Zi-wu Ren, Zhen-hua Wang, Li-ning Sun, 2015. A hybrid biogeography-based optimization method for the inverse kinematics problem of an 8-DOF redundant humanoid manipulator. *Frontiers of Information Technology & Electronic Engineering*, **16**(7):607-616. [doi:10.1631/FITEE.14a0335]

A hybrid biogeography-based optimization method for the inverse kinematics problem of an 8-DOF redundant humanoid manipulator

Key words: Inverse kinematics problem, 8-DOF humanoid manipulator, Biogeography-based optimization (BBO), Differential evolution (DE)

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Introduction

- The redundant humanoid manipulator has characteristics of multiple degrees of freedom and complex joint structure, and it is not easy to obtain its inverse kinematics solution.

- To solve the inverse kinematics problem of the redundant humanoid manipulator, a hybrid biogeography-based optimization (HBBO) algorithm, which is based on BBO and differential evolution (DE), is presented.

- An 8-DOF redundant humanoid manipulator is employed as an example, and the HBBO is applied to solve its inverse kinematics problem.

Hybrid biogeography-based optimization algorithm (HBBO)

Algorithm 1 Hybrid migration operator in HBBO

```
for each habitat i ∈ {1, 2, ..., m} do
    Randomly choose index r1 ≠ r2 ≠ i
    Normalize the immigration rate λ
    for each SIV k ∈ {1, 2, ..., n} do
        Select habitat H_i with probability ∝ λ_i
        if H_i is selected then
            Select habitat H_j with probability ∝ ϑ_j
            H_i(k) ← H_j(k)
        else
            if rand(·) ≤ CR | k = randn then
                H_i(k) ← H_gbest(k) + F (H_r1(k) − H_r2(k))
            else
                H_i(k) ← H_i(k)
            end if
        end if
    end for
end for
```

Algorithm 2 Gaussian mutation operator in HBBO

```
for each habitat i ∈ {1, 2, ..., m} do
    Compute the probability P_i
    Select SIV H_i(k) with mutation probability m_i
    if H_i(k) is selected then
        Update H_i(k) with the Gaussian mutation
            operator
    end if
end for
```

Algorithm 3 HBBO algorithm

```
Generate a random set of habitats H_1, H_2, ..., H_m
Evaluate the HSI value for each habitat
Initialize the generation counter t = 1
while the halting criterion is not satisfied do
    Sort the population from best to worst
    Compute the migration rates λ and ϑ for each
        habitat based on HSI
    Implement the hybrid migration operator shown
        in Algorithm 1
    Update the probability for each habitat
    Perform the Gaussian mutation operator shown in
        Algorithm 2
    Recompute the HSI value for the population
    t = t + 1
end while
```

Model for the 8-DOF redundant humanoid manipulator

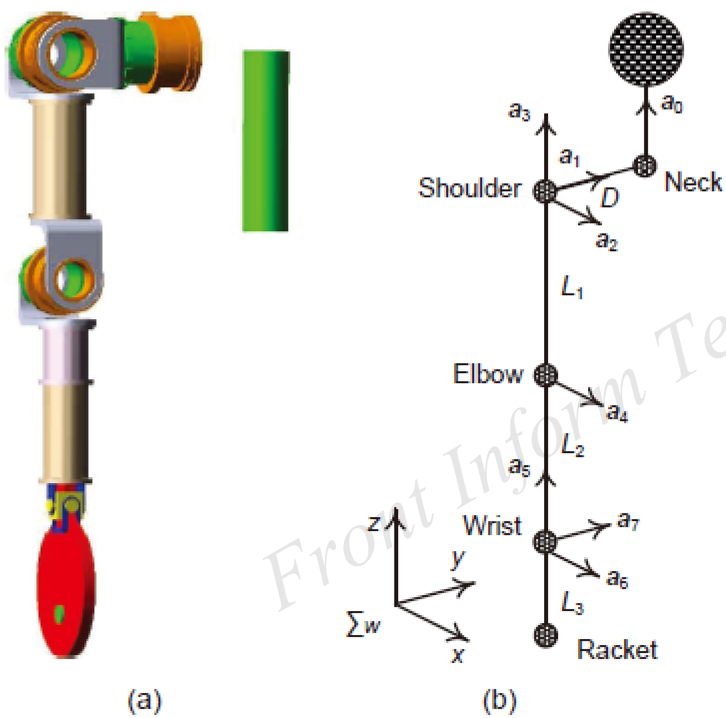

Fig. 1 Simulation model (a) and joint structure model (b) for an 8-DOF humanoid manipulator. a_0 is the rotation direction of the waist joint, and $a_1 - a_7$ are the rotation directions of the shoulder, elbow, and wrist joint, respectively. $\sum W$ is the world-coordinate system, D the shoulder breadth, L_1 the length from the shoulder center to the elbow center, L_2 the length from the elbow center to the wrist center, and L_3 the length from the wrist center to the racket center

Simulation results (1)

Table 2 HBBO results over 10 independent runs of the inverse problem for different α

α	Best	Average	Worst	Standard deviation	Convergence rate
10^{-4}	9.7847×10^{-5}	2.9094×10^{-2}	2.9004×10^{-2}	9.1686×10^{-2}	20%
10^{-5}	8.0733×10^{-6}	9.8058×10^{-6}	1.0437×10^{-5}	6.4780×10^{-7}	100%
10^{-6}	9.0915×10^{-7}	2.0063×10^{-2}	2.0056×10^{-1}	6.3419×10^{-2}	90%
10^{-7}	9.3703×10^{-8}	1.0826×10^{-2}	9.8405×10^{-2}	3.0845×10^{-2}	70%

Table 3 Results over 10 independent runs of the inverse kinematics problem under four different methods

Method	Best	Average	Worst	Standard deviation
Standard genetic algorithm	3.6036×10^{-2}	4.2291×10^{-2}	4.7253×10^{-2}	4.2084×10^{-3}
Differential evolution	8.4257×10^{-6}	2.0782×10^{-2}	5.7474×10^{-2}	2.8712×10^{-2}
Biogeography-based optimization	1.5693×10^{-2}	6.8393×10^{-2}	1.6791×10^{-1}	6.0563×10^{-2}
Hybrid biogeography-based optimization	8.0733×10^{-6}	9.8058×10^{-6}	1.0437×10^{-5}	6.4780×10^{-7}

Simulation results (2)

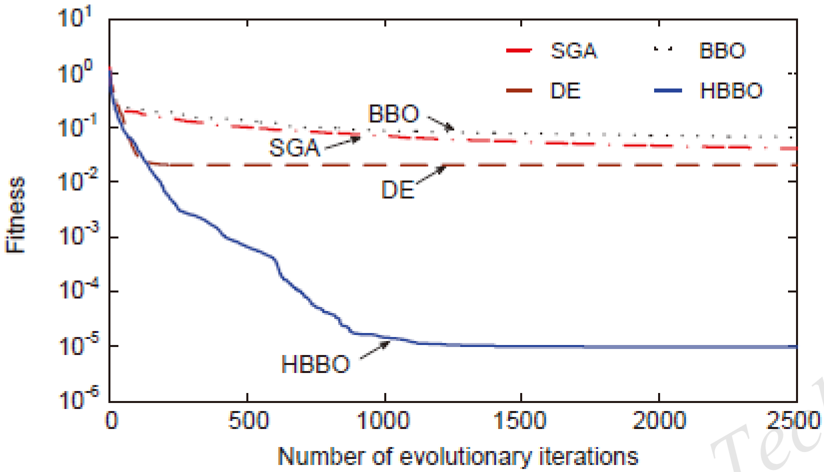

Fig. 2 Average evolution curves under different algorithms on the inverse kinematics problem of the humanoid manipulator

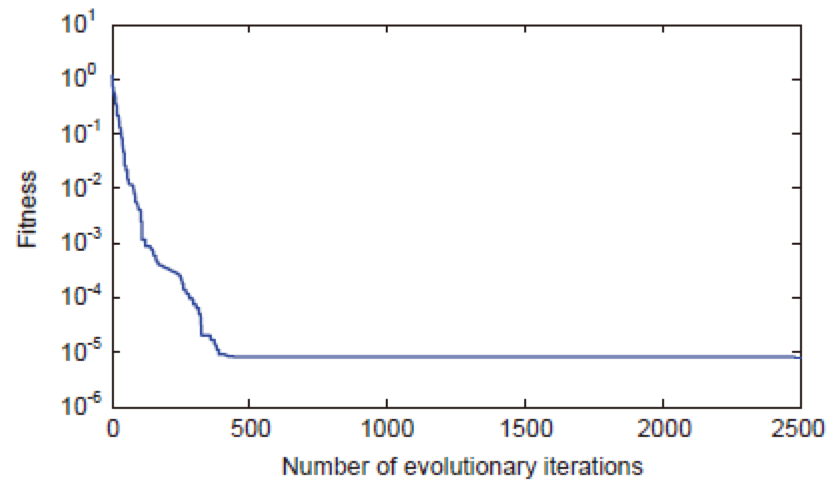

Fig. 3 A typical evolution curve of the fitness under HBBO

Position and orientation of the 8-DOF humanoid manipulator configurations

Fig. 4 Position and orientation of the 8-DOF humanoid manipulator configurations

Conclusions

- The hybrid biogeography-based optimization (HBBO) algorithm, which is a hybridization of two different evolutionary algorithms shows good optimization performance in terms of the obtained solutions.
- Compared to SGA, DE and BBO methods, the proposed HBBO algorithm is competent for the inverse kinematics problem of the 8-DOF redundant humanoid manipulator.