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A Review on Implementation of Super Twisting Control Algorithm

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Abstract—**In order to attenuate the chattering effect in sliding mode control, various methodologies have proposed in last few decades. This paper describes the implementation of super twisting algorithm as a controller, differentiator and observer in the presence of uncertainties. Super twisting controller attenuate the effect of chattering and obtain the smooth control to the system and converge the system to its desired position in a finite time. Difference proposed methodologies and their results are discussed that how super twisting controller implemented in different applications.**

Index Terms—**Sliding Mode Control, Super twisting algorithm, observer, second order sliding mode control, Chattering.**

1) INTRODUCTION

For the uncertain systems, it is difficult to design controllers to handle uncertainties in plant proficiently. This has directed to the development of robust control methods. High gain feedback is a simple illustration of robust control methodology in which the effect of any parametric uncertainties can be ignored using appropriately high gain. The SLIDING MODE CONTROL (SMC) is one of the most capable robust control methods, which is able to reject bounded matched perturbation theoretically. [1]Robustness property of sliding mode control allows it to handle uncertain systems efficiently. Chattering [2]is the main disadvantage of SMC because the chattering effect limits its practical application. Higher order sliding mode [3]has all the properties of conventional (SMC) and it provides finite time convergence of sliding variable and its derivatives also. To avoid this drawback, several methodologies are proposed in sliding mode literature. Following are the main three approaches to attenuate chattering.

—The high-order sliding-mode approach [10], [11]. It allows for finite-time convergence to zero of sliding variable and its derivative too. The most effective second order sliding mode algorithm is the super twisting algorithm (STA) (see, for example, [10]). STA is a continuous controller ensuring all the main properties of first order sliding mode control for the system with smooth matched bounded uncertainties/disturbances with bounded gradients. Super-Twisting Control is one amongst them. The STC developed by Levant [4] and it plays a superior role among the sliding mode controllers. Disparate other second order sliding mode (SOSM) controllers, STC is proper to a system (in general, any order) where control appears in the first derivative of the sliding variable because it has the benefits of compensates uncertainties, needs only information of sliding variableprovide finite time convergence to origin of sliding variable and its derivative simultaneously and generates continuous signal which regrets the chattering effect.[5], [6] STA is the first continuous Second order Sliding Mode Control and it can be used as controller, differentiator and observer.

In this paper a review will be represented of super-twisting algorithm implementation as a controller and as an observer. Different Methods will be presented in Literature review. And in the last section all methods will be concluded.

2) LITERATURE REVIEW

In this review different methods will be discussed here about the implementation of super twisting algorithm.

Davila, Fridman, and Levant proposed an Observer in their paper in which the velocity of perturbed mechanical system is reconstructed from the position measurements [20]. It was assumed that the nominal functions Such as inertia, Centripetal force, Coulomb Friction & gravitational forces were known. All the solution was in Filippo's Sense. The main task was to design a finite-time convergent observer of the velocity for the original system, when only the position and the nominal model are available, reduce error (In order to prove the convergence of the state estimates to the real states) & finite time convergent (To reduce Chattering Effect to zero). The control input was assumed to be given by some identified feedback function. The alteration of the second-order sliding-mode super-twisting algorithm with finite time convergence was used[22]. AnObserver was proposed and uncertainties were bounded with some positivefinite constants. Conditions were proved using Theorem 1 and by the help of Figure 1.

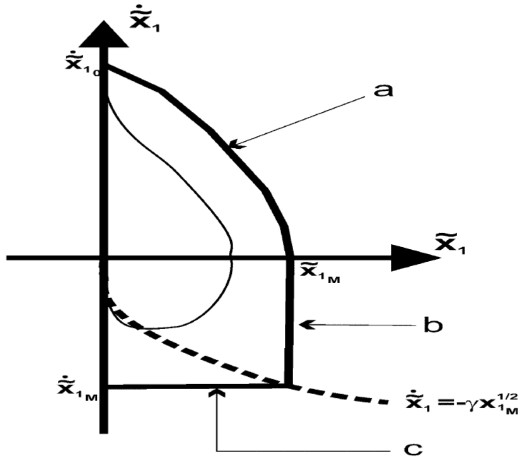

Figure 1: Majorant Curve for the finite time convergent observer [20].

It was proved that how the error went to zero in finite time and time convergence which satisfied the separation principle theorem automatically. Which means that controller and the observer can be separately designed. The gains of the proposed observer can be selected ignoring the elasticity terms.

Chalanga et al. n.d. Stated in their paper that If only output is accessible for perturbed double integrator system and super twisting control is to be designed then we need mutually states information[17]. Using super twisting observer, it is possible to approximate other state in finite time in the occurrence of disturbance. It was shown in the paper that when super twisting control was implemented based on super twisting observer then it was not possible to achieve second order sliding mode using continuous control on the selected sliding surface because in sliding equation a “sign(e)” term produces which did not allow to continuity and the function did not work as super twisting control[17]. Two methodologies were proposed to circumvent the above problem in their paper. In the first method, control input was discontinuous which might not be desirable for practical systems. In second method continuous STC was proposed which was based on high order sliding mode observer shown in Figure 2 which achieves SOSM on the selected sliding surface. For simplicity, it was considered only the perturbed double integrator, which could be generalized for an arbitrary order. It was shown that when STC is applied based on super-twisting observer (STO) then it is not conceivable to achieve second order sliding mode (SOSM) using continuous control on the selected sliding surface. Only double integrator perturbed was selected the, which could be generalized for an arbitrary order. This method was applied for the position control of industrial emulator. And the results were awesome.

Tayebi-Haghighi, Piltan, and Kim Proposed the design of a robust composite high-order super-twisting sliding mode controller (HOSTSMC) for robot manipulators because manipulators are widely

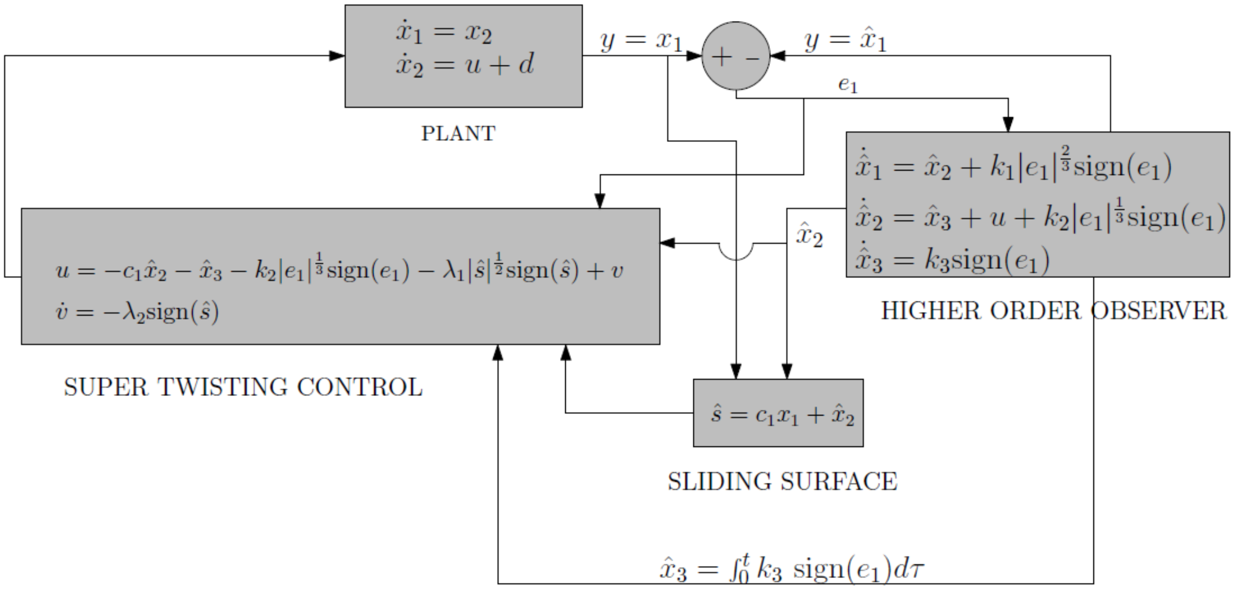

Figure 2: Block diagram of the Super-twisting Control based on HOSM Observer [17].

used in industrial manufacturing for many composite and specialized applications[24].in their research, first Traditional sliding mode controller was proposed. But it was not enough to get desired position and attenuate chattering. Then a robust combined high-order super-twisting sliding mode controller was proposed by combining a higher-order super-twisting sliding mode controller as the main controller with a super-twisting higher-order sliding mode observer as unidentified state measurement and uncertainty estimator in the presence of uncertainties as shown inFigure 3.

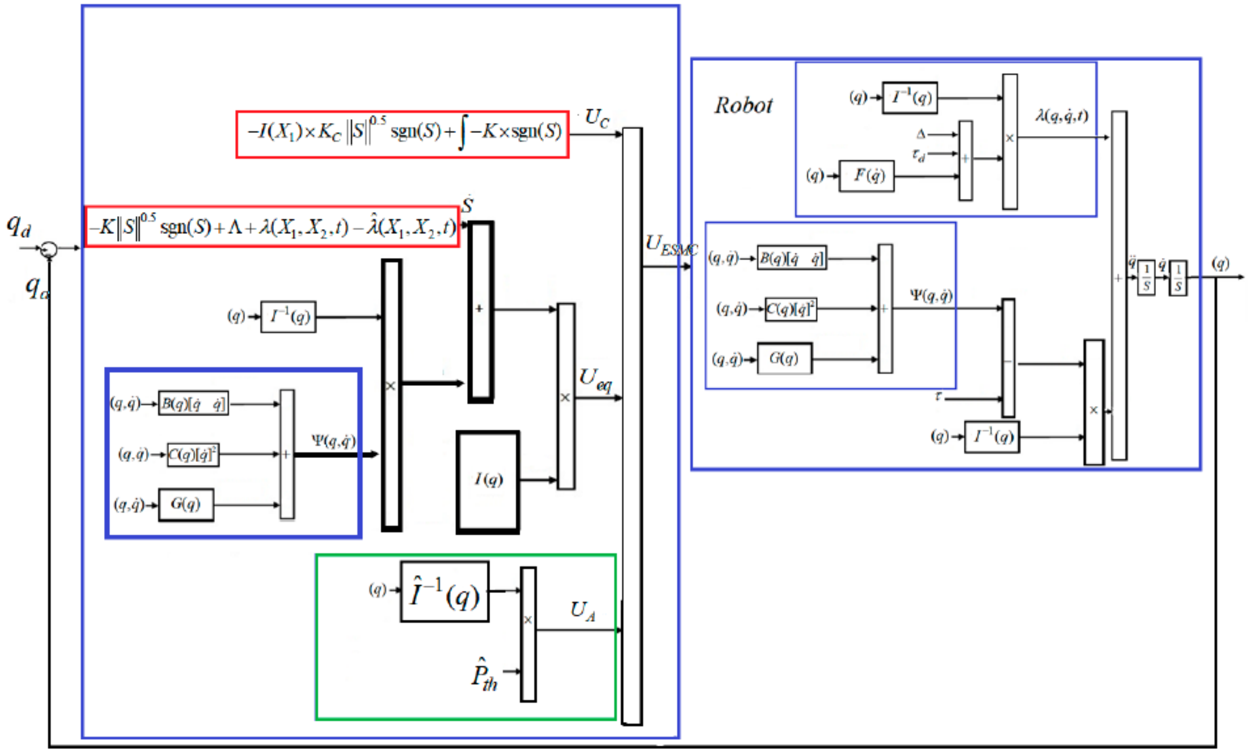

Figure 3: Block diagram of HOSTSMC for robot manipulator [24].

The proposed method was adaptively improved the traditional sliding mode controller (TSMC) and theestimated state sliding mode controller (ESMC) to reduce the chattering. The efficiency of a HOSTSMC was tested over six degrees of freedom (DOF) using a Programmable Universal Manipulation Arm (PUMA) robot manipulator. The proposed method results were the TSMC and ESMC, yielding 4.9% and 2% average performance progresses in the output position root-mean-square (RMS) error and average error, respectively.

Cruz, Alazki, and Hernández proposed a controller base on Super Twisting Algorithm (robust nonlinear controller) to decrease the chattering problem of sliding mode control with the robustness of robotic manipulator[18]. The main idea of this work was to design the controller for 5-DOF robotic manipulator CRS Catalyst-5 based in STA shown inFigure 4. This Robot had to default a PD controller, improve the control of the trajectory tracking is the priority. The robotic system must be controlled knowing its main features as it's kinematic and dynamic. By simulations, it was proved that the Super Twisting controller method has presented good performance in reaching the control objective. The proficiency of the control law proposed was validated for each joint using the 5-DOF robotic manipulator. The results showed that STC have better performance than the PD controller. The stabilization of the position of the desired position of the PD controller presents over shoots, the STC arrived smoothly, and its tracking error was smaller. From the results obtained in the simulation for trajectory tracking, the two controller's present good trajectory tracking for the stabilization of the position with the desired position, but the trajectory tracking error of the STC is smaller than PD Controller.

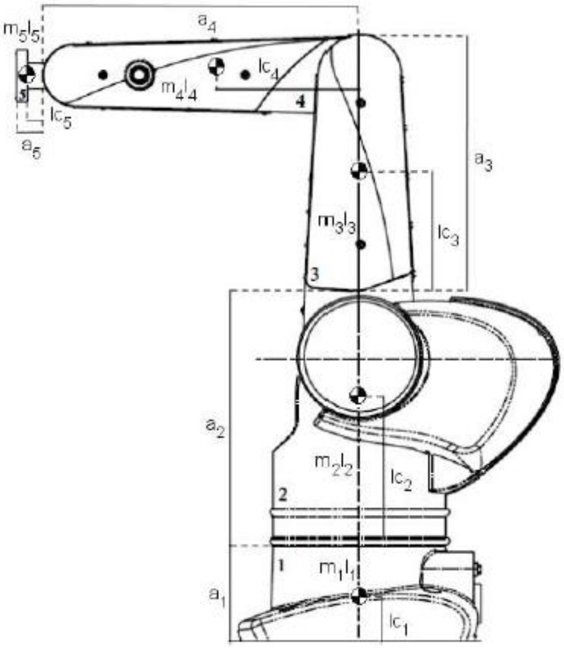

Figure 4:CRS Catalyts-5robotarm[18].

Behnamgol, Vali, and Mohammad zaman proposed a smooth second order sliding mode which was the modified form of super twisting control[16]. This method was used because super twisting method guarantees the asymptotic stability. Control structure was able to control the matched uncertainties of nonlinear system, and finite time stability. In the paper first, the conventional first order and second order sliding mode controller was presented in which showed that the control signal was not smooth. Then new finite time second or sliding mode controller was presented. The main advantage of using this control was to control the chattering effect from non-linear system. Finite time stability was proved by using Lyapunov function. This method was applied to non-linear system with uncertainties which improved the control signal smoothness which proved that control layer method gives the best performance than boundary layer method.

Dávila, Moreno, and Fridman Proposed the novel based Lyapunov based variable gain super twisting algorithm which ensures the system to move to its desired position with in finite time convergence[19]. Uncertainties were bounded with gradient of matched perturbed unknown functions. The proposed methodology makes the control tactic global like in the variable gains first order sliding mode control but also delivers chattering phenomenon alleviation. The convergence time to the sliding surface was estimated. The efficiency of the proposed design actions was validated with simulations and experimental results the Furuta pendulum.

Abu Khadra Proposed the super-twisting controller which had been implemented to control a Duffing chaotic system[12]. An appropriate sliding variable had been selected to solve the stabilization, tracking cases. The schematic Diagram of Duffing hole control system in Simulink is shown inFigure 5.The simulation results obtained were clearly shown the good performance of the controller in controlling a chaotic system with uncertainty to any randomly desired trajectory with high accuracy. The steady state error was reduced to zero. The STC controller could be also applied to synchronization of chaos, since the problem could be changed into the nth order tracking problem of state. It had been observed that a proper selection of the control parameters influences the control effort and the error, so that a method for tuning the parameters was required.

Babaei, Malekzadeh, and Madhkhan Proposed Adaptive super-twisting sliding mode control to control the 6-DOF nonlinear and uncertain air vehicle[14]. Two approaches were applied using adaptive super-twisting sliding mode control approach. The first one was a single-channel controller that was designed on the basis of decoupled equations of motion. The other one was a three-channel controller that was designed which was based on the coupling equations of motion laterally with an adaptive super-twisting observer. The stability of the closed loop system of the observer was proven. It was concluded that both single-channel andthree-channel ASTA controllers were definitely more robust and effective than PID controller.

Behera, Chalanga, and Bandyopadhyay proposed a note in which the stability of an uncertain system with actuator saturation using super-twisting controller (STC) was analyzed[15]. For the ensuring of finite-time stability a new proof of STC of the system was proposed using formal method which given a new gain conditions. Then, using this proposed proof, the largest possible DOA was designed such that the control signal always respects the saturation limit of the actuator while ensuring the finite-time stability of the system which was useful in practice.

Zhao, Huang, and Zhang proposed a super-twisting adaptive sliding mode control scheme for the design of TSR to eliminate the vibration ofthe tether to assure a successful capture in station-keeping phase[25]. The dynamic model of tethered space robot is derived by considering the perturbations in space environment. Both uncontrolled and controlled situations were simulated in this paper. The simulation results shown that the proposed controller was effective. Moreover, after relatingwith normal sliding mode control algorithm, it was verified that the proposed control scheme could avoid thechattering of normal sliding mode control and was robust for unknown boundary disturbances. It was concluded that the controltorques of proposed control scheme were continuous and fuel economized instead of the high frequencies chattering of SMC.

Raj et al. proposed a finite-time sliding mode and super-twisting control for fighter aircraft. First, a finite time stabilizing (FTS) nonlinear flight control law for insignificant aircraft model with presumed parameterswas designed[23]. Second, a discontinuous sliding mode (DSM) flight controller was developed to counteract the effect of

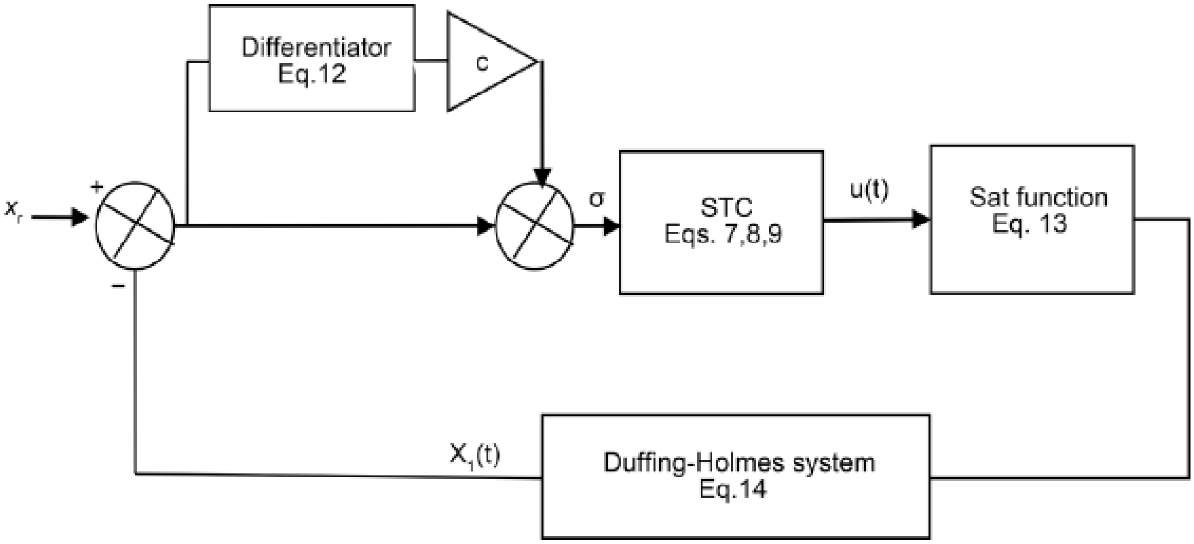

Figure 5:Schematic diagram of the closed loop control system[12].

uncertainties in the model. A DSM control law might cause a control chattering phenomenon. Third, for robust control, a super-twisting (STW) sliding mode control law was proposed. In the closed-loop sys-tem, using the FTS and STW control laws, a finite time control of the aircraft was proficient. Also, this compound control system had the ability to attenuate unwanted control chattering. It was shown that in a closed-loop system, including the compound control, the trajectory tracking error and its first derivative converged to zero in finite time. Fourth, using similar steps, composite control systems for finite time control of the roll angle, angle of attack, and sideslip angle were designed, but the details of derivation were not shown in order to save space. Fifth, simulation results for a nonlinear sweptwing fighter aircraft were obtained, which was shown that the designed compound controllers achieveacceptable simultaneous longitudinal and lateral maneuvers in spite of parametric uncertainties.

Hu et al.proposed a novel adaptive multivariable STC approach, which had taken advantage of a time-varying nonlinear function defined in the nonlinear sliding surface[21].STC algorithm was proposed to achieve the lane keeping control in the presence of the unidentified and unmatched turbulences, considering removing the chattering effect. Nonlinear function was adopted to improve the transient performance. It was concluded that High-fidelity CarSim-Simulink simulations of the proposed controller compared with a traditional SMC approach with different driving situations had verified the efficiency and robustness of the proposed approach with DDAS in yielding a high-performance, fast and accurate lane keeping control in the faulty direction-finding situation.It was also suggested that more efforts can put in the modeling and details of the vehicle and suspension structures when design of the control design.

Ahmad et al. proposed super twisting control algorithm for developing artificialpancreas in type 1 diabetes patients.Bergmans minimal model was presented forstudying dynamical behavior of the glucose and insulin inside human body[13]. Control mechanism based on classical SMC was intended and compared with the super twisting control algorithm which was based on thehigher order SMC. A common drawback of classical SMC was the high frequency chattering in control signal which was lessened by using super twisting SMC approach. Super twisting SMC controller was designed andsubjected to external disturbances for confirming the required robustness of the closed loop. A relativeanalysis of the classical SMC and super twisting SMC was given analysis. Meal disturbance todiabetes patient was also explicitly clarified and is given in simulation results. According to Numerical simulation results, it was concluded that controller shown robustness to exterior disturbances, no chattering, less control effort and accurate output tracking, thus proposed controller could be considered as a suitable choice for designing automatic insulin pumps for diabetes patients.

3) CONCLUSIONS

It is concluded that super twisting controller can be implemented in any dynamical real system where precision and robustness needed. It is also concluded that STC has the benefits of uncertainties compensation, needs only information of sliding variable, provide finite time convergence to origin of sliding variable and its derivative simultaneously and generates continuous signal which regrets the chattering effect. It is also concluded that in robotics, it is difficult to find the velocity of the system so super twisting algorithm allows to estimate the velocity in the form of observer. It is also concluded that when STC is implemented based on super-twisting observer (STO) then it is not possible to achieve second order sliding mode (SOSM) using continuous control on the chosen sliding surface.

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