Nomenclature

\( \mathbf{a} \) approach vector of hand
\( a_x, a_y, a_z \) direction cosines of \( \mathbf{a} \)
\( \begin{bmatrix} \mathbf{i}^{-1}A_1 \end{bmatrix} \) D-H transformation matrix
\( c_i \) \( \cos(q_i) \)
\( c_{ij} \) \( \cos(q_i + q_j) \)
\( c_{ijk} \) \( \cos(q_i + q_j + q_k) \)
\( d_{ij} \) Euclidean distance between the \( i^{th} \) and \( j^{th} \) individual
\( D_{ij} \) Distance between \( i^{th} \) sphere on robot and \( j^{th} \) sphere on obstacle
\( N \) total number of individuals in the population
\( n \) number of variables in optimization problem
\( n^\prime \) niche size parameter
\( \mathbf{n} \) normal vector of hand
\( n_x, n_y, n_z \) direction cosines of \( \mathbf{n} \)
\( n_k \) actual number of solutions in the vicinity of the \( k^{th} \) optimal solution in the population
\( \bar{n}_k \) expected value of number of solutions near the \( k^{th} \) optimal solution in the population
\( \tilde{n}_k \) standard deviation of the number of solutions near the \( k^{th} \) optimal solution in the population
\( n_{ci} \) niche count of \( i^{th} \) individual
\( \mathbf{o} \) orientation vector of hand
\( O_x, O_y, O_z \) direction cosines of \( \mathbf{o} \)
\( [O_i] \) link geometric data in the link coordinate frame of the robot
\( [O_0] \) link geometric data in the base coordinate frame of the robot
\( P_m \) probability of mutation
\( \{^0P_h\} \) position vector of the robot hand
\( \{^0P_w\} \) position vector of the robot wrist
\( \{^0P_{w,des}\} \) desired position vector of the robot wrist
\( q^l_k, q^u_k \) lower and upper bounds of \( k^{th} \) design variable
\( q_{k,p}^{(1)}, q_{k,p}^{(2)} \) parents of \( k^{th} \) design variable
\( q_{k,c}^{(1)}, q_{k,c}^{(2)} \) children of \( k^{th} \) design variable
\( \{q_{cur}\} \) vector of wrist positioning joint variables at current configuration of robot
vector of wrist positioning joint variables at desired goal position of robot

\( \Delta q \) total joint displacement

\( r \) number of niches in the search space

\( [^iR_j] \) rotation matrix describing \( i^{th} \) coordinate frame with respect to \( j^{th} \) coordinate frame

\( s/N \) ratio of number of individuals sought as partner for selection of an individual \( 'i' \) to total number of individuals in population

\( S_i \) \( \sin(q_i) \)

\( S_{ij} \) \( \sin(q_i + q_j) \)

\( S_{ijk} \) \( \sin(q_i + q_j + q_k) \)

\( S_h(d_{ij}) \) sharing function values for \( i^{th} \) individual

\( t \) current generation number

\( t_{\text{max}} \) maximum number of generations allowed

\( [^0T_i] \) homogeneous transformation matrix describing \( i^{th} \) coordinate frame with respect to the base coordinate frame

\( [^0T_h] \) homogeneous transformation matrix describing hand coordinate frame with respect to the base coordinate frame

\( [^3T_j] \) homogeneous transformation matrix describing \( i^{th} \) coordinate frame with respect to \( j^{th} \) coordinate frame

\( u \) random number between 0 and 1

\( w_1, w_2 \) weights in objective function

\( \beta \) spread factor parameter of SBX operator

\( \eta \) distribution index for SBX operator

\( \eta_m \) distribution index for mutation

\( \Delta_{\text{max}} \) maximum perturbation allowed in the parent solution during mutation

\( \theta_i, d_i, a_i, \alpha_i \) D-H parameters of robot link

\( \psi \) deviation measure of population

\( \lambda_1, \lambda_2, \lambda_3 \) indexes used to index spheres during spherization of links

\( \lambda_{1,\text{max}} \) maximum value of \( \lambda_1 \)

\( \lambda_{2,\text{max}} \) maximum value of \( \lambda_2 \)

\( \lambda_{3,\text{max}} \) maximum value of \( \lambda_3 \)

\( \varepsilon_i, \chi \) modelling tolerance of spherization

\( \| \| \) Euclidean distance