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Design of Conventional and Intelligent Controllers for Biped Robot

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***Abstract*— Robotics play a vital role in recent times. All the industries are moving towards automation for better performance and higher efficiency. In this paper biped robot leg is considered as bench mark problem. Biped robot has many applications in gaming, walking and automation. This paper discusses about controlling the movement of the biped robot's leg. The simple nonlinear model of a robotic leg is considered [1] [2] [3]. Different types of controllers such as P, PI and PID are developed for the robot control and analyzed based on error criteria and time domain specifications. Different controller parameter like Ki, Kp, Kd have been obtained using Ziegler Nicholas method and Tyreus Luyben method. The Kp, Ki, Kd values has also been found using heuristics algorithm such as BFO, PSO, Firefly algorithm. There are two types of controller structure, one is ideal and other is parallel structure .The Simulation results are shown via step response . The above said methods are simulated by tuning the parameter values of Kp, Ki, Kd and the response are compared for all the controllers using MATLAB.**

***Index Terms*— Biped robot, PID controller, BFO, PSO, Firefly Algorithm.**

I. Introduction

The research regarding the walking of biped robot was conducted in Japan during the 1970s . The Biped Robots was designed to get as close to the freedom of movement of human lower body, it has 12 degree of freedom. The frame is made of acryl-sheet and model servos are used as actuators . It is not yet clear how humans will use biped humanoid robots effectively. One of the main reasons for this is due to the fact that the artificial intelligence of a robot does not meet the expectations of human. Thus far, most biped robots work by means of an operator's orders or through a well distinct program without the need of self-decision. Some of the existing models are ASIMO of Honda, QRIO of Sony, WABIAN of Waseda university and HRP-2 of AIST. These Biped robots may play an important role in terms of mobility. The Sizes of the frame were minimized in order to manage a payload of over 100kg. Due to this Structural bending occurred and developed a structural vibration while robot walked. This causes the riding person to experience a swinging motion which caused further disturbance to the robot. Due to this the leg was shaking in air ,thus the landing point become imprecise and the walking constancy is lowered. So it is required to stabilize the walking pattern of the Biped robot. In order to do so, PI and PID controllers are designed using Ziegler Nicholas method and Tyreus Luyben method and other heuristics algorithm such as BFO, PSO, FA algorithms. PID controllers are easy to use and they provide robust and reliable performance.

II. Design of PID Controllers

A. Mathematical Model

Mathematical model of the robot is derived based on the relationship between angular rotations about the hip joint to the input torque generated by leg muscle [2]. Dc motor operated leg is considered for mathematical modelling which includes the terms armature windings, resistances, inductance and back electromotive force. A cylindrical model of robot leg is considered [3]. The robot's transfer function obtained after the linearization of non-linear model [3] is represented as given below.

$$P(s) = \theta(s)/\Delta(s) = \frac{15.24}{s^2+2.657s+11.73}$$

B. Ziegler – Nicholas Method

In this method, K_I and K_D values are given zero and K_P (proportional gain) is increased in steps till sustained oscillations are obtained.Proportional gain at which sustaained oscillations are obtained is called ultimate gain and it is denoted as K_U and period of oscillations is called ultimate period which is denoted as P_U. Once K_U and P_U values are obtained we can calculate the values of P ,I and D by using the formulae [4] [5] [6].

C. Tyreus - Luyben Method

This method is similar to Ziegler- Nichols method .In this method ultimate gain(K_U) and ultimate period (P_U) are obtained in a manner similar to Ziegler Nichols method. Once K_U and P_U are obtained we can calculate the values of P, I and D from the formulae [4] [5] [6].

III. Development of Heuristic Algorithms

Heuristics algorithm is the best way to find a possible solution for a problem .There are many types of algorithms . The commonly used algorithms are Bacterial Foraging Optimization (BFO) [10], Particle Swarm Optimization (PSO) [7] and Firefly Algorithm (FA) [8] [9] which are used to find the best solutions available in a faster and in an efficient manner.

A. Particle Swarm Optimization

Particle swarm optimization (PSO) [12] is a computational method that solves the problem in increasing steps to improve the accuracy of the solution with concern to the given problem. PSO was found in the year 1995 by Kennedy and Eberhart and it was proposed for simulating social behaviour in fish school and flock of birds . It keep track of three global variables and they are target value or condition ,global best value representing which particle's data is currently closest to the target and Stopping value indicating when the algorithm should stop if the target was not found . Each particle consists of data representing a possible solution , a Velocity value indicating how much the data can be changed and a personal best (pBest) value indicating the closest the particle's data has ever come to the target [11].

$$V_i(t+1) = W^t.V_i^t + C_1R_1(P_i^t - S_i^t) + C_2R_2(G_i^t - S_i^t)$$

$$X_i(t+1) = X_i^t + V_i(t+1)$$

Where $C_1 = C_2$=2.1 , W^t is weight of inertia and it equals 0.75, V_i^t is the current velocity of the particle, $V_i(t+1)$ -updated velocity of particle , X_i^t -current position of particle, $X_i(t+1)$ -updated position of particle, R_1, R_2 are the random numbers.

<u>Pseudo Code</u>

```
For each particle
{
   Initialize particle
}

Do until maximum iterations or minimum error criteria
{
   For each particle
   {
      Calculate Data fitness value
      If   the fitness value is better than p Best
      {
         Set Personal Best = current fitness value
      }
      If Personal Best is better than Global Best
      {
         Set Global Best = Personal Best
      }
   }

   For each particle
   {
      Calculate particle Velocity
      Use Global Best and Velocity to update particle Data
   }
```

B. Bacterial Foraging optimization

It is been widely used as a global optimization algorithm technique for distribution optimization and control . It is used to solve the problem by implementing the solutions in real time which are arose in several time domain specifications. BFO is a non-gradient optimization problem which is inspired by the foraging strategy of E.Coli bacteria such that it maximizes their energy intake per unit time spent in foraging. The results obtained in BFO are much better than the PSO technique. There are four principles noted from bacteria and they are Chemo taxis, Swarming, Reproduction, Elimination dispersal. This process simulates the movement of an E.Coli cell through swimming and tumbling via flagella.

Suppose θi (j, k, and l) represents the ith bacterium at jth chemo tactic, kth reproductive, and lth elimination–dispersal step. C (i) is a scalar and indicates the step size taken in the random

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direction. Then, in computational chemo taxis, the movement of the bacterium may be represented by

$$\theta i(j+1,k,l) = \theta i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^{T}(i).\Delta(i)}}$$

where Δ indicates a unit length vector in the random direction.

C. Firefly Algorithm

The firefly algorithm was discovered by Xin –She Yang and inspired by the flashing behavior of fireflies. Fireflies use the flashing behavior to attract other fireflies ,usually for sending signals to opposite sex .However, in mathematical model , used inside firefly algorithm ,simply the fireflies are unisex, and any firefly can attract other fireflies . Firefly algorithm is similar to bacterial foraging optimization in some ways . It is based on two things and they are change in light intensity and formulation of attractiveness.

Variation in light intensity can be logically expressed with the following Gaussian form:

$$I(r) = I_0 e^{-\gamma d^2}$$

Where I = new light intensity, I_0 = original light intensity, and γ = light absorption coefficient.

The attractiveness towards the luminance can be analytically represented as:

$$\beta = \beta_0 e^{-\gamma d^2}$$

Where β = attractiveness coefficient, and β_0 = attractiveness at r = 0.

The above equation shows a characteristic distance $\Gamma = 1/\sqrt{\gamma}$ over which the attractiveness changes significantly from β0 to β0e^{-1}. The attractiveness function *β (d)* can be any monotonically decreasing functions such as the following form;

$$\beta(d) = \beta_0 e^{-\gamma d^m}, \quad (m \geq 1)$$

For a fixed γ, the characteristic length becomes;

$$\Gamma = \gamma^{-1/m} \rightarrow 1, m \rightarrow \infty$$

Conversely, for a given length scale Γ, the parameter γ can be used as a typical initial value (that is $\gamma = 1/\Gamma m$).

The Cartesian distance between two fireflies *i* and *j* at x_i and x_j, in the *n* dimensional search space can be mathematically expressed as;

$$d_{ij}^{t} = \left\| X_j^t - X_i^t \right\|_2 = \sqrt{\sum_{k=1}^{n} (X_{j,k} - X_{i,k})^2}$$

In FA, convergence speed and optimization accuracy depends mainly on the guiding parameters, and that helps to update the agent values. Most of the heuristic algorithms are guided by the randomization operator. Due to the randomization parameter, the optimization accuracy and the convergence will not be in expected level in most of the search cases. Hence, in this work, Brownian distribution guided firefly algorithm is adopted to obtain enhanced values of the PID parameters:

$$X_i^{t+1} = X_i^t + \beta_0 e^{-\gamma d_{ij}^2} (X_j^t - X_i^t) + \alpha \,.\, \text{sign(rand - ½)} \;\oplus\; \text{Brownian Search}$$

Where, X_i^{t+1} = updated position of firefly, X_i^t = initial position of firefly, and $\beta_0 e^{-\gamma d_{ij}^2} (X_j^t - X_i^t)$ = attraction between fireflies.

IV. RESULTS AND DISCUSSIONS

The table1 shows the parameter values of PI, PID controller obtained by different tuning methods and heuristics algorithm. Heuristics approaches like PSO, BFO, FA are carried out 5 to 10 times and the average value is taken as optimum controller values. Depending on the output response; time domain specifications and error criteria is noted.

TABLE I: PID PARAMETERS

Controller	Kp	Ki	Kd
ZN PID	2.1664	5.4191	0.2167
TYL PI	1.1515	0.6542	-
TYL PID	1.675	0.9517	0.2126
BFO PID	0.4432	0.1219	0.0760
PSO PID	2.3293	1.1403	3.1021
FA PID	0.0634	0.7203	0.4478

From the parameters in table I, the robot leg is tuned to attain the desired angle. The controllers are compared by time domain specifications and error criteria as shown in table II.

TABLE II: PERFORMANCE EVALUATION

Controller	Peak time(s)	Rise time(s)	Settling time(s)	IAE	ISE
ZN PID	7.3	.3	83.4	1.512	3.373
TYL PI	0.6	0.5	25.9	5.326	10.4
TYL PID	3.8	13.1	23.1	2.416	4.013
RELAY ZN PI	90.1	90.1	90.1	27.93	50.22
RELAY ZN PID	34.1	34.1	34.1	10.07	18.87
RELAY TYL PI	464.3	464.3	464.3	156	295.9
RELAY TYL PID	241.1	241.1	241.1	127.2	58.72
BFO PID	114.6	114.6	114.6	63.11	217.11
PSO PID	8.2	8	8.8	1.223	1.4960
FA PID	6.2	5.9	6.5	7.602	22.49

From Table II, it can be conclude that normal tuning methods like Ziegler Nicholas and Tyreus Luyben methods and have lesser settling time and small error values. The Relay tuning method have larger settling time and large error values compared to other methods. Heuristics approaches like BFO has larger settling time and larger error values but other approaches like PSO, FA have lesser settling time and small error values compared to other methods. The normal tuning methods have large overshoot and unwanted oscillations and they are eliminated or minimized to an extinct by using heuristics approaches. From the table, it can be concluded that PSO and FA algorithm gives best results and can be used to stabilize the walking pattern of the of the Biped Robot. The graphical responses of different controllers are shown in figure 1 and 2.

From Figure 1 , it can be observed that the conventional controller has unwanted oscillations. IPD structure are modified form of PID structure and they are more flexible in nature.

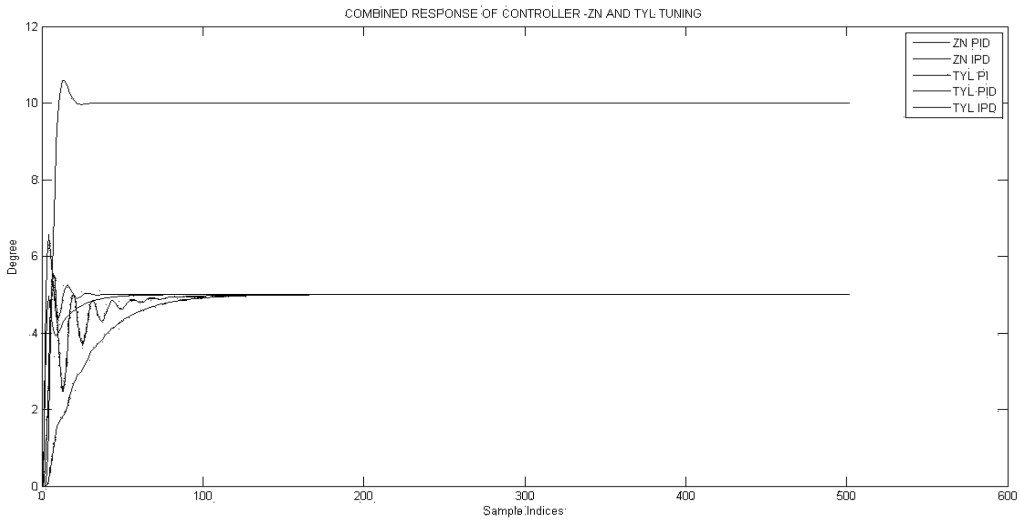

Fig. 1 Combined Response of PI, PID, IPD using Ziegler Nicholas and Tyreus-Luyben

From Figure 3 , it can be observed that in heuristics approach the oscillations are eliminated and these approaches have faster settling time and minimum error compared to other methods . Using these approaches the walking of Biped robot can be stabilized.

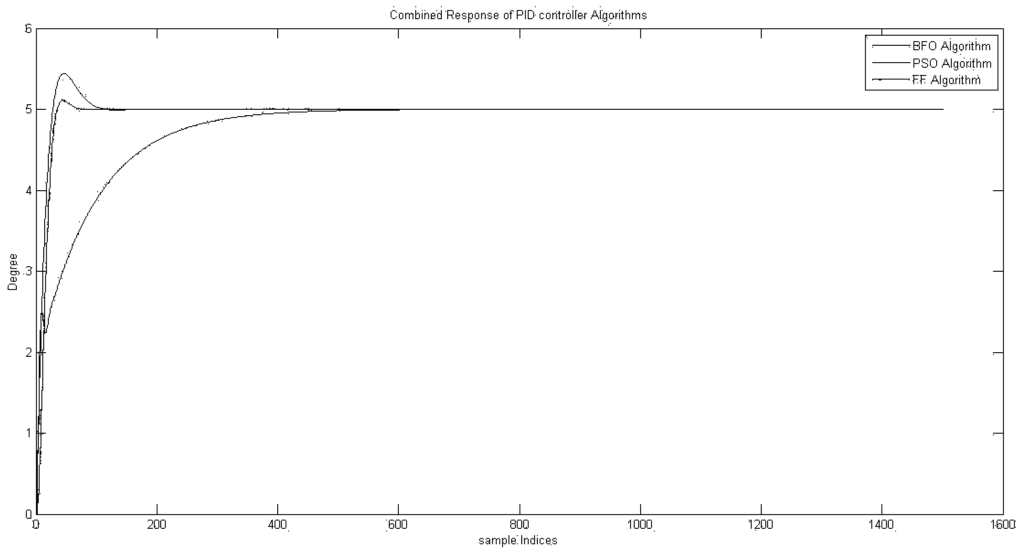

Fig. 2 Combined response of BFO, PSO, FA algorithms

V. CONCLUSION

In this paper, design of PID controller using different Tuning methods and heuristics approach to control the walking of Biped robots is described. Heuristics algorithm like BFO, PSO, FA algorithms are considered. Performance of all the controller is evaluated by time domain specification and error indices. On comparing; PSO and FA algorithm have least settling time and minimum error indices. These two algorithms have the best output response with faster settling time but among the two; Firefly algorithm has the best output response and can used to control the walking angle of the Biped robot.

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