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Simulation of Digital Control of Human Arm Based PSO Algorithm in Virtual Reality

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Abstract

Soft computing research is concerned with the integration of artificial intelligent tools in a complementary hybrid framework for solving real world problems. This paper tries to explore the potential of using soft computing methodologies in control of plant (human arm),utility and effectiveness of soft computing approaches for the control of seven degree of freedom of human arm with structured is presented. It presents a PID tuning method that uses a Particle Swarm Optimization (PSO) as a main gain of PID tuning using multi objective to improve the time response of system such settling time and overshoot. The method implements in the 3D space using Virtual Reality (VR) to compare between the proposed tuning rules and the traditional tuning rules under disturbance load . MATLAB Ver.2009a software is used to show the efficiency of the proposed tuning rule. Simulation results demonstrate that better performance can be achieved with this method relative to 1) trial and error tuning 2)Ziegler-Nichols tuning 3)conventional tuning .

Keywords— PID Controller, Particle Swarm Optimization, Human Arm, Virtual Reality.

محاكاة لسيطرة رقمية على ذراع انسان باستخدام طريقة حشد الجزيئات في البيئة الافتراضية

الخلاصة

بحوث الحسابات الناعمة تهتم بتكاملِ الأدواتِ الذكيةِ في إطار هجين مكمّل لحَلّ مشاكلِ العالم الحقيقي .هذا البحث يحاول إسْتِكْشاف الإمكانيةِ لإستعمال الحسابات الناعمة للسيطرة على ذراع إنساني، فائدة وتأثير إستعمال الحسابات الذكية لسيطرةِ على سبعة مِنْ درجةِ حريةِ الذراعِ الإنسانيِ تقدم في هذا البحث .يقدم البحث طريقة لاختيار قيم ال PID باستعمال أمثلية حشود الجزيئةِ و استعمال دالة متعددة الاهداف لتحسين وقت الاستقرار و مقدار اكبر خطا . تُطبّقُ الطريقةُ في فضاء 3D باستعمال الواقع الافتراضي لمقارنة الطريقة المقترحة مع الطرق الاعتيادية. برنامج ال

MATLAB Ver.2009a استعمل في هذا البحث لبيان كفاءة الطريقة المقترحة.نتائج المحاكاة اظهرت كفاءة الطريقة المقترحة بالمقارنة مع 1) تَضْبيط التجربة والخطأِ 2) تَضْبيط Ziegler-Nichols 3) تَضْبيط تقليدي

1. Introduction

Robotics is one of the main disciplines in the industry which can be used in the development of new technologies. The synergy of robotics with the different applications like submarine task, car assembly operation, vision systems and artificial intelligence allows the innovation and reduces the manufacture costs. For this purpose, it is important that the robot programmers are able to visualize and test the behavior of the robots in different circumstances and with different parameters [1].

The problem of controlling robot manipulators still offers many practical and theoretical challenges due to the complexities of the robot dynamics and the requirement to achieve high precision position tracking [2]. Therefore it is necessary to control the path which enables the tool of the robot to follow with high accuracy to avoid robot or tool destruction. In most control systems such as robots, PID controller considered the most and popular control Algorithm, because of its simple structure, ease of design and the robustness in operating condition [3].

As PID controller has simple structure, easy to understand, the tuning technique provides adequate performance in the vast majority of applications, however, because the response of a plant depends on three parameters (P, I, and D) and gain must be manually tuned by trial and error. Most PID tuning rules use conventional methods. This requires considerable technical experience to apply tuning formulas to determine PID controller parameters [4].

The main objective of the present work is to show a control of human arm, where, the parameters of PID controller are tuned using particle swarm optimization. Virtual reality allows to manipulate the human arm system and to visualize the robot's behavior from different perspectives.

2. Tuning of PID Controller

Ziegler-Nichols tuning rule was the first such effort to provide a practical approach to tune a PID controller. The key step of the Ziegler-Nichols tuning approach is to determine the ultimate gain and period. This method is applied directly since they provide simple tuning rules to determine the PID parameters. However, since they rely on a minimum amount of dynamic information by making a certain assumption about nature of the controlled process, such as linearity, weak interactions within the process, absence of noise, etc.

Recently, the computational intelligence has purposed genetic algorithms (GA) and particle swarm optimization (PSO) as opened paths to a new generation of advanced process control. Usually such an optimum system performance is defined by a continuous function which is obtained by minimizing the sum of the square of the error between the actual and desired output. The GA and PSO are non-gradient based optimization and search algorithm and belongs to probabilistic search algorithms, which have attracted much attention from the research community. These algorithms generally mimic some natural phenomena, for example the PSO in contrast relies on cooperation rather than competition and good solutions in the problem set are shared with their less-fit brethren so that the entire population improves and poorly performing members are not killed off as in GA.

They are promising approaches due to their effectiveness in searching very large spaces and the ability to perform global search for best forecasting model. Moreover, they are generally easy to program, can efficiently make use of large numbers of processors, do not require continuity in the problem definition, and generally are better suited for finding a global, or near global, solution. The PSO have been used for tuning PID controller and have proved successful results [5]. In the PSO algorithm, instead of using evolutionary operators such as mutation and crossover, to manipulate algorithms, for a d-variable optimization problem, a flock of particles are put into the d-dimensional search space with randomly chosen velocities and positions knowing their best values so far (Pbest) and the position in the d-dimensional space. The velocity of each particle, adjusted according to its own flying experience and the other particle's flying experience. For example, the i^{th} particle is represented as

$$x_i=(x_{i1},x_{i2},\ldots,x_{id}) \tag{1}$$

where x_{ij} is i^{th} particle in j^{th} dimension space [5]. The best previous position of the i^{th} particle is recorded and represented as:

$$Pbest_i=(Pbest_{i1}, Pbest_{i2},\ldots, Pbest_{id}) \tag{2}$$

The index of best particle among all of the particles in the group is d $gbest_d$. The velocity for particle *i* is represented as

$$v_i=(v_{i1},v_{i2},\ldots,v_{id}) \tag{3}$$

The modified velocity and position of each particle can be calculated using the current velocity and the distance from $Pbest_{i,d}$ to $gbest_d$ as shown in the following formulas :

$$v_{ij}^{(k+1)} = w \times v_{ij}^{(k+1)} + c1 \times rand\,() \times (pbest_{ij} - x_{ij}^{(k)}) + c2 \times rand\,() \times (gbest_{ij} - x_{ij}^{(k)}) \tag{4}$$

$$x_{ij}^{(k+1)} = x_{ij}^{(k)} + v_{ij}^{(k+1)} \tag{5}$$

i=1,2,….n
j=1,2,..m
where

i is a particle number.
j is the PID parameter number.
k is a iteration number.
x is the PID parameter .
v is a moving vector.
pbest is a personal best of particle *i*.
gbest is a global best of all particles.
w, *c1* and *c2* are weight parameters.
rand( ) is a uniform random number from 0 to 1.

3. PSO based Optimal PID Controller Design

This paper describes the application of PSO to the fine-tuning of the parameters for PID controllers. Having ability for global optimization is expected to overcome some weakness of conventional approaches and to be more acceptable for industrial practices. A multi-objective optimization method for parameter tuning of PID controller based on PSO algorithm is proposed, which consists of the following two steps:

3.1 Objective function

The most crucial step in applying optimization problem is to choose the objective functions that are used to evaluate fitness of each particle. Some works use performance indices as the objective functions. The objective functions are Integral of Time multiplied by Squared Error (ITSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE), integral term become summation in the discrete time [6].

$$IAE = \int |e(t)| dt \quad , ITAE = \int t |e(t)| dt \quad , ISE = \int (e(t))^2 dt \quad , ITSE = \int t (e(t))^2 dt \tag{6}$$

3.2 The fitness values

The PID controller is used to minimize the error signals, or we can define more rigorously, in the term of error criteria: to minimize the value of performance indices mentioned above. And because the smaller the value of performance indices of the corresponding chromosomes the fitter the chromosomes will be, and vice versa, we define the fitness of the chromosomes as

$$fitness \quad value = \frac{1}{objective \quad function} \tag{7}$$

In this paper a multi objective is introduce to get better time response by replace fitness value in Eq (7) by

$$proposed \quad fitness \quad value = \frac{1}{w * ts + w * ov + objective \quad function} \tag{8}$$

Where

Objective function is taken from Eq (6).

w >>1 since the value of performance index is very large with respect to the settling time and over shot.

4. Human Arm Dynamic

The development of a high-DOF, kinematic is discusses human arm model that can be used to predict realistic human arm postures. One may deal with human arm by 7-DOF and assume the origin at shoulder joint. The first joint is the shoulder joint s with 3 DOFs. The elbow joint e has only one DOF. The wrist joint w is of the same type as the shoulder joint s and also has 3 DOFs. Conventional controllers for industrial robots are based on independent joint control schemes in which each joint is controlled separately by a simple position servo loop with predefined constant gains. This control scheme is adequate for simple pick-and-place tasks, for which industrial robots are often used, where only point-to point motion is of concern. However, in tasks where precise tracking of fast trajectories under different payloads is required, the existing robot control system is severely inadequate. The independent joint control approach to robot manipulator control is very useful for simplifying controller implementation. The key issue involved in such an approach is the suppression of disturbances at each robot joint due to dynamic coupling and gravity loading [7].

In this paper, the proposed scheme is based on the principle of treating each joint as a subsystem in which the joint dynamics are modeled by a third order system. The structure of Human arm which has 7 Degree Of Freedom this mean seven motor are used to represent movement of human arm with independent joint control. The equations describing the dynamic behavior of the armature control DC motor are given by the following equation [8];

$$G(s) = \frac{kb}{JmLas^{3} + (Ra + BLa)s^{2} + (kbkT + RaB)s} \tag{9}$$

The typical vales of motor parameters for human arm are[9]:

La= 0.3e-3H, Jm = 6.52e-6 Kg-m2/rad,B = 0.0000157 N-m/(rad/sec),Ra = 1.71Ω,

kB = 0.0445 N-m/Ampere ,kT = 0.0047 volt/(rad/sec).

Consider these parameters in the Eq (9) with these values become:

$$G(s) = \frac{.0445}{2.15x10^{-9}s^{3} + 1.227\ x10^{-3}s^{2} + 0.000236\ s} \quad (10)$$

5. Virtual Reality

Virtual reality is a technology which is often regarded as a natural extension to 3D computer graphics with advanced input and output devices. This technology has only recently matured enough to warrant serious engineering applications .Several companies and government agencies are currently investigating the application of VR techniques to their design and manufacturing processes. The state of the technology is appropriate for undertaking projects aiming to demonstrate the feasibility and usefulness of VR in facilitating the design of a product. In very simple terms, VR can be defined as a synthetic environment which gives a person a sense of reality. This definition would include any synthetic environment which gives a feeling of ‘being there. VR generally refers to environments that are computer generated, although there are several immersive environments that are not entirely synthesized by computer. Examples of these include the use of a video camera to achieve telepresence or the use of hardware-augmented immersive environments. The exposure most people have to the concept of VR is through reports in the media, science magazines, and science fiction. However, to the researchers involved in the actual science of VR, the applications are much more mundane, and the problems are much more real [8].

6. Proposed Model and Simulation for a Human Arm

The simulator was built using MATLAB with Virtual Reality Toolbox. MATLAB provides powerful engineering tool including frequently used mathematical functions. It is easy to implement control algorithm including visualization of data used in the algorithm. In addition, by using Virtual Reality Toolbox, it is convenient to treat 3D objects defined with VRML (Virtual Reality Modeling Language). Thus, it is possible to build a simulator within a relatively short period. Virtual Reality (VR) is a system which allows one or more users to move and react in a computer generated environment. The basic VR systems allow the user to visual information using computer screens. The simulation contain two part ,first,bulding model for human arm in VRML,second, constitution the simulink model in MATLAB then call and run the model of human arm using virtual reality toolbox. To realize the VRML model for Human arm save the file as All.wrl file, which is the file format for Virtual Reality software, the VRML model of the Human arm was designed in V-Realm Builder 2.0 .In Fig.1 is presented the VRML model of the Human arm.

The VRML model represents a Human arm. It is manipulated by a simple simulink model as it can be seen in Fig.2. As it can be seen from Fig.2 the Human arm is represented by several blocks: the first one named Arm Angle which is represent the desired angle to produce desired motion, the second block is dynamic part which contain PID controller and third part is simulation part using virtual reality.

The Virtual Reality Toolbox is a solution for interacting with virtual reality models of dynamic systems over time. It provides a flexible MATLAB interface to virtual reality worlds. After creating MATLAB objects and associating them with a virtual world, the virtual world can be controlled by using functions and methods. From MATLAB, the user can also view the world with a VRML viewer, determine its structure, and assign new values to all available nodes and their fields.

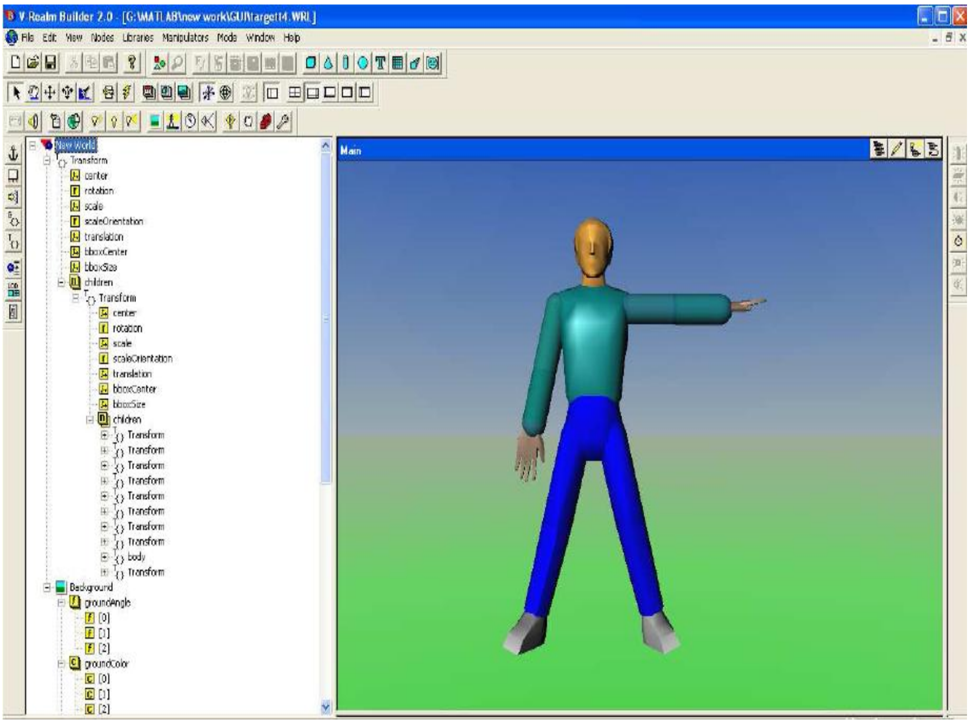

Fig. 1. The VRML model of the Human Arm

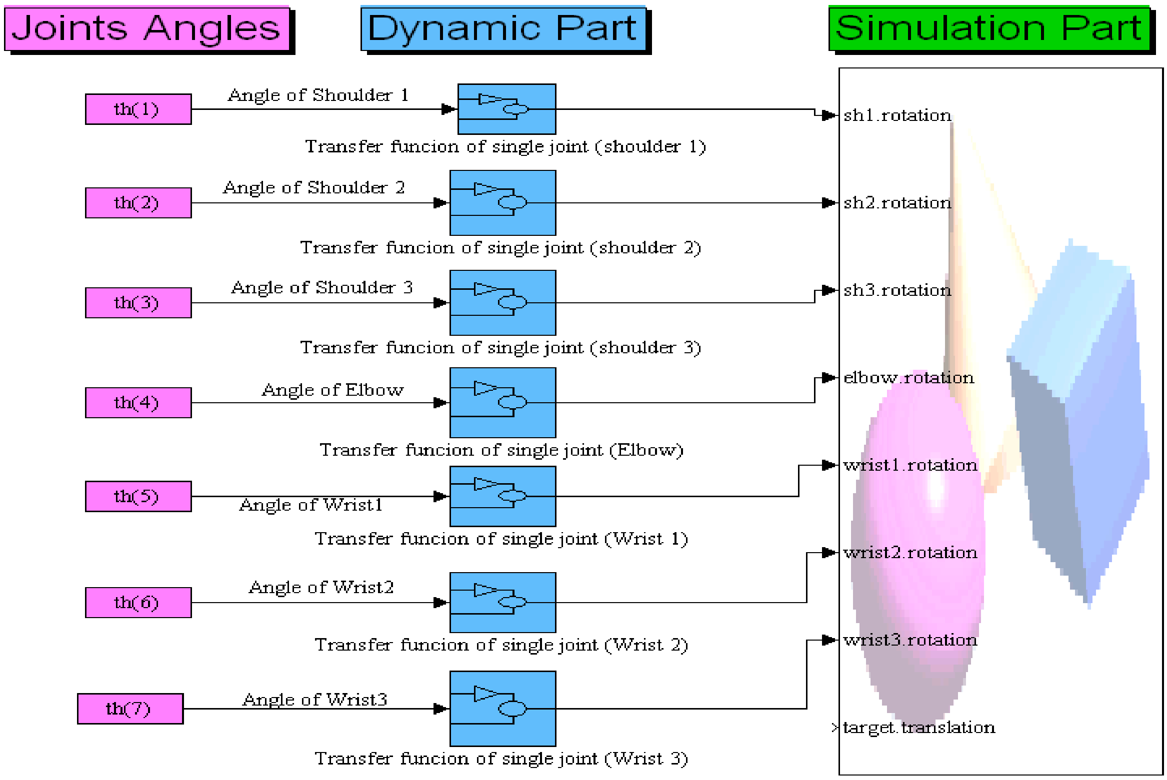

Fig. 2. The Simulink model for A Human Arm

7. Simulation Result

The implemented simulation of human arm which built in VR technique, and control of joints are achieved by MATLAB Ver.R2009a. Fig.2 represents the connection between MATLAB\Simulink , the moving commands for this model are calculated in MATLAB and then they implement in VR. The response of the PSO designed PID will then be analyzed for the smallest overshoot, fastest rise time and the fastest settling time .Some experimental results are provided here to demonstrate the performance of the trial and error tuning, Ziegler-Nichols tuning, conventional tuning and proposed tuning. The comparison of the performances using all methods is made as shown in Table 1.

Fig's 3, 4 and 5 show the trajectory of human arm in x ,y and z direction respectively in reaching position with point $[42.4 \;\; 9.8 \;\; 10.9]^T$ (cm) with angle(in rad) of arm=[0.1659 1.2619 -0.0839 0.1576 0.1313 0.1332 0.1935] .It has been found that the performance of proposed is better than other techniques in terms of time response such settling time, rise time and over shoot. Notice, from the step response , that the performance of the proposed technique is better than the other techniques in approach to steady state .Fig's 3,4 and 5 show that , the transient specifications of human arm trajectory obtained by the Modified ITSE Based PSO method is better than the values provided by the ITSE Based GA method especially in Yaxis and Z-axis. This small value of the overshoot is due to using mltiobjective function in optimization technique instead of using single objective which is based on the error the virtual reality is used to simulate the motion of human arm for conventional tuning and proposed tuning as shown in Fig .6 and Fig. 7 with respect to the time at different state.

Table .1 Time Response Of Different Method

Tuning Method	t_s (sec)	t_r (sec)	overshoot (%)
Ziegler-Nichols	0.147	0.003	69.45
Trial and error	0.404	0.164	1.1×10^{-5}
ITSE	0.109	0.009	48.1185
Modified ITSE	0.084	0.047	0.0158
AIE	0.118	0.013	32.6803
Modified AIE	0.118	0.055	7.1×10^{-5}
ITAE	0.123	0.020	19.8692
Modified ITAE	0.140	0.062	5.9×10^{-5}
ISE	0.115	0.018	22.1581
Modified ISE	0.112	0.055	7.9×10^{-5}

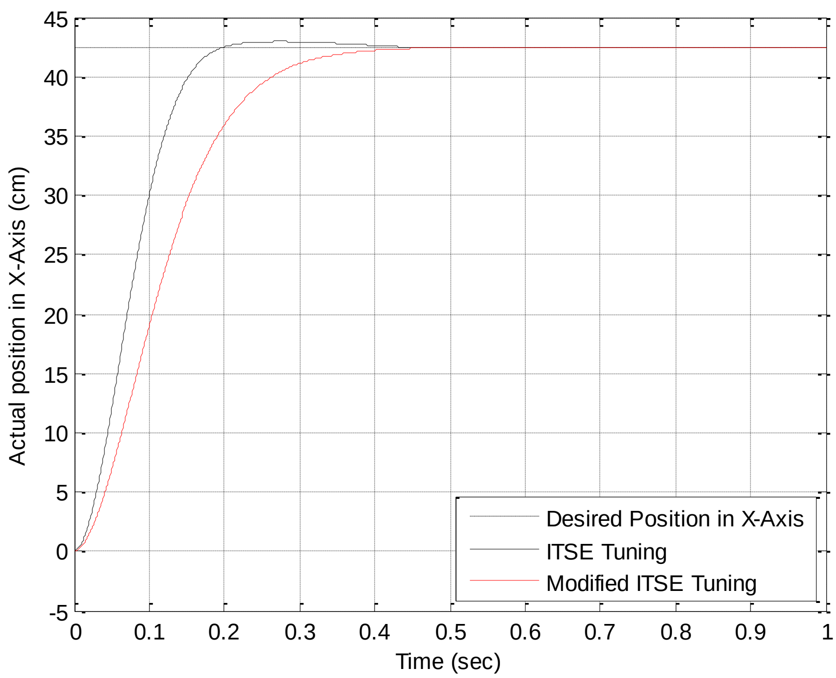

Fig. 3 Actual Response of Human Arm in X-axis with PD Controller

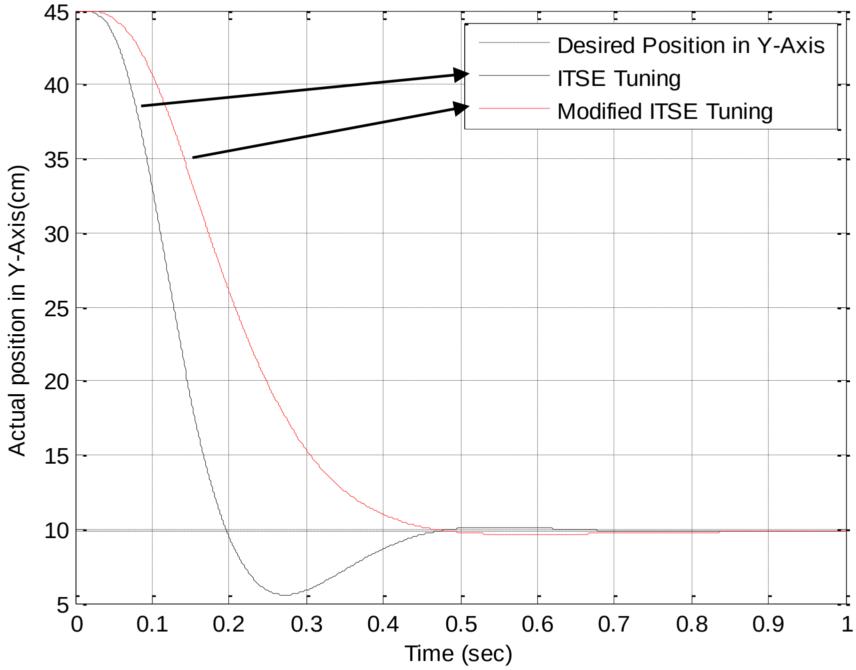

Fig. 4 Actual Response of Human Arm in Y-axis with PD Controller

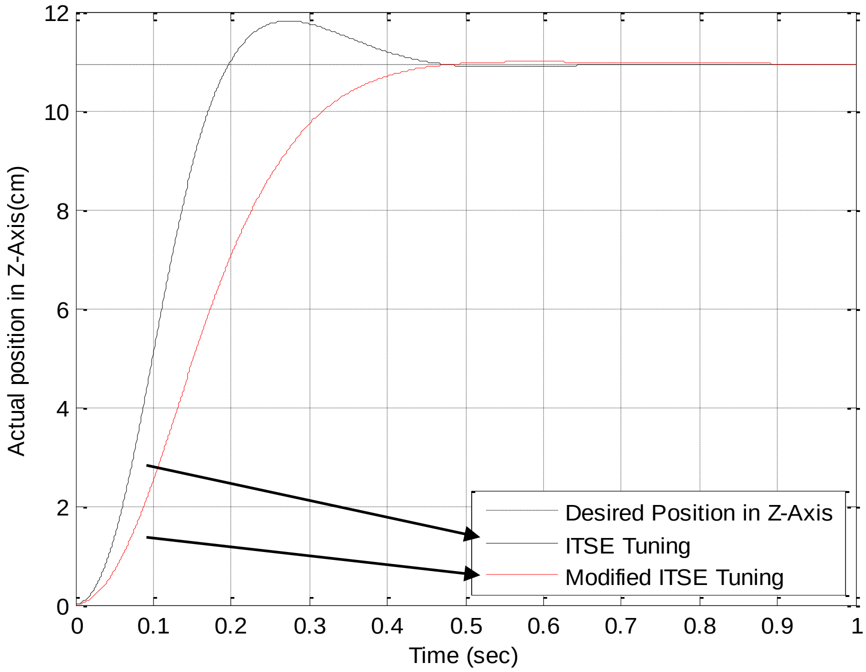

Fig. 5 Actual Response of Human Arm in Z-axis with PD Controller

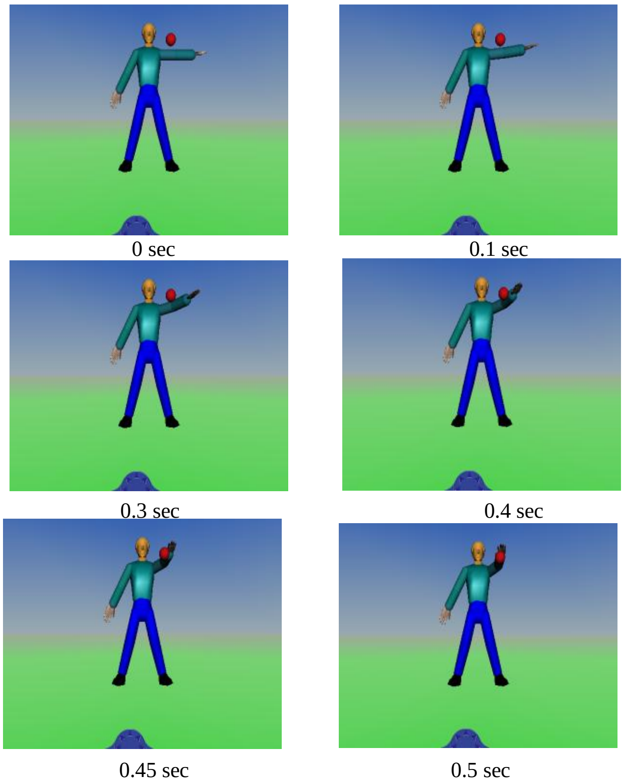

Fig. 6 Human arm movements with proposed tuning method at different time

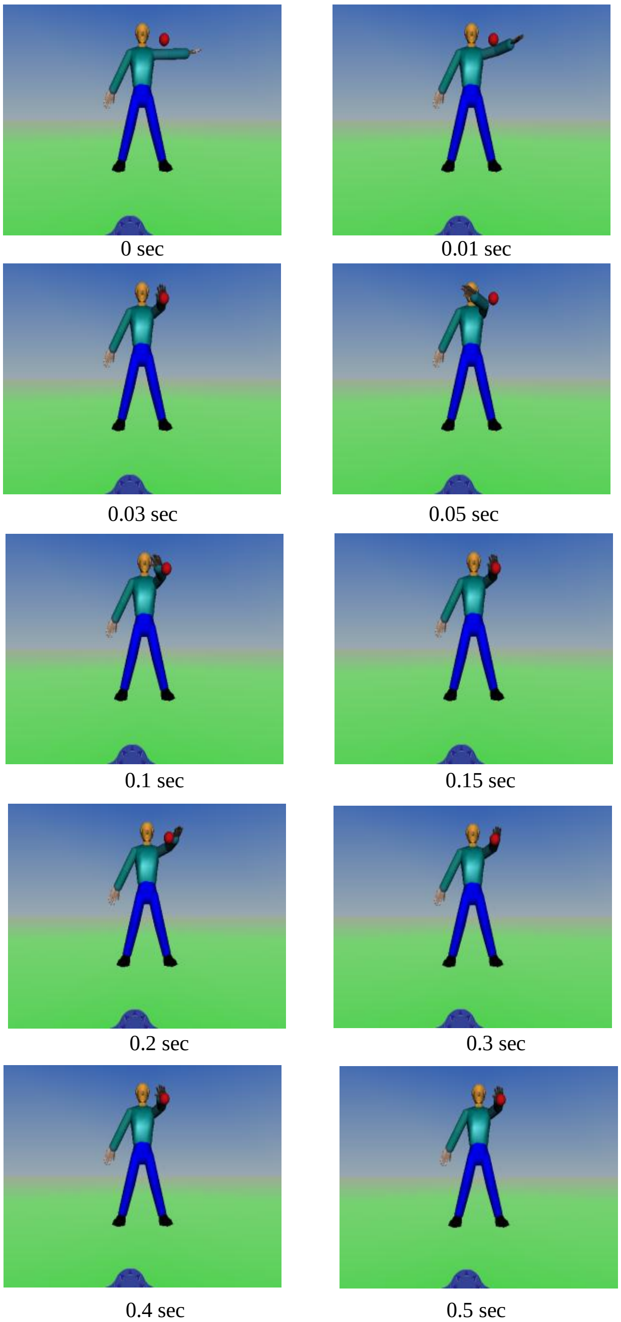

Fig. 7. Human arm movements with conventional method at different time

8. Conclusions

PID controller is a good technique in control theory, but there are drawbacks when using in nonlinear systems. Tuning PID gains using conventional methods is boring and difficult to obtain the optimal results such lower rise time ,settling time and over shot so the a new fitness function is a good choice for tuning PID gains . A proposed method was used for control 7 DOF human arm, it uses PSO algorithm for determining PID gains. From the obtained results, it can be concluded that, the ability of performing of particle swarm optimization based PID tuning or human arm. Simulation result shows that, the proposed method has much faster and accurate response than response of the other classical methods. It is much better in terms of the rise time, the settling time and overshot than the other method. The Virtual Reality is useful to test the viability of designs before the implementation phase on a virtual reality prototype, the ability of performing of PSO based PID tuning or human arm.Simulation result using virtual reality shows that, the proposed method has much faster and accurate response than response of the other classical methods. It is much better in terms of the rise time, the settling time and overshot than the genetic method.

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