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Implementation of GA in Designing Control System for Paraplegic Walking Movement using Walker

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Abstract: Due to the complex nature of the humanoid model structure and unavailability of its mathematical model, the model of humanoid structure is developed and then simulated in MSC Visual Nastran to find the dynamics of humanoid model walk with walker and the reference trajectories for normal walk are obtained. Further estimation of the joint torques and the development of a controller to control the movement of the humanoid model with walker is being done. To guide the humanoid model according to the reference trajectories, the controllers are designed. Genetic Algorithm (GA) is employed to optimize the PID controller's parameters so that the developed model follows the reference trajectories.

Key words: Paraplegia . humanoid model . Genetic Algorithm (GA) . MSC visual Nastran 4-D . walking gait . PID controller

INTRODUCTION

For humans, walking is the main form of transportation without a vehicle or riding animal. Paraplegia is a situation where the lower half of the patient's body is paralyzed or abnormal and cannot move due to Spinal Cord Injury (SCI). All this means that the paraplegics will experience lack of motor control and sensation in the lower extremities and are unable to provide the lower extremity force and motions (plantar/dorsiflexion, knee/hip extension and knee/hip flexion) [4].

Several models of gait walking have been described in the previous research done by different authors [1, 5, 8, 12, 15]. Kinematical models have been designed to analyze human walking [10, 14]. Different mathematical models have been developed and studied to analyze human movement. Researchers from various areas of mathematics have studied walking. Collins and Stewart [13] used group theory to analyze the properties of various coupled non-linear oscillators. They predicted that fixed central pattern generators (CPGs) should be capable of changing between gaits by varying very few parameters [6]. Collins then went on to test this with a selection of CPG models and found that it was generally possible to make simple CPGs that produce different gaits by varying only a few internal parameters whilst leaving the connectivity unchanged [7]. This was a simpler solution than many previously proposed which suggested, for instance, that different coordinating neurons might be needed for different gaits [14, 16]. Musculoskeletal models have been analyzed and designed in different computer simulation tools [1, 5, 11].

A real time humanoid model is developed in MSC visual Nastran 4-D to obtain reference trajectories. To follow up these reference trajectories a control system is developed. The controllers are both tuned manually and using GA to follow the reference trajectories.

This paper is organized as follows. Section 2 presents the development of the humanoid model, walker, humanoid walking gait and its phases. Section 3 gives the controller design structure. A brief overview of GA and the proposed GA based tuned control system is described in section 4. The results are shown in section 5. Finally, the conclusion is given in section 6.

HUMANOID MODEL

Development of humanoid structure: The main function of humanoid model is to present dynamics and real physical human body in terms of length and weight. The parameter of each body segment was based on anthropometrical data provided by Winter [17]. Winter formularized the length of each body segment as the fraction of total human height, while the total human body weight is determined in terms of the collective weights of all body segments. Figure 1 illustrates the length of each body segment of a complete human body. An accurate model development is very important so that an accurate control system may be developed to perform walking movement using walker. To do so, using computer aided design tool is needed that can simulate the designed model in real

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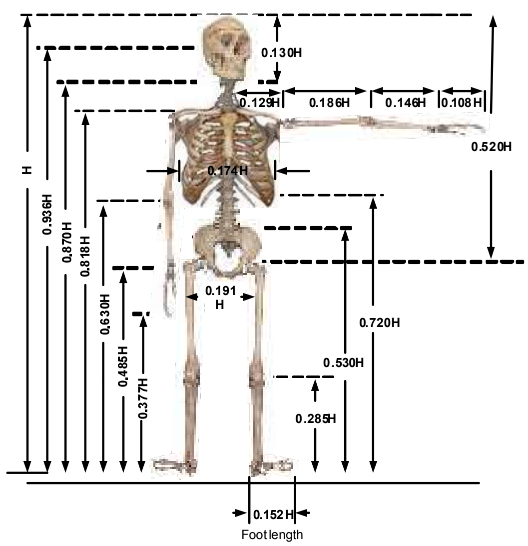

Fig. 1: Body segment length expressed as a fraction of the body height

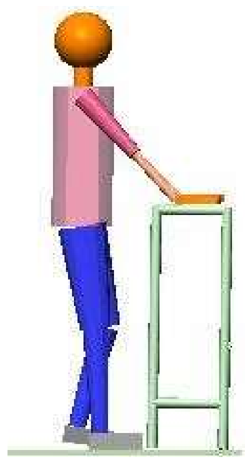

Fig. 2: Humanoid model developed

time. Firstly humanoid model is developed in Solid Edge and is used in MSC visual Nastran to obtain the reference trajectories. Although the humanoid model has numerous degrees of freedom but the present work is restricted only to left hip, left knee, right hip and right knee. Revolute motors are used for these specified joints to obtain the reference trajectories in terms of instantaneous angles for a normal human walking. Figure 2 shows the model developed in MSC visual Nastran.

Walking movement: Coordinated motion, locomotion and walking in particular, are central aspects of human behavior. Human walking can be approximated as a mechanical process governed by Newton's laws of motion.

Phases of walking movement: Walking is the most convenient way to travel short distances. Free joint mobility and appropriate muscle force increases walking efficiency. As the body moves forward, one limb typically provides support while the other limb is advanced in preparation for its role as the support limb.

The gait cycle of each leg is divided into the stance phase and the swing phase. The stance phase is the period of time during which the foot is in contact with the ground. The swing phase is the period of time in which the foot is off the ground and swinging forward. In walking, the stance phase comprises approximately 60% of the gait cycle and the swing phase about 40%. The difference of swing to stance phase changes as the speed of walking or running increases.

DESIGN OF CONTROL SYSTEM

To control the movement of the humanoid model according to the reference trajectories a multivariable control system is designed. PID controllers are used to track the reference trajectories of the revolute motors used for each left hip, left knee, right hip and right knee. To achieve satisfactory performance, multivariable control methods must be used. Consider the case of 4×4-square system. The system can be modeled as:

$$y = \psi(\theta)\, u \qquad (1)$$

where output and control vectors satisfying y, $u \in \Re^4$ and 4×4-square matrix of system transfer function $\psi(\theta) \in \Re^{4\times 4}$.
The error can be calculated as:

$$e_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} = r_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} - y_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} \qquad (2)$$

where error, reference and output vectors are e, r and $y \in$ is $\Re^4$ respectively.
The equation of the controllers is given as:

$$u_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} = G_c(s)\, e_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} \qquad (3)$$

where control and error vectors e, $u \in \Re^4$ and $G_c(s) \in \Re^{4\times 4}$ is transfer function matrix of control system.
The equation of the system is given by:

$$y_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} = \psi(\theta)\, u_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} \quad (4)$$

where

$$y = [y_{l-h}\; y_{l-k}\; y_{r-h}\, y_{r-k}]^T$$

and

$$u = [u_{l-h}\; u_{l-k}\; u_{r-h}\, u_{r-k}]^T$$

The control system is given by:

$$u_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} = G_c(s)\, e_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} \quad (5)$$

where e, u $\in \Re^4$ and $G_c(s) \in \Re^{4\times4}$.

$$\begin{bmatrix} u_{l-h} \\ u_{l-k} \\ u_{r-h} \\ u_{r-k} \end{bmatrix} = \begin{bmatrix} [PID]_{l\text{-}h} & & & \\ & [PID]_{l\text{-}k} & \mathbf{0} & \\ & \mathbf{0} & [PID]_{r\text{-}h} & \\ & & & [PID]_{r\text{-}k} \end{bmatrix} \begin{bmatrix} e_{l-h} \\ e_{l-k} \\ e_{r-h} \\ e_{r-k} \end{bmatrix} \quad (6)$$

Various components are strongly coupled with each other, a small change in any joint may produce disturbance in all other joints. As the precise mathematical model is not easy to derive which may describe the dynamic behavior of the humanoid model. So to achieve the desired trajectories, a closed loop control system has been designed.

PROBLEM FORMULATION

To control the movement of the humanoid model using PID controllers the reference trajectories are needed, so that the humanoid model shows the normal walking by following these trajectories. In order to follow the reference trajectories, PID controllers are tuned to move the model.

In this paper, GA is used as an optimization tool to tune the PID controllers to obtain optimal parameter values of PID controllers which will control the movement of the model. The objective function is defined in terms of errors and GA will search the optimal solution in terms of parameter of the PIDs so that the error minimization is achieved.

Objective function: To design the four GA based PID controllers so that it will follow the reference trajectories given by the visual Nastran 4-D. The objective function can be defined as:

$$J = J_{left} + J_{right} \quad (7)$$

where

$$J_{left} = w_2\left(\int_0^3 e\,dt\right)_{Hip} + w_2\left(\int_0^3 e\,dt\right)_{Knee}$$

and

$$J_{right} = w_3\left(\int_0^3 e\,dt\right)_{Hip} + w_4\left(\int_0^3 e\,dt\right)_{Knee}$$

$$e_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} = r_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} - y_{\begin{bmatrix} l-h \\ l-k \\ r-h \\ r-k \end{bmatrix}} \quad (8)$$

where e is the error, r is the reference trajectory and y is the output of the plant and $w_1 = w_2 = w_3 = w_4 = 1$.

Optimization problem: In this paper, the objective function J is minimized based on the coefficients of the PID controller parameters. i.e.,

Minimize J
Subjected to:

$$K_{P,i}^{min} \le K_{P,i} \le K_{P,i}^{max}$$
$$K_{I,i}^{min} \le K_{I,i} \le K_{I,i}^{max}$$
$$K_{D,i}^{min} \le K_{D,i} \le K_{D,i}^{max}$$

where $i \in [1,2,3,4]$
GA is used to optimize the proposed design in searching the optimal controller parameter values as shown in Fig. 4. The bounds of the PID controller parameters are given Table 2. The GA parameter values are given in Table 3. The movement of humanoid model is controlled by closed loop control system as shown in Fig. 5. The desired movement of the humanoid model walking using walker can be achieved by interfacing Matlab/Simulink with MSC visual Nastran as shown in Fig. 6.

RESULTS AND SIMULATIONS

The MSC visual Nastran is used to simulate the humanoid walking with walker for a time interval of 3 seconds to obtain the reference trajectories. The initial and final positions of the humanoid model in MSC visual Nastran is shown in Fig. 7. Then the humanoid

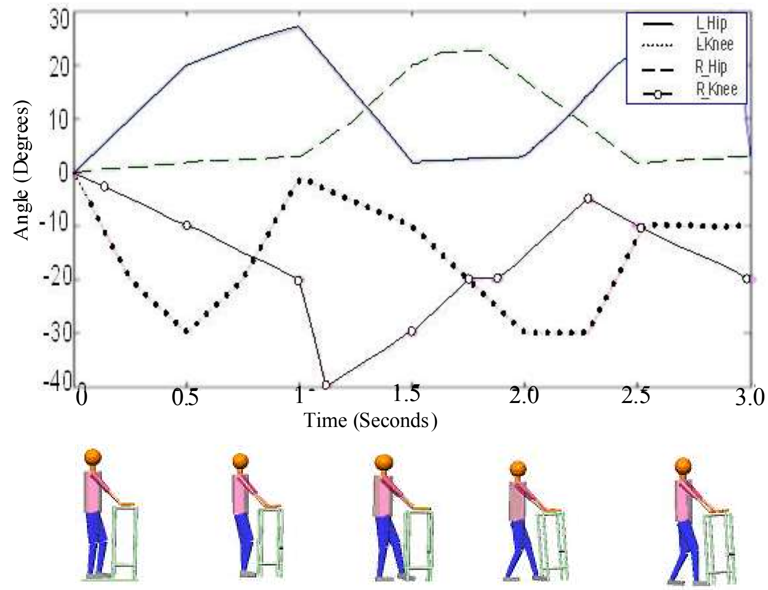

Fig. 3: Shows walking gait for complete two steps

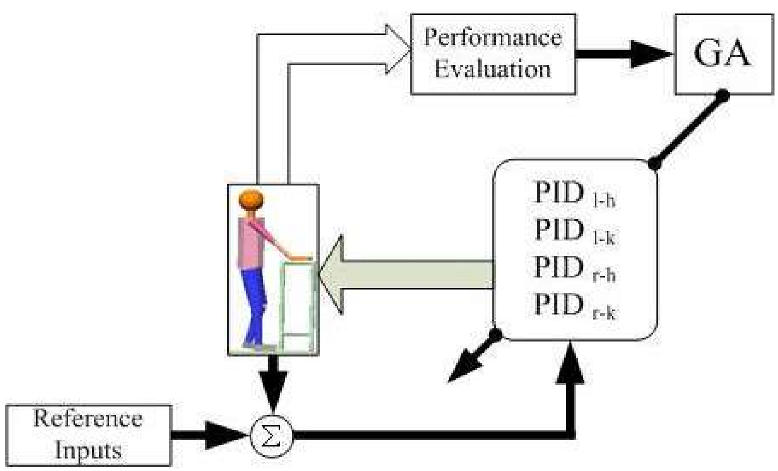

Fig. 4: Design methodology

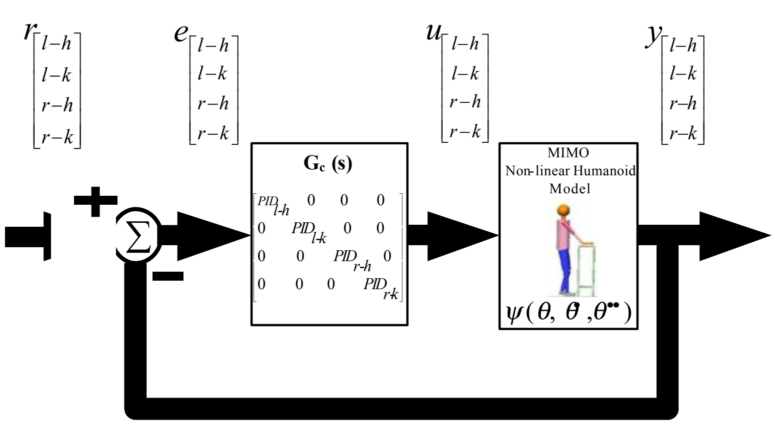

Fig. 5: Closed loop control system of the inverse humanoid model

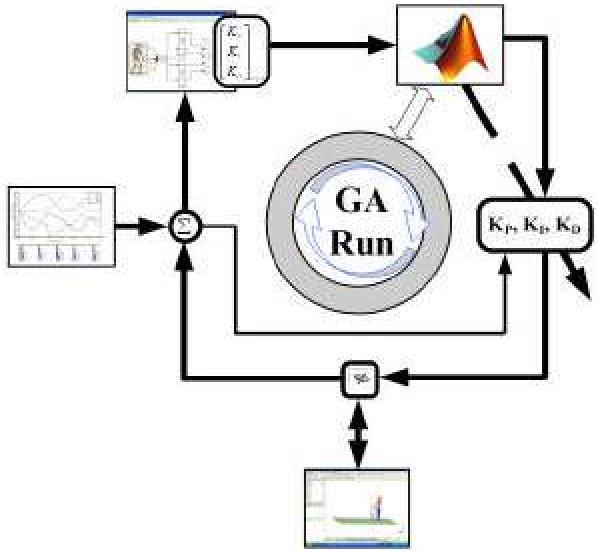

Fig. 6: Interface diagram

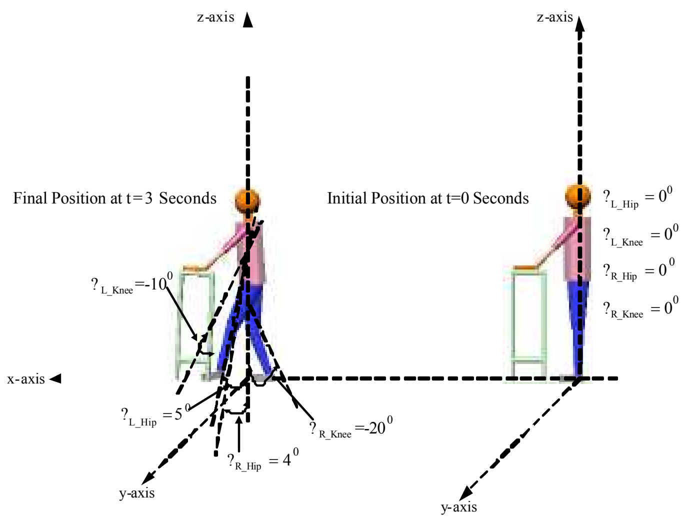

Fig. 7: Initial position and final position of humanoid model in MSC visual Nastran

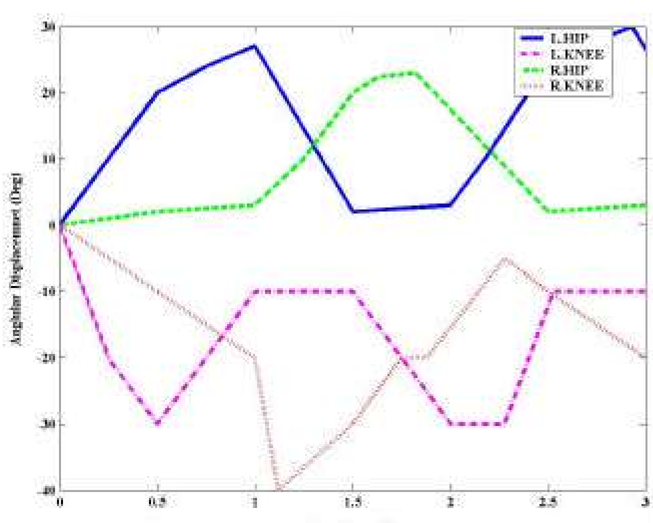

Fig. 8: Angular displacement

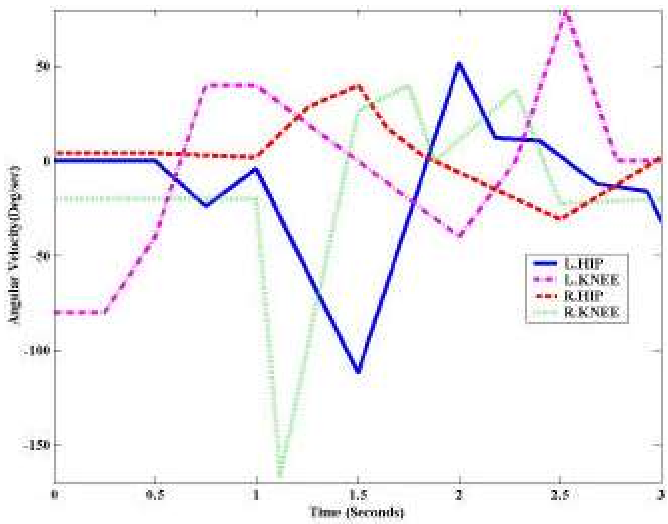

Fig. 9: Angular velocity

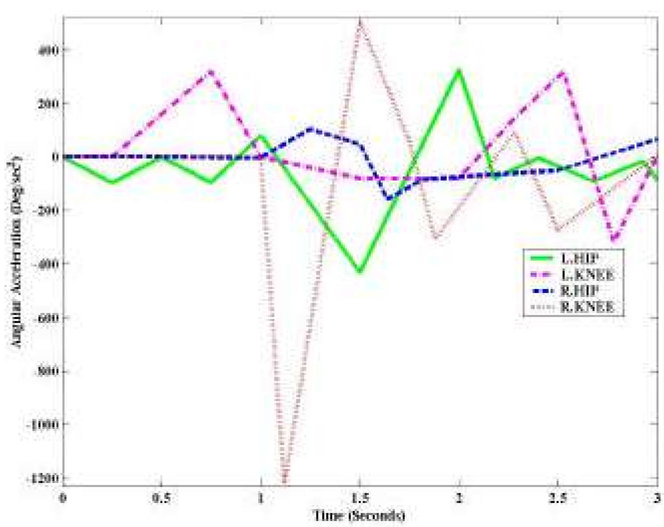

Fig. 10: Angular acceleration

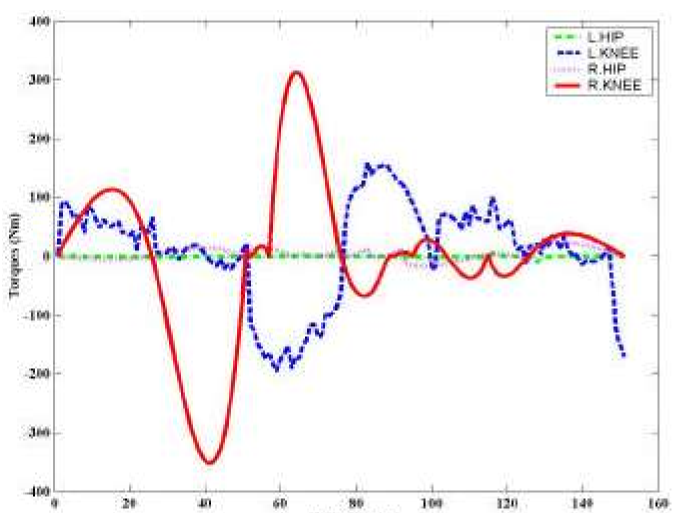

Fig. 11: Torques

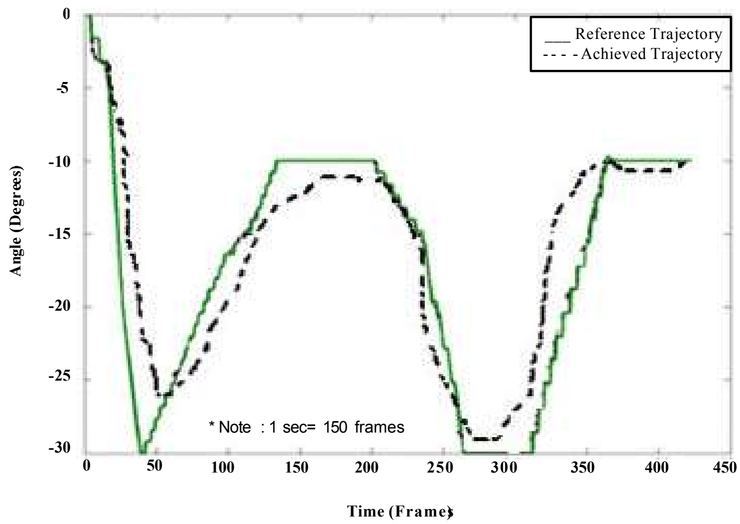

Fig. 12: Reference and achieved left knee trajectory

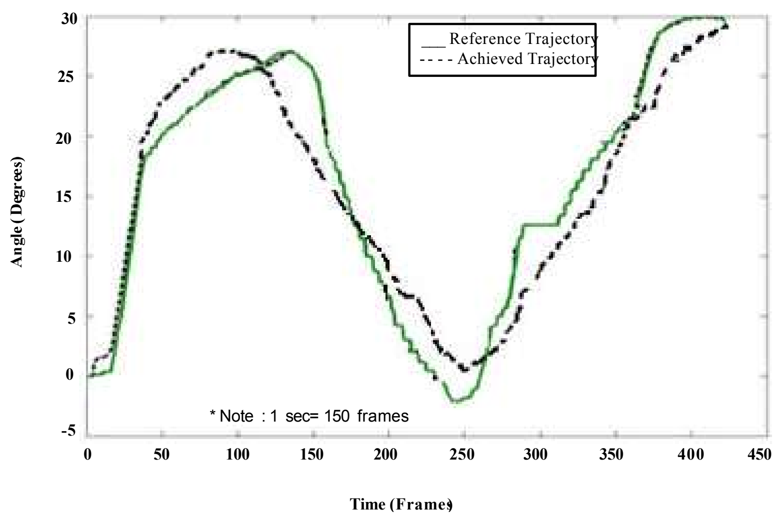

Fig. 13: Reference and achieved left hip trajectory

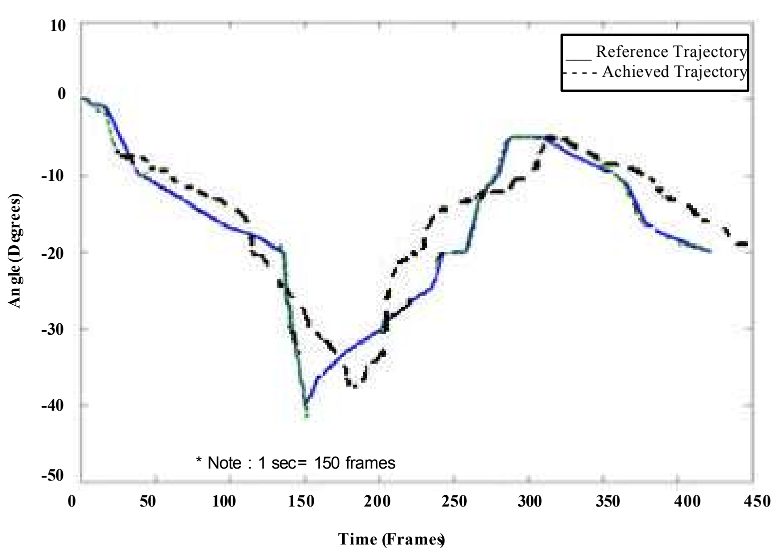

Fig. 14: Reference and achieved right knee trajectory

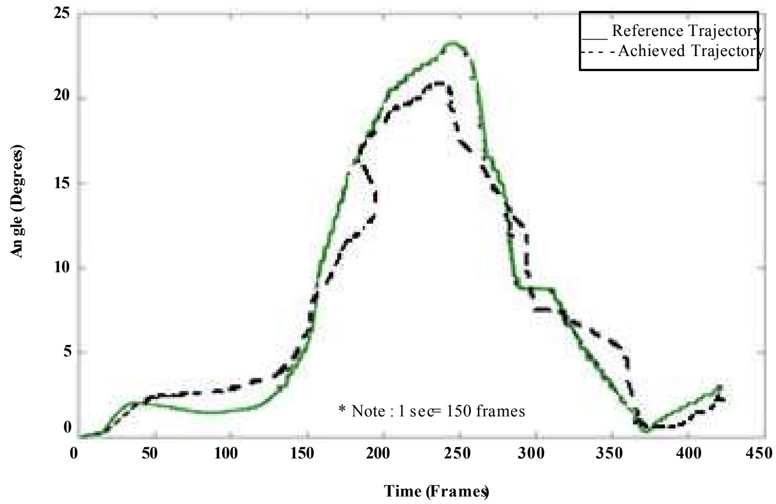

Fig. 15: Reference and achieved right hip trajectory

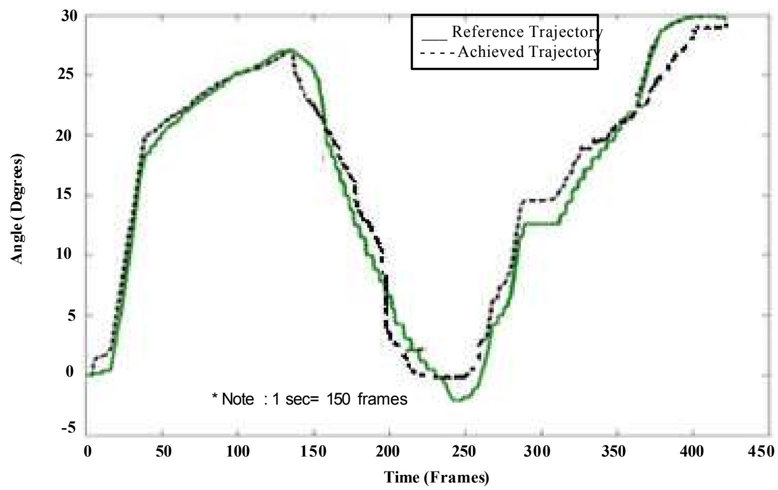

Fig. 16: Reference and achieved left hip trajectory

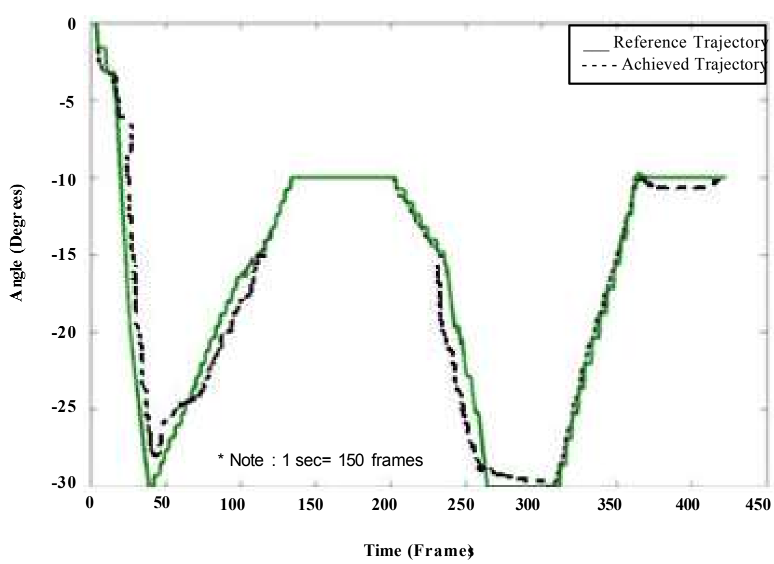

Fig. 17: Reference and achieved left knee trajectory

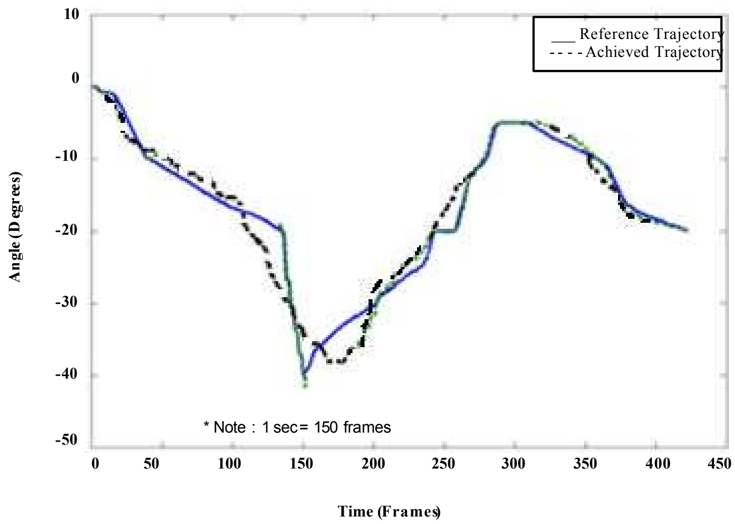

Fig. 18: Reference and achieved right knee trajectory

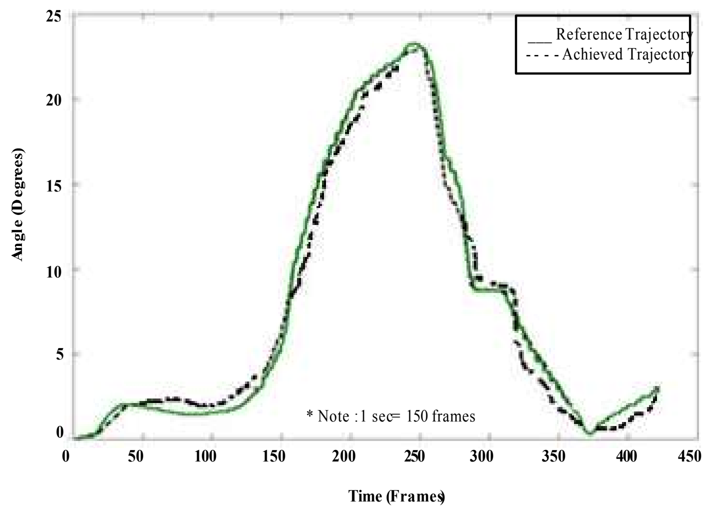

Fig. 19: Reference and achieved right hip trajectory

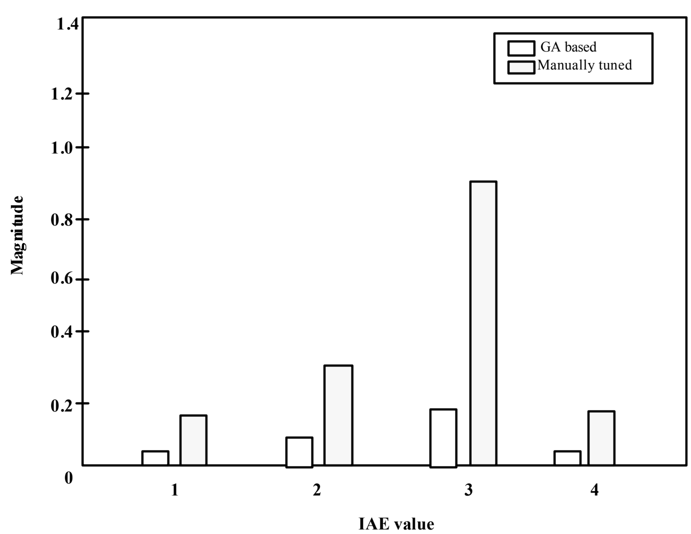

Fig. 20: Comparison between the PIDs tuned manually and PIDs tuned by GA for IAE

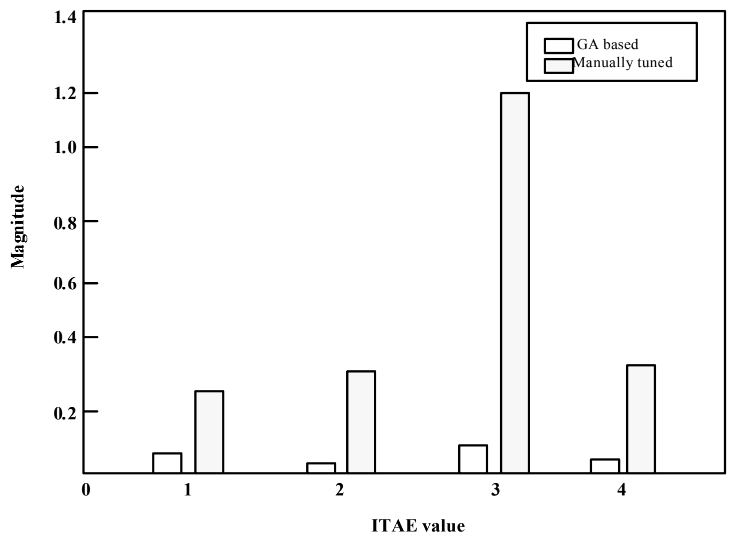

Fig. 21: Comparison between the PIDs tuned manually and PIDs tuned by GA for ITAE

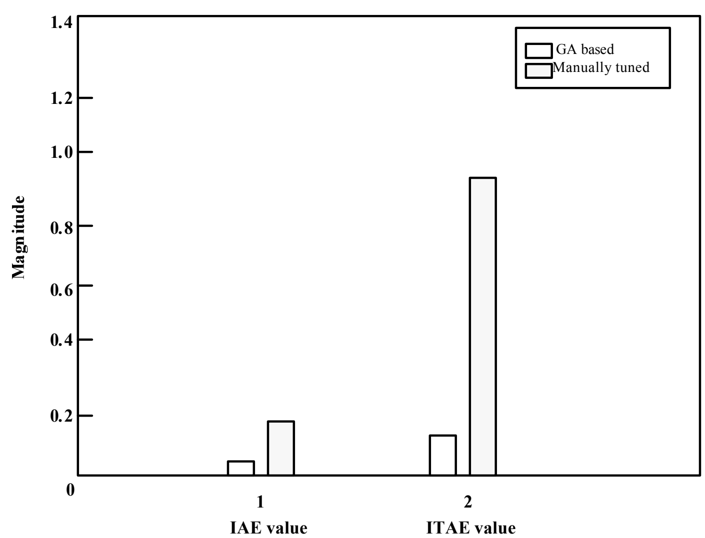

Fig. 22: Comparison between the combined PIDs tuned manually and PIDs tuned by GA for IAE and ITAE

model is moved using closed loop control system and the PID controller parameters are tuned to follow the reference trajectories. The corresponding angular displacement, velocity and acceleration are given in Fig. 8-10 respectively. The torques plots of the reference trajectories of left hip, left knee, right hip and right knee respectively are shown in Fig. 11.

The optimized PID controllers parameter values are given in Table 4. The trajectories following by manually tuned PID based control system for left knee, left hip, right knee and right hip respectively are shown in Fig. 12-15. While GA based tuned PID controllers of the closed loop control system trajectories following plots are given in Fig. 16-19 (9) for left hip, left knee, right hip and right knee respectively.

The IAE and ITAE are used to show the static and dynamic performance of both manually and GA based tuned PID controllers described in equations 9 and 10.

$$\mathrm{IAE} = \int_0^3 \left(|e_{l-h}|^2 + |e_{l-k}|^2 + |e_{r-h}|^2 + |e_{r-k}|^2\right).dt \qquad (9)$$

$$\mathrm{ITAE} = \int_0^3 t.\left(|e_{l-h}|^2 + |e_{l-k}|^2 + |e_{r-h}|^2 + |e_{r-k}|^2\right).dt \qquad (10)$$

Figure 20 shows the IAE value of both GA based and manually tuned PID controllers. It is observed that the IAE value of GA based tuned are less than that of manually tuned PIDs for all four joints. Figure 21

Table 1: Phases of the walking movement

S. No	Phase	Activity	Cycle
1	Initial Phase	Trunk movement with still legs	10%
2	First Step/Left foot	Forward Acceleration	10%-40%
3	Back to initial position	Deceleration/Balancing Body	40%-50%
4	Second Step/Right foot	Forward Acceleration	50%-80%
5	Final phase	Back to still position	80%-100%

Table 2: The parameters bounds for optimization

S. No	Parameters	Min	Max
1	K_{P1}	0	50
2	K_{I1}	0	50
3	K_{D1}	0	50
4	K_{P2}	0	50
5	K_{I2}	0	50
6	K_{D2}	0	50
7	K_{P3}	0	50
8	K_{I3}	0	50
9	K_{D3}	0	50
10	K_{P4}	0	50
11	K_{I4}	0	50
12	K_{D4}	0	50

Table 3: GA parameters

S. No	Parameter	Value
1	Maximum generations	100
2	Population size	20
3	Crossover probability	0.6
4	Mutation probability	0.1

Table 4: Parameters values of manually tuned and GA based tuned PID controllers

		Value	
S. No	Parameters	Manually tuned	GA tuned
1	K_{P1}	41.0	5.6
2	K_{I1}	2.0	16.0
3	K_{D1}	1.7	25.9
4	K_{P2}	11.0	3.7
5	K_{I2}	4.0	3.1
6	K_{D2}	4.6	47.0
7	K_{P3}	13.0	4.25
8	K_{I3}	10.0	20.0
9	K_{D3}	12.0	15.0
10	K_{P4}	23.0	7.8
11	K_{I4}	3.0	40.1
12	K_{D4}	5.0	39.7

shows the ITAE value of both GA based and manually tuned PID controllers. It is observed that the ITAE value of GA based tuned are less than that of manually tuned PIDs for all four joints. The combined IAE and ITAE values for both GA based and manually tuned of four PID controllers are given in Fig. 22. These figures show that GA has given better results of error minimization than that of manual tuning.

CONCLUSION

In this paper, the simulation of humanoid walking using walker has been presented. The humanoid model is developed and the humanoid gait with walker is analyzed, simulation and control has been done in Visual Nastran with Matlab/ Simulink. The movement of humanoid model in MSC visual Nastran has been controlled by using PID controllers for closed loop control system in Matlab/Simulink. PIDs are tuned so that it will follow the reference trajectories. The tuning of PIDs is carried out by using GA and through manual tuning and the respective performances are compared. The results show that the tuning of PIDs using GA is performed more efficiently in minimizing the error than that of manual tuning.

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