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SIMULATION OF SHANK-FOOT 2-DOF MANIPULATOR WITH COMPUTED TORQUE CONTROL FOR TRAJECTORY GENERATION

Gamini Suresh[1], K. Balakrishna Reddy[2], M. Nagarjuna[3]

[1, 2,3] Department of Mechanical Engineering, Vignan Foundation for Science Technology and Research, A.P, India.

[1]gaminigsuresh@gmail.com, [2]kbalakrishna19@gmail.com, [3]yadeedya319@gmail.com.

Corresponding Author: K.Balakrishna Reddy

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Abstract

Exoskeletons and external assistive devices for human locomotion plays an predominant role in now a days. To assist elderly people and injured content, a shank foot manipulator is modelled and analysed. This shank foot manipulator is a 2 degree of freedom link which is represented by dynamic equation of non linear differential equation. Numerical solution is employed to obtain the closed form solutions. The trajectory generated by the manipulator is discussed with the control strategies like computed torque control with the use of MATLAB. Due to the uncertainties and non linearity nature, it becomes complex to attain the motion control in a accurate position. With the ease of computed torque control, the manipulator is made to be in a desired position.

Keywords: Shank-foot manipulator, Control, Desired Trajectory generation.

I. Introduction

The total weight of the body will act on the foot through limbs and shank. During the natural walking, sit stand activities, turning, tilting foot over obstacles, all the regular actives of life, the shank and foot connected with ankle undergoes several transformations internally and externally with the activity to be performed.

In the cases of elderly content and injured people this ankle functions less effectively causing pain and strain to the individual while transforming the overall weight to the ground with required locomotion. This transformation involves several factors to consider like, the type of surface on which the subject is to move, friction, speed etc.

The control strategy of the wearable exoskeleton is adopted to complaint the wearer safety [I]. This can be achieved by compensating its reasonable uncertainties. Much of research works are being carried out in the design and control of AFO devices to perform the their daily activities. To attain the desired trajectory of shank and foot appropriate orthosis has to developed. The dynamics of the driving system is essential with number of actuated degrees of freedom in the device [II]. The feedback obtained by the nonlinear systems is linearised by adopting the control method of torque which is used in most of the robotic systems in lieu their robustness [III-IV]. In this context it compares the torque required for the orthosis depends on identical trajectories. The complexity of tuning matsuoka oscillator is discussed. To obtain the rythamic commands of robotic arm joints are the method is applied, based on the joint motion data oscillator behaviour is modified [V]. However this is compared to that of robotic arm.

In order to describe the manipulator model it is considered the equation of dynamic motion. By the computed torque control technique with the advent of forward dynamic approach, the trajectory control of shank-foot is attained. The motto is to serve and enhance the mobility of elderly subject and with lower limb impairments. This can be attained by designing of the targeted trajectory for shank-foot model. For this purpose trajectories [VI] are defined with the advent of inverse kinematics transformation. In order to control the model, Inverse kinematic transformation is utilized to obtain joint space trajectories from specified circular trajectory [VII-VIII]. The 2 DOF system is explained with Lagrange's equation which depicts the nonlinear time variant forward dynamics of the model. The circular trajectory and internally generated trajectories are are tracked by PID based computed torque control method [IX-X]. and later one with proportional derivative based control [XI-XII]. With uncertainties in each trajectory [XII-XIII]., like external disturbances and friction incurred in motion are considered for both the control techniques are analysed [XV-XVI], with MATLAB. The proposed system obtains satisfactory results.

II. Model of the Shank Foot

A planar 2 DOF, manipulator with revolutary joints as shown in the sketch.

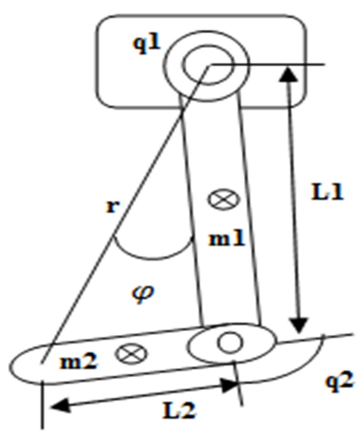
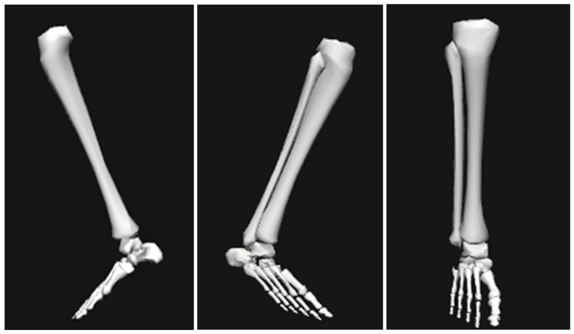


Fig. 1: Two degree of freedom model.

III. Shank Ankle Foot Diagrams



(a) (b) (c)

Fig. 2: (a) & (b) represents the sagittal view.(c) represents the frontal view.

IV. Dynamic Motion Equation

The general type of the conditions of movement is yielded, as below.

$$M(\dot{q_i}) + N(qi, \ddot{q_i}) + \tau_d = \tau \quad (1)$$

Where

- 'q_i' is position variable vector of the joint.
- '$\dot{q}i$' is variable vector of joint acceleration
- '$\ddot{q_i}$' is variable vector of joint acceleration.
- ' M ' is the mass matrix.
- 'τ_d' represents torque vector with uncertainty.
- 'τ' represents the forces applied externally.

$$N_I(q, \ddot{q}) = C_I(q, \ddot{q})\,\dot{q} + F_I(\dot{q}) + G_I(q) \quad (2)$$

The equation (a) represents the nonlinear equation that consists of $C_1 q, \dot{q})$ the Coriolis vector, $F_I(\dot{q})$ is the torque vector of the joint friction and $G_I(q)$ the torque vector due to gravity. With the assumption of uniform mass distribution over the links the manipulator model, equations of motion are given by following mass matrix.

$$\mathbf{M} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$$

Coriolis vector matrix:

$$\mathbf{C}(q, \dot{q}) = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix}$$

Gravity vector matrix:

$$\mathbf{G}(q) = [\ q_1 \ \ q_2]$$

Where,

$$\left.\begin{aligned} M11 &= I_1+I_2+m_1L_2+ m_2L_1r_2\cos(q_2) \\ M12 &= I_2+ m_2L_1r_2\cos(q_2) \\ M21 &= I_2 + m_2L_1r_2\cos(q_2) \\ M22 &= I_2 \end{aligned}\right\} \quad (3)$$

$$\left.\begin{aligned} C_{11} &= -\ 2m_{2\,X}\, L_{1X}\, r_2 \sin(q_2)(\dot{q}_2) + b1 \\ C_{12} &= -\ m_{2\,X}\, L_{1\,X}\, r_{2\,X} \sin(q_2)(\dot{q}_2) \\ C_{21} &= m_{2\,X}\, L_{1\,X}\, r_{2\,X} \sin(q_2)(\dot{q}_{10}) \\ C_{22} &= b_2 \end{aligned}\right\} \quad (4)$$

$$\left.\begin{aligned} G(q1) &= (m_1r_1 + m_2L_1)g\sin(q_1) + m_2gr_2\sin(q_1 + q_2) \\ G(q2) &= m_2gr_2\sin(q_1 + q_2) \end{aligned}\right\} \quad (5)$$

Joint Friction Torque Vector:

$$Fn = V_n\,\dot{q}n \quad (6)$$

Disturbance torque vector:

$$\tau_{dn} = k_n \text{ x sign } (\dot{q}n_n) \quad (7)$$

where k_n is a sinusoidal signal. For generating low power torque two actuators are required.

$$\tau_n = 1 \quad (8)$$

The generalised torque γ_i is written as:

$$\gamma_n = \tau_n - b_n\,\dot{q}n \quad (9)$$

The Coriolis vector equation consists of coefficient of damping (bn). The fore mentioned unique condition of movement dependeds on Lagrange's strategy.

V. Generation of the Path of the Desired & Actual Trajectory

This segment characterizes the assignment to be done by the manipulator (orthosis) model so that it will serve its rehabilitative reason. Cartesian space has to transform from joint space is recommended.

$$P_i(t_x) = (x_i(t_x), y_i(t_x))$$

The lower-limb is constrained by the actuators by means of points qn for n = 1, 2.Subsequently it is convenient that the cartesian direction $(x_i(t_x), y_i(t_x))$ is changed over into a joint space direction (q1(t), q2(t)) with the end target of control. The circular pattern is characterized as a component of time (t_x) as,

$$\left.\begin{aligned} X_i(t_x) &= (0.50)(1) + 0.33 \text{ x } sin(t) \\ Y_i(t_x) &= (-3.5)(1) - 0.33 \text{ x } cos(t) \end{aligned}\right\} \quad (10)$$

Computing this joint space direction is determined by inverse kinematic transformations. The change to decide q2, q1, in F, is characterized as below.

$$r(t_x) = \sqrt{x(tx)2 + y(tx)2}$$

$$COS(q_2(t)) = \frac{r(t)^2 - L_1^2 + L_2^2}{2L_1L_2}$$

$$B = \pm\sqrt{1 - cos^2}(q_2) = \pm\sqrt{1 - A^2}$$

$$q_2 = \text{arc tan2(B,A)}$$

$$\tan\psi = \frac{(L_1 + L_{2\cos(q_2)})}{L_{2\sin(q_2)}} \quad (11)$$

$$\tan(\psi + q_1) = \frac{y}{x}$$

$$q_1 = arc\ tan2(y,x) = -arctan2(-(L_1 + L_{2\cos(q_2)}), L_{2\sin(q_2)})$$

Computed-Torque Control:

The feedback linearization from the non linear systems is attained by the control method, is examined with the straightforward PD and PID control methods.

Computed-Torque PID Control:

Based on the Eq.(i), the desired trajectory q_d has been characterized for the required movement, in this manner the manipulator based control is given by

$$\tau = M(\dot{q})\ (\ddot{q}_d - u) + N\ (q, \ddot{q}) + \tau_d \quad (12)$$

Considering a PID feedback system for the stabilization of the system the control law written as

$$\tau = M(\dot{q})(\ddot{q}_d + k_v\dot{e} + k_i \int e + k_p e) + N(q, \ddot{q}) + \tau_d \quad (13)$$

Where

- k_v is derivative gain of the controller
- k_i is integral gain of the controller
- k_p is proportional gain of the controller

Computed-Torque Simple PD Control:

Internally generated trajectory is given by

$$\tau_1 \dot{x}_1 = c - x_1 - \beta v_1 - \gamma y_2 - \sum_{i+} hg$$

$$\tau_1 \dot{v}_1 = y_1 - v_1$$

$$\tau_1 \dot{x}_2 = c - x_2 - \beta v_2 - \gamma y_1 - \sum_{i-} hg$$

$$y_i = \max(x_i, 0)$$

$$y_{out} = y_1 - y_2$$

This was imagined to plan a control strategy utilizing the common elements of the shank-foot. The direction may in this way be characterized as

$$q_d = y_{out}$$

To guarantee the control of each of the joints, PD control method is employed as characterized in

$$u = k\,(q_d - q) - b\,\dot{q}$$

where

- k is stiffness
- b is damping coefficient

$$\boldsymbol{T_i} = M_i\,(q^* \ddot{q}_d) - k_i\,(q_d + q) + b_i\,\dot{q}) + N_i\,(q, \dot{q}) + \tau_d$$

VI. Physiological Parameters

Table 1: Physiological Parameters considered.

S. No	Parameters	Units	Values
1	First Link (L_1)	Meters	0.3
2	Second link (L_2)	Meters	0.1
3	Link-1 mass (m_1)	Kilogram	2.80
4	Link-2 mass (m_2)	Kilogram	1.18
5	Link-1 inertia (I_1)	kg.m^2	0.075
6	Link-2 inertia (I_2)	kg.m^2	0.014
7	Earth gravity (g)	M /s^2	9.8
8	Link-1 damping Coeffiecient (b_1)	Nm / s^2	0.3
9	Lijnk-2 damping Coeffiecient (b_2)	Nm / s^2	0.5
10	Knee joint angle $q_1(0)$ *initial condition*	Radian	0.45
11	Ankle joint angle $q_2(0)$ *initial condition*	Radian	0.25
12	Knee joint friction threshold (v_1)	Radian	2.0

VII. Results and Discussion

Simulation is performed for the conformity of the proposed control method. In the elapsed time of ten seconds and for 240 seconds and readings are measured at every 0.002 seconds.Fig-2 & 3 Plots the position errors of the joint-1 and joint-2 respectively. Fig-4&5, plots the velocity errors of the first joint and second joint respectively. Fig-5 Plots Comparison of actual and desired position for link-1 & 2 respectively.

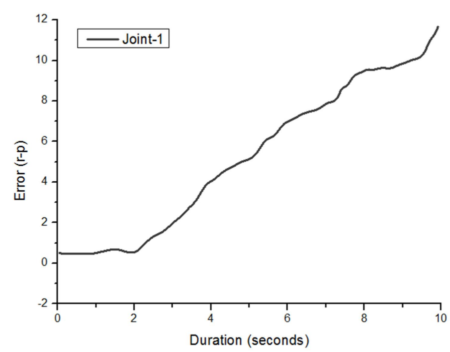


Fig. 2: Joint-1 position error.

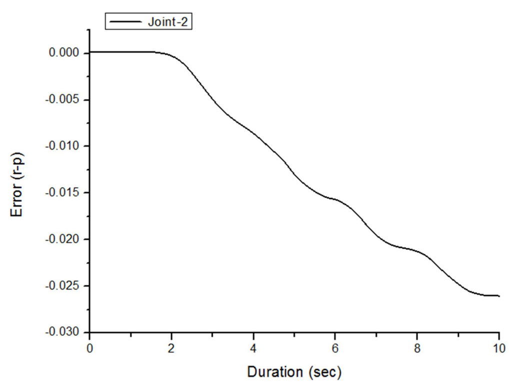


Fig. 3: Joint-2 position error.

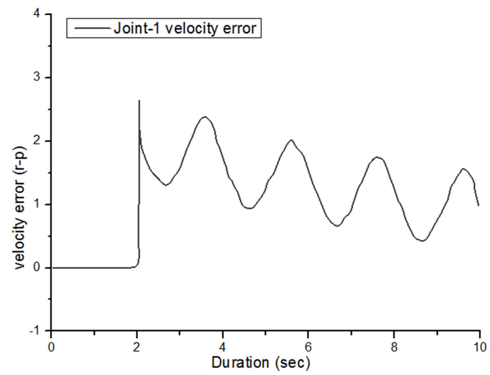


Fig. 4: Velocity error for joint-1

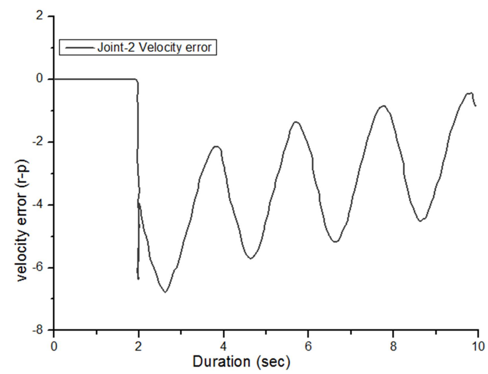


Fig. 5: Velocity error for joint-2

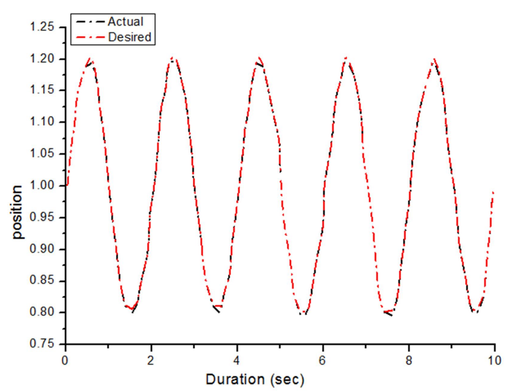


Fig. 6: Comparison of actual and desired position.

VIII. Conclusion

The proposed 2 DOF manipulator with the controlled torque, performance is simulated. The results of the simulation are validated with the control method and by generating the desired trajectory by the manipulator.

1. The obtained position errors were less for initial state conditions and increases with time as simulation plots shown.

2. However the velocity errors were vanished with time progression, even though it appear at intial conditions. There is no error between actual and desired position of the links initially, but they appears with time progression within its control.

3. Hence it is required to control the manipulator for initial conditions and computed torque controller is applicable for long run applications.

4. During the static conditions the like standing the position errors were present in order to make the manipulator ready for transforming into dynamic state like walking.

5. Due to this transformation the velocity errors vanishes with time even though the position errors were present for the links at initial conditions.

References

I. Merabet, A. & Gu, J. 2010. Advanced Nonlinear Control of Robot Manipulators. INTECH,Open Access Publisher.

II. Kordasz, M., Kuczkowski, K. & Sauer, P. 201-Study on possible control algorithms forlower limb rehabilitation system. In: Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on. IEEE,1–6.

III. Tomachika Ozaki, Tatsuya Suzuki, Takeshi Furuhashi, Shigeru Okuma, Yoshiki Uchikawa. "Trajectory Control of Robotic Manipulators Using Neural Networks".*IEEE Transactions on Industrial Electronics,* Vol. 38, No. 3, June 1991.

IV. Suel Jung, "Neural Network Controllers for Robot Manipulators". PhD Dissertation, University of California*,* 1996.

V. Suel Jung, T.C. Hsia, "Neural Network Reference Compensation Technique for Position Control of Robot Manipulators"*, Proceedings of the IEEE International Conference on Neural Networks,* Vol. 3, pp. 1765-1770, 1996.

VI. Amol A. Khalate, Gopinathan Leena, Goshaidas Ray,'An Adaptive Fuzzy Controller for Trajectory Tracking of Robot Manipulator', Intelligent Control and Automation, 2011, 364-370

VII. Koren Ward,' Rapid Simultaneous Learning of Multiple Behaviours with a Mobile Robot' Proc. 2001,Australian Conference on Roboics and Automation ,Sydney,14-15 Nov 2001

VIII. J.Y.S. Luh, Conventional controller design for Industrial robots-a tutorial, IEEE Trans. Systems Man Cybernet. 1983, 298–316.

IX. Pradeep K. Khosla, Takeo Kanade, Experimental of Evaluation of Nonlinear Feedback and Feedforward Control Schemes for Manipulators, The International Journal of Robotirs Research, Vol. 7, No. 1, February 1988.

X. J.J.E. Slotine, W. Li, Adaptive Manipulator Control: A Case Study, IEEE Trans. Automat. Control 33, 1988 , 995– 1003.

XI. Mark W.Spong and M.Vidyasagar, ”Robot Dynamics and control” John Wiley & Sons,2004.

XII. John M Hollerbach , 'Computer, Brains and the Control Movement', Manchester Institute of Technology,Artificial Intelligence Laboratory, June 1982.

XIII. Jolly Shah, Dr. S.S.Rattan, Prof. B. C. Nakra,' Kinematic Analysis of a Planer Robot Using Artificial Neural Network', International Journal of Robotics and Automation, September 2012, 145-151.

XIV. Dodds ,A two-link manipulator: simulation and control design Advisor: Dr. Mahboub Baccouch , University of Nebraska at Omaha Omaha, NE, 68134, March 2012

XV. Duy Nguyen-Tuong, Jan Peters,' Learning Robot Dynamics for Computed Torque Control using Local Gaussian Processes Regression', ECSIS Symposium on Learning and Adaptive Behaviors for Robotic Systems, 2008.

XVI. R. K. Mandava and P. R. Vundavilli, “Study on Influence of Hip Trajectory on the Balance of a Biped Robot,” pp. 265–272.