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How to Use IQPSO for Optimal Trajectory Planning of a Backup Space Robot to Cause the Least Amount of Base Disturbance

[1]NENAVATH DASHARATH ,M.Tech Associate Professor , ndasharath86@gmail.com
[2]JOGU PRAVEEN, M.Tech Assistant Professor, jpraveen.pec@gmail.com
Department-ECE
Pallavi Engineering College Hyderabad, Telangana 501505.

ABSTRACT

Practical use of a free-oating redundant space robot has grown in popularity as aeronautical technology has advanced. The issue of how to reduce disturbances at the base has received attention from academics. The position of a base might be altered if the space robot moves. Reducing the base interference that has been causing problems thanks to the space robot's kinetic actions. The article lays forth the simplified idea of a redundant space robot, which includes a stand and a manipulator with 7 moving parts.

Introduction

The free-oating redundant space robot's practical applicability has grown in recent years along with aeronautical technology [1, 2]. The issue with among the many concerns of base operators, one of the most scientists in the academy [3] Strategy development has has been crucial to the work of the obsolete space robot [4, 5]. They had a manipulator and a govern the base. These include nondependent, movable, freely flying, and swimming [6]. In the foundation of There was no one in charge of the redundant space robot. A non-homonymic limitation applies to the redundant space robot. Eventually, it will come to an end. Posture was associated with the articulation at the moment and its past transition [7]. More and more academics have spoken in on the the issue of the base's instability [8]. A procedure called it was suggested that the interference diagram be improved. It could lessen the emotional upheaval. However, its memory was enormous and its processing performance slow [9]. That's the word from due to its nonholonomic nature, Vafa and Dubowsky developed a self-correcting motion technique back in 1993. Is technique could only tweak their starting stance, not their joints' final condition. Was unalterable [10]. For their part, Shi et al. a strategy for planning based on swarms of quantum-behaved particles application of quasi-particle swarm optimization (QPSO) to the global route 2010 is the target year for the release of the planned mobile robot. Not only could it search, but it the quickest route that takes into account existing impediments [11]. Path planning for a soccer robot is a challenge that must be conquered. A strategy was developed by Meng et al. It addressed issues with the sluggish reactions of earlier soccer robots [12]. In 2015, Hu et al. proposed a strategy based on Particle swarm optimization (QPSO) that is quantum-friendly Base disturbance maximizing trajectory planning. They had not

Faster searches with additional parameters [13]. Xiangxin Zeng devised a strategy to lessen disruption at the base. It planned its routes using the Gauss pseudo general approach. Using this strategy, we are able to derive a movement trajectory. Not only kept going, but also never broke into a hiccup [14]. A path Particle annealing simulation-based plan formulation by Zhang et al. in 2016. It proposal intended to lessen base-to-shell contact The Manipulator of Space [15].

Description of Kinematic Equations

Figure 1 depicts a rudimentary form of the space robot system, which consisted of a base and a manipulator with 7 joints. Table 1 lists the various D-H parameters. The Space Manipulator Pose (Version 2.1) included the posture and the mental state. One in the +e position be written as this formula shows.

$$S_p = \left[\, p_x \;\; p_y \;\; p_z \,\right]^T, \qquad (1)$$

where p_x, p_y, and p_z Show how the three components of point P in S relate to one another previous quaternion expressions had been used to convey one's feelings in this manner. To this end, Jack made a proposal to elucidate the mood in 1992 [19]; this is seen here. Formula:

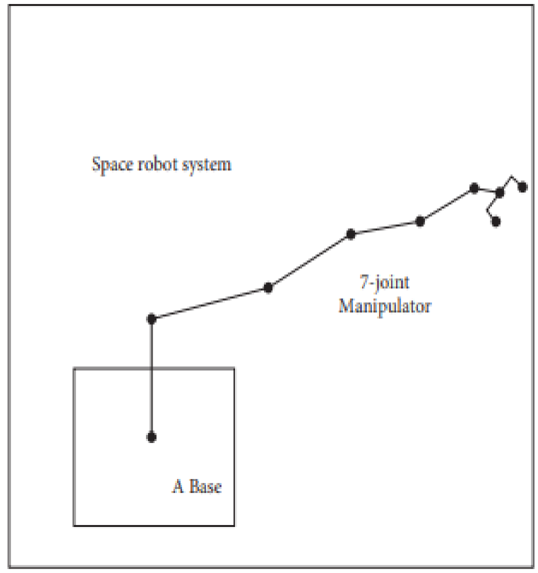

Figure 1: +e simplified model of the space robot system.

Table 1: +e D-H parameters of the model.

k	α_{k-1} (rad)	a_{k-1}	d_k	θ_k
1	$-\pi/2$	0	d_1	θ_1
2	$\pi/2$	0	0	θ_2
3	$-\pi/2$	0	d_3	θ_3
4	$\pi/2$	0	0	θ_4
5	$-\pi/2$	0	d_5	θ_5
6	$\pi/2$	0	0	θ_6
7	0	0	d_7	θ_7

$$\begin{cases} Q = \eta + q_1 \vec{i} + q_2 \vec{j} + q_3 \vec{k} = \eta + q, \\ \eta^2 + q_1^2 + q_2^2 + q_3^2 = 1. \end{cases} \qquad (2)$$

Quaternion is sometimes abbreviated as Q, where the scalar component and q is is the vector component. The parameter-relationship descriptions are as follows.

$$\begin{bmatrix} \dot{\eta} \\ \dot{q} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 0 & -\omega^T \\ \omega & -\tilde{\omega} \end{bmatrix}\begin{bmatrix} \eta \\ q \end{bmatrix} = \frac{1}{2}\begin{bmatrix} -q^T \\ \eta E - \tilde{q} \end{bmatrix}\omega. \quad (3)$$

The quaternion describes the following attitude error:

$$\begin{cases} \delta\eta_b = \eta_{b0}\eta_{bf} + q_{b0}^T q_{bf}, \\ \delta q_b = \eta_{b0}q_{bf} - \eta_{bf}q_{b0} - \widetilde{q_{b0}q_{bf}}. \end{cases} \quad (4)$$

Kinematic Equations are Determined. The following formula describes the location of end-effectors.

$$p_e = r_0 + b_0 + \sum_{k=1}^{7}(p_{k+1} - p_k), \quad (5)$$

Where per denotes the end-location, effectors' r0 the centre of the base, and b0 the base vector. The velocity of the tool's tip was determined by in the preceding formula (5), which is shown below: formula

$$v_e = \dot{p}_e = v_0 + \omega_0 \times (p_e - r_0) + \sum_{k=1}^{7}\left[k_j \times (p_e - p_k)\right] \cdot \dot{\theta}_k, \quad (6)$$

Where ve represents the end-effectors speed, v0 and 0 the base speed and angular velocity, joint matrices are indicated by and k. It's possible that the end-angular effectors' velocity might be stated in the format below:

$$\omega_e = \omega_0 + \sum_{k=1}^{7} k_k \dot{\theta}_k, \quad (7)$$

) where Jb represents the Jacobian matrix of the base and Js is the Jacobian matrix of the space manipulator. +erefore, v0 and ω0 are described in the following formula

$$\begin{bmatrix} v_0 \\ \omega_0 \end{bmatrix} = -I_b^{-1} I_{bs}\dot{\theta} = \begin{bmatrix} J_{vb} \\ J_{wb} \end{bmatrix}\dot{\theta}, \quad (9)$$

Where (Ib, Ibs, and Jvb are matrices denoting the base inertia, connected inertia, and component Jacobian, respectively. matrix centered on v0, and Jb is the Jacobian matrix of the b-the row. about ω0. Once all the numbers are entered, the final answer looks like this: formula

$$\begin{bmatrix} v_e \\ \omega_e \end{bmatrix} = \left[J_s - J_b I_b^{-1} I_{bs}\right]\dot{\theta} = J^*(\psi_b, \theta, m_i, I_i)\dot{\theta}, \quad (10)$$

Space Robot System Equations.3. This formu may be used to explain the space robot system's equation:

$$X_b = \begin{bmatrix} Q_b \\ P_b \end{bmatrix}, \quad (11)$$

Where Xb represents the base's posture, Qb represents its attitude, and Pb represents its location. The space robot system equation may be determined using numerical integration using the following expressions (12)

$$\mathbf{Q}_b(t) = \int_0^t \frac{1}{2}\begin{bmatrix} -q_b^T \\ \eta_b I - \tilde{q}_b \end{bmatrix} J_{bs\_\omega}\dot{\theta}\mathrm{d}t, \quad (12)$$

$$\mathbf{P}_b = \int_0^t J_{bs\_v}\dot{\theta}\mathrm{d}t. \quad (13)$$

The extended Jacobian matrix was employed in Equation (12) to perform an attitude update. The formula (13) was similarly has been put to use in updating the position. According to the evidence shown below, the primary motivation for optimum trajectory design was to minimize the impact on the base: formula

$$\left\| X_{b0} - X_{bf} \right\| \longrightarrow 0, \quad (14)$$

$$\theta_i(0) = \theta_{i0} \quad \theta_i(t_f) = \theta_{id}, \quad (15)$$

$$\dot{\theta}_i(0) = \ddot{\theta}_i(0) \quad \dot{\theta}_i(t_f) = \ddot{\theta}_i(t_f), \quad (16)$$

$$\theta_{i\min} \le \theta_i(t) \le \theta_{i\max}, \quad i = 1, 2, \ldots, 7, \quad (17)$$

Where i0 is the starting angle, id is the ending angle, imin is the lowest angle, and imax is the maximum angle for each joint. Joint angles, to directly constrain the +e range angle of each joint caused by a sinusoidal function. Then, it was included into the function sinusoidal +the five-order function, as seen in, may be used to parameterize the angle at each joint. Complete the following form

$$\theta_i(t) = \alpha_{i1}\sin\left(\beta_{i5}t^5 + \beta_{i4}t^4 + \beta_{i3}t^3 + \beta_{i2}t^2 + \beta_{i1}t + \beta_{i0}\right) + \alpha_{i2}, \quad (18)$$

$$\alpha_{i1} = \frac{\theta_{i\max} - \theta_{i\min}}{2}, \quad \alpha_{i2} = \frac{\theta_{i\max} + \theta_{i\min}}{2}, \quad (19)$$

$$\theta(t) = \alpha_{i1}\sin\left(\beta_{i5}t^5 - \frac{5}{2}\beta_{i5}t_f t^4 + \frac{5}{3}\beta_{i5}t_f^2 t^3 + \sin^{-1}\left(\frac{\theta_{i0} - \alpha_{i2}}{\alpha_{i1}}\right)\right) + \alpha_{i2}. \quad (20)$$

$$\dot{\theta}(t) = \alpha_{i1}\cos\left(\beta_{i5}\left(t^5 - \frac{5}{2}t_f t^4 + \frac{5}{3}t_f^2 t^3\right) + \sin^{-1}\left(\frac{\theta_{i0} - \alpha_{i2}}{\alpha_{i1}}\right)\right)\left(\beta_{i5}\left(5t^4 - 10t_f t^3 + 5t_f^2 t^2\right)\right), \quad (21)$$

$$\begin{aligned}\ddot{\theta}_i(t) = &-\alpha_{i1}\sin\left(\beta_{i5}\left(t^5 - \frac{5}{2}t_f t^4 + \frac{5}{3}t_f^2 t^3\right) + \sin^{-1}\left(\frac{\theta_{i0} - \alpha_{i2}}{\alpha_{i1}}\right)\right)\left(\beta_{i5}\left(5t^4 - 10t_f t^3 + 5t_f^2 t^2\right)\right)^2 \\ &+ \alpha_{i1}\cos\left(\beta_{i5}\left(t^5 - \frac{5}{2}t_f t^4 + \frac{5}{3}t_f^2 t^3\right). + \sin^{-1}\left(\frac{\theta_{i0} - \alpha_{i2}}{\alpha_{i1}}\right)\right)\left(\beta_{i5}\left(20t^3 - 30t_f t^2 + 10t_f^2 t\right)\right).\end{aligned} \quad (22)$$

Using Eqs. (15) and (16) above, we can get the formula for the parameters: (23)

$$\begin{aligned}\beta_{i0} &= \sin^{-1}\left(\frac{\theta_{i0} - \alpha_{i2}}{\alpha_{i1}}\right), \\ \beta_{i1} &= \beta_{i2}, \\ \beta_{i3} &= \frac{5}{3}\beta_{i5}t\frac{2}{f}, \\ \beta_{i4} &= -\frac{5}{2}\beta_{i5}t_f.\end{aligned} \quad (23)$$

$$\beta = [\beta_{15}, \beta_{25}, \beta_{35}, \beta_{45}, \beta_{55}, \beta_{65}, \beta_{75}], \quad (24)$$

$$F(\beta) = \frac{\|\delta q_b\|}{J_q} + \frac{\|\delta p_b\|}{J_p} + \frac{L_{\dot{\theta}}}{J_{\dot{\theta}}} + \frac{L_{\ddot{\theta}}}{J_{\ddot{\theta}}}, \quad (25)$$

Improved QPSO Algorithm

Introduction to the QPSO Algorithm +e QPSO algorithm has its genesis in quantum theory, namely in the study of superposition and probability [20]. Each and every atom might be communicated because to the superposition state's unique characteristic, the population took on a remarkably varied array of shapes and sizes. Using this tactic. What's more, the state that each particle is in right now probability via the other was used to explain property. This meant that the QPSO algorithm was able to locate the worldwide optimum price. Also, it couldn't take use of any other parameters [21]. On the other hand, the QPSO algorithm was not without difficulties personal flaws In this case, the particles may in the shape of a cluster. Hence, the particles would collect in a single or several locations, where it might be readily trapped into a regional sweet spot [22]. The M-particles that made up the QPSO algorithm those things that stood for answers to problems. Right now, this is where the it particle is located:

Formula:

$$X_i(t) = [X_{i1}(t), X_{i2}(t), \ldots, X_{iN}(t)], \quad i = 1, 2, \ldots, A, \quad (2$$

$$P_i(t) = [P_{i1}(t), P_{i2}(t), \ldots, P_{iN}(t)], i = 1, 2, \ldots, A. \quad (27$$

$$G_i(t) = [G_{i1}(t), G_{i2}(t), \ldots, G_{iN}(t)], i = 1, 2, \ldots, A. \quad (28$$

$$P_i(t) = \begin{cases} P_i(t-1) & \text{if } f[X_i(t)] \geq f[P_i(t-1)], \\ X_i(t) & \text{if } f[X_i(t)] < f[P_i(t-1)]. \end{cases} \quad (29)$$

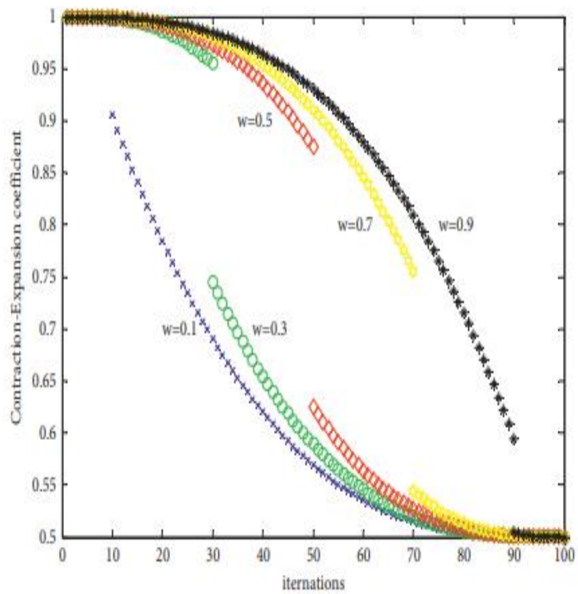

Figure 2: +e changing curves of λ

$$\begin{cases} g = \arg \min_{1 \leq i \leq A} \{f[P_i(t)]\}, \\ G(t) = P_g(t), \end{cases} \quad (30)$$

Where g is the particle index and is 1, 2,..., A's best possible location on Earth. The particle development equations (31)(32) might be written as follows:

$$\begin{cases} p_{ij}(t) = \varphi_j(t) \cdot P_{ij}(t) + [1 - \varphi_j(t)] \cdot G_j(t), \\ \varphi_j(t) \in U(0, 1), \end{cases} \quad (31)$$

$$\begin{cases} X_{ij}(t+1) = p_{ij}(t) \pm \lambda \cdot |C_j(t) - X_{ij}(t)| \cdot \ln[1/u_{ij}(t)], \\ u_{ij}(t) \in U(0, 1), \end{cases} \quad (32)$$

New and Improved Algorithm for QPSO. Because of its slow convergence and propensity to become stuck in a local optimum [23], the improved QPSO (IQPSO) method was devised. Except parameter was

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the population size and number of iterations. Singular regulating factor

$$\lambda = \begin{cases} a - \dfrac{(a-b)\cdot t^3}{w \cdot N^3}, & t \leq w \cdot N, \\ b + \dfrac{(a-b)\cdot (N-t)^3}{(1-w)\cdot N^3}, & t > w \cdot N. \end{cases} \quad (33)$$

In this equation, a = 1, b = 0.5, N = maximum number of iterations, t = current number of iterations, and w = plus quantity between t and N. (0, 1). As the multiple w curves were evolving, +e did as well. Similarly to what is seen in Figure 2. Listed below is an example of the IQPSO algorithm in action. Photograph 3. This study proposes the IQPSO algorithm as a means of addressing this problem. The value of the best trajectory parameter. +en the 7-joint space robot's design may be figured out. Which had the minimum possible value as a constraint the disruption at the base? +e IQPSO partial encoding technique is introduced in. This is Diagram No. 4.

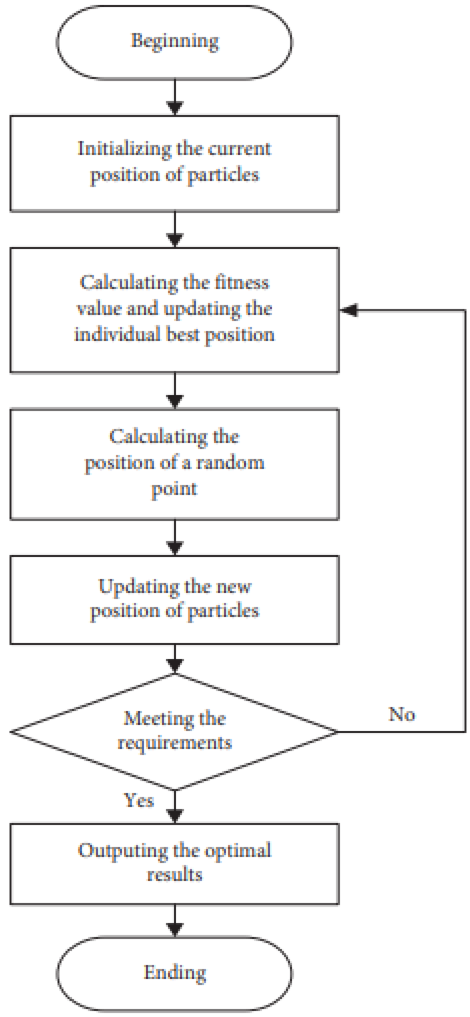

Figure 3: Process of the IQPSO algorithm.

Experiments and Simulations

Everyone knows that Math Works, a corporation based in the United States, created MATLAB. Mathematics programmers made extensive use of it. However, this software's creation was essential in multiple domains. An accurate evaluation requires that the tests of trajectories and numerical simulations use the MATLAB software, and the results of that paper.

QPSO, PSO, and SAPSO results were compared to those produced using the IQPSO method.

Table 2 [24] displays four commonly used test routines. Many algorithm parameters, such as Particles: M; Iterations: t; Maximum: N D axis, awe amount, c1 and c2 acceleration coefficient c2, and l. +eye for the annealing constant

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$$M = 30, N = 100, D = 10, w_{pso} = 0.5, w_{IQPSO} = 0.1, \quad (3$$
$$c_1 = c_2 = 2, l = 0.5.$$

In this study, each experiment was repeated fifty times in duplicate. Table 3 displays the outcomes of the numerical simulations, including the best and worst value. E computational cost of doing the same experiment 50 times in isolation is as shown in Table 4, which is timed in seconds Experiments in Trajectory Planning. The optimum trajectory planning problem with the goal of reducing base disturbance of the was solved using the suggested IQPSO algorithm as additional proof of its efficacy. Robots in space are redundant, and the issue of determining trajectories is complex. Have been translated into a mathematical answer, which was It has already been explained at length in this work. Parameterization of Here is the formula for IQPSO's settings:

$$M = 30,\ N = 100,\ D = 7,\ w = 0.5. \qquad (35)$$

$$\begin{cases} \beta_{\mathrm{IQPSO}} = 1.0e^{-4} * \begin{bmatrix} -0.001729319115994; -0.0000261058232 \\ 0.002958454474523; 0.00016790922711 \\ -0.173692323936252; 0.0032003772937 \\ -0.205714762901253 \end{bmatrix} \\ f(\beta)_{\mathrm{IQPSO}} = 1.223010798218512e^{-10}. \end{cases}$$

Table 2: +e four standard test functions.

	Standard function	Search range	f_{min}
Sphere	$f_1(x) = \sum_{i=1}^{D} x_i^2$	$[-100, 100]^D$	0
Rastrigin	$f_2(x) = \sum_{i=1}^{D} [x_i^2 - 10\cos(2\pi x_i) + 10]$	$[-10, 10]^D$	0
Griewank	$f_3(x) = (1/4000)\sum_{i=1}^{D} x_i^2 - \prod_{i=1}^{D} \cos(x_i/\sqrt{i}) + 1$	$[-50, 50]^D$	0
Schwefel	$f_4(x) = \sum_{i=1}^{D} \lvert x_i \rvert + \prod_{i=1}^{D} \lvert x_i \rvert$	$[-10, 10]^D$	0

Table 4: +e computing time

Standard functions	QPSO	PSO	SAPSO	IQPSO proposed
f_1	1.447	1.266	1.265	**1.263**
f_2	1.337	1.648	1.289	**0.916**
f_3	**0.901**	1.338	1.607	1.410
f_4	1.437	1.588	1.592	**1.434**

The text in bold means the optimal results achieved by the four algorithms.

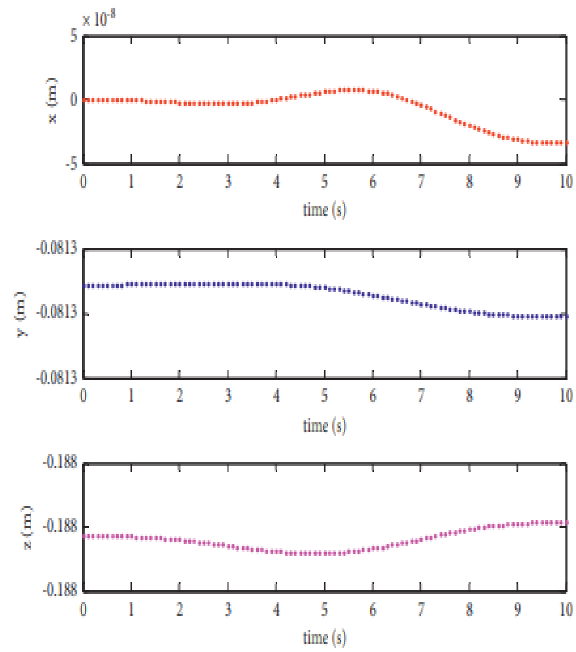

Figure 5: +e position of the base obtained by the IQPSO algorithm.

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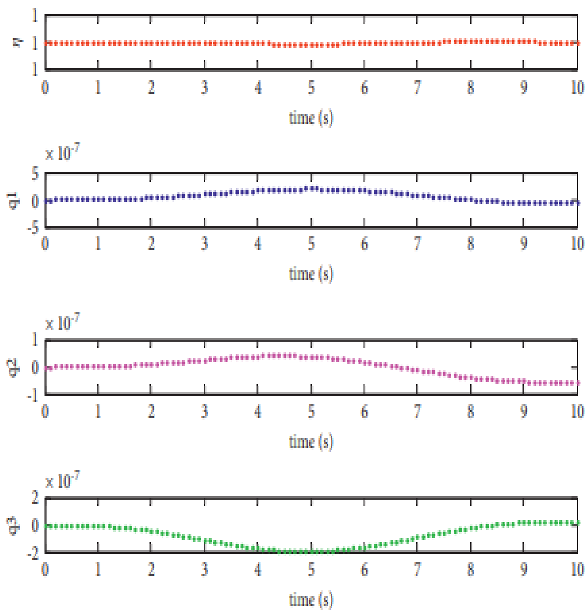

Figure 6: +e attitude of the base obtained by the IQPSO algorithm.

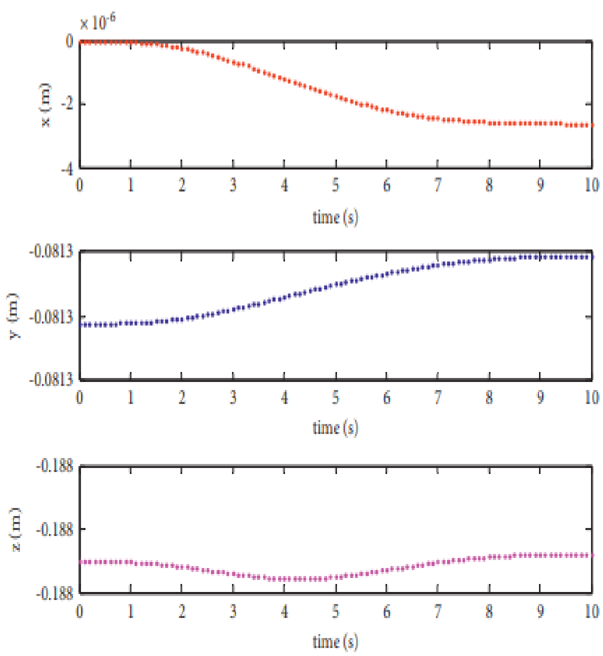

Figure 7: +e position of the base obtained by the QPSO algorithm.

Figure 6 illustrates the gradual shift in base orientation over time.

was $[1.000000000000000; \; -0.000000060486705; \; -0.000000055551370; \; 0.000000025741104]$.

As indicated in the following equations, the QPSO algorithm determined the optimum parameters and the fitness value.

$$\begin{cases} \beta_{QPSO} = 1.0e^{-4} * \begin{bmatrix} -0.053727145056947; 0.000014734907040; \\ 0.069479886180796; -0.000187541265537; \\ 0.370120344884837; 0.024346823909793; \\ 0.072405199767136 \end{bmatrix}, \\ f(\beta)_{QPSO} = 1.787582295257875e^{-8}. \end{cases} \quad (37)$$

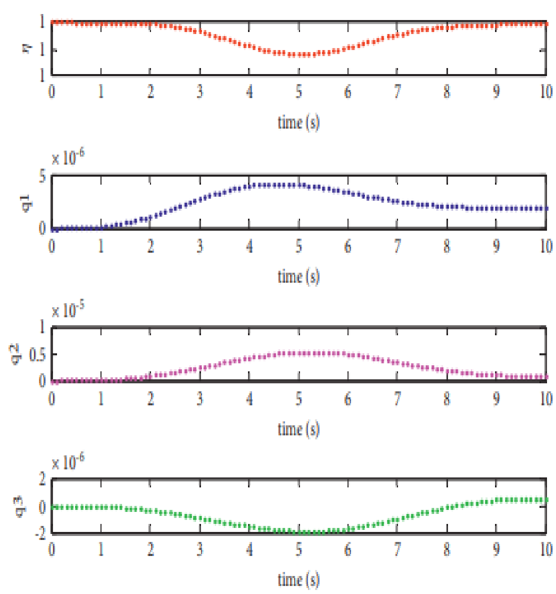

Figure 8: +e attitude of the base obtained by the QPSO algorithm.

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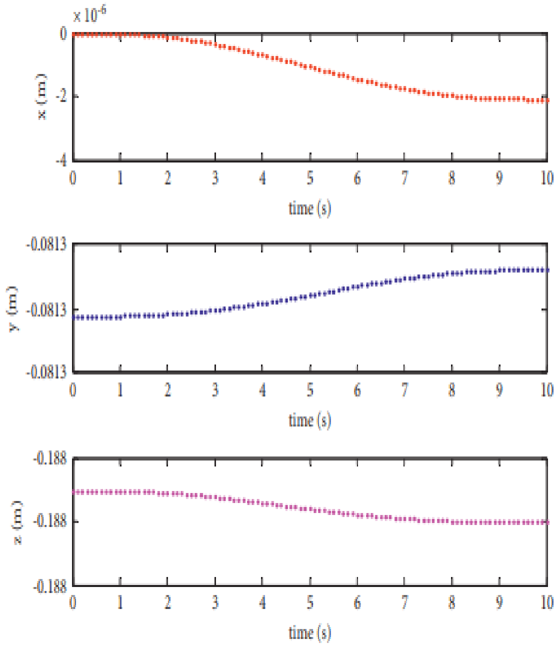

Figure 9: +e position of the base obtained by the PSO algorithm.

Base movement with time is seen in Figure 7.

was [−0.000002614389786; −0.0812902815437 −0.188036781531653].

From Figure 8, it can be seen that the attitude of the t was [0.999999999998799; 0.000001894650 0.000000896566092; 0.000000506153035].

$$\begin{cases} \beta_{PSO} = 1.0e^{-5} * \begin{bmatrix} -0.209594516686051; -0.000210216283730 \\ 0.273603505071900; 0.001617425203244; \\ 0.259691788163232; -0.098117637819463; \\ -0.963511035955538 \end{bmatrix} \\ f(\beta)_{PSO} = 1.614561098924839e^{-8}. \end{cases}$$

(3

Conclusions

In this research, we describe a method to the optimization of the trajectory planning issue that is based on the IQPSO algorithm. The space robot model was constructed so that the issue could be stated mathematically. Kinematic equations of the obsolete space robot were put in place. In order to lessen the impact of the joint's trajectory on the body, the 5- It used a third-order sine polynomial. Surprisingly, the the fitness function of the free-flying redundant space robot was defined using a single parameter, "," and the trajectory planning issue was written as a nonlinear programming problem. An issue with optimality. At long last, a revised proposal has been Particle swarm optimization with quantum-friendly behaviour (IQPSO) a fitness function optimization approach was used. +e The IQPSO algorithm quickly found the best possible solution. In contrast to the PSO and QPSO algorithms, as well as SAPSO methodology, it not only provides dependable results but has a quick rate of convergence as well. These benefits may be shown by test-bed tests using reference-function planning a course of action Based on +rough simulation findings, resulted in the conclusion that the suggested IQPSO algorithm providing the best possible value on a global scale. In addition, it compatible with figuring out the best trajectory making preparations to lessen the impact on the base of the redundant a mechanical alien from beyond space.

References

[1] L. Liu, W. Yao, and Y. Guo, "Prescribed performance Tracking control of a free-flying Flexible-joint space robot with disturbances under

input Saturation," Journal of the Franklin Institute, vol. 358, pp. 4571–4601, 2021.

[2] T. Rybus, M. Wojtunik, and F. L. Basmadji, "Optimal Collision-free path planning of a free-floating space robot using Spline-based Trajectories," Acta Astronautica, vol. 190, pp. 395–408, 2022.

[3] A. Hilli, M. Ibadi, S. Abdulshaheed, and S. H. Hadi, "Optimal path finding in Stochastic Quasi-Dynamic Environments using particle swarm optimization," Expert Systems with Applications, vol. 186, Article ID 115706, 2021.

[4] G. Rekleitis and E. Papadopoulos, "On-orbit Cooperating space robotic Servicers Handling a Passive Object," IEEE Transactions on Aerospace and Electronic Systems, vol. 51, no. 2, pp. 802–814, 2015.

[5] A. Flores-Abad, O. Ma, S. Pham, and S. Ulrich, "A Review of space Robotics Technologies for on-orbit Servicing," Progress in Aerospace Sciences, vol. 68, no. 68, pp. 1–26, 2014.

[6] C. Xiaoqian, Y. Jianping, Y. Wen, and Z. Yong, "Spacecraft on-orbit Servicing technology," Beijing: China Astronautic Publishing House, vol. 1, no. 1, pp. 8–10, 2009.

[7] Y. Li and C. P. Dang, "+e development of Orbital Servicing technology in space," Ordnance Industry Automation, vol. 31, no. 5, pp. 79–82, 2012.