Optimum point trajectory tracking of a robotic manipulator system using Extremum Seeking control

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Abstract.

Robotic manipulators have extensive applications including grasping, recognition, and viewpoint optimization. Trajectory tracking is extremely important in such applications. Some of the applications require the optimum tracking of trajectory. The complexity, uncertainty, and nonlinearities of the robotic manipulators make it difficult. Extremum-seeking control (ESC) gives the ability to track a varying maximum of a performance variable. It is an adaptive and model-free approach that provides the ability to track the optimum path of a robotic manipulator. In this paper, a perturbation-based ESC controller has been designed that tracks the optimum point of the trajectory of a robotic manipulator. Robotic manipulators being multi-input multi-output (MIMO) systems two objective functions are required. A sinusoidal perturbation has been added to the control input. Objective functions have been designed utilizing the control input. Furthermore, the applications of ESCs have been discussed and presented here, which imparts an understanding of this technique in various application areas.

Keywords. Extremum- seeking control, Robotic-manipulator, trajectory tracking.

1. INTRODUCTION

Robotic manipulators are highly uncertain, nonlinear, and complex systems. With the advent of technology robotic systems have gained much popularity and have been employed in many industrial applications. Robotic systems provide ease and comfort to human lives by embedding a certain amount of autonomy. Because of the large applications in industry effective control methods are extremely important. Researchers are continuously exploring ways to control these robotic systems and provide autonomous solutions for performing industrial tasks. ESC is a control strategy that tracks a varying maximum or minimum of a performance function [1]. This technique is an adaptive approach that adapts to parameter changes A sinusoidal perturbation is added to the control input u, making it perturbation type ESC. Based on the control law, this method provides the optimum value of the objective function [2]. In some applications, a robotic manipulator has to track the optimum position in the specified trajectory to perform the task, ESC can track that optimum value. In [6] the authors proposed a novel fractional order extremum seeking control (FOESC) that improved the convergence, robustness, and performance by incorporating the fractional calculus in ESC. Simulation and experimental analysis validate the proposed scheme and show better performance as compared to the classic extremum-seeking algorithm. ESC provides a robust and stable response. *Meroslav Kristic et-al.* [7] performed stability analysis of ESC and proved the stability of ESC by averaging method and singular perturbation analysis further author suggested improvement in stability and performance of ESC by including a dynamic compensator in the ESC algorithm [8]. Researchers are continuously finding ways to improve the ESC. In [9], The authors designed a novel fast ESC to improve the static and dynamic performance of ESC without any steady state oscillations. In this paper, the authors designed the perturbation-based extremum-seeking controller for tracking of optimum trajectory value for a two-link robotic manipulator.

2. MATERIAL AND METHODS

The dynamics of a two-link robotic manipulator has been given as follows:

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

The $q, \dot{q}$ are the angular positions and velocities of both the links. *M(q)* is the mass matrix, *C(q)* is centripetal coriolis matrix and $G(q)$ is the gravitational force and τ is the applied torque to the robot manipulator. This section illustrates the ESC technique, types of ESC and its applications in various sectors.

2.1. Extremum Seeking Control (ESC)

Tracking a varying maximum or minimum of a performance function called extremum seeking control [1]. It is an equation-free adaptive control approach that adapts to parameter changes. It is an optimization technique in which a sinusoidal perturbation is added to the control input u. Based on the control law, this method provides the optimum value of the objective function [2]. Extremum-seeking controller tracks that optimum value. Extremum-seeking control is a local optimizer and changes in the system dynamics are faster than the perturbations. Figure 1. describes the extremum-seeking control method.

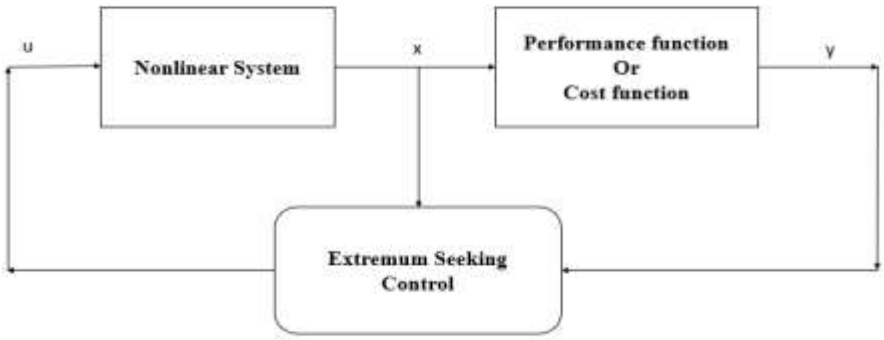

Figure 1. Block diagram of Extremum Seeking Control

Berk Calli et.al. [4] presented a detailed analysis of the ESC techniques by performing a comparison and robustness analysis of each of the ESC techniques. Authors characterized these techniques as sliding mode ESC, neural network-based ESC, approximation-based ESC, and adaptive ESC. Robotic systems have high nonlinearities, uncertain dynamics, and high disturbance, perturbation-based ESC gives robust trajectory performance. In conclusion, the authors suggested the use of approximation-based ESC when noise is not much effective, neural network ESC is preferred in the presence of significant noise while perturbation-based ESC is much more effective when a high level of noise and uncertain dynamic effects are present. Thus, perturbation-based ESC is found to be the most robust. ESC techniques are classified as shown in Figure 2. [4].

Figure 2. Classification of Extremum Seeking Control Techniques [4][5]

2.2. Applications of ESC

Extremum-seeking control is suitable for the system's disturbances and variations in the parameters. It has applications in areas like renewable energy (solar array optimization), the automotive industry, and robotic systems [3]. ESCs have applications in the systems that have disturbances and variations in the parameters over time. ESCs find applications in most of the fields mainly the have applications in Automotive Industry, Renewable energy, process control, and robotic systems. ESC is a model-free approach this property makes it popular thus ESC finds applications in many different areas where the optimum value is required. *Denis dochain et.al.* [10] presented a survey of ESC techniques and their applications to process and reaction systems. The authors implemented two approaches the perturbation-based ESC and model-based ESC on an isothermal reaction system. For model-based approaches, two conditions namely model structure is known and unknown have been used. Simulation results show the stability and convergence of both control approaches. In [11] [12], the authors presented an adaptive ESC for continuous stirred tank bioreactors and a non-isothermal CSTR without knowing much about the growth dynamics. An adaptive seeking algorithm has been implemented to maximize the cost function. ESC has been used in renewable energy for applications like solar array optimization and wind turbine power enhancement. Due to varying external conditions, sometimes it is required to change the operating conditions to get the desired power output out of the system. This is referred to as solar array optimization and maximum power point tracking. In [13] authors presented the maximum power point tracking using ESC. Researchers [14] [15] have been implanting this technique in solar energy to get the maximum power through optimization of the parameters. In [16], the authors have designed the ESC to maximize the power output of a wind turbine with load reduction. Control and optimization of power in wind energy [17] [18] systems find wide applications of ESC. Automotive electronics is a rapidly improving industrial application that imparts safety and comfort to human beings. ESC finds applications in antilock braking system (ABS) design [19] to optimize the forces applied on the breaks. Thus, ESC has wide applications in various fields.

3. Results and Discussions

Robotic manipulators being highly nonlinear, uncertain, and multi-input multi-output (MIMO) systems, two separate ESCs using two different objective functions have been designed for two different links. A cubic polynomial trajectory has been considered as the reference, having optimum values of π/4 and π/6 respectively. J_1 and J_2 are the objective functions used to track the optimum value of trajectories of the links.

$$J_1 = (pi/4) - (0.89 - u)^2 + C \tag{2}$$

$$J_2 = (pi/6) - (0.72 - u)^2 + C \tag{3}$$

u is a control input, and a sinusoidal perturbation is added to this control input. C is a constant term. Figure 3. shows the reference cubic polynomial trajectory of both links.

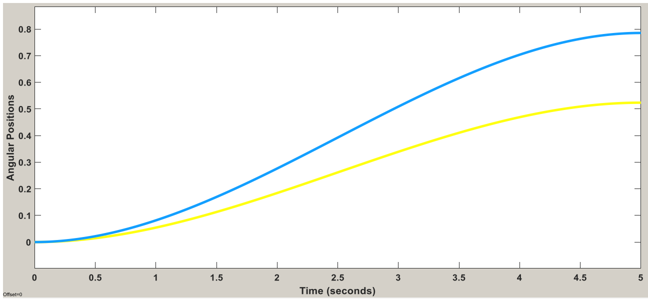

Figure 3. References Trajectories

Figure 4. shows the output of ESC for both links. Figure 5. shows the optimum value trajectory tracking for both links, where both objective functions have been able to track the optimum value of trajectories. It is clear from both figures that the designed controller is able to seek the optimum value in the reference trajectories.

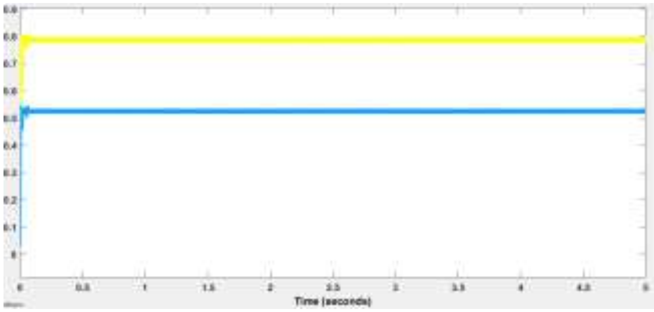

Figure 4. Output of ESC

The Simulink model of the ESC has been shown in Figure 6. The polynomial trajectory as shown in Figure 3. has been given as a reference. A sinusoidal perturbation has been included in the control law, this changes the control law and estimates the best input.

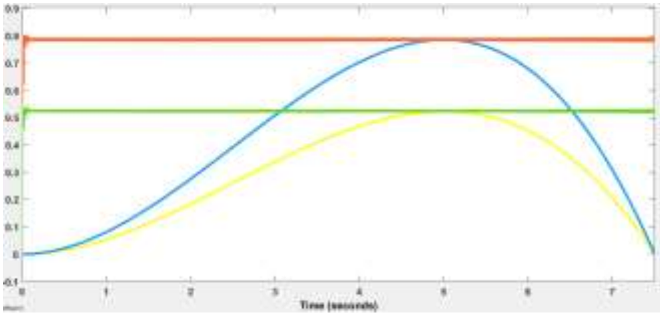

Figure 5. optimum value tracking of the reference trajectory

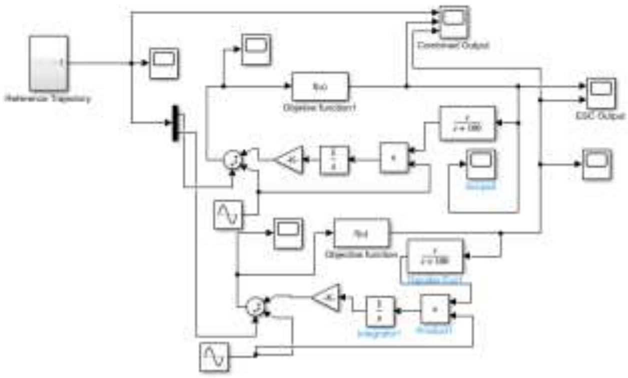

Figure 6. Simulink diagram of ESC design of robotic manipulator.

Two different objective functions have been incorporated each on the different links of a robotic manipulator. The output of the proposed controller has been shown in ESC output.

4. CONCLUSION

Robotic manipulators have various applications in industry, some of the applications require tracking of optimum value of the desired trajectory. Because of the complex, nonlinear, and uncertain nature of the robotic system, it becomes much more difficult to track the optimum value in such applications. Extremum-seeking control is a real-time adaptive optimization approach that adapts the system parameters to unknown dynamics with the help of an objective function. In this paper, a perturbation-based ESC is designed to track the optimum value of the cubic reference trajectory with the help of the objective functions. Because of the MIMO nature of robotic manipulators, two objective functions have been designed utilizing the control input. Furthermore, the applications of ESCs have been discussed and presented here, which imparts an understanding of this technique in various application areas.

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