Optimal Design of Super Twisting Control with PSO Algorithm for Robotic Manipulator

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Abstract

Robotic manipulators are nonlinear and coupling systems exposing to external disturbance. They are used in wide industrial applications; the suitable selection of a nonlinear robust controller is required. Sliding Mode Controller (SMC) was designed to achieve these requirements, but unfortunately the chattering phenomenon was the main drawback of the conventional SMC. It leads to destructive of some components of a real system and subsequent loss in its accuracy. Hence, the design of Super-Twisting Controller (STC) is suggested for chattering elimination. In previous literatures, the accomplishment of the manual adjustment for the parameters of STC was a large burden and time consuming process. Therefore, a new combination of Particle Swarm Optimization (PSO) algorithm with STC is proposed for optimal tuning of STC parameters. The simulation results demonstrate the superiority of the super twisting technique for chattering mitigation comparing to the conventional SMC. Also, STC tuned via PSO proves its effectiveness and robustness to different types of external disturbances without the needs for the knowledge of their upper boundary values. Besides, the performance of the controlled system is faster and more accurate in the criteria of overshoot, settling time and rise time compared to the manual adjusting of super twisting controllers.

Keywords: Super Twisting Control, Sliding Mode Control, Particle Swarm Optimization Method, Robotic Manipulator, Robust Optimal Control.

1. INTRODUCTION

Robotic manipulators have being used for many purposes in industrial automation systems, research and mining fields, medical applications, in laboratories. Because of high challenges in the dynamic model of robotic manipulator [1], its performance has largely depended on the control technology that is used which has a direct impact on the overall performance of system. Furthermore, robotic manipulator suffers from different kind of disturbances such as joint frictions, unknown payloads, and non-model dynamics. Therefore, the accurate and high precision control systems become a persistent need. Consequently, the development of robust, nonlinear, and adaptive control strategy is contentiously required. The inverse dynamics, computed torque techniques, and the feedback linearization were among the controller methods that were used earlier in literatures [2-3]. The feedback linearization methods were based on the cancellation of nonlinearities, so the robustness to the variables uncertainty is appeared. H_∞ Control method was used in [4-5], but it is barely sufficient for this problem due to the continual nature of the disturbances. On the other hand, robust control systems such as sliding modes and Lyapunov methods were also applied to face the problems of robot manipulators.

Sliding Mode technique (SMC) is an effective tool in control non-linear systems due to its robustness features. It is composed of two stages. The first one is to select a sliding surface in the state space that the state trajectories are forced to remain along it (sliding phase). The second is the reaching phase; a discontinuous state-feedback is designed to force the system trajectory to reach the sliding surface in a finite time [6]. A demonstration of its good performance in control systems can be found in detail by Utkin et al. in [7]. The sliding mode dynamics can be stabilized with a proper choice of the sliding surface.

The SMC controller has many advantages such as: system order reduction, finite time convergence, and its robustness against disturbances, while the trajectories are not robust against perturbations during reaching phase. The main drawback of the SMC was the appearing of small oscillations of finite frequency with the output signal which is known as chattering phenomena caused by the switching frequency of the control [8]. This phenomenon is harmful because it decreases the control accuracy; the moving mechanical parts suffer from high wear, and high heat is lost in power circuits [9].

Several approaches were proposed to reduce the chattering problems. The most common one is the boundary layer approach; the states are forced to remain within a small boundary layer about the surface by using saturation function rather than the sign discontinuous function [10]. A boundary layer is employed using fuzzy logic to reduce chattering [11]. The chattering problem can also be overcome by intelligent systems such as GA, which can be utilized in choosing the sliding surface slope and thickness of the boundary layer [12-13]. Also, the theory of higher-order sliding mode (HOSM) was introduced to overcome the above mentioned problems; its concept was illustrated in details [14]. HOSM provides an effective technique for the reduction or even practical elimination of the chattering problem without compromising the benefits of the standard sliding mode. A sliding surface in HOSM is designed in order to make the sliding variable and its high order time derivatives reach it in finite time [15]. There are several types of HOSM control algorithms, among them the sub-optimal controller, the terminal sliding mode controllers, the twisting controller and the super-twisting controller [16]. The super-twisting algorithm is nowadays preferable over the classical siding mode, since it eliminates the chattering phenomenon [17-18]. The appropriate choice to the parameters of STC has a big effect on the overall performance and the accuracy of the controller.

PSO is one of the modern smart heuristic algorithms developed through the simulation of simplified social behavior to solve nonlinear optimization problems [19]. Since its appearance, it has been a hotspot of research and promising technique for real world optimization problems [20-22]. Due to its simple concept, easy implementation as well as its quick convergence, nowadays PSO has gained much attention and has wide applications in different fields [23]. The successful applications of this robust optimization algorithm have been reported not only in the area of control theory but also in a wide variety field of research. For instance, in [24], a new particle swarm optimization algorithm was applied to optimum design of the armored vehicle scheme. In [25], multi-objective optimization of vehicle crashworthiness was performed using a new particle swarm based approach. In [26], a probability matrix based particle swarm optimization was applied for the capacitated vehicle routing problem. In [27], the particle swarm optimization algorithm was used for a vehicle routing problem with heterogeneous fleet, mixed backhauls, and time windows. Also, power optimization of gas pipelines was performed with aid of an improved particle swarm optimization algorithm in [28].

This work discusses and compares two strategies for creating robust control in an environment of dynamic disturbances. The first strategy utilizes the conventional sliding mode control SMC while the second proposes the super-twisting control with an intelligent gains tuned by PSO. Also, a comparative study was done to the transient response of the non-linear robot manipulator in terms of settling time and rise time with the proposed strategies. The proposed controller is designed and simulated using MATLAB/ Simulink software.

The remaining of this paper is organized as follows. Section 2 reviews the mathematical model of two links robot manipulator. The conventional slide mode control along with the proposed supper twisting controller and the design of control law for robotic manipulator are described in sections 3 and 4 respectively. A brief presentation of PSO algorithm and its application for the proposed optimal design of STC are outlined in section 5. A simulation study of the suggested controller along with the conventional controller is carried on in section 6 and finally, the concluding comments are presented in section 6.

2. SYSTEM DESCRIPTION

The structure of the two links rigid manipulator system are shown in Fig. 1. It composed of two revolute joints to support the angular motion between the links. The link is moved by controlling torque applied by the actuator at the joint of manipulator. The system parameters are recorded in table1.

Parameter	Symbol	Value
Mass of link1	m_1	1 Kg.
Mass of link2	m_2	1 Kg.
Length of link 1	l_1	1m
Length of link 2	l_2	1m
Gravity acc.	G	9.8 m/s^2
torque to joint	τ	N·m
Ang. Pos. of link1	q_1	Rad
Ang. Pos. of link2	q_2	Rad

TABLE 1: The Manipulator Parameters.

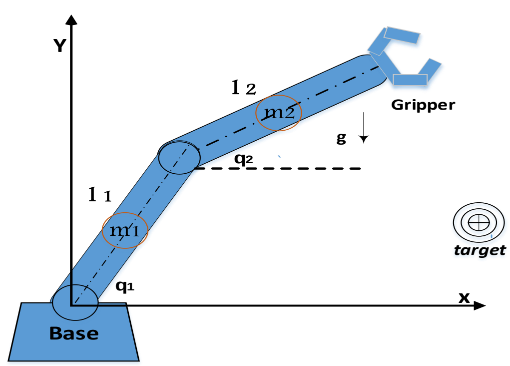

FIGURE 1: The Two Links Manipulator Schematic Diagram.

2.1 System Dynamics

The dynamic equations of 2DOF rigid manipulator are deduced according to Lagrange Euler Formulation [29-30]. The final form of dynamic equation of manipulator is described in (1, 2, and 3).

$$\tau = M(q)\ddot{q} + V(q,\dot{q}) + G(q) + \tau_d \tag{1}$$

$$\begin{bmatrix}\tau_1\\ \tau_2\end{bmatrix} = M(q)\begin{bmatrix}\ddot{q}_1\\ \ddot{q}_2\end{bmatrix} + \begin{bmatrix}-m_2 l_1 l_2(2\dot{q}_1\dot{q}_2 + \dot{q}_2^2)\\ m_2 l_1 l_2 \dot{q}_1^2 \sin q_2\end{bmatrix} + \begin{bmatrix}(m_1+m_2)g l_1 \cos q_1 + m_2 g l_2 \cos(q_1+q_2)\\ m_2 g l_2 \cos(q_1+q_2)\end{bmatrix} + \tau_d \tag{2}$$

$$M(q) = \begin{bmatrix} (m_1+m_2)l_1^2 + m_2 l_2^2 + 2m_2 l_1 l_2 \cos q_2 & m_2 l_2^2 m_2 l_1 l_2 \cos q_2 \\ m_2 l_2^2 m_2 l_1 l_2 \cos q_2 & m_2 l_2^2 \end{bmatrix} \quad (3)$$

Where, $M(q) \in R^{2\times2}$is the symmetric positive definite manipulator inertia matrix $V(q,\dot{q})$is the Coriolis and Centrifugal matrix, and $G(q)$ is the vector of gravitational torque. q Is the joint position, $\dot{q}$ is the velocity and $\ddot{q}$is the acceleration, all of them are vectors belonging to $\in R^2$. $\tau_d \in R^2$ Symbolizes the vector of external disturbances and non-modelled dynamics such that the upper bound of the disturbance is$|\tau_d| \le \delta$, δ is a certain positive value. Let $N(q,\dot{q}) = V(q,\dot{q}) + G(q)$, hence the relation (1) can be rewritten as the following form:

$$\tau = M(q)\ddot{q} + N(q,\dot{q}) + \tau_d \quad (4)$$

The controller objective is to get the suitable input torque τ such that the joints angular positions can accurately reach the desired values q_{d1} and q_{d2}in finite time in spite of existing an external disturbances, τ_d. The error and the first time derivative of error are defined in the general form as depicted in (5-7).

$$q_e = \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}, \ \dot{q}_e = \begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \end{bmatrix} \quad (5)$$

$$e_1 = q_{d1} - q_1, \ e_2 = q_{d2} - q_2 \quad (6)$$

$$\dot{e}_1 = \dot{q}_{d1} - \dot{q}_1, \dot{e}_2 = \dot{q}_{d2} - \dot{q}_2 \quad (7)$$

Hence, the objective is to drive $q_e \to 0$ and $\dot{q}_e \to 0$. To solve this problem and achieve the required target, both of the conventional sliding mode control technique and the super-twisting controller are suggested.

3. SLIDING MODE CONTROLLER DESIGN

The concept of both the sliding mode and the sliding surface was explained in [31]. The sliding mode control is an attractive technique to control systems subject to bounded external disturbances and model uncertainty. In the conventional sliding mode control, the control signal consists of two parts. One is called the “equivalent control” and the other is the “switching control”. The equivalent control deals with the dynamics of the nominal system and the sliding surface, while the switching signal is used to keep the system trajectories onto the selected sliding surface in spite of existing disturbances. The sliding surface is linear with a constant slope, “c” which determines the system performance. For small values of c, the reaching time is short, while the system dynamics are slow [32]. The design procedure for the control system for the robot manipulator is outlined in the following equations. The sliding function is choosing as follows,

$$s(t) = \dot{q}_e(t) + cq_e(t) = \dot{q} - \dot{q}_d + cq_e(t) \quad (8)$$

And the control signal is represented as in (9)

$$u(t) = u_{eq}(t) + u_{sw}(t) \quad (9)$$

The equivalent control is computed by putting, $\dot{s}(t) = 0$, keeping $s(t) = 0$, [33].

$$\dot{s}(t) = \ddot{q}_e(t) + c\dot{q}_e(t) = \ddot{q} - \ddot{q}_d + c\dot{q}_e(t) = 0 \quad (10)$$

Considering the dynamic equation of the system in (4) without external disturbances and the substitution in (10), (11) can be obtained and then the equivalent control signal can be computed by putting (11) equals zero as follows.

$$\dot{s}(t) = -M^{-1}N(q) + M^{-1}\tau - \ddot{q_d} + c\dot{q_e}(t)$$
$$= f + bu_{eq} - \ddot{q_d} + c\dot{q_e}(t) = 0 \quad (11)$$

Where: $f = -M^{-1}N(q),\ b = M^{-1},\ \tau = u$. Consequently, the equivalent control is deduced in (12) as follows:

$$u_{eq} = \frac{-f - c\dot{q_e} + \ddot{q_d}}{b} \quad (12)$$

After adding the switching control signal to the above equivalent control, the input control using SMC is $u(t)$ which is computed as described in (13).

$$u(t) = \frac{-f - c\dot{q_e} + \ddot{q_d} - ksgn(s)}{b} \quad (13)$$

The term ($ksgn(s)/b$) represents the switching part of the control signal, $u_{sw}(t)$. It is used to make the system trajectories go towards the sliding surface in the reaching mode or used to reject the disturbances. Also, "k" is a positive definite gain vector. However, a serious high-frequency oscillations will appear in any real system whose input is supposed to switch infinitely fast by using this function and resulting in actuators damage. This drawback is called chattering phenomena.

To reduce the chattering, the boundary layer is the most famous method. The basic idea of this method is to replace the sign function by a saturation function, $sat\ (s/\in)$, where ∈ is the thickness of the boundary layer [34-35]. The system is stabilized by driving the state to a small region containing the state space origin. The boundary layer control is a continuous function of state, therefore it is smooth and chattering free. However, when the state measurements are corrupted with noise whose level is significant with respect to the boundary layer width, the boundary layer design can no longer avoid chattering. Therefore, super twisting controller is suggested to face the chattering problem and explained in detail in the following section.

4. SUPER TWISTING CONTROL LAW

In order to avoid chattering, the super-twisting algorithms are developed to control systems with relative degree one which means; s is continuous and $\dot{s}$ is discontinuous [36-37]. In this kind of controllers, the system trajectories are characterized by twisting around the origin in phase plane ($\dot{s}(t)$ vs. $s(t)$ plane) as shown in Fig. 2.

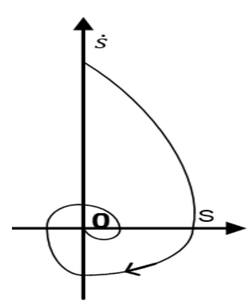

FIGURE 1: Phase Trajectory of Super-twisting Algorithm.

In super twisting algorithm, the control signal $u(t)$ consists of three terms. They are: the equivalent control, the continuous function of the sliding variable, and the discontinuous part with integrator as formulated in (14) and (15) [9].

$$u = u_{eq} - C|s|^{\rho} sign(s) + u_1 \tag{14}$$

$$\dot{u_1} = -W\, sign(s) \tag{15}$$

Where the equivalent control term, u_{eq} is defined as in equation (12), and C and W are certain positive gains, the designed parameter ρ is chosen as ρ=0.5. The value of W is selected such that greater than the upper bound of disturbance, δ in order to ensure the stability. Also the sufficient conditions for a finite time convergence to the sliding surface [9], [37] are:

$W > \frac{\Phi}{\Gamma_m}$, $0 < \rho \leq 0.5$ and $C^2 \geq \frac{4\Phi\Gamma_M(W+\Phi)}{\Gamma_m{}^2\Gamma_m(W-\Phi)}$, such that if $|s| < s_0$ there are positive boundary constants values, s_0, Γ_m, and Φ are defined from the inequities (16).

$$0 < \Gamma_m \leq \frac{\partial}{\partial u}\dot{s}(t,x,u) \leq \Gamma_M \text{ , and } \left|\frac{\partial}{\partial t}\dot{s}(t,x,u) + \frac{\partial}{\partial x}\dot{s}(t,x,u) f(t,x,u)\right| \leq \Phi \tag{16}$$

Because of the complexity of the aforementioned computations which are time consuming, it is hardly to determine the values of these boundaries and consequently the values of the controller parameters cannot be estimated. Instead of this mathematical calculation for STC parameters, PSO is proposed to optimally tune the controller parameters by using integral absolute error (IAE) and integral square error (ISE) indices. Consequently, the controlled system response can be improved by the optimal value of the control torque and the manipulator reaches rapidly to the desired position. This control law guarantees the continuity of the control signal and allows suppression of the chattering. Lyapunov stability criterion was used to confirm the controller stability as demonstrated extensively in [38]. An overview of the standard PSO and a brief description of its concept are presented in the following section.

5. OPTIMAL STC WITH PSO

The first pioneer introducing the particle swarm optimization was Kennedy and Eberhart in 1995 [19], the idea of PSO algorithm was inspired from the living creature social behavior such as birds and others. The first PSO generation is started randomly with a set of particles (solutions to the problem) and after that updating the PSO algorithm through new generations to find the best solution. Each particle in the swarm memorizes the best solution track that has yet accomplished in the search space and the best solution value is named pbest. Also, the location of the global best value found so far through any particle in the swarm is called the gbest. The location of each particle in the swarm is affected by two parameters values which are its best position reached and the best position of its neighbouring particles. The particle is accelerated toward pbest and gbest locations by generating a random numbers. Both of the particle location and its velocity is updated in each iteration using the following equations:

$$v_i(k+1) = \omega_i v_i(k) + \mu_1 rand_1()\left(pbest - x_i(k)\right) + \mu_2 rand_2()(gbest - x_i(k)) \tag{17}$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \tag{18}$$

Where: *v(k + 1)*, *v(k)* are the velocity of a particle in iteration *k + 1* and *k* respectively, while *x(k + 1)* and *x(k)* are the particle positions in the following iterations *k + 1* and *k*. Both of $rand_1$ and $rand_2$ are random numbers generated from (0 to 1). The particle self-confidence is μ_1 and usually given value in range from (1.5 to 2.0), while μ_2 is called the swarm confidence [22] and usually takes value in the range (2.0–2.5). The inertia weight (ω) is used to fulfil the balancing between the search space exploration and its exploitation and plays very vital role in the convergence behavior of PSO. In each generation, the inertia weight is reduced dynamically from 1.0 to near 0 using the following equation.

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}} * iter \tag{19}$$

Where: $iter_{max}$ is the number of maximum iterations, and $iter$ is the current iteration number. ω_{max}, and ω_{min} are the maximum and minimum values of inertia weight. PSO algorithm in this paper is proposed for tuning STC parameters and our proposed PSO parameters are: μ_1= *1.5*, μ_2= *2*, also, the number of iterations *N = 10* and the swarm size = *20*. The range of STC parameters for W and C vectors are obtained. Both of W1 and W2 are: (0.1 to 2), while the range of C1 and C2 are: (0.1 to 3) and (0.1 to 4) respectively. The optimal STC parameters by PSO are adjusted by minimizing the error between the desired and the actual output. Two objective functions based on error indices are used and each function defines the specific error performance criterion being implemented to optimize the performance of STC controlled system. The fitness of each particle in the swarm is evaluated in each iteration depending on the following objective functions: Integral of Square of the Error (ISE),

$$I_{ISE} = \int_{t=0}^{n} e_1^2(t)\,dt + e_2^2(t)\,dt \tag{20}$$

And integral of Absolute Magnitude of the Error (IAE),

$$I_{IAE} = \int_{t=0}^{n} |e_1(t)|dt + |e_2(t)|dt \tag{21}$$

Where: e_1 and e_2 are the trajectories errors between system input and output calculated over a time interval *t* equals 10 sec. for both the first and second link of robot manipulator respectively, and n is the number of samples. Selection of the range of the STC control parameters using PSO is low complexity compared to the mathematical method which is depicted from (14) to (15).

6. SIMULATION RESULTS AND DISCUSSION

To verify the accuracy and the efficiency of the proposed control algorithms, the simulation of the two links rigid manipulator have been carried out using MATLAB/SIMULINK Software (v. 2016a). The simulator is verified by comparing its input/output with simulator derived in other published work [39]. Both the conventional SMC and the STC algorithms are simulated and coupled with the system as shown in Fig. 3.

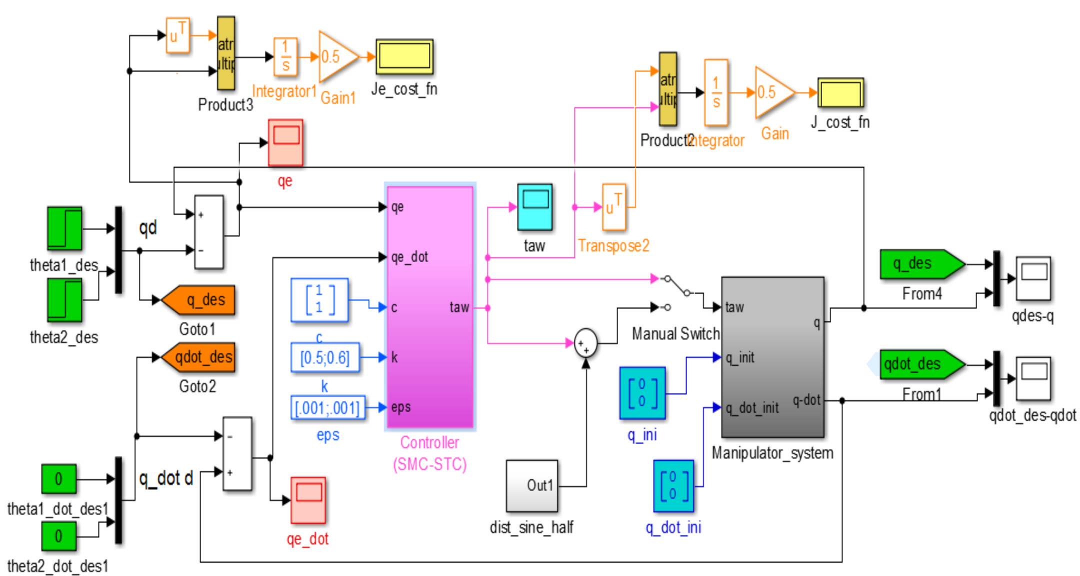

FIGURE 3: The Block Diagram of The Controlled System.

Firstly, the behavior of the controlled system with the computed control torque using the conventional SMC without and with different types of external disturbance are shown in figures

(4-6). The designed SMC parameters are tuned manually and selected as c [1 1], k = [0.5, 0.6], and ϵ = [0.001 0.001]. Both constant and sinusoidal external disturbances, $d_1 = 1$, $d_2 = \sin(2t)$ is added in time interval $1 \leq t \leq 2$and are used to verify the robust characteristic of the controller.

Secondly, the performance of the system is tested by using the super twisting controller. Both of the super twisting controllers either the conventional or that tuned by PSO prove their superiority in chattering suppression as shown in figures (7-9) comparing to the results of SMC shown in previous figures (4-6).

Finally, the performance of the controlled system via STC whose parameters are tuned by the proposed PSO is evaluated in terms of settling time and rise time and through reducing the error between the desired and actual outputs using IAE and ISE indices. The time responses results of robotic manipulator with the designed STC whose parameters are tuned manually or by PSO in presence of different types of disturbance such as constant and sine wave disturbances are shown in figures (7-9). Also, the cost functions of PSO performance in tuning the parameters of STC using IAE and ISE criterions are depicted in figures (10-11). Moreover, the transient response characteristics of robotic manipulator controlled by STC whose parameters are manually adjusted or tuned by PSO using IAE and ISE performance indices in terms of rise time and settling time for step input are described in tables 2-3. Also, the values of IAE and ISE are recorded in the same table. The initial conditions for the manipulator in simulation process are chosen as follows: $q = 0$, and $\dot{q} = 0$.

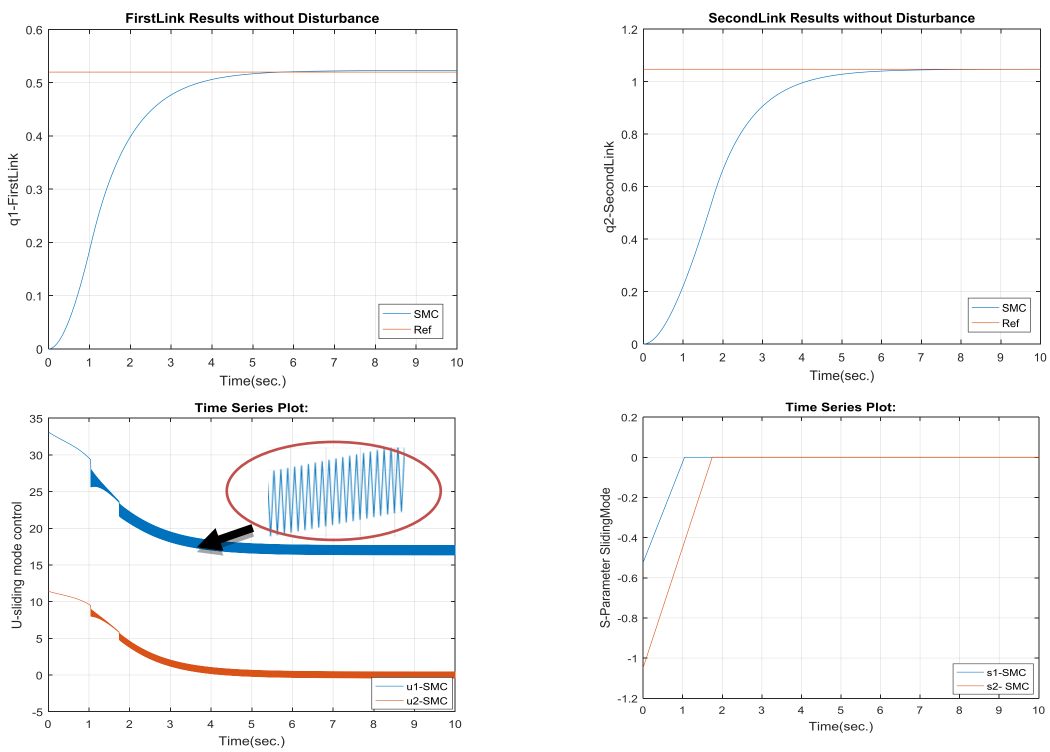

FIGURE 4: The responses of the two joints angles, the control signal and the s-functons of robot manipultor using SMC without disturbance.

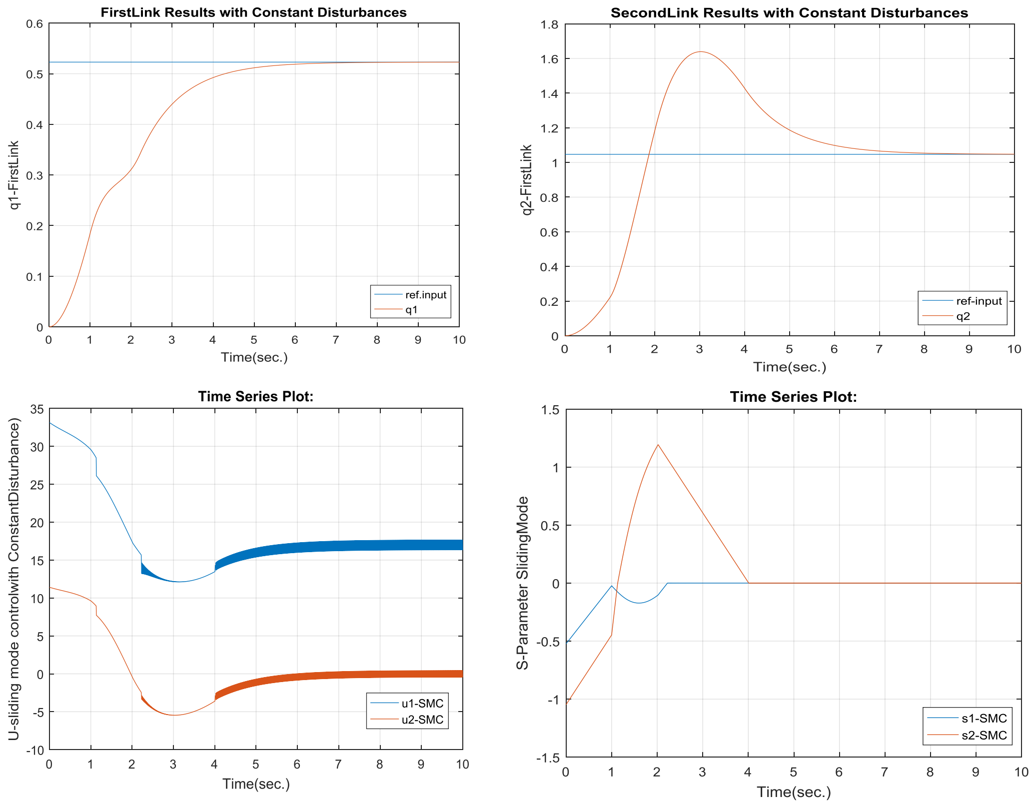

FIGURE 5: The responses of the two joints angles, the control signal and the s-functons of robot manipultor using SMC with constant disturbance.

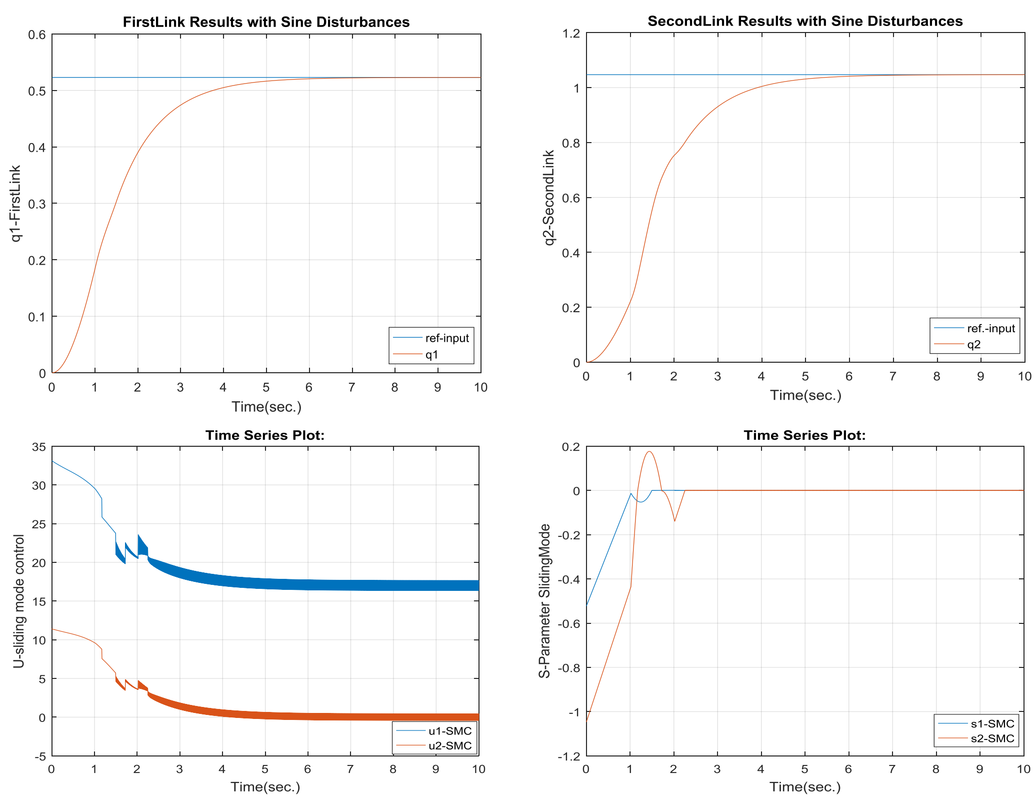

FIGURE 6: The responses of the two joints angles, the control signal and the s-functons of robot manipultor using SMC with sinsoidal disturbance.

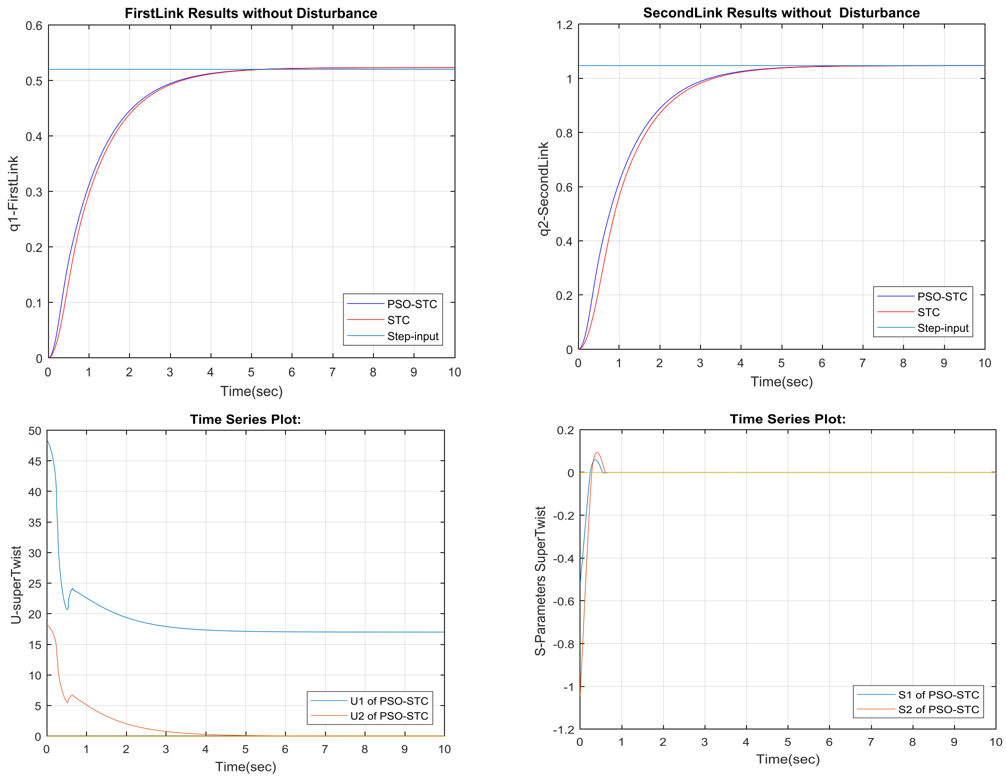

FIGURE 7: The responses of the two joints angles, the control signal and the s-functons of robot manipultor using STC tuned manually or by PSO without disturbance.

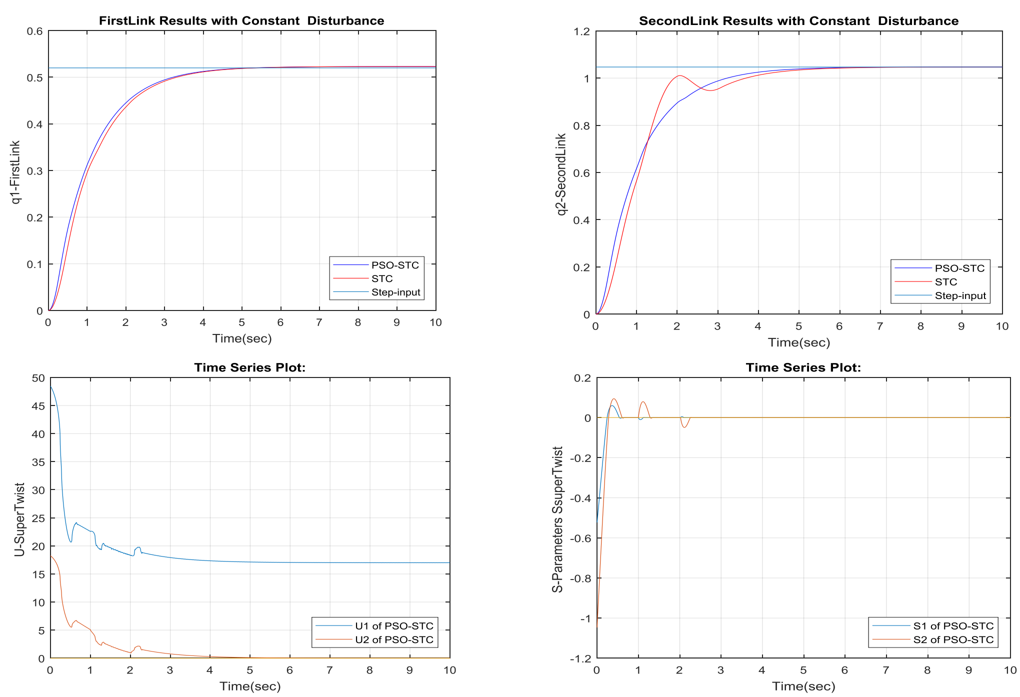

FIGURE 8: The responses of the two joints angles, the control signal and the s-functons of robot manipultor using STC tuned manually or by PSO with constant disturbance.

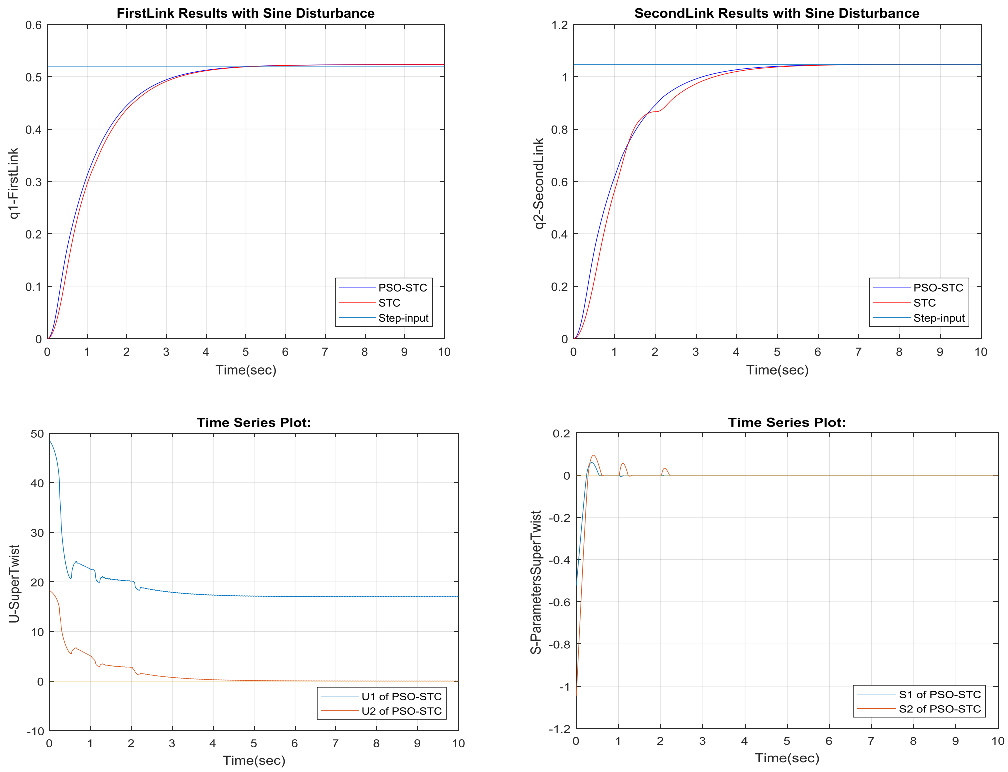

FIGURE 9: The responses of the two joints angles, the control signal and the s-functons of robot manipultor using STC tuned manually or by PSO with sinsoidal disturbance.

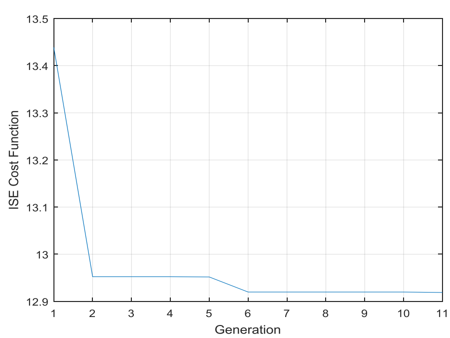

FIGURE 10: Cost function of manipulator with STC tuned by PSO using ISE Indices.

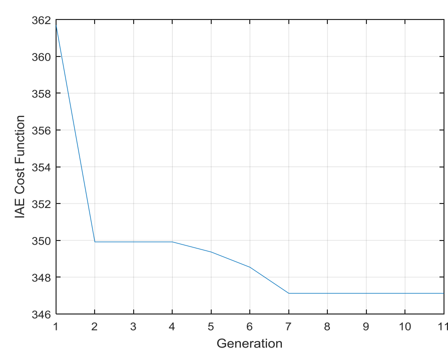

FIGURE 11:. Cost function of manipulator with STC tuned by PSO using IAE Indices.

Model Parameters	Nominal Model		With Constant Disturbance		With Sine Disturbance	
	Without PSO	PSO	Without PSO	PSO	Without PSO	**PSO**
Rise Time	0.080	0.062	0.0809	0.062	0.0809	**0.062**
Settling Time	4.1	4	4.1	4	4.1094	**4**
Over shoot	0	0	0	0	0	**0**
ISE	14	12.95	13.72	12.91	13.93	**12.92**
IAE	378.8	347.2	360	345.8	378.8	**345**

TABLE 2: Transient response characteristics of the first link (q1) with step input.

Model Parameters	Nominal Model		With Constant Disturbance		With Sine Disturbance	
	Without PSO	PSO	Without PSO	PSO	Without PSO	**PSO**
Rise Time	0.0928	0.066	0.0928	0.066	0.0928	**0.066**
Settling Time	4.13	4	4.4950	4	4.2633	**3.97**
Over shoot	0	0	0	0	0	**0**
ISE	14	12.95	13.72	12.91	13.93	**12.92**
IAE	378.8	347.2	360	345.8	378.8	**345**

TABLE 3: Transient response characteristics of the second link (q2) with step input.

The simulation results prove the ability of the designed STC whose parameters are tuned using PSO to achieve the demand output and converge to its desired value in a short rise time and settled in a small time if compared to the results of STC in which its parameters adjusted manually as shown in figures (7-9). Besides, the designed control input to the robot manipulator using the STC is efficient, robust to any type of disturbances and without the chattering problem comparing to the control input of the conventional SMC whose results are shown in figures (4-6). It is noticed that the control signal suffers from chattering, and the second joint angle has large overshoot in case of existing constant disturbance and the system move away and return around the sliding surface before settle in presence of sinusoidal disturbance.

Also, PSO technique proves its simplicity as heuristic algorithm and its ability to tune the STC parameters in less time without the needs for knowledge about the boundary values of external disturbance if comparing with the manual adjusting to the parameters of STC. In addition, the transient response characteristics of system with STC whose parameters tuned by PSO are faster comparing to those with the manually adjusted of STC. It is found that the rise time of the controlled system using STC tuned by PSO ranges from 0.0062 to 0.0066 for the first and second link respectively, and the settling time for both of the two links $q_1$and $q_2$in presence of external disturbance equals 4 sec and 3.97 sec. respectively, and the outputs with no overshoots as depicted in Table 2 and Table 3. The global best values found for STC parameters using the iterative PSO algorithm are depicted in Table 4.

STC parameters	Values
W_1	2
W_2	2
C1	2.9
C2	4

TABLE 4: The Parameters of STC Tuned by PSO.

7. CONCLUSION

This work contributes to the control problem of the two links robotic manipulator by utilizing two robust controllers' methodology. The first one is the sliding mode controllers that ensure system insensitivity to external disturbance. However, they exhibit a serious drawback which is high frequency oscillations named chattering. The second methodology is the super-twisting sliding mode control. The simulation results of STC controller to robotic manipulator prove its robustness and ability to suppress the chattering problem associated with the controlled system by the conventional SMC. Also, STC guarantees high accuracy in presence of external disturbance and can tolerate any type of disturbance.

The main contribution of this work is the utilizing of intelligent optimization technique to tune the parameters of STC algorithm, Instead of the manually adjusted to the parameters of STC which is time consuming and a burden process. To the best of the authors' knowledge, the integration of the Particle Swarm Optimization with the Super Twisting Control is a novel approach. PSO is more suitable than the other optimization heuristic techniques due to its simplicity, its quick convergence and consume a small time in tuning the STC. The results prove the efficiency of the proposed STC controller tuned by PSO and its ability in convergence to be around the desired position value in small rise time and settling time compared to the STC whose parameters adjusted manually, even in the presence of noise. The transient response of system with STC tuned by PSO is faster and its rise time is almost around 0.0066sec., while the settling time for both of the two links in presence of external disturbance is approximately around 4 sec., and the outputs have no overshoots.

8. FUTURE WORK

The integration of the particle swarm optimization with the super twisting control algorithm will be used for robot has more degree of freedom. Using adaptive super twisting technique to get adaptive gains which is important point to design the controller with reduced knowledge on uncertainties and perturbations. Try to use other optimization techniques for comparison with PSO.

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