# Evolution Of Optimization Algorithm Operated Robotic Arms With Different DOF

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**Abstract**: In this paper, the main emphasis is on reviewing the different types of optimization techniques proposed on the different axis of rotation of the robotic arms. The optimization depends on the various parameters of the robotic arm for the movement and the end-effectors. For a small change in the movement of the source to the destination, several variables will give rise to changes in the accuracy and efficiency of the robotic arm. Various parameters like forward and inverse kinematics analysis, position error, joint displacements, velocity, acceleration, energy, path planning and obstacle avoidance etc. have been optimized using different various optimization techniques on different degrees of freedom robotic manipulators. Some Evolutionary algorithms such as Ant colony optimization, Bacterial foraging optimization, Artificial bee colony, Firefly algorithm, and Grey wolf optimization have been discussed. Comparative reviews for different variables for the different axis of rotation of robotic arms have been performed.

**Index Terms**:ABC algorithm, ACO algorithm, ANFIS, Firefly algorithm, Grey wolf optimization, MATLAB.Abbreviations: DOF, degrees of freedom; FK, forward kinematics; IK, inverse kinematics; ANFIS, adaptive neuro-fuzzy inference system; GA, genetic algorithm; PSO, particle swarm optimization; ACO, ant colony optimization; BFO, bacterial foraging optimization; ABC, artificial bee colony; FFA, firefly algorithm; GWO, grey wolf optimization; MA, metaheuristic algorithms; FL, fuzzy logic; evolutionary algorithm, GUI, graphics user interface; SVM, support vector machine; SUMT, sequential unconstrained minimization techniques; NN, neural networks; ANN, artificial neural networks; MLPNN, multi-layer perceptron neural networks; RBF, radial basis function; SQP, sequential quadratic programming.

## 1. INTRODUCTION

TODAY'S Industrial manipulators find applications in almost every aspect of human life. They merely not used only for pick and place operations but can also be used in mining and submarine where a human can't work easily. In the medical fields, different types of surgeries can be done very easily with more precision and efficiency. During the robotic operations for the different axis of rotation manipulators, various parameters will change. For a small change in the rotation, the output shows significant changes in the parameters. For these changes to restrain various optimization techniques were used. In the last six decades, researchers worked on different aspects of optimization of robotic arms. First, a symbolic system described lower-pair mechanisms due to the use of Matrix algebra [1] provided four parameters to obtain the transformation matrix for the kinematics solution. After that, with the developments in manufacturing technologies various techniques like Iterative methods, Lazy A* search [2], [3], [4], [5] Algebraic properties, Symbolic preprocessing and matrix computation [6] was used for displacement analysis, eigenvalues and to the optimized path. Also Bilevel GA, Binary coded GA [7], [8] and GA [9], [10], [11], [12], [13] depends on reproduction of the new offspring with crossover and mutation was used to optimize trajectory planning and singularity robotics toolbox [27], [28, [29], GA toolbox [30], Peter Corke toolbox [31], [32], and GUI [33], [34, [35] used to find the kinematics, Jacobian matrix, dynamics, forces, inertia, and circle path tracking of different DOF manipulators.Optimization algorithms were also used for the minimization of position error [36], [37] due to inverse kinematics solutions. Manipulators consume energy during the movement from one position to end-effectors of the arm. A large amount of energy will be consumed if we will not follow an optimized path. In this, the different algorithms were explained for minimum energy consumption [38], [39], [40] for the sum of all the configuration of the different axis of rotation robotic arms. Soft Some researchers worked on the Workspace of different industrial robotic arms using numerical methods [14] for the computation of the boundaries of the planar manipulators, the recursive fitting algorithm [15] for spatial hyper-redundant arms and with MATLAB [16], [17] on anthropomorphic redundant robots and KR-16KS Kuka Robot arm. For the different DOF robotic arms Motion planning method [18], Singularity isolation plus compact QP (SICQP) method [19], Pseudoinverse method [20], Lie algebra, Screw theory via dual quaternion algebra [21] was studied for forward and inverse kinematics solutions. Different neural network training algorithm techniques like Back Propagation neural network-like structure [22], Multi-layer perceptron neural networks (MLPNN) [23], [24], radial basis function neural network [25], and double Neural network (NN) [26] using Q-learning reinforcement technique was applied to minimize the positional error, lessen the computational time, movement analysis, good average speed and convergence. Different types of robotics toolbox and simulators have been used to obtain the two dimensional (x-y) and 3D (x-y-z) view and output for different DOF of industrial manipulators. Some robotics toolbox used today's are MATLAB

rotation angles.

Hybrid techniques are finding applications in today's manufacturing industry. When optimization is applied to a particular parameter the results seem to be efficient, but during this other variables may change and give rise to error, inefficient results, and inaccuracy. To overcome these problems incurred during the movement of the manipulators' different hybrid algorithms by combining two or more techniques can be used to obtain desired trajectory and path planning. FL having different membership functions in the MATLAB with Artificial neural network (ANN) giving a hybrid technique called the adaptive neuro-fuzzy inference system (ANFIS), & ANN with GA, Minimum constrained GA, and pattern search [40], etc. was used to solve inverse kinematics problems and control the motion of the manipulators. With the increase in the DOF, the complexity of the manipulator increases and there will not be any unique solution for the


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multimodal equations. Some multi-objective optimization algorithms used for different DOF manipulators were multi-objective GA [41] and multi-objective PSO [42] that was based on populations and swarm robots to increase the performance of manipulators. Some other soft computing techniques, the PSO and FFA [43], GWO [44], MA [45], EA [46], and ACO [47], etc. finds applications in improving the accuracy and convergence of robotic arms. In the movement of the manipulators sometimes due to the presence of obstacles, kinematics solution cannot be obtained accurately. Sometimes there may be one or more obstacles in the target path from one location to another location. Due to obstacles positional error, convergence and efficiency cannot be restrained. Some optimizations used were Q-learning reinforcement method Quadratic polynomial, Sequential unconstrained minimization techniques, Sequential quadratic programming method, Gradient Projection Method, Geometric method [48], [49], [50], [51] to avoid obstacles and to increase accuracy, convergence and efficiency of the manipulator Embedded FL with PSO [52], [61], [62], and with the radial basis function neural network [63], BFO [73], [74], SVM [76], [77] and Naïve bayes algorithm [78], and ABC [80], etc. are the novel techniques for kinematics solution.

## 2 OPTIMIZATION TECHNIQUES

Some evolutionary techniques that have been used in the last two decades for optimizing results are explained below. They are as follows: ACO. It is a nature-inspired metaheuristic technique which was inspired by the searching capability of real ants. Ants prospect their food by exploring the surrounding area of their nest in an erratic way [47]. The ACO can be used in finding the optimal trajectory of the manipulator without any obstacle [67], [69]. BFO. It is a biologically encouraged algorithm based on mimicking the foraging behavior of Escherichia coli (E. Coli) bacteria [73]. They can run or tumble for their entire lifetime. Foraging of bacteria was based on two facets Chemotaxis and Mimicking chemotactic movement [74]. In Chemotaxis, bacterium moves in small steps to search for nutrients. It has been used for locating, handling, and ingesting food. ABC. It is a stochastic search algorithm which was inspired by the behavior of honey bees for the search of a food source [32]. A food source position constitutes a possible solution of the problem for the optimization. It can be useful in multidimensional and multimodal optimization problems. Artificial bees have been divided into employed bees, onlookers and scouts. The honey bee swarm can exchange information and memorize the environment. It uses the iterative process and is a swarm-based algorithm [80]. Its disadvantages were premature convergence, and unbalanced exploration-exploitation. FFA. It is a swarm intelligence technique that was inspired by the short and rhythmic flashes produced by a process of bioluminescence in an insect. Unisex fireflies have been enticed by a flashing light. The light intensity decreases naturally when the distance between them increases [43]. The main purpose of the firefly's flash signal was used to attract other fireflies and as a protective warning toward the predator. This method is not useful for high dimensional and nonlinear problems. It has robustness over the target position. GWO. It is also a swarm based intelligent metaheuristic algorithm inspired by grey wolves. They belong to the canidae family and live in a group. The leadership hierarchy has four types of grey wolves having alpha, beta, delta, and omega. Alpha is the leader and decision maker. Beta and delta assist alpha in decision making and omega wolves will be the followers. Hunting will be implemented based on searching, encircling, and attacking prey. This algorithm can be easily implemented due to its simple structure. It has faster convergence due to the continuous reduction of the search space.

## 3 COMPARATIVE STUDY AND DISCUSSION

The Comparison has been done between different soft computing techniques, depending on different variables like Mean square error, Singularity, Computational and travelling time, Position, Velocity, Acceleration, Jerks, kinematics, Lagrangian functions, Jacobian, Dynamics, Path planning etc. of different DOF robotic arms. A comparative study for the different axis of rotation industrial manipulators using different optimization techniques for kinematics, obstacle avoidance, and energy consumption has been presented shown in Table 1 and Table 2.

***TABLE 1***

*Comparative study of Optimization Techniques used for FK and IK Analysis of different DOF robotic arms*

| S. No. | Year | Author | Number of DOF/ General solution | Parameters/ Variables | Optimization /Simulation |
|---|---|---|---|---|---|
| 1 | 1955 | Denavit, J. et al. [1] | General equations | Lower pair mechanism | Matrix algebra |
| 2 | 1964 | Uicker, J. J. et al. [2] | n DOF | Workspace, Displacement analysis | Iterative algorithm |
| 3 | 2001 | Chapelle, F. et al. [9] | 6 DOF (Puma560 and GMF arc mate) | IK solution | GA (Tournament selection) |
| 4 | 2008 | Albert, F. Y. C. et al. [12] | 3 DOF | IK solution, Efficiency, motion control, and accuracy | GA using DMC Crossover, Stochastic method of GA |
| 5 | 2000 | Snyman, J. A. et al. [14] | 3 DOF | Workspace | Numerical method |
| 6 | 1998 | Aspragathos, N. A. et al. [21] | 5 DOF (5R) | FK problem | Lie algebra, Screw theory via Dual Quaternion Algebra |
| 7 | 2008 | Alavandar, S. et al. [22] | 2 DOF, 3 DOF | IK solution | Hybrid ANFIS, Back Propagation NN like structure |

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|---|---|---|---|---|---|
| 8 | 2010 | Daya, B. et al. [23] | 2 DOF or higher DOF | IK solution | Neural network architecture, MLPNN |
| 9 | 2015 | Jha, P. et al. [24] | 5 DOF | Mean square error | ANN, ANFIS, MLPNN, Gradient descent type |
| 10 | 2010 | Chiddarwar, S. S. et al. [25] | 6 DOF (6R Kuka Kr Serial robot) | FK solution, Root Mean square error, less computational time | Comparison of RBF and MLPNN |
| 11 | 2013 | Koker, R. [27] | 6 DOF (Stanford) | Minimum Position error, FK solution | Hybrid ANN and GA |
| 12 | 2013 | Fang, J. et al. [28] | 4 DOF (SCARA) | FK and IK solution | MATLAB, Robotics Toolbox |
| 13 | 2018 | Franco, C. L. et al. [32] | 2 DOF, 3 DOF, 5 DOF, 6 DOF, 7 DOF | FK solution, Circle Path tracking | Peter Corke toolbox, Comparison between ABC, Bat, Cuckoo Search, DE, Differential Search, CMAES, GA, PSO algorithms |
| 14 | 2011 | Ramirez Arias, J. [36] | 3 DOF (3R) | FK and IK solution, Minimum Position error, Efficiency | GA |
| 15 | 2015 | Ayyildiz, M. et al. [37] | 4 DOF (Serial robot manipulator with five joints) | IK solution | Comparison between GA, PSO, Quantum PSO, Gravitational search algorithm |
| 16 | 2015 | Mohammed, A. A. et al. [38] | 4 DOF (RA-02 manipulator) | FK and IK solution | MATLAB, Screw theory, Robotics Toolbox |
| 17 | 2013 | Glumac, S. et al. [41] | 6 DOF (redundant manipulator) | IK solution | Micro immune and micro genetic algorithms (μGA), Multi-objective optimization, Parento Frontier |
| 18 | 2013 | Bhushan, B. et al. [43] | General equations | Position and velocity vector | Comparison between PSO and FFA |
| 19 | 2015 | Mirjalili, S. [44] | General equations | Efficiency | Comparison GWO for MLP with PSO, GA, ACO, ES algorithms |
| 20 | 2008 | Pham, D. T. et al. [46] | Articulated robotic arm | IK solution | Comparison MLPNN using Bees algorithm with Back Propagation and EA |
| 21 | 2017 | El-Sherbiny, A. et al. [55] | 5 DOF | Minimization error function, FK solution | Hybrid ANN, ANFIS & GA |
| 22 | 2016 | Momani, S. et al. [57] | 3DOF | IK solution | Comparison of Conventional GA and the Continuous GA |
| 23 | 2011 | Dahari, M. et al. [59] | 6 DOF (Kuka KR-16KS) | FK and IK solution | MATLAB |
| 24 | 2011 | Bingul, Z. et al. [61] | 2 DOF (Planar robot) | Root mean square error | MATLAB, PSO, PID controller |
| 25 | 2012 | Zhizhong, L. et al. [64] | 5 DOF (6 DOF with one virtual Joint) | FK and IK solution | MATLAB |
| 26 | 2012 | Lazarevska, E. [65] | 4 DOF (SCARA) | IK solution | Hybrid MATLAB, ANFIS, Relevance vector learning algorithm, Takagi Sugeno type |
| 27 | 2013 | Shah, J. et al. [68] | 5 DOF (Pravak robot arm) | FK solution | MATLAB |
| 28 | 2014 | Duka, A. [69] | 3 DOF (Planar manipulator) | FK solution | Feed-forward NN |
| 29 | 2014 | Deshpande, V. et al. [70] | 5 DOF (Vertical articulated arm) | FK and IK solution | MATLAB, Matrix inversion method |
| 30 | 2014 | Jha, P. et al. [71] | 4 DOF (SCARA) | Minimum mean square error | ANN, MLPNN, gradient descent type |
| 31 | 2014 | Abaas, T. F. et al. [72] | 5 DOF (Lab-Volt R5150 robot arm) | Workspace, FK solution | MATLAB |
| 32 | 2012 | Aghajarian, M. [73] | n DOF | Dynamics, Integral Time Absolute Error and Integral Square Error | Comparison between BFO with PSO algorithm |
| 33 | 2013 | Vijayan, A. et al. [78] | 5 DOF (6 DOF end effector) | Accuracy and efficiency, FK problem | MATLAB, Linear SVM, Naïve Bayes algorithm |
| 34 | 2009 | Karaboga, D. et al. [80] | General equations | Performance | Comparison between ABC with GA, PSO, DE algorithms |

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|---|---|---|---|---|---|
| 35 | 2019 | Dereli, S. et al. [81] | 7 DOF | IK solution | Comparison between ABC, FFA, and PSO algorithms |

***TABLE 2***
*Comparative study of Optimization Techniques used for Obstacle avoidance and Energy Consumption of different DOF robotic arms*

| S. No. | Year | Author | Number of DOF | Parameters/ Variables | Optimization |
|---|---|---|---|---|---|
| 1 | 2015 | Menasri, R. et al. [8] | 3DOF, 5 DOF | Trajectory planning, Multiple Obstacle avoidances | Binary coded GA |
| 2 | 2008 | Kazem, B. I. et al. [11] | 3 DOF | FK, minimize travelling time and space, Quadrinomial and quintic polynomials, Obstacle avoidance | GA |
| 3 | 1998 | Nearchou, A. C. [20] | 4 DOF, 7 DOF and 10 DOF | Minimum Positional error, Joint displacement, Obstacle avoidance | Comparison between Modified GA and the Pseudoinverse method |
| 4 | 2012 | Duguleana, M. et al. [26] | 6 DOF (Power Cube manipulator) | Jacobian, good average speed, Multiple Obstacle avoidances | Q-learning reinforcement technique using the double neural network |
| 5 | 2015 | Mahdavian, M. et al. [30] | 4 DOF (Surena-III robot) | Jacobian, optimizing energy and moving obstacle avoidance | MATLAB, GA toolbox, Lagrange method |
| 6 | 2007 | Manjunath, T. C. [33] | 5 DOF (Articulated arm) | FK, obstacle avoidance | GUI, C++ language |
| 7 | 2014 | Mohammed, A. et al. [38] | 6 DOF (ABB IRB140 industrial robot) | Workspace, Path planning, Inverse dynamics, Forces and torques, Minimum Energy Consumption | MATLAB, Recursive Newton-Euler Algorithm |
| 8 | 2014 | Števo, S. et al. [39] | 6 DOF (ABB IRB 6400FHD) | Minimum operating time and energy consumption | GA |
| 9 | 2017 | Elshabasy, M. M. Y. B. et al. [40] | 3 DOF (Planar Redundant manipulator) | Lagrangian Equation, Minimum Energy consumption | Hybrid technique GA constrained Fmin function, GA-Pattern Search |
| 10 | 2016 | Dai, Y. et al. [47] | 6 DOF | Convergence, accuracy and heuristic of the algorithm, Obstacle avoidance | Screw Theory and ACO algorithm |
| 11 | 2001 | Saramago, S. F. P. et al. [48] | 6 DOF (Stanford) | Jacobian, Travelling time and minimum energy consumption, Dynamics, Obstacle avoidance | Spline functions, Lagrangian Functions, SUMT |
| 12 | 2004 | Chettibi, T. et al. [49] | 6 DOF (Puma560) | Joint positions, velocities, jerks, and torques, Obstacle avoidance | Clamped cubic spline model, Sequential Quadratic Programming (SQP) method |
| 13 | 2010 | Secară, C. et al. [50] | 4 DOF | Jacobian, Positional error, Joint displacement, Obstacle avoidance | MATLAB, GA (Tournament selection), Gradient Projection method |
| 14 | 2012 | Nammoto, T. et al. [51] | 7 DOF | IK solution, No singularity problem, Obstacle avoidance | MATLAB, Geometric approach |
| 15 | 2011 | Sharma, G. S. et al. [54] | 3 DOF | Travelling time, Minimum joint movement, Trajectory planning, minimize energy consumption and Obstacle avoidance | Comparison between GA and Geometrical approach |

It is concluded from the comparison Table 1 and Table 2 that different soft computing techniques for DOF robotic arms with different variables have been proposed. An optimization technique cannot optimize all the variables simultaneously. Some researchers used one or more techniques for multi-objective problems. Hybrid techniques can also be proposed for the multi-variables and multi-DOF robotic arms.

## 4 CONCLUSION

This paper presents the review of various soft computation techniques used for the kinematics and dynamics solution of different DOF industrial manipulators. The comparison has been made to show the various optimization algorithms used for the different DOF for the different parameters. The comparison has also been done for obstacle avoidance and energy consumption for DOF manipulators. It has been shown that optimization algorithms can be suitable for one or more variable but may not provide high performance and accurate results for all the parameters simultaneously. So hybrid techniques can be employed using different combinations of algorithms as compared in the review tables.

## 5 FUTURE SCOPE

This paper can be used further for other combinations of optimization algorithms for different conditions of convergence. Hybrid techniques can be proposed to make all the variables fittest that are not fit nor adapt to fit using one technique.

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