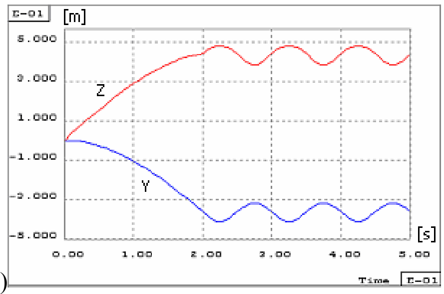


Fig.5. Position task of motor 2.

When the arm is stiff (the compliant modules are in the extreme position) the effective motion of the end effector on Y, Z axis is presented on Fig.6a and the motor torque $\mathbf{Q_{20}}$ is presented in Fig.6b. The motor torque variations are about 70 [Nm] high.



a)

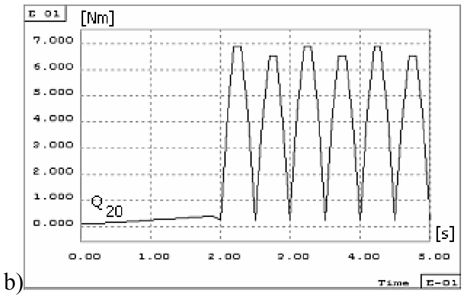


Fig.6. Effective motion and motor torque by stiff arm.

When the arm is compliant, with stiffness in the compliant modules equal to **k_2=50[Nm/rad], k_3=40[Nm/rad], k_4=25[Nm/rad]**, the end effector's motion gives the impression shown in a fig.7a and the motor torque **Q_{20}** is presented in the fig.7b. The available compliance reduces the load of the motors till **40[Nm],** under the inaccurate execution of the defined position before.

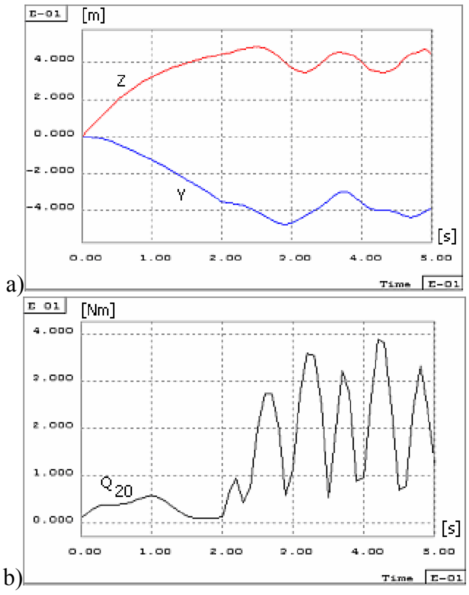


Fig.7. Effective motion and motor torque by compliant arm.

The damping in compliant modules with next values **b_2= b_3= b_4=2 [Nms/rad]** improves the position execution with small phase deflection shown on fig. 8a and fig. 8b.

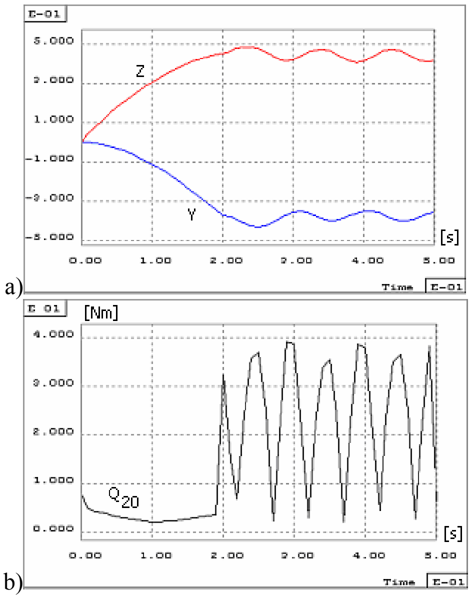


Fig.8.Effective motion and motor torque with damping.

The compliance of the robot arm restricts the performance of position tasks requiring high velocities. In the next simulation, the frequency of the motor harmonic motions **q_{20}** reaches **f=25Hz** with the same amplitude **A=20^0**. The effective motion of the end effector is presented in Fig.9a, while the motor torque **Q_{20}** is presented in Fig.9b.

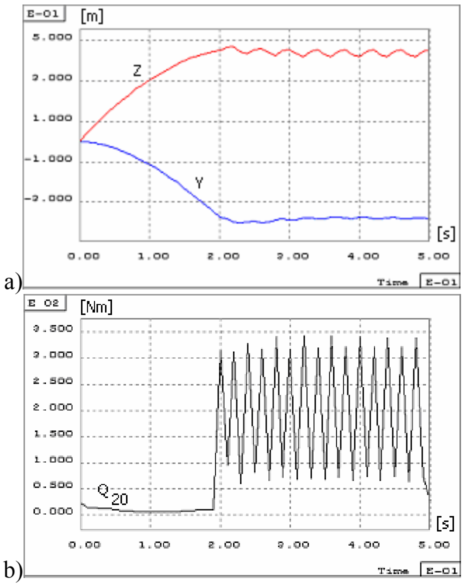


Fig.9. Effective motion and motor torque by high frequency.

The motor torques increase their values (**350 [N/m],** Fig.9 b) without performance of amplitudes set before (Fig.9a). Because of that, the robots with passive compliance are suitable for realization of slow tasks, usually needed a control of contact forces and ensured safety of the mutual interaction.

3.2. Influence of the compliance on the motor forces.

Here in this experiment it is investigated influence of the compliance on the motor and contact forces during the contact between the hand and the environment. The robot has a position task in the plane. The trajectory of the endefector on Y and Z axes and the variation of the motor torque **Q_{20}** are shown in Fig.10a) and Fig.10b). To investigate the contact interaction, the **Z** motion is restricted thought vertical barrier situated on **0.400 [m]** over the **Z** axis, shown in Fig.11.

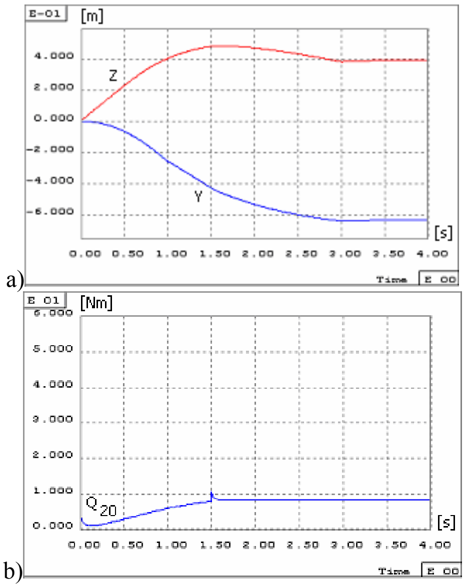


Fig.10. Endeffector trajectory and motor torque without contact.

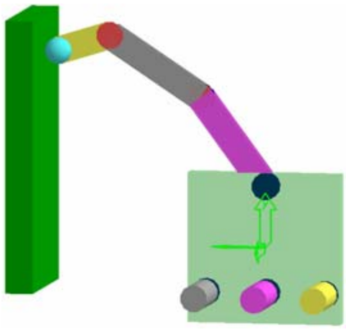


Fig.11. Contact of the compliant arm with vertical barrier.

If the arm is stiff, the robot can not perform the task on **Z** direction with amplitude **0.500[m].** When the arm is compliant with stiffness and damping of compliant modules **k_2=50[Nm/rad], k_3=40[Nm/rad], k=25[Nm/rad],** and **b_2=b_3=b_4=2 [Nms/rad],** the task is executed with change of the trajectory on **Y** and **Z** axes and motor torque **Q_{20}** shown in Fig.12a) and fig.12b).

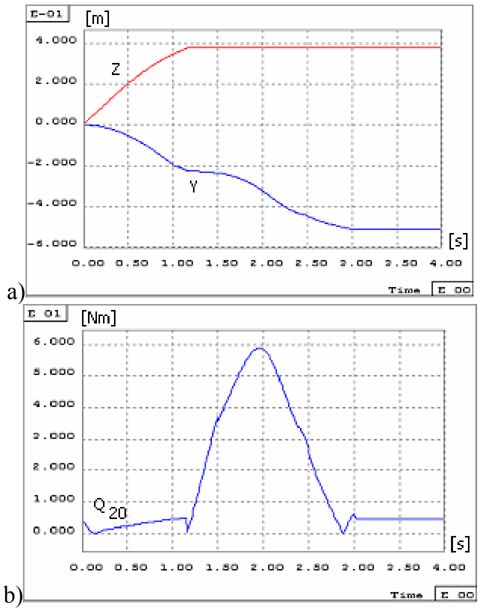


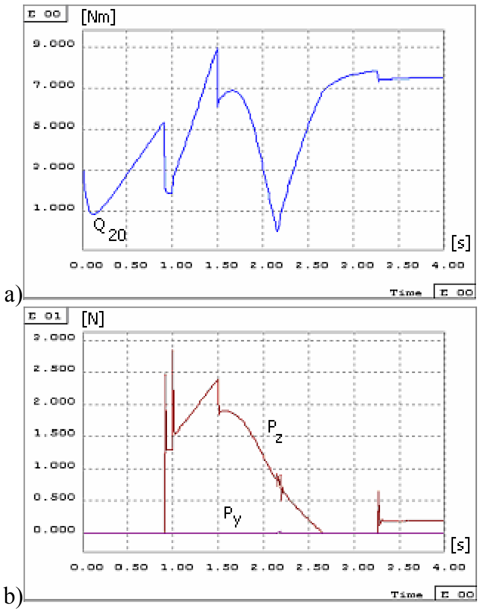
Fig.12.Endeffector trajectory and motor torque by contact.

According Fig.12b the task execution requires a big load of the actuators during contact - **Q_{20}** reaches **60 [N/m],** related with high values of the contact force (**100[N]).** If the robot has weak motors (admissible torques equal to **10[N/m]**) the task can not be executed.

By means of compliant modules enabling adjustment the stiffness, the above task can be executed with lower contact force and high interaction safety. So with stiffness of compliant modules equal to **k_2 = 5 [Nm/rad], k_3 = 4 [Nm/rad], k_4 = 2,5 [Nm/rad]**, and damping **b_2= b_3= b_4=2 [Nms/rad],** the task is executed with Y and Z trajectory according Fig.12a). The change of motor torque is shown in Fig.13a) and the change of the contact force **P_Z** by **Z** direction – in Fig.13b). The maximum value of the motor torque is **9[Nm],** and the maximum value of the contact force is **25[N].**

CONCLUSION

The virtual model and corresponding simulations indicate the possibilities of the passive approach to create human oriented robots. The compliance which is introduced does not allow precise positioning and fast performance, but decreases the contact force and ensures the interaction safety. The stiffness adjustment allows reduction of the contact force and the motor torques to the desired values. Creation of a compliant arm with the derived structure supposes a high robustness of the motion with respect to unexpected disturbances on one hand and a natural human safety on the other. The compliance defines the initial response of the unexpected influences and the safety of the consecutive mutual interaction.



a) b)

Fig.13. Motor torque and contact force by compliant contact.

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