## Influence of The Two Mechanisms

**Table 1** The results of mechanism comparison

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **F1** |  |  | **F2** | |  |  | **F3** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 0.0000E+00 | 0.0000E+00 |  | | 0.0000E+00 | 0.0000E+00 |  | 0.0000E+00 | 0.0000E+00 |
| CCCSA | 2.8806E-08 | 1.2725E-08 |  | | 2.8578E-03 | 2.1582E-03 |  | 2.4434E-02 | 4.5341E-02 |
| CMSCSA | 3.6581E-26 | 1.0454E-25 |  | | 5.2623E-49 | 2.3853E-48 |  | 1.9409E-26 | 3.0814E-26 |
| CSA | 9.7250E-01 | 5.2789E-01 |  | | 6.4028E-05 | 4.9271E-05 |  | 4.7287E-01 | 4.0824E-01 |
|  | **F4** |  |  | **F5** | |  |  | **F6** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 6.1930E+02 | 2.6611E+02 |  | | 6.1491E+02 | 2.7632E+00 |  | 8.2457E+02 | 1.2194E+01 |
| CCCSA | 3.6608E+02 | 6.1683E+01 |  | | 6.1494E+02 | 2.9858E+00 |  | 8.0846E+02 | 6.7049E+00 |
| CMSCSA | 7.4787E+03 | 1.8148E+03 |  | | 6.3068E+02 | 3.2167E+00 |  | 9.4593E+02 | 1.9226E+01 |
| CSA | 8.0335E+02 | 2.6674E+02 |  | | 6.3102E+02 | 2.5908E+00 |  | 9.2782E+02 | 1.9246E+01 |
|  | **F7** |  |  | **F8** | |  |  | **F9** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 1.3821E+03 | 1.8853E+02 |  | | 1.4003E+03 | 3.5453E-02 |  | 1.6108E+03 | 8.3725E-01 |
| CCCSA | 1.1659E+03 | 1.5468E+02 |  | | 1.4003E+03 | 5.1357E-02 |  | 1.6105E+03 | 5.6823E-01 |
| CMSCSA | 4.5238E+03 | 4.5758E+02 |  | | 1.4003E+03 | 9.2745E-02 |  | 1.6122E+03 | 4.0029E-01 |
| CSA | 4.4917E+03 | 5.6930E+02 |  | | 1.4003E+03 | 1.0751E-01 |  | 1.6123E+03 | 4.7474E-01 |
|  | **F10** |  |  | **F11** | |  |  | **F12** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 4.3641E+03 | 8.5957E+03 |  | | 2.5478E+03 | 4.7335E+02 |  | 2.5000E+03 | 0.0000E+00 |
| CCCSA | 2.5604E+03 | 1.3195E+03 |  | | 2.2960E+03 | 3.2265E+02 |  | 2.6153E+03 | 1.1222E-02 |
| CMSCSA | 2.8125E+03 | 1.2491E+03 |  | | 3.6301E+03 | 1.5852E+03 |  | 2.5000E+03 | 0.0000E+00 |
| CSA | 2.1538E+03 | 2.3637E+02 |  | | 2.4102E+03 | 9.4304E+01 |  | 2.6164E+03 | 7.8663E-01 |
|  | **F13** |  |  | **F14** | |  |  | **F15** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 2.6000E+03 | 0.0000E+00 |  | | 3.5670E+03 | 1.2183E+03 |  | 5.2187E+03 | 4.4910E+03 |
| CCCSA | 2.6140E+03 | 1.1442E+01 |  | | 4.3433E+03 | 5.5308E+02 |  | 6.0434E+03 | 1.3105E+03 |
| CMSCSA | 2.6000E+03 | 0.0000E+00 |  | | 7.0639E+03 | 1.5253E+03 |  | 3.2000E+03 | 0.0000E+00 |
| CSA | 2.6148E+03 | 1.1738E+01 |  | | 8.0533E+06 | 2.3605E+07 |  | 1.8960E+04 | 3.0822E+04 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Overall Rank** | | | |  | | |  |  |  |
|  | Rank | +/=/- | AVG |  | |  | |  |  |  |
| CCMSCSA | 1 | ~ | 1.7333 | |  | |  |  |  |  |
| CCCSA | 2 | 7/4/4 | 2.0667 | |  | |  |  |  |  |
| CMSCSA | 3 | 10/4/1 | 2.7333 | |  | |  |  |  |  |
| CSA | 4 | 12/2/1 | 3.3333 | |  | |  |  |  |  |

## Comparison with Conventional Algorithms

**Table 2** Comparison results of CCMSCSA with ten conventional algorithms

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **F1** |  |  | **F2** | |  |  | **F3** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 0.0000E+00 | 0.0000E+00 |  | | 0.0000E+00 | 0.0000E+00 |  | 0.0000E+00 | 0.0000E+00 |
| SMA | 0.0000E+00 | 0.0000E+00 |  | | 0.0000E+00 | 0.0000E+00 |  | 3.7694E-03 | 5.8038E-03 |
| HGS | 0.0000E+00 | 0.0000E+00 |  | | 0.0000E+00 | 0.0000E+00 |  | 0.0000E+00 | 0.0000E+00 |
| WOA | 0.0000E+00 | 0.0000E+00 |  | | 2.5837E+01 | 4.3056E+01 |  | 4.7107E+00 | 1.2589E+01 |
| GWO | 0.0000E+00 | 0.0000E+00 |  | | 5.5878E-181 | 0.0000E+00 |  | 6.5907E-151 | 2.7863E-150 |
| SCA | 1.0514E-59 | 3.3409E-59 |  | | 3.9383E+00 | 1.7967E+01 |  | 7.7140E-02 | 2.8961E-01 |
| PSO | 4.7437E+01 | 6.4603E+00 |  | | 1.8765E+02 | 2.2914E+01 |  | 3.8596E+00 | 2.3621E-01 |
| DE | 1.2057E-94 | 9.3672E-95 |  | | 1.3904E+03 | 5.1862E+02 |  | 4.6808E-15 | 7.5810E-15 |
|  | **F4** |  |  | **F5** | |  |  | **F6** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 5.6427E+02 | 2.2107E+02 |  | | 6.1499E+02 | 2.9613E+00 |  | 8.2130E+02 | 8.1719E+00 |
| SMA | 3.2165E+04 | 7.5885E+03 |  | | 6.2437E+02 | 2.2788E+00 |  | 9.6456E+02 | 2.6675E+01 |
| HGS | 1.0391E+04 | 7.1230E+03 |  | | 6.1823E+02 | 3.7642E+00 |  | 8.0422E+02 | 4.8932E+00 |
| WOA | 3.5364E+04 | 2.3401E+04 |  | | 6.3559E+02 | 3.2879E+00 |  | 9.8440E+02 | 4.0958E+01 |
| GWO | 2.9663E+04 | 1.0159E+04 |  | | 6.1281E+02 | 2.9453E+00 |  | 8.7626E+02 | 1.8265E+01 |
| SCA | 3.7428E+04 | 5.0035E+03 |  | | 6.3387E+02 | 2.5367E+00 |  | 1.0426E+03 | 1.8790E+01 |
| PSO | 9.9276E+02 | 1.2677E+02 |  | | 6.2304E+02 | 3.5038E+00 |  | 9.7773E+02 | 2.0655E+01 |
| DE | 4.3255E+02 | 1.5073E+02 |  | | 6.1874E+02 | 1.9633E+00 |  | 8.0070E+02 | 6.8276E-01 |
|  | **F7** |  |  | **F8** | |  |  | **F9** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 1.4918E+03 | 2.8916E+02 |  | | 1.4003E+03 | 4.6942E-02 |  | 1.6108E+03 | 7.4710E-01 |
| SMA | 4.5630E+03 | 5.6360E+02 |  | | 1.4045E+03 | 3.3803E+00 |  | 1.6118E+03 | 4.2879E-01 |
| HGS | 1.2118E+03 | 1.6227E+02 |  | | 1.4008E+03 | 3.1526E-01 |  | 1.6110E+03 | 7.3223E-01 |
| WOA | 4.9055E+03 | 6.5275E+02 |  | | 1.4003E+03 | 1.4729E-01 |  | 1.6127E+03 | 4.2714E-01 |
| GWO | 3.2241E+03 | 7.4388E+02 |  | | 1.4028E+03 | 4.9845E+00 |  | 1.6109E+03 | 6.8057E-01 |
| SCA | 6.9897E+03 | 5.4900E+02 |  | | 1.4449E+03 | 8.8649E+00 |  | 1.6128E+03 | 2.3686E-01 |
| PSO | 5.2329E+03 | 5.5266E+02 |  | | 1.4003E+03 | 8.9269E-02 |  | 1.6118E+03 | 4.5070E-01 |
| DE | 1.0169E+03 | 6.2904E+00 |  | | 1.4003E+03 | 6.4904E-02 |  | 1.6114E+03 | 3.1629E-01 |
|  | **F10** |  |  | **F11** | |  |  | **F12** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 3.1422E+03 | 2.2953E+03 |  | | 2.6085E+03 | 5.5985E+02 |  | 2.5000E+03 | 0.0000E+00 |
| SMA | 1.6579E+05 | 1.7170E+05 |  | | 1.9657E+04 | 1.1621E+04 |  | 2.5000E+03 | 0.0000E+00 |
| HGS | 1.1733E+04 | 7.7923E+03 |  | | 6.0634E+03 | 3.1436E+03 |  | 2.5000E+03 | 0.0000E+00 |
| WOA | 1.4322E+04 | 3.4046E+04 |  | | 2.3394E+04 | 1.1933E+04 |  | 2.6265E+03 | 2.4479E+01 |
| GWO | 1.1452E+07 | 2.1835E+07 |  | | 1.6261E+04 | 6.6657E+03 |  | 2.6318E+03 | 7.2507E+00 |
| SCA | 1.3973E+08 | 7.7986E+07 |  | | 1.6640E+04 | 7.6115E+03 |  | 2.6688E+03 | 1.7418E+01 |
| PSO | 2.1671E+06 | 4.5393E+05 |  | | 2.3346E+03 | 8.2197E+01 |  | 2.6160E+03 | 4.3308E-01 |
| DE | 7.5484E+03 | 4.7535E+03 |  | | 4.8226E+03 | 1.3837E+03 |  | 2.6152E+03 | 1.3876E-12 |
|  | **F13** |  |  | **F14** | |  |  | **F15** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 2.6000E+03 | 0.0000E+00 |  | | 3.2702E+03 | 5.6388E+02 |  | 4.7562E+03 | 4.3323E+03 |
| SMA | 2.6000E+03 | 0.0000E+00 |  | | 1.6217E+04 | 2.0544E+04 |  | 1.8416E+04 | 2.3792E+04 |
| HGS | 2.6000E+03 | 1.3282E-04 |  | | 3.8555E+03 | 2.3179E+03 |  | 3.2937E+03 | 5.1295E+02 |
| WOA | 2.6052E+03 | 3.9250E+00 |  | | 5.6848E+06 | 4.7230E+06 |  | 1.0346E+05 | 6.8623E+04 |
| GWO | 2.6000E+03 | 6.3833E-04 |  | | 5.3507E+05 | 1.2181E+06 |  | 4.0283E+04 | 2.1808E+04 |
| SCA | 2.6001E+03 | 3.9574E-02 |  | | 1.3699E+07 | 7.4902E+06 |  | 2.2782E+05 | 9.6717E+04 |
| PSO | 2.6289E+03 | 7.4924E+00 |  | | 7.3744E+04 | 1.0726E+05 |  | 1.3463E+04 | 5.3254E+03 |
| DE | 2.6263E+03 | 2.2850E+00 |  | | 6.7434E+03 | 9.9666E+03 |  | 6.2531E+03 | 1.5995E+03 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Overall Rank** | | | |  | | |  |  |  |
|  | Rank | +/=/- | AVG |  | |  | |  |  |  |
| CCMSCSA | 1 | ~ | 1.5333 | |  | |  |  |  |  |
| SMA | 4 | 11/4/0 | 4.3333 | |  | |  |  |  |  |
| HGS | 2 | 6/6/3 | 2.4000 | |  | |  |  |  |  |
| WOA | 6 | 13/2/0 | 6.0667 | |  | |  |  |  |  |
| GWO | 4 | 12/2/1 | 4.3333 | |  | |  |  |  |  |
| SCA | 7 | 15/0/0 | 7.2000 | |  | |  |  |  |  |
| PSO | 5 | 13/1/1 | 5.2667 | |  | |  |  |  |  |
| DE | 3 | 12/0/3 | 3.6667 | |  | |  |  |  |  |

**Table 3** The p-values of CCMSCSA versus other conventional algorithms

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | SMA | HGS | WOA | GWO | SCA | PSO | DE |
| F1 | 1.0000E+00 | 1.0000E+00 | 1.0000E+00 | 1.0000E+00 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F2 | 1.0000E+00 | 1.0000E+00 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F3 | 1.2207E-04 | 1.0000E+00 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F4 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 4.7292E-06 | 1.5658E-02 |
| F5 | 1.7344E-06 | 2.2551E-03 | 1.7344E-06 | 6.8359E-03 | 1.7344E-06 | 2.1266E-06 | 5.2165E-06 |
| F6 | 1.7344E-06 | 2.1266E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F7 | 1.7344E-06 | 1.4773E-04 | 1.7344E-06 | 1.9209E-06 | 1.7344E-06 | 1.7344E-06 | 1.9209E-06 |
| F8 | 1.7344E-06 | 2.3534E-06 | 1.2544E-01 | 5.3197E-03 | 1.7344E-06 | 2.9894E-01 | 4.8603E-05 |
| F9 | 1.0246E-05 | 1.9861E-01 | 1.7344E-06 | 4.5281E-01 | 1.7344E-06 | 5.7517E-06 | 2.8308E-04 |
| F10 | 1.7344E-06 | 2.8786E-06 | 3.7243E-05 | 3.5152E-06 | 1.7344E-06 | 1.7344E-06 | 1.7988E-05 |
| F11 | 1.7344E-06 | 3.1817E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 4.7162E-02 | 2.6033E-06 |
| F12 | 1.0000E+00 | 1.0000E+00 | 2.5631E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 4.3205E-08 |
| F13 | 1.0000E+00 | 7.8125E-03 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F14 | 2.4414E-03 | 3.1250E-01 | 1.7181E-06 | 1.7344E-06 | 1.7344E-06 | 3.4053E-05 | 2.3534E-06 |
| F15 | 3.5994E-03 | 3.1250E-02 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.4936E-05 | 6.8359E-03 |

## 4.4. Comparison with Advanced Algorithms

**Table 4** Comparison results of CCMSCSA with seven advanced algorithms

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **F1** |  |  | **F2** | |  |  | **F3** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 0.0000E+00 | 0.0000E+00 |  | | 0.0000E+00 | 0.0000E+00 |  | 0.0000E+00 | 0.0000E+00 |
| IGWO | 1.5185E-259 | 0.0000E+00 |  | | 3.1214E-89 | 1.6835E-88 |  | 1.2206E-30 | 6.6531E-30 |
| OBLGWO | 0.0000E+00 | 0.0000E+00 |  | | 0.0000E+00 | 0.0000E+00 |  | 0.0000E+00 | 0.0000E+00 |
| ALCPSO | 4.2652E-03 | 2.2578E-02 |  | | 6.4337E+01 | 3.5239E+02 |  | 5.1430E-05 | 6.7293E-05 |
| CESCA | 6.5837E+00 | 2.4923E+00 |  | | 4.5951E+03 | 2.8154E+03 |  | 2.1986E+01 | 8.0134E+00 |
| OBSCA | 1.4676E-88 | 5.6017E-88 |  | | 4.3732E-24 | 2.3784E-23 |  | 5.1477E-22 | 2.2357E-21 |
| m\_SCA | 0.0000E+00 | 0.0000E+00 |  | | 1.0894E-210 | 0.0000E+00 |  | 1.1051E-162 | 2.2228E-162 |
| BMWOA | 7.0131E-03 | 5.9948E-03 |  | | 2.9048E-01 | 1.0145E+00 |  | 8.5780E-03 | 9.3173E-03 |
|  | **F4** |  |  | **F5** | |  |  | **F6** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 7.4273E+02 | 3.9646E+02 |  | | 6.1468E+02 | 2.8934E+00 |  | 8.2255E+02 | 1.3121E+01 |
| IGWO | 6.2356E+03 | 2.7403E+03 |  | | 6.1957E+02 | 2.6503E+00 |  | 8.8298E+02 | 1.4264E+01 |
| OBLGWO | 2.5543E+04 | 6.1498E+03 |  | | 6.1444E+02 | 2.5150E+00 |  | 8.8721E+02 | 1.6479E+01 |
| ALCPSO | 4.9525E+02 | 8.1954E+02 |  | | 6.1768E+02 | 2.5084E+00 |  | 8.2533E+02 | 1.0626E+01 |
| CESCA | 1.1185E+05 | 1.3934E+04 |  | | 6.4210E+02 | 1.0939E+00 |  | 1.2140E+03 | 1.5457E+01 |
| OBSCA | 5.1473E+04 | 1.0805E+04 |  | | 6.3209E+02 | 1.4177E+00 |  | 1.0652E+03 | 2.0172E+01 |
| m\_SCA | 2.7365E+04 | 8.4627E+03 |  | | 6.2072E+02 | 3.3615E+00 |  | 9.4460E+02 | 2.2669E+01 |
| BMWOA | 5.5273E+04 | 6.8344E+03 |  | | 6.3300E+02 | 3.2483E+00 |  | 9.6701E+02 | 1.6621E+01 |
|  | **F7** |  |  | **F8** | |  |  | **F9** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 1.3382E+03 | 1.3770E+02 |  | | 1.4003E+03 | 5.2851E-02 |  | 1.6109E+03 | 7.2694E-01 |
| IGWO | 3.4101E+03 | 5.3149E+02 |  | | 1.4005E+03 | 3.3850E-01 |  | 1.6116E+03 | 6.3208E-01 |
| OBLGWO | 3.4656E+03 | 5.2265E+02 |  | | 1.4035E+03 | 5.9500E+00 |  | 1.6114E+03 | 6.5654E-01 |
| ALCPSO | 1.6216E+03 | 3.5409E+02 |  | | 1.4006E+03 | 2.8628E-01 |  | 1.6118E+03 | 3.6579E-01 |
| CESCA | 8.8584E+03 | 3.1658E+02 |  | | 1.6466E+03 | 2.2790E+01 |  | 1.6136E+03 | 1.6079E-01 |
| OBSCA | 6.2483E+03 | 4.7367E+02 |  | | 1.4636E+03 | 1.3606E+01 |  | 1.6130E+03 | 1.9607E-01 |
| m\_SCA | 4.2801E+03 | 6.0318E+02 |  | | 1.4138E+03 | 9.8916E+00 |  | 1.6116E+03 | 6.0268E-01 |
| BMWOA | 4.8806E+03 | 5.2434E+02 |  | | 1.4003E+03 | 1.0172E-01 |  | 1.6125E+03 | 3.5754E-01 |
|  | **F10** |  |  | **F11** | |  |  | **F12** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 3.0894E+03 | 2.1338E+03 |  | | 2.7598E+03 | 6.0241E+02 |  | 2.5000E+03 | 0.0000E+00 |
| IGWO | 2.3697E+04 | 2.5094E+04 |  | | 3.4172E+03 | 1.2478E+03 |  | 2.6214E+03 | 2.9170E+00 |
| OBLGWO | 6.5251E+06 | 1.3733E+07 |  | | 1.9337E+04 | 6.6964E+03 |  | 2.5000E+03 | 0.0000E+00 |
| ALCPSO | 1.1845E+04 | 1.6533E+04 |  | | 3.1280E+03 | 8.1755E+02 |  | 2.6153E+03 | 1.7111E-02 |
| CESCA | 4.1939E+09 | 1.2090E+09 |  | | 4.2560E+05 | 2.1034E+05 |  | 3.0381E+03 | 1.5329E+02 |
| OBSCA | 1.7816E+08 | 1.2878E+08 |  | | 2.7126E+04 | 9.3815E+03 |  | 2.6902E+03 | 1.5690E+01 |
| m\_SCA | 1.8744E+07 | 2.3381E+07 |  | | 1.0456E+04 | 4.8796E+03 |  | 2.6390E+03 | 1.1239E+01 |
| BMWOA | 1.0019E+05 | 6.8297E+04 |  | | 3.2969E+04 | 2.0050E+04 |  | 2.5006E+03 | 5.7507E-01 |
|  | **F13** |  |  | **F14** | |  |  | **F15** |  | |
|  | Avg | Std |  | | Avg | Std |  | Avg | Std |
| CCMSCSA | 2.6000E+03 | 0.0000E+00 |  | | 3.5157E+03 | 8.4922E+02 |  | 4.7428E+03 | 3.7907E+03 |
| IGWO | 2.6000E+03 | 5.1180E-03 |  | | 1.8076E+06 | 4.0783E+06 |  | 2.6668E+04 | 1.1153E+04 |
| OBLGWO | 2.6000E+03 | 2.2988E-07 |  | | 9.5295E+05 | 2.5681E+06 |  | 5.7080E+04 | 3.8763E+04 |
| ALCPSO | 2.6359E+03 | 8.1704E+00 |  | | 3.6056E+06 | 7.3666E+06 |  | 1.2436E+04 | 7.4456E+03 |
| CESCA | 2.6643E+03 | 1.9045E+01 |  | | 1.8239E+07 | 3.3235E+06 |  | 1.4354E+06 | 3.6072E+05 |
| OBSCA | 2.6000E+03 | 2.3731E-04 |  | | 1.6600E+07 | 6.0216E+06 |  | 4.4567E+05 | 1.6249E+05 |
| m\_SCA | 2.6000E+03 | 5.0281E-04 |  | | 3.4143E+06 | 7.1976E+06 |  | 4.5898E+04 | 1.6751E+04 |
| BMWOA | 2.6003E+03 | 2.1643E-01 |  | | 4.0284E+05 | 4.4568E+05 |  | 5.5081E+04 | 5.5448E+04 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Overall Rank** | | | |  | | |  |  |  |
|  | Rank | +/=/- | AVG |  | |  | |  |  |  |
| CCMSCSA | 1 | ~ | 1.1333 | |  | |  |  |  |  |
| IGWO | 3 | 14/1/0 | 3.6000 | |  | |  |  |  |  |
| OBLGWO | 2 | 9/6/0 | 3.0000 | |  | |  |  |  |  |
| ALCPSO | 4 | 12/2/1 | 3.9333 | |  | |  |  |  |  |
| CESCA | 8 | 15/0/0 | 8.0000 | |  | |  |  |  |  |
| OBSCA | 7 | 15/0/0 | 6.1333 | |  | |  |  |  |  |
| m\_SCA | 5 | 14/0/1 | 4.4000 | |  | |  |  |  |  |
| BMWOA | 6 | 15/0/0 | 5.4000 | |  | |  |  |  |  |

**Table 5** The p-values of CCMSCSA versus other advanced algorithms

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | IGWO | OBLGWO | ALCPSO | CESCA | OBSCA | m\_SCA | BMWOA |
| F1 | 1.7333E-06 | 1.0000E+00 | 1.7333E-06 | 1.7333E-06 | 1.7333E-06 | 1.0000E+00 | 1.7333E-06 |
| F2 | 1.7344E-06 | 1.0000E+00 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F3 | 1.7322E-06 | 1.0000E+00 | 1.7311E-06 | 1.7311E-06 | 1.7311E-06 | 1.7311E-06 | 1.7311E-06 |
| F4 | 1.7333E-06 | 1.7333E-06 | 4.4493E-05 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F5 | 1.4936E-05 | 7.4987E-01 | 1.7423E-04 | 1.7344E-06 | 1.7344E-06 | 4.7292E-06 | 1.7344E-06 |
| F6 | 1.7344E-06 | 1.9209E-06 | 2.5364E-01 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F7 | 1.7344E-06 | 1.7344E-06 | 1.2506E-04 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F8 | 4.2843E-01 | 5.7924E-05 | 2.1630E-05 | 1.7344E-06 | 1.7344E-06 | 3.8822E-06 | 2.3038E-02 |
| F9 | 7.2695E-03 | 4.0697E-02 | 1.9729E-05 | 1.7344E-06 | 1.7344E-06 | 5.2872E-04 | 1.7344E-06 |
| F10 | 4.2857E-06 | 6.3391E-06 | 1.6046E-04 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F11 | 2.0671E-02 | 1.7344E-06 | 6.2683E-02 | 1.7344E-06 | 1.7344E-06 | 2.3534E-06 | 1.7344E-06 |
| F12 | 1.7344E-06 | 1.0000E+00 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 |
| F13 | 1.7333E-06 | 6.2500E-02 | 1.7333E-06 | 1.7333E-06 | 1.7333E-06 | 1.7333E-06 | 1.7333E-06 |
| F14 | 1.7300E-06 | 1.7300E-06 | 2.1619E-05 | 1.7333E-06 | 1.7333E-06 | 1.7333E-06 | 1.7333E-06 |
| F15 | 1.7344E-06 | 1.7344E-06 | 7.5137E-05 | 1.7344E-06 | 1.7344E-06 | 1.7344E-06 | 3.1817E-06 |

## Scalability Test

**Table 6** Scalability test results

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| F | Method | Dim=50 | | Dim=100 | |
|  |  | Avg | Std | Avg | Std |
| F1 | CCMSCSA | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
|  | CSA | 2.7686E+00 | 8.1881E-01 | 5.9258E+00 | 9.0794E-01 |
| F2 | CCMSCSA | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
|  | CSA | 3.2905E-01 | 1.1239E-01 | 9.0295E+01 | 1.6846E+01 |
| F3 | CCMSCSA | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |
|  | CSA | 3.4879E+00 | 6.5880E-01 | 6.8258E+00 | 9.5948E-01 |
| F4 | CCMSCSA | 6.0072E+03 | 2.2964E+03 | 2.4639E+04 | 6.8562E+03 |
|  | CSA | 2.3343E+03 | 6.2090E+02 | 1.9862E+04 | 4.8605E+03 |
| F5 | CCMSCSA | 6.3391E+02 | 3.9365E+00 | 6.9981E+02 | 5.3818E+00 |
|  | CSA | 6.5907E+02 | 4.2644E+00 | 7.3957E+02 | 5.5838E+00 |
| F6 | CCMSCSA | 9.0004E+02 | 2.2269E+01 | 1.2109E+03 | 3.3687E+01 |
|  | CSA | 1.0809E+03 | 2.8681E+01 | 1.3980E+03 | 4.5179E+01 |
| F7 | CCMSCSA | 1.9785E+03 | 2.5732E+02 | 8.7977E+03 | 1.0286E+03 |
|  | CSA | 7.7797E+03 | 8.0010E+02 | 1.6743E+04 | 1.3860E+03 |
| F8 | CCMSCSA | 1.4003E+03 | 3.1190E-02 | 1.4004E+03 | 3.2193E-02 |
|  | CSA | 1.4003E+03 | 1.0396E-01 | 1.4004E+03 | 1.1784E-01 |
| F9 | CCMSCSA | 1.6194E+03 | 9.5156E-01 | 1.6429E+03 | 8.3230E-01 |
|  | CSA | 1.6214E+03 | 6.0354E-01 | 1.6441E+03 | 6.8592E-01 |
| F10 | CCMSCSA | 4.0138E+03 | 3.7287E+03 | 3.8395E+04 | 1.8968E+05 |
|  | CSA | 3.8827E+03 | 1.4280E+03 | 4.0826E+03 | 1.3667E+03 |
| F11 | CCMSCSA | 4.1802E+03 | 1.5361E+03 | 2.2670E+04 | 5.9986E+03 |
|  | CSA | 2.7331E+03 | 1.8214E+02 | 5.7054E+03 | 1.5332E+03 |
| F12 | CCMSCSA | 2.5000E+03 | 0.0000E+00 | 2.5000E+03 | 0.0000E+00 |
|  | CSA | 2.6527E+03 | 2.9364E+01 | 2.5412E+03 | 8.3660E+01 |
| F13 | CCMSCSA | 2.6000E+03 | 0.0000E+00 | 2.6000E+03 | 0.0000E+00 |
|  | CSA | 2.6629E+03 | 2.5094E+01 | 2.7154E+03 | 3.5940E+01 |
| F14 | CCMSCSA | 3.1000E+03 | 0.0000E+00 | 3.1000E+03 | 0.0000E+00 |
|  | CSA | 3.1272E+07 | 1.0601E+08 | 5.5773E+04 | 7.0182E+04 |
| F15 | CCMSCSA | 3.2000E+03 | 0.0000E+00 | 3.2000E+03 | 0.0000E+00 |
|  | CSA | 1.1493E+05 | 1.6329E+05 | 4.4007E+05 | 2.0071E+05 |

## FS Experimental Results and Analysis

**Table 7** Comparison results of CCMSCSA with other binary metaheuristic algorithms on fitness values

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Function** | **Metric** | **CCMSCSA** | **BGWO** | **BGSA** | **BALO** | **BBA** | **BSSA** |
| Breast cancer | Avg | 9.259E-02 | 9.767E-02 | 9.916E-02 | 9.160E-02 | 1.577E-01 | 9.359E-02 |
| Std | 7.963E-03 | 9.635E-03 | 1.078E-02 | 1.309E-02 | 1.423E-02 | 1.555E-02 |
| Heart | Avg | 6.370E-02 | 8.097E-02 | 7.662E-02 | 5.909E-02 | 1.349E-01 | 7.470E-02 |
| Std | 3.536E-02 | 4.177E-02 | 3.466E-02 | 2.245E-02 | 4.414E-02 | 3.590E-02 |
| Heart EW | Avg | 7.662E-02 | 8.801E-02 | 8.795E-02 | 8.366E-02 | 1.743E-01 | 8.328E-02 |
| Std | 2.238E-02 | 3.480E-02 | 1.766E-02 | 3.646E-02 | 4.783E-02 | 3.242E-02 |
| Lymphography | Avg | 1.806E-02 | 2.411E-02 | 2.382E-02 | 1.927E-02 | 6.903E-02 | 1.967E-02 |
| Std | 5.114E-03 | 2.607E-02 | 2.712E-02 | 1.945E-02 | 6.005E-02 | 2.279E-02 |
| Vote | Avg | 2.279E-02 | 2.298E-02 | 2.237E-02 | 1.742E-02 | 4.840E-02 | 1.977E-02 |
| Std | 1.621E-02 | 2.735E-02 | 2.496E-02 | 1.755E-02 | 3.973E-02 | 1.643E-02 |
| Australian | Avg | 9.259E-02 | 9.767E-02 | 9.916E-02 | 9.160E-02 | 1.577E-01 | 9.359E-02 |
| Std | 1.718E-02 | 2.580E-02 | 1.976E-02 | 1.883E-02 | 3.545E-02 | 1.686E-02 |
| Dermatology | Avg | 1.897E-02 | 9.706E-03 | 9.265E-03 | 9.559E-03 | 3.138E-02 | 1.603E-02 |
| Std | 2.812E-03 | 2.703E-03 | 1.211E-03 | 1.867E-03 | 1.390E-02 | 4.069E-03 |
| Glass | Avg | 1.225E-01 | 1.292E-01 | 1.351E-01 | 1.209E-01 | 1.696E-01 | 1.262E-01 |
| Std | 6.097E-02 | 5.247E-02 | 4.965E-02 | 3.794E-02 | 7.179E-02 | 5.034E-02 |
| JPN data | Avg | 3.754E-02 | 4.319E-02 | 3.944E-02 | 3.804E-02 | 7.321E-02 | 3.765E-02 |
| Std | 3.149E-02 | 4.903E-02 | 3.194E-02 | 3.901E-02 | 5.559E-02 | 4.057E-02 |
| Segment | Avg | 2.938E-02 | 2.464E-02 | 2.505E-02 | 2.423E-02 | 4.219E-02 | 2.880E-02 |
| Std | 3.752E-03 | 4.763E-03 | 7.624E-03 | 6.751E-03 | 9.606E-03 | 5.232E-03 |

**Table 8** Comparison results of CCMSCSA with other binary metaheuristic algorithms on the number of features selected

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Function** | **Metric** | **CCMSCSA** | **BGWO** | **BGSA** | **BALO** | **BBA** | **BSSA** |
| Breast cancer | Avg | 5.9 | 3.8 | 5.8 | 4.8 | 5.3 | 5.8 |
| Std | 0.4714 | 1.2517 | 1.075 | 0.56765 | 0.99443 | 1.2517 |
| Heart | Avg | 6.5 | 5.5 | 6.2 | 5.3 | 4.4 | 5.7 |
| Std | 0.84984 | 1.4337 | 1.4757 | 1.8288 | 1.1738 | 1.6364 |
| Heart EW | Avg | 6.2 | 5.5 | 6.4 | 6.2 | 6 | 6.1 |
| Std | 1.4757 | 1.354 | 2.0656 | 0.91894 | 1.2472 | 1.1005 |
| Lymphography | Avg | 6.5 | 4.1 | 4.3 | 4.8 | 8.4 | 4.8 |
| Std | 1.8409 | 1.1972 | 1.6364 | 1.5492 | 2.0656 | 2.044 |
| Vote | Avg | 5.3 | 3.3 | 3 | 2.6 | 6.7 | 4.3 |
| Std | 1.9465 | 1.3375 | 1.8856 | 1.2649 | 1.3375 | 2.4967 |
| Australian | Avg | 5.9 | 3.8 | 5.8 | 4.8 | 5.3 | 5.8 |
| Std | 1.6633 | 1.9889 | 1.6865 | 1.5492 | 1.6364 | 2.1499 |
| Dermatology | Avg | 12.9 | 6.6 | 6.3 | 6.5 | 15.2 | 10.9 |
| Std | 1.912 | 1.8379 | 0.82327 | 1.2693 | 1.6865 | 2.7669 |
| Glass | Avg | 4.3 | 4.2 | 4.3 | 4 | 4.1 | 4.4 |
| Std | 1.1595 | 1.2293 | 0.82327 | 0.66667 | 0.99443 | 0.96609 |
| JPN data | Avg | 2.6 | 2.7 | 2.9 | 2.7 | 4.8 | 2.7 |
| Std | 0.84327 | 0.94868 | 0.99443 | 1.4944 | 1.6193 | 0.67495 |
| Segment | Avg | 7.1 | 5.3 | 5.3 | 5.3 | 7.3 | 6.1 |
| Std | 1.5951 | 1.0593 | 1.1595 | 1.4944 | 1.767 | 1.6633 |

**Table 9** Comparison results of CCMSCSA with other binary metaheuristic algorithms on KNN error rate

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Function** | **Metric** | **CCMSCSA** | **BGWO** | **BGSA** | **BALO** | **BBA** | **BSSA** |
| Breast cancer | Avg | 7.528E-02 | 8.852E-02 | 8.257E-02 | 7.838E-02 | 2.423E-01 | 7.671E-02 |
| Std | 9.990E-03 | 1.313E-02 | 9.990E-03 | 1.513E-02 | 4.675E-02 | 1.842E-02 |
| Heart | Avg | 4.074E-02 | 6.296E-02 | 5.556E-02 | 4.074E-02 | 2.741E-01 | 5.556E-02 |
| Std | 3.683E-02 | 4.636E-02 | 3.599E-02 | 2.733E-02 | 1.554E-01 | 4.001E-02 |
| Heart EW | Avg | 5.556E-02 | 7.037E-02 | 6.667E-02 | 6.296E-02 | 2.963E-01 | 6.296E-02 |
| Std | 2.619E-02 | 4.076E-02 | 2.342E-02 | 3.924E-02 | 1.145E-01 | 3.514E-02 |
| Lymphography | Avg | 0.000E+00 | 1.339E-02 | 1.250E-02 | 6.250E-03 | 2.418E-01 | 6.667E-03 |
| Std | 0.000E+00 | 2.831E-02 | 2.635E-02 | 1.976E-02 | 2.159E-01 | 2.108E-02 |
| Vote | Avg | 6.559E-03 | 1.333E-02 | 1.368E-02 | 9.785E-03 | 1.054E-01 | 6.667E-03 |
| Std | 1.383E-02 | 2.811E-02 | 2.400E-02 | 1.576E-02 | 1.038E-01 | 1.406E-02 |
| Australian | Avg | 7.528E-02 | 8.852E-02 | 8.257E-02 | 7.838E-02 | 2.423E-01 | 7.671E-02 |
| Std | 2.217E-02 | 3.119E-02 | 2.241E-02 | 2.117E-02 | 8.542E-02 | 2.318E-02 |
| Dermatology | Avg | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 4.715E-02 | 0.000E+00 |
| Std | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 5.718E-02 | 0.000E+00 |
| Glass | Avg | 1.038E-01 | 1.115E-01 | 1.171E-01 | 1.038E-01 | 2.653E-01 | 1.071E-01 |
| Std | 6.467E-02 | 5.303E-02 | 5.450E-02 | 3.785E-02 | 1.475E-01 | 5.182E-02 |
| JPN data | Avg | 2.583E-02 | 3.125E-02 | 2.625E-02 | 2.583E-02 | 2.461E-01 | 2.542E-02 |
| Std | 3.338E-02 | 5.312E-02 | 3.391E-02 | 4.452E-02 | 1.647E-01 | 4.412E-02 |
| Segment | Avg | 1.126E-02 | 1.126E-02 | 1.169E-02 | 1.082E-02 | 5.584E-02 | 1.342E-02 |
| Std | 4.654E-03 | 3.651E-03 | 7.372E-03 | 6.534E-03 | 4.288E-02 | 4.764E-03 |