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Optimal Trajectory Generation of Parallel Manipulator

Chandan Choubey and Jyoti Ohri

Abstract

In this paper we have designed an optimal trajectory generation (OTG) method to generate easy and errorless continuous path motion with quick converging by using Gray Wolf Optimization (GWO) method. This OTG method finds the trajectory path with minimum tracking-error, combined speed, joint increasing speed wrinkle as well as joint lurching move to follow a smooth along with error-free continuous path.

Keywords: Gray Wolf Optimization, Trajectory Generation algorithm, Parallel Manipulators, Error-Free Path Motion

1. Introduction

We know that the biological system basically influence the field of robot like the upper portion of human arm with a few sequential connections, this serial structure are called serial robots. The serial robots structure acquire large space, lack of precision and low load handling capability are its major drawbacks. Parallel manipulators was introduced by the researchers to reduce the disadvantages of series manipulators [1, 2].

The performance of parallel manipulator has become more advance in the recent scenario as compared to the series manipulator. The parallel manipulator has so many benefits as compared to series like precision, load handling ability, accuracy and many more. The parallel manipulators are used in aerodynamics [3], medical surgery [4–7], machine equipment's [8, 9], and object pick and place [10, 11].

A parallel manipulator consist of a movable plate connected with a fixed plate with hinged legs which is controlled by a dc motor separately. The number of orientation of legs is considered as degrees of freedom (DOF) of movable plate with respect to fixed plate, this type of arrangement is called as coupling systems.

The parallel robotic arm generally provides high and smooth speed, acceleration with accurate path tracking. For tracking continuous path, parallel manipulator must satisfied following specifications like error-free tracking, minimum settling time and robustness against uncertainties [12].

2. Literature survey

Almas shintemirov *et.al* [13] proposed an optimal path by spherical parallel manipulator (SPM), controlled by servomotors with default setting of position

control. For such type of system there are three approaches to get forward kinematics, a structural space and servomotors reference paths.

Damien six *et.al* [14] had evolved a new flying robot considered as one of parallel manipulators. This robot has three similar legs connected between fixed and moving stages, are controlled by quadrotors a stage. For constructing new architecture of aerial robotics, requires quadrotor with strong body.

Soheil zarkandi [15] had proposed a parallel manipulator for CNC machine, used for object holding in the 4-axis. This manipulator has two degree-of-freedom i.e. translational and rotational. It consist of two translational DOF and one rotational DOF.

Guilherme sartori Natal *et.al* [16] had tentatively compared the R4 controlled type manipulator with three control methods and provides high acceleration. First method, the redundant controlling is specifically done by a PID controller in working space. Secondly, based on dynamic configuration of redundant R4, a dual working space with feed forward control method was implemented because of inappropriate outcomes of first method. Thirdly, upgrading such type of controller, generates high acceleration above 100G in order to achieve path tracking.

Bikash kumar Sarkar [17], had shown the reproduction concentrate over the using pressurized water activated 2DOF equal controller pondered to the posture (hurl and pitch) control application. The framework model is pondered to the ease pressure driven part setups like corresponding valve with dead band, low speed water powered chamber and so forth. The streamlined numerical model of the controller has been created in this investigation. To examine the control execution by a model free fluffy tuned feed forward inclination PID regulator for present control application, this model has been utilized.

Yogesh singh *et.al* [18] has introduced a controller called U-formed planar equal controller which tends to the opposite elements of three levels of opportunity (DOF) where the introduced controller has three legs comprising of kaleidoscopic revolute (PPR) joint course of action in which every leg had one dynamic kaleidoscopic joint. A versatile sliding mode control, joined with an aggravation onlooker for the movement control of the controller was evaluated like a relative subsidiary (PD). The controlled mechanical controller was changed into decoupled elements utilizing this plan thus that the movement execution was gainful to quantify.

Jiantao Yao *et.al* [19] has built up the ability and the exhibition of the equal controller as for the repetitive incitation. While expanding a drive for the center PRPU uninvolved imperative branch to make it an excess incitation branch, it is expected to manage coordination and circulation of the main impetus of the equal controller with repetitive activation and need to understand the control system dependent on elements, based on the first 5UPS/PRPU equal controller. The component that exist the repetitive incitation from the viewpoint of level of opportunity and settled in a powerful model dependent on Lagrangian technique is improved by bringing in the arrangements excess sorts and pieces of 5UPS/PRPU equal controller with repetitive activation.

3. Optimal trajectory generation algorithm

The industrial robots were broadly used in various fields like automotive and aircraft industries and many more. The use of industrial robots, generally carry out repeated tasks such as pick and place, welding, assembling, etc. Their adaptability and capability to perform complex tasks in a significant workspace makes them useful in SME (small and medium enterprise). The characteristic advantages they offer in machine applications like prototyping, cleaning and pre-machining of cast

parts as well as in end-machining of middle tolerance parts, have increased their usage rapidly.

An input is produced in the control system of the robotic manipulators by trajectory generation for executing the required task with satisfactory performance since a path-constrained motion is followed by the robotic manipulator. The path of the robotic trajectories is assembled offline at first, and later it is assembled online by the end-effectors. There are two approaches in offline trajectory - hand level and joint level. By using Jacobian transformation, these joint coordinates are transformed into Cartesian coordinates for each sampling.

By using opposite kinematics, the Cartesian coordinates are transformed into joint coordinates. Joint level approach costs less expensive in terms of computational complexity than other approaches while controlling the robotic manipulators. Moreover, this joint level approach has an added advantage of considering only the kinematic constraints during the trajectory generation, while ignoring the dynamic constraints that increase the computational effort.

An Optimal Trajectory Generation Algorithm (OTGA) [20] is developed to generate smooth motion trajectories with minimum time for Dof parallel manipulators. For optimal trajectory generation, the Gray Wolf technique is employed with constraints and objective functions, this proposed OTG algorithm uses minimal tracking error. Moreover, for smooth continuous motion of the robotic manipulators, joint speed, acceleration and jerks were also considered along with it. So by using both objective constraints, the Gray Wolf optimization technique selects an optimal trajectory at every iteration as shown in **Figure 1**.

3.1 Trajectory generation remarks

A reference trajectory is created by using the developed Optimal Trajectory Generation [21] manipulators. The path constraint motion of the industrial robots plays a vital role in welding, cutting, surgery and machining applications. A sample reference trajectory with 15 segments is shown below in **Figure 2**.

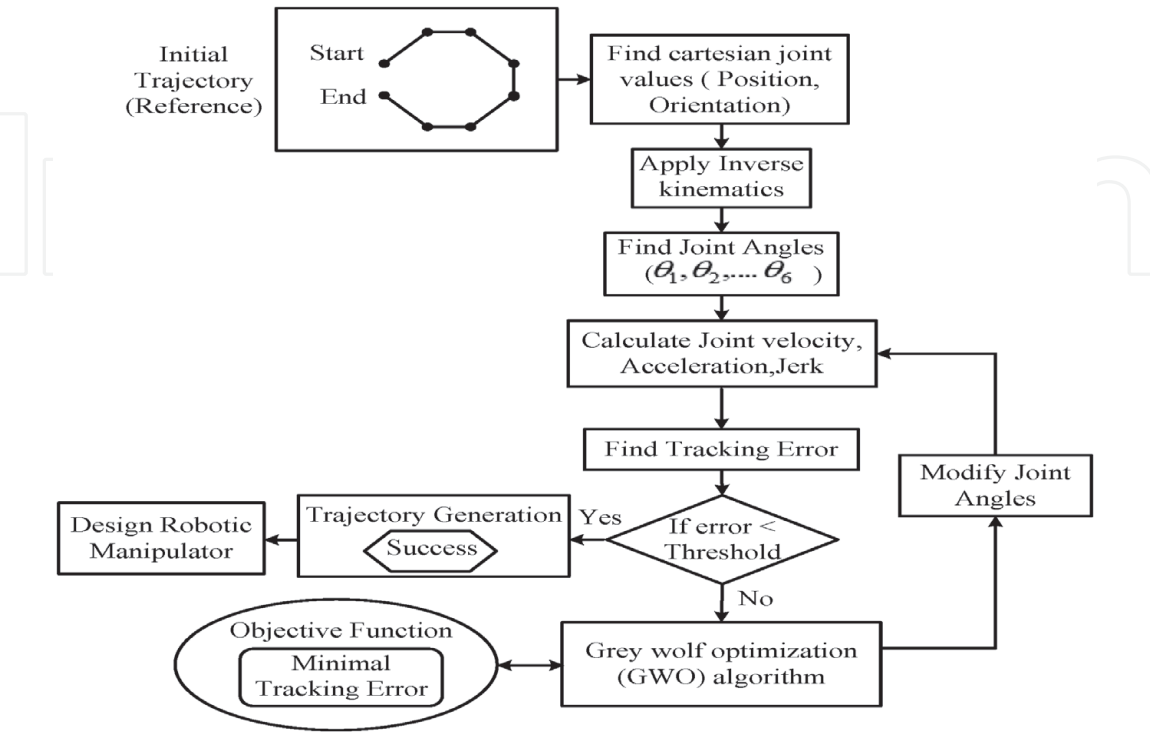


Figure 1.
The schematic diagram of OTGA.

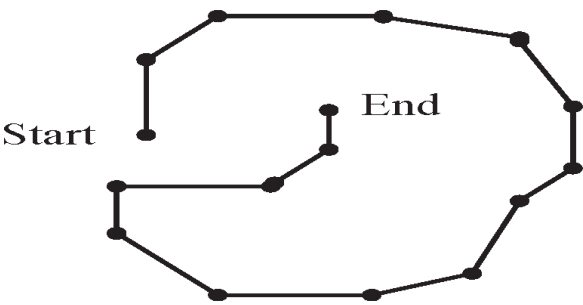


Figure 2.
Reference trajectory.

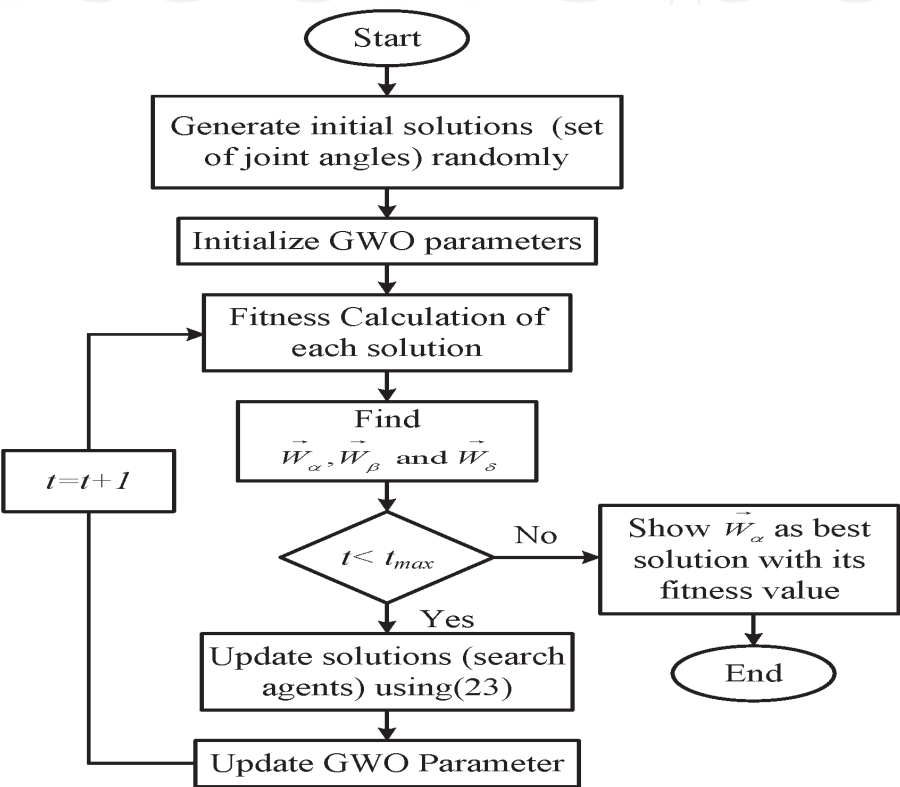


Figure 3.
GWO flow chart.

Based on the reference trajectory, the design of 6 DOF robotic manipulator is analyzed. For analysis, primary trajectory is approximately created and then optimized using Gray Wolf optimization algorithm. The primary trajectory is calculated for each segment starting from the ‘Start’ segment to the ‘End’ segment on the reference trajectory.

3.2 GWO for the optimal trajectory generation

In this section, the Gray Wolf Optimization (GWO) algorithm is employed for the optimal trajectory generation [21–26]. Here, initially the joint coordinates of the parallel robotic arms are obtained using opposite kinematic approach. Then this sets of joint coordinates, they are optimally fixed by minimizing the path tracing error. After this, the manipulator joint coordinates like speed, acceleration and jerk are calculated by utilizing the finest set if joint angles. The flowchart for the GWO methodology is described below in **Figure 3**.

3.2.1 Objective function

For selecting and tracking of a continuous path with minimal tracking error is the prime function of the developed OTG method. This tracking error function can be framed as,

$$\text{Tracking Error} = \min (p_d(i) - p_a(i)) \quad (1)$$

Where, $p_d(i)$ denotes the desired trajectory for $(i)^{th}$ robotic arm; $p_a(i)$ defines the current trajectory for $(i)^{th}$ robotic arm. Also, the following conditions must be satisfied in order to get a smooth continuous path motion.

$$\min \{J_v, J_a, J_j\} \quad (2)$$

Such as, $J_v = \frac{d\theta}{dt}$; $J_a = \frac{dJ_v}{dt}$; $J_j = \frac{dJ_a}{dt}$.

On Basis of minimum tracking error, during each recurrence, joint velocity (j_v), joint acceleration (J_a) and joint jerk (J_j) obtained for each set of manipulator joint.

3.3 The Gray Wolf Optimization (GWO)

The Gray Wolf Optimization (GWO) is an effective optimization method which emulates the leadership grading, trapping protocol and hunting mechanism of gray wolves in nature. In GWO, the process of optimal trajectory tracking is performed by four gray wolves namely; alpha, beta, delta and omega wolves. Decisions about hunting, time and place are being made by the alpha, The beta and gamma wolves is basically considered as subordinate wolves that help the alpha in decision making, the timid part of the gray wolves hierarchy is being represented by omega only.

3.3.1 Fitness evaluation

Following steps are there to evaluate the fitness function as written below.

$$\text{Fitness}(A_n^t) = \min (\text{Tracking Error}) + \min \{J_v, J_a, J_j\} \quad (3)$$

Mathematical approach for search operation:

In GWO, the α , β and δ wolves guide each other and encircles the prey. It is pretended that α , β and δ gives an appropriate knowledge regarding the exact location of the prey from overall solution. Due to which, the primary best solutions are achieved and now it is considered to generate newer solutions, which can be systematically established as beneath:

$$\vec{W}(t+1) = \vec{W}_r(t) - \vec{M} \cdot \vec{Q} \quad (4)$$

In the above Eq. (4), \vec{Q} can be given as,

$$\vec{Q} = \left| \vec{S} \cdot \vec{W}_r(t) - \vec{W}(t) \right| \quad (5)$$

\vec{W} is represented as the gray wolf actual location, \vec{W}_r represents prey desired location, \vec{M} and \vec{S} represents the coefficient vectors respectively and 't' denotes the no.

of operations. We can obtain the coefficient vectors \vec{M} and \vec{S} by the equations given below:

$$\vec{M} = 2\vec{m} \cdot \vec{x}_1 - \vec{m} \quad (6)$$

$$\vec{S} = 2 \cdot \vec{x}_2 \quad (7)$$

Here ' \vec{m} ' denotes the constant value that decreases from 2 to 0 and \vec{x}_1 and \vec{x}_2 denotes any random values between $[0, 1]$. \vec{m} is selected within the range between 2 to 0 in every operations as per the below equation,

$$\vec{m} = 2 - t \left(\frac{2}{t_{\max}} \right) \quad (8)$$

Where, ' t_{\max} ' represents the maximum allowed iterations. Assuming that, the information about the position of prey is possibly confirmed by the Alpha, Beta and Delta solutions; whereas the updates in position of Omegas is govern by previous solutions. The position updating of wolves is depended on all three best solutions as shown below:

$$\vec{W}_1 = \left| \vec{W}_\alpha(t) - \vec{M}_1 \cdot \vec{Q}_\alpha \right| \quad (9)$$

$$\vec{W}_2 = \left| \vec{W}_\beta(t) - \vec{M}_2 \cdot \vec{Q}_\beta \right| \quad (10)$$

$$\vec{W}_3 = \left| \vec{W}_\delta(t) - \vec{M}_3 \cdot \vec{Q}_\delta \right| \quad (11)$$

Where, \vec{Q}_α , \vec{Q}_β , \vec{Q}_δ are calculated as:

$$\vec{Q}_\alpha = \left| \vec{S}_1 \cdot \vec{W}_\alpha - \vec{W} \right| \quad (12)$$

$$\vec{Q}_\beta = \left| \vec{S}_2 \cdot \vec{W}_\beta - \vec{W} \right| \quad (13)$$

$$\vec{Q}_\delta = \left| \vec{S}_3 \cdot \vec{W}_\delta - \vec{W} \right| \quad (14)$$

Based on the above Eqs. (10)-(12), the solution for next iteration will be obtained as follows:

$$\vec{W}(t+1) = \frac{(\vec{W}_1 + \vec{W}_2 + \vec{W}_3)}{3} \quad (15)$$

The process of updating of wolf current positions takes place continuously until the maximum iteration is reached. If the overall optimum solution is does not reached to its maximum, or likewise the new solution will be updated for which the best feasible solution take place and hence based on the best suitable solution the next updates will be executed continuously. Due to this, the optimal continuous path is selected with error-free tracking path.

3.4 The Genetic Algorithm (GA)

Genetic Algorithm (GA) is ordered among three distinct parts for example multiplication, hybrid and change and it is expounded momentarily in couple of

Algorithm Parameters	Outcome
Variables counts	6 [$\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$]
Maximum Generation	250
Population Size	60
Encoding	Binary
Selection	Uniform
Crossover	0.7
Mutation	0.3
Total number of counts	258

Table 1.
Transformative algorithm parameters of GA.

steps [27]. The chromosome shaped by six factors of lattice $\theta(\text{jointangle})$ [28, 29] to accomplish ideal worth. Variation boundaries of GA are appeared in the beneath **Table 1**.

4. Result analysis

In this section, the analysis for the developed GWO based OTG method and GA for optimal planning of the trajectory for designing the 6 DOF Robotic manipulator. The applied methods are implemented by MATLAB.

A 3-degree-of-freedom (3-DOF) planar parallel manipulator performing high-speed, high-acceleration, and high-accuracy trajectory tracking as similar to the novel experimental pick-and-place manipulator is designed and constructed. At the time of trajectory tracking, multiple closed-loop performance specifications like tracking accuracy, settling time, control effort, and robustness to parameter uncertainty must be satisfied simultaneously. Commonly, closed loop requirement is clashing, i.e., when one requirement is improved, others may break down.

An Optimal Trajectory Generation Algorithm (OTGA) is created for producing least time smooth movement directions for 6 DOF equal controllers. The proposed OTGA utilizes the Gray Wolf enhancement procedure for the ideal direction age utilizing numerous goal capacities. Alongside this, to follow the smooth movement of mechanical controllers, the joint speed, joint increasing speed and joint jerks requires optimal value. At each cycle, the proposed Gray Wolf improvement method chooses the ideal directions utilizing the goal limitations.

The below graph 1 to 6 in **Figure 4** shows, the comparison of joint velocity for all active joints angles $\theta_1, \theta_2, \dots, \theta_6$ of the manipulator between the proposed and existing methods. The below simulated results shows smooth motion with optimal velocity at each joints of the robotic arm (manipulator).

The below graph 1 to 6 in **Figure 5** shows, the comparison of joint acceleration for all active joints angles $\theta_1, \theta_2, \dots, \theta_6$ of the manipulator between the proposed and existing methods. The below simulated results shows smooth motion with optimal acceleration at each joints of the robotic arm (manipulator).

The below graph 1 to 6 in **Figure 6** shows, the comparison of joint jerks for all active joints angles $\theta_1, \theta_2, \dots, \theta_6$ of the manipulator between the proposed and existing methods. The below simulated results shows smooth motion with minimum jerks at each joints of the robotic arm (manipulator).

The above figures show that the comparison between projected GWO technique, existing GA and default methods for trajectory generation. We have taken

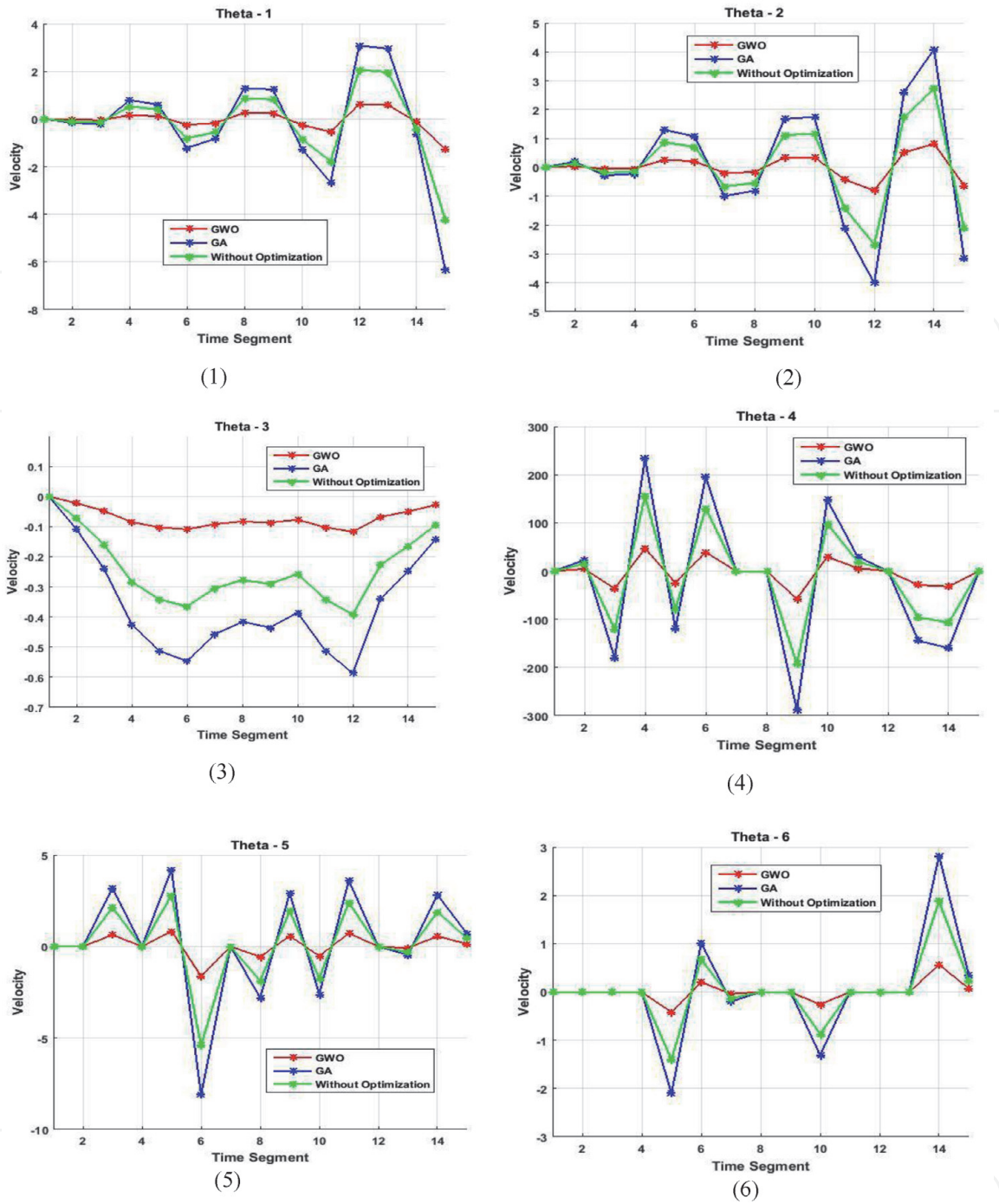


Figure 4.
Comparison plot for time segment vs. velocity for proposed and existing method.

three measurements named as acceleration, jerk and velocity in which all these are going to be compare with different time segments. It is clearly shows that the proposed method achieves minimum effective value as compared to the exiting techniques.

5. Discussion and conclusions

An optimal trajectory generation methodology is proposed which generates errorless continuous path motion with fast converging the Gray Wolf Optimization (GWO) method. The proposed OTG method using GWO algorithm is compared

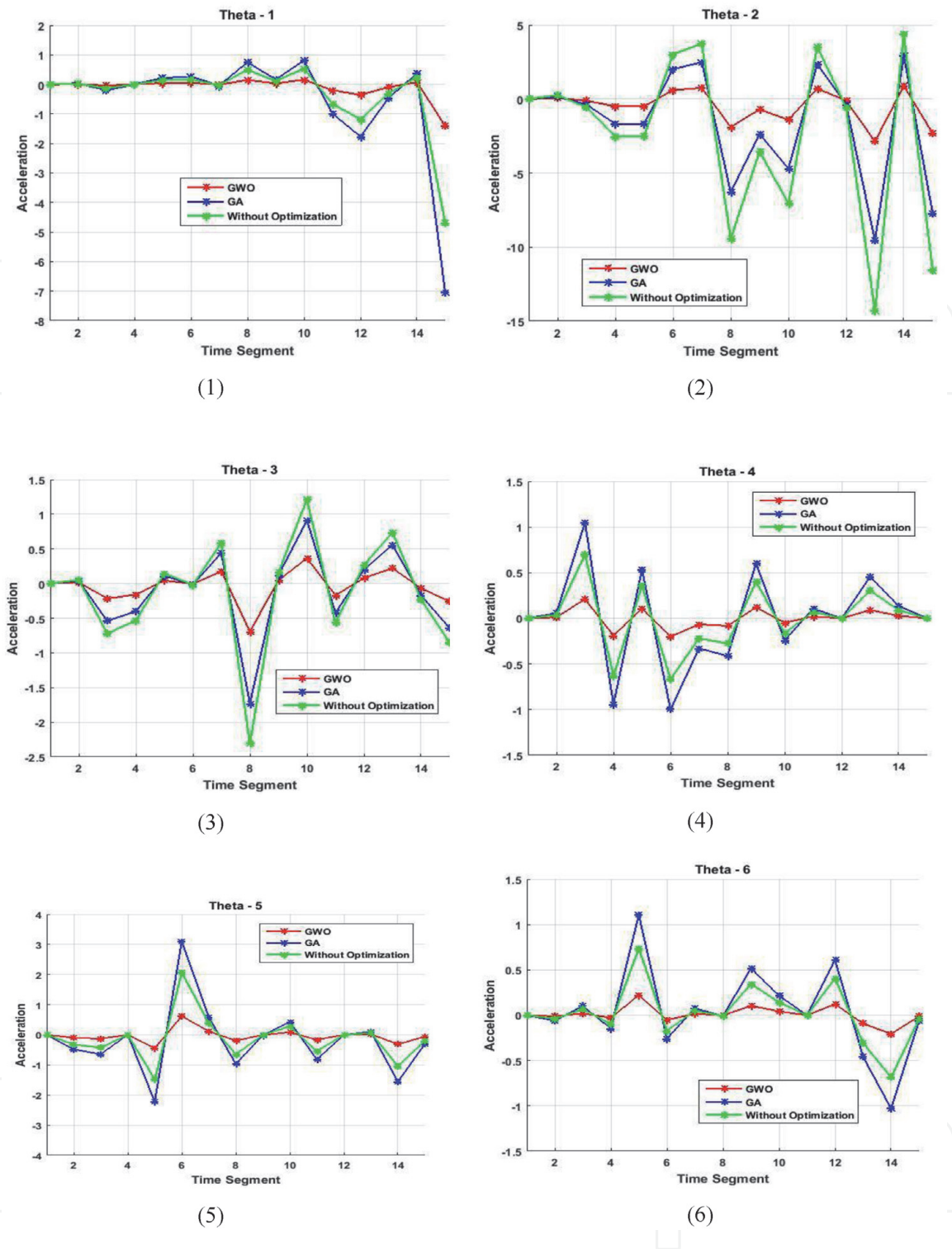


Figure 5.
Comparison plot for time segment vs. acceleration for projected and existing method.

with the GA (Genetic Algorithm) based trajectory generation method and a traditional trajectory generation method.

The mean, maximum and minimum acceleration value is also less for the proposed OTG with GWO method when compared to the existing methods. The least acceleration value is attained for the joint angle. Finally, the Joint jerk value is also calculated for all the joint angles using proposed and exiting methods with 15 segments.

The comparison of joint velocity, joint acceleration and joint jerks for all active joints angles $\theta_1, \theta_2, \dots, \theta_6$ of the manipulator between the proposed and existing

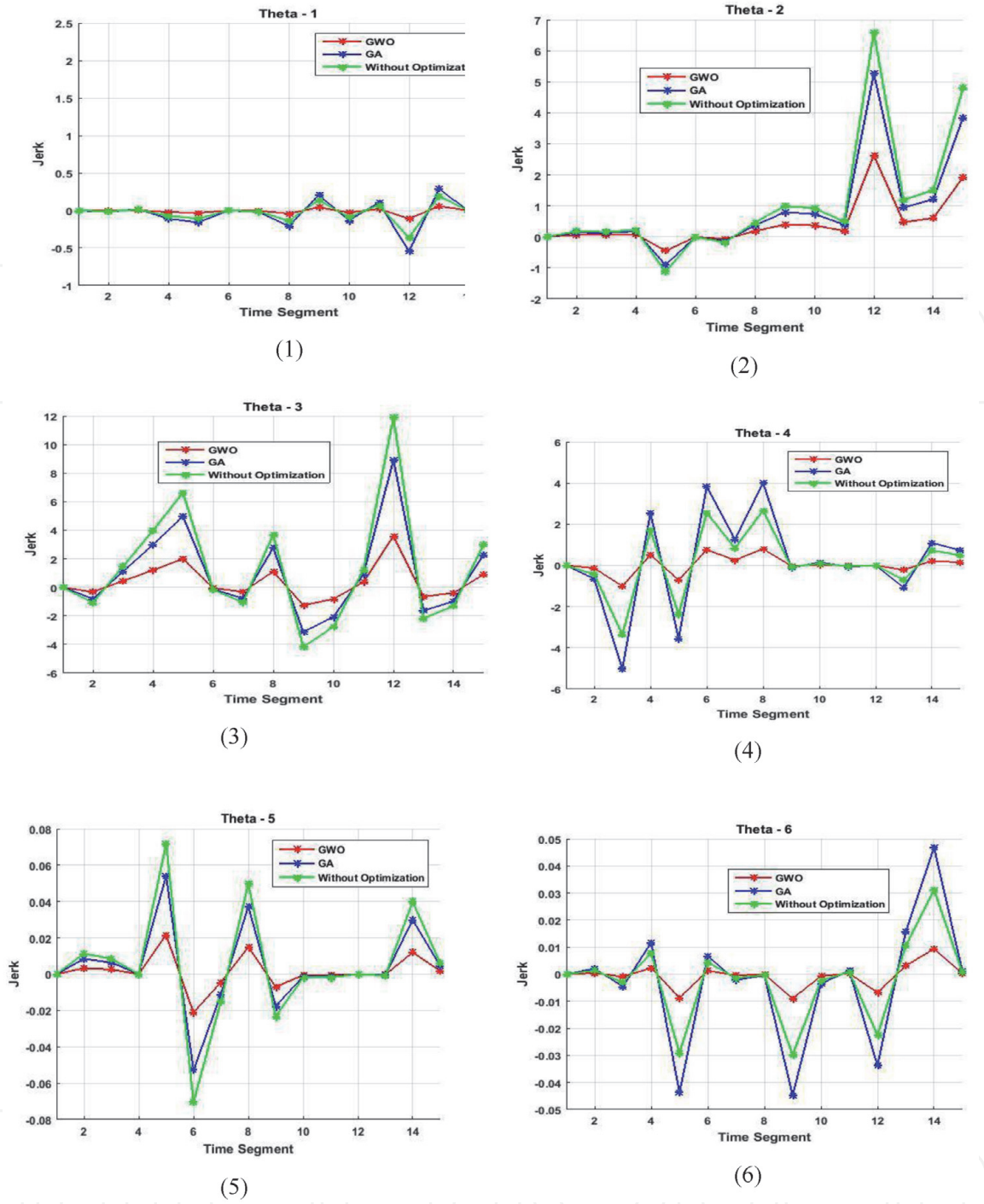


Figure 6.
Comparison plot for time segment vs. jerk for proposed and existing method.

methods. The below simulated results shows smooth motion with optimal velocity at each joints of the robotic arm (manipulator).

Comparison results can be summarized as follows:

- i. The maximum average velocity of the proposed GWO based OTG is observed 1.75 times lesser than GA based OTG and 1.01 times greater than non-optimize method.
- ii. The acceleration maximum average value of the proposed GWO based OTG is observed that 4.03 times and 3.92 times lesser than GA based OTG and non-optimize method.

- iii. The jerk maximum average value of the proposed GWO based OTG is observed that 2.41 times and 2.04 times lesser than GA based OTG and non-optimize method.
- iv. Proposed OTG GWO generates minimum 118.4% and maximum 236.1% better velocity, minimum 156.4% and maximum 592% better acceleration, and minimum 108.7% and maximum 310.7% better jerk.

The efficiency of projected methodology has been analyzed with the actual research works. The experimental result shows that a good optimization of developed OTG method in terms of shared speed, joint speed ripples, and joint lurching move measures. This proves that the proposed OTG algorithm works effectively to follow the optimal trajectory with less tracking error and smooth continuous path motion.

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