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SOME RESULTS OF CONTROL AND SIMULATION OF NEURO ARM ROBOT

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Abstract: In this paper they are presented the control algorithms of integer and fractional order PID control in the position control of a 3 DOF`s robotic system (NeuroArm). Finally, the effectiveness of proposed control is illustrated on given robot as well as using model of NeuroArm.
Keywords: NeuroArm robot, PID Control, Simulation, Fractional calculus

1. INTRODUCTION

Robots today are making a considerable impact on many aspects of modern life, from manufacturing to healthcare, [1], [2]. Unlike the industrial robotics domain where the workspace of machines and humans can be segmented, applications of intelligent machines that work in contact with humans are increasing, which involve e.g. haptic interfaces and teleoperators, cooperative material-handling, power extenders and such high-volume markets as rehabilitation, physical training, entertainment. In that way, robotic systems are more and more ubiquitous in the field of direct interaction with humans, in a so called friendly home environment. As one of these robotic systems capable of operating in such environments is NeuroArm robotic system. It is an integral part of the Laboratory of Applied Mechanics, Mechanical Engineering in Belgrade, (Fig. 1). Within NeuroArm Manipulator System – there are a rich set of options that enable scientists and engineers to configure your robot that will meet the needs. From the mechanical point of view NeuroArm a robotic arm has 7 degrees of freedom. This robot has highly configurable advanced PID controllers, the actuator's torque high intensity, i.e. 3 Amp Maxon DC motor with planetary gearing and high-resolution encoders for each robot joint, respectively. These provide a good/smooth control in closed feedback loop in respect to position, velocity, acceleration of a given profile, as well as control which based on the torque (*torque control*).

Also, in classical control theory, state feedback and output feedback are two important techniques in system control. Specially, the PID controller is by far the most dominating form of feedback in use today. Due to its functional simplicity and performance robustness, the PID controllers are still used for many industrial applications such as process controls, motor drivers, flight control, instrumentation, etc.

In this paper, we suggest and obtain a new algorithms of classical as well as fractional order PID control in the control of given robotic system. The objective of this work is to find out suitable – "optimal" settings of parameters of classical PID well as for a fractional $PI^{\beta}D^{\alpha}$ controller in order to fulfil different design specifications for the closed-loop system, taking advantage of the fractional orders, α and β.

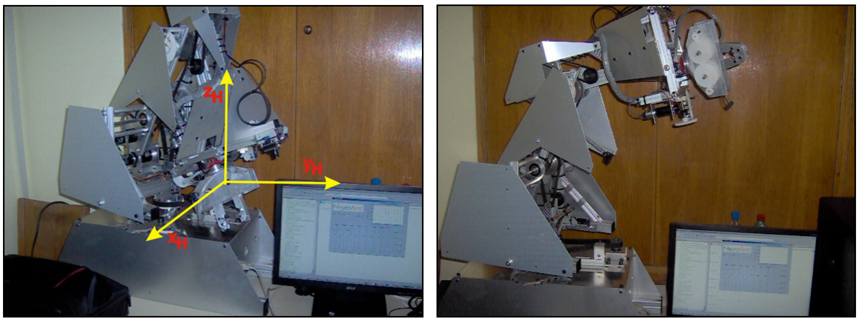

Figure 1. a) left-Laboratory Robot – NeuroArmTM, Department of Mechanics, Faculty of Mechanical Engineering, BU, Belgrade, initial position; b) right – final position of robot

2. CONTROL OF NEUROARM ROBOT

2.1. Model of NeuroArm robot – 3DOF

Here, the Rodriguez` method [2] is proposed for modeling the kinematics and dynamics of the robotic system on the contrary Denavit-Hartenberg's method. In our case, it is presented a robotic system with 3 revolute joints, i.e. with $n=3$, DOFs (see Figure 2) where an end-effector orientation will not be considered here, but only its position in space. The equations of motion of the RS without end-effector can be expressed in a covariant form of Langrange`s equation of second kind as follows [1,2]:

$$\sum_{\alpha=1}^{n} a_{\gamma\alpha}\ddot{q}_{\alpha} + \sum_{\alpha=1}^{n}\sum_{\beta=1}^{n}\Gamma_{\alpha\beta,\gamma}\dot{q}_{\alpha}\dot{q}_{\beta} = Q_{\gamma} \quad \gamma=1,2,3 \ \text{ or } \ A(\boldsymbol{q})\ddot{\boldsymbol{q}} + C(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{g}(\boldsymbol{q}) = \boldsymbol{Q}^{a} \tag{1}$$

Besides, the position vector of the end-effector r_H

$$\vec{r}_H(q) = \sum_{i=1}^{n}\left(\vec{\rho}_{ii} + \xi_i q^i \vec{e}_i\right) = \sum_{i=1}^{n}\left(\prod_{j=1}^{i}\left[A_{j-1,j}\right]\right)\left(\left(\vec{\rho}_{ii}^{(i)}\right) + \xi_i q^i\left(\vec{e}_i^{(i)}\right)\right) \tag{2}$$

written as a multiplication of matrices of transformation $\left[A_{j-1,j}\right]$, position vectors $\vec{\rho}_{ii}$ and $\xi_i q^i \vec{e}_i$.

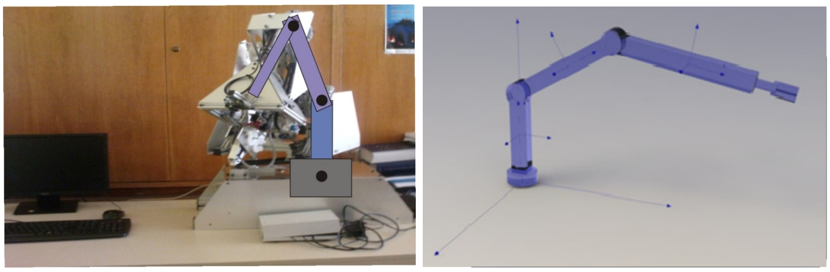

Figure 2. Model of Neuro Arm with 3 DOF

2.2. Position control system design

The task of position control of robotic system means to determine the three components of vector of external torques Q^a that allow execution of motion $q(t)$ as

$$\lim_{t\to\infty}\boldsymbol{q}(t) = \boldsymbol{q_d} \tag{3}$$

where q_d denotes the vector of desired joint trajectory variables. To solve position control problem we will consider a class of robotic system *called computed torque* controllers [1], [4]. As a result, a complicated nonlinear controls design problem will be converted into a simple design problem for a linear system consisting of decoupled subsystems, and choose Q^a as follows:

$$\boldsymbol{Q}^{a} = A(\boldsymbol{q})\boldsymbol{Q}_R + C(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{g}(\boldsymbol{q}) \tag{4}$$

Substituting (4) into the (1) yields

$$\ddot{\boldsymbol{q}}(t) = \boldsymbol{Q}_R \tag{5}$$

where Q_R denotes output of PD controller. The resulting control scheme appears in Figure 3 (nonlinear term $N(q,\dot{q})$ is equivalent to $C(\boldsymbol{q},\dot{\boldsymbol{q}}) + \boldsymbol{g}(\boldsymbol{q})$).

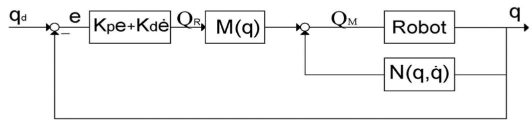

Figure 3. Block diagram scheme of proposed robot control

One way to select control signal Q_R is as PD feedback

$$\boldsymbol{Q}_R = K_P\boldsymbol{e}(t) + K_D\dot{\boldsymbol{e}}(t) \tag{6}$$

where $e = q_d - q$ is output error. Now (5) becomes

$$\ddot{\boldsymbol{q}}(t) + K_D\dot{\boldsymbol{q}}(t) + K_P\boldsymbol{q}(t) = K_P\boldsymbol{q}_d(t) + K_D\dot{\boldsymbol{q}}_d(t) \tag{7}$$

The closed loop characteristic polynomial is

$$f(s) = \prod_{i=1}^{3}\left(s^2 + K_{Di}s + K_{Pi}\right) \tag{8}$$

and the systems is asymptotically stable as long as the K_{Pi}, K_{Di} are all positive for $i = 1,2,3.$ Also, it is undesirable for the robot to exhibit overshoot, since this could cause impact at the surface of a box. Therefore, gain matrices are selected for critical damping $\xi = 1$ as follows:

$$K_P = diag\{36,36,36\}, K_D = diag\{12,12,12\} \tag{9}$$

System's response for $q_{di} = h(t),\ i = 1,2,3$ is obtained, and results are compared with those obtained from robot simulation environment and Figure 4 illustrates it. Control torque values are shown on the right hand side of Figure 4.

2.3. Fractional order PID controller – $PI^{\beta}D^{\alpha}$

Fractional order PID controller (FOPID), [5] is the generalization of a standard (integer-order) PID (IOPID) controller, whereas its output is a linear combination of the input and the fractional integer/derivative of the input. Recently, published results of FOPID [5], indicate that the use of a FOPID controller can improve both the stability and performance robustness of feedback control systems. However, FOPID itself is an infinite dimensional linear filter and the tuning rules of FOPID controllers are much more complex in compared classical PID controllers. Unlike conventional PID controller, there is no systematic and rigor design or tuning method existing for FOPID controller. The time equation of the FOPID controller is given by:

$$u(t) = K_p e(t) + K_d\, {}_0D_t^{\alpha} e(t) + K_i\, {}_0D_t^{-\beta} e(t) \tag{10}$$

For practical digital realization, the derivative part in s-domain has to be complemented by the first order filter

$$G_{FOPID}(s) = K_p\left(1 + \frac{1}{s^{\beta}T_i} + \frac{T_d s^{\alpha}}{(T_d / N)s + 1}\right), \tag{11}$$

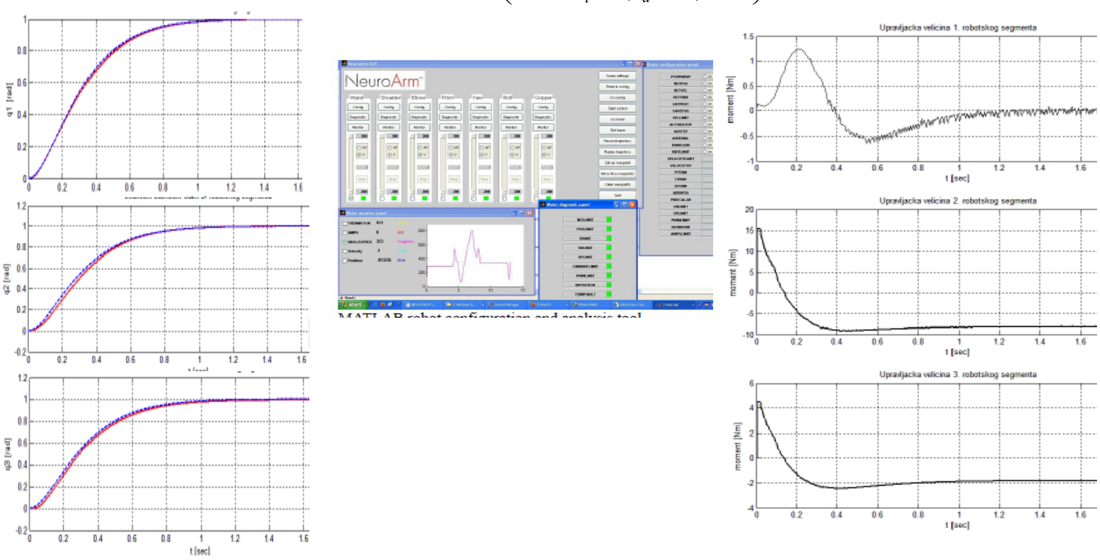

Figure 4. The step responses of the $q_i(t),\ i = 1,2,3$ and control $Q_i(t),\ i = 1,2,3$

The parameters are: gain K_p, K_d, K_i, noninteger order of derivative α and integrator β, as well as the integral time constant, $T_i = K_p / K_i$, and the derivative $T_d = K_d / K_p$.

Simulation studies have been carried out to verify the effectiveness of the proposed fractional PID controller tuned by genetic algorithms for robot control. Both the FOPID and the IOPID controllers are designed based on the proposed GA. For calculation of fractional derivatives and integrals the Crone approximation of second order was used.

In Table 1 They are presented the optimal parameters of the FOPID as well as IOPID controller using GA. Simulation results, here only for q(2), are presented as follows:

Table 1. The optimal parameters of the FOPID controller and the IOPID controller based on GA

controller		K_p	K_i	K_d	α_I	α_D	J
PID	1.	199	2	24	-	-	0.98651
	2.	212	2	26	-	-	0.84875
	3.	246	1	28	-		0.68718
FrPID	1.	199	2	24	0.020	0.965	0.52316
	2.	212	2	26	0.145	0.933	0.50342
	3.	246	1	28	0.135	0.932	0.47705

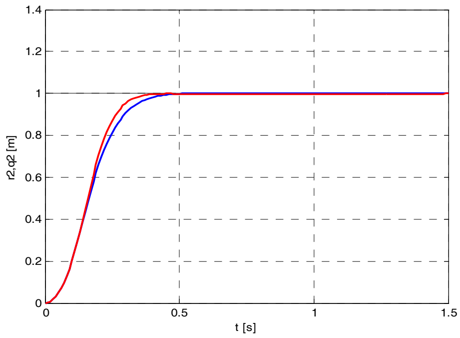

Figure 5. The step responses of the $q_2(t)$ – using the optimized FOPID and IOPID controller

3. CONCLUSION

This paper presents the possibilities of advanced control of robotic systems (NeuroArm). Firstly, it is determined the parameters for the conventional PID control algorithm applying *computed torque method*. Then it is applied integer and fractional order PID controller where they are tuned by genetic algorithms for robot control. Finally, the effectiveness of suggested advanced PID control is demonstrated with on given robot with three degrees of freedom.

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