PAPER

Supplementary File for "Hierarchical Chaotic Wingsuit Flying Search Algorithm with Balanced Exploitation and Exploration for Optimization"

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In this file, we provide supplementary materials regarding the algorithm "A Four-layered Hierarchical Chaotic Wingsuit Flying Search" (MCWFS). Tables 2—4 give the results on 30 IEEE CEC2017 functions with 30, 50, and 100 dimensions. It consists of 30 functions, including uni-modal functions (F1-F3), multi-modal functions (F4-F10), hybrid functions (F11-F20), and composite functions (F21-F30). The experiment results on IEEE CEC2011 are given on Table 1.

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Table 1 Experimental results of MCWFS and other state-of-the-art competitors on 22 CEC2011 benchmark functions.

FUN	MCWFS	CWFS	WFS	CCWFSSE
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
G1	1.773E+01 ± 4.551E+00	1.850E+01 ± 4.776E+00 ≈	2.198E+01 ± 2.663E+00 +	**9.110E+00 ± 5.455E+00** −
G2	-1.907E+01 ± 3.378E+00	-1.929E+01 ± 3.320E+00 ≈	-1.156E+01 ± 2.351E+00 +	-1.232E+01 ± 2.586E+00 +
G3	1.151E-05 ± 2.249E-14	1.151E-05 ± 3.444E-14 ≈	1.151E-05 ± 1.006E-12 +	**1.151E-05 ± 6.966E-19** −
G4	**1.692E+01 ± 2.841E+00**	1.696E+01 ± 2.759E+00 ≈	1.694E+01 ± 2.831E+00 ≈	1.745E+01 ± 3.359E+00 ≈
G5	**-3.382E+01 ± 1.767E+00**	-3.375E+01 ± 1.862E+00 ≈	-2.953E+01 ± 3.209E+00 +	-2.984E+01 ± 2.935E+00 +
G6	**-2.422E+01 ± 3.023E+00**	-2.419E+01 ± 3.309E+00 ≈	-2.141E+01 ± 3.251E+00 +	-2.224E+01 ± 2.940E+00 +
G7	**6.830E-01 ± 1.007E-01**	6.968E-01 ± 1.136E-01 ≈	1.120E+00 ± 1.766E-01 +	1.114E+00 ± 1.668E-01 +
G8	2.272E+02 ± 9.827E+00	2.273E+02 ± 8.141E+00 ≈	2.426E+02 ± 1.190E+01 +	2.202E+02 ± 1.400E+00 −
G9	**1.574E+05 ± 5.913E+04**	2.166E+05 ± 7.427E+04 +	8.013E+05 ± 1.003E+05 +	1.770E+06 ± 1.388E+05 +
G10	**-1.913E+01 ± 2.427E+00**	-1.860E+01 ± 2.597E+00 ≈	-1.171E+01 ± 1.838E+00 +	-1.688E+01 ± 2.017E+00 +
G11	5.188E+04 ± 5.637E+02	5.211E+04 ± 5.812E+02 +	4.183E+05 ± 1.344E+05 +	1.598E+06 ± 1.723E+05 +
G12	2.248E+07 ± 4.894E+05	2.340E+07 ± 5.855E+05 +	2.494E+07 ± 4.744E+05 +	4.347E+07 ± 1.076E+06 +
G13	1.548E+04 ± 2.185E+01	1.548E+04 ± 2.060E+01 ≈	1.548E+04 ± 2.286E+01 ≈	**1.546E+04 ± 9.263E+00** −
G14	**1.907E+04 ± 1.206E+02**	1.913E+04 ± 1.215E+02 +	1.915E+04 ± 1.600E+02 +	1.913E+04 ± 1.879E+02 +
G15	**3.308E+04 ± 9.287E+01**	3.309E+04 ± 7.295E+01 ≈	3.755E+04 ± 1.728E+04 +	3.364E+04 ± 3.569E+03 +
G16	**1.336E+05 ± 2.883E+03**	1.362E+05 ± 2.861E+03 +	1.395E+05 ± 3.277E+03 +	1.408E+05 ± 4.971E+03 +
G17	**1.920E+06 ± 1.420E+04**	1.928E+06 ± 1.051E+04 +	1.948E+06 ± 9.147E+03 +	3.134E+08 ± 6.084E+08 +
G18	**9.434E+05 ± 2.552E+03**	9.451E+05 ± 2.483E+03 +	1.162E+06 ± 2.781E+05 +	3.295E+07 ± 7.989E+06 +
G19	**9.773E+05 ± 3.055E+04**	1.045E+06 ± 4.628E+04 +	1.903E+06 ± 7.896E+05 +	3.751E+07 ± 1.010E+07 +
G20	**9.436E+05 ± 2.544E+03**	9.450E+05 ± 2.595E+03 +	1.177E+06 ± 3.366E+05 +	3.286E+07 ± 7.478E+06 +
G21	**1.531E+01 ± 2.837E+00**	1.585E+01 ± 3.403E+00 ≈	2.175E+01 ± 3.832E+00 +	2.349E+01 ± 3.552E+00 +
G22	**2.010E+01 ± 3.349E+00**	2.139E+01 ± 3.721E+00 +	2.646E+01 ± 3.394E+00 +	3.470E+01 ± 5.386E+00 +
	+/ ≈ /−	10/12/0	20/2/0	17/1/4
	HGSA	GLPSO	IMODE	SIS
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
G1	1.417E+01 ± 6.503E+00 −	1.234E+01 ± 5.582E+00 −	2.479E+01 ± 3.729E+00 +	1.779E+01 ± 4.611E+00 ≈
G2	**-2.456E+01 ± 2.283E+00** −	-1.645E+01 ± 4.390E+00 +	-2.244E+00 ± 4.192E-01 +	-1.492E+01 ± 4.053E+00 +
G3	1.151E-05 ± 1.927E-12 +	1.151E-05 ± 7.394E-18 +	1.151E-05 ± 1.790E-11 +	1.151E-05 ± 3.838E-16 +
G4	1.752E+01 ± 1.377E+00 ≈	1.750E+01 ± 2.079E+00 ≈	2.165E+01 ± 8.897E-01 +	1.993E+01 ± 2.997E+00 +
G5	-3.301E+01 ± 2.108E+00 +	-2.517E+01 ± 2.629E+00 +	-1.197E+01 ± 1.428E+00 +	-3.222E+01 ± 3.366E+00 +
G6	-2.190E+01 ± 2.297E+00 +	-2.074E+01 ± 3.021E+00 +	1.175E+01 ± 2.834E+01 +	-1.358E+01 ± 1.220E+00 +
G7	7.128E-01 ± 1.318E-01 ≈	1.705E+00 ± 1.194E-01 +	2.471E+00 ± 2.533E-01 +	9.553E-01 ± 3.309E-01 +
G8	2.204E+02 ± 2.135E+00 −	**2.200E+02 ± 0.000E+00** −	2.184E+03 ± 9.807E+02 +	2.279E+02 ± 1.094E+01 ≈
G9	2.101E+05 ± 3.875E+04 +	1.331E+06 ± 7.222E+04 +	2.876E+06 ± 1.039E+05 +	1.702E+05 ± 5.916E+04 ≈
G10	-1.286E+01 ± 6.137E-01 +	-1.839E+01 ± 1.952E+00 +	-1.008E+01 ± 4.597E+00 +	-1.616E+01 ± 5.290E+00 +
G11	**5.120E+04 ± 4.833E+02** −	3.949E+05 ± 2.065E+05 +	2.649E+08 ± 2.422E+07 +	5.260E+04 ± 5.432E+02 +
G12	**2.050E+07 ± 1.768E+05** −	3.577E+07 ± 7.933E+05 +	5.584E+07 ± 9.539E+05 +	2.288E+07 ± 6.181E+05 +
G13	4.673E+04 ± 3.697E+04 +	1.547E+04 ± 1.610E+01 −	3.071E+04 ± 2.486E+04 +	1.547E+04 ± 1.934E+01 ≈
G14	1.914E+04 ± 1.348E+02 +	1.921E+04 ± 1.747E+02 +	1.928E+04 ± 1.156E+02 ≈	1.935E+04 ± 2.449E+02 +
G15	3.325E+04 ± 2.413E+01 +	3.312E+04 ± 9.556E+01 +	2.139E+05 ± 2.661E+05 +	3.359E+04 ± 3.315E+03 +
G16	1.430E+05 ± 2.014E+03 +	1.383E+05 ± 2.295E+03 +	4.623E+07 ± 1.419E+07 +	1.394E+05 ± 2.849E+03 +
G17	1.941E+06 ± 6.685E+03 +	2.028E+06 ± 8.295E+04 +	1.165E+10 ± 1.959E+09 +	2.030E+06 ± 1.757E+05 +
G18	9.436E+05 ± 1.688E+03 ≈	1.395E+07 ± 3.240E+06 +	1.225E+08 ± 9.029E+06 +	9.511E+05 ± 2.668E+04 +
G19	1.189E+06 ± 1.018E+05 +	1.570E+07 ± 3.952E+06 +	1.236E+08 ± 8.986E+06 +	1.132E+06 ± 1.016E+05 +
G20	9.438E+05 ± 1.906E+03 ≈	1.441E+07 ± 3.586E+06 +	1.225E+08 ± 9.029E+06 +	9.486E+05 ± 1.117E+04 +
G21	2.650E+01 ± 5.342E+00 +	1.919E+01 ± 3.866E+00 +	7.682E+01 ± 1.018E+01 +	1.856E+01 ± 3.691E+00 +
G22	3.740E+01 ± 5.824E+00 +	2.380E+01 ± 2.991E+00 +	6.927E+01 ± 9.479E+00 +	2.345E+01 ± 3.629E+00 +
	13/4/5	18/1/3	21/0/1	18/4/0

Table 2 Experimental results of MCWFS and other state-of-the-art competitors on 30 CEC2017 benchmark functions($D = 30$).

FUN	MCWFS	CWFS	WFS	CCWFSSE
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
F1	4.276E+03 ± 4.200E+03	4.194E+03 ± 4.692E+03 ≈	7.061E+08 ± 3.322E+08 +	1.697E+09 ± 9.678E+08 +
F2	1.016E+06 ± 4.190E+06	1.015E+08 ± 5.666E+08 +	3.638E+28 ± 1.613E+29 +	1.123E+27 ± 4.232E+27 +
F3	2.336E-01 ± 2.783E-01	6.862E-01 ± 1.087E+00 +	1.500E+04 ± 4.385E+03 +	1.939E+04 ± 6.346E+03 +
F4	8.043E+01 ± 2.464E+01	8.752E+01 ± 1.281E+01 ≈	2.454E+02 ± 5.224E+01 +	2.553E+02 ± 7.085E+01 +
F5	6.645E+01 ± 1.702E+01	**6.548E+01 ± 1.331E+01** ≈	1.447E+02 ± 2.978E+01 +	1.477E+02 ± 3.180E+01 +
F6	3.159E+00 ± 2.555E+00	2.736E+00 ± 1.957E+00 ≈	2.550E+01 ± 5.934E+00 +	2.380E+01 ± 6.219E+00 +
F7	9.825E+01 ± 1.457E+01	9.886E+01 ± 1.372E+01 ≈	2.344E+02 ± 3.747E+01 +	2.623E+02 ± 3.592E+01 +
F8	**6.307E+01 ± 1.348E+01**	6.348E+01 ± 1.344E+01 ≈	1.350E+02 ± 3.097E+01 +	1.408E+02 ± 3.450E+01 +
F9	9.448E+00 ± 9.583E+00	1.369E+01 ± 1.221E+01 +	1.769E+03 ± 1.126E+03 +	2.062E+03 ± 1.067E+03 +
F10	**2.371E+03 ± 4.400E+02**	2.417E+03 ± 3.761E+02 ≈	4.599E+03 ± 6.497E+02 +	4.422E+03 ± 6.962E+02 +
F11	**1.009E+02 ± 3.197E+01**	1.063E+02 ± 4.113E+01 ≈	3.211E+02 ± 6.943E+01 +	2.897E+02 ± 5.959E+01 +
F12	1.786E+05 ± 2.096E+05	1.156E+06 ± 1.153E+06 +	9.802E+07 ± 7.885E+07 +	5.959E+07 ± 3.995E+07 +
F13	2.015E+04 ± 1.241E+04	4.012E+04 ± 2.257E+04 +	7.474E+05 ± 8.142E+05 +	2.512E+06 ± 4.763E+06 +
F14	1.967E+02 ± 4.116E+01	1.325E+03 ± 1.951E+03 +	7.673E+03 ± 7.822E+03 +	1.463E+04 ± 1.234E+04 +
F15	6.704E+03 ± 5.253E+03	2.750E+04 ± 1.775E+04 +	1.553E+05 ± 1.581E+05 +	1.961E+05 ± 1.857E+05 +
F16	**4.530E+02 ± 1.733E+02**	5.046E+02 ± 1.677E+02 +	9.717E+02 ± 2.496E+02 +	8.847E+02 ± 2.671E+02 +
F17	**1.459E+02 ± 7.120E+01**	1.514E+02 ± 8.154E+01 ≈	3.222E+02 ± 1.068E+02 +	2.854E+02 ± 1.215E+02 +
F18	2.428E+04 ± 1.406E+04	7.159E+04 ± 3.975E+04 +	2.156E+05 ± 1.481E+05 +	3.582E+05 ± 3.680E+05 +
F19	7.107E+03 ± 1.163E+04	8.852E+04 ± 9.108E+04 +	1.104E+06 ± 1.130E+06 +	4.128E+05 ± 3.178E+05 +
F20	2.436E+02 ± 9.637E+01	2.470E+02 ± 8.115E+01 ≈	3.918E+02 ± 1.084E+02 +	3.507E+02 ± 1.316E+02 +
F21	2.597E+02 ± 1.314E+01	2.620E+02 ± 1.374E+01 ≈	3.332E+02 ± 2.850E+01 +	3.335E+02 ± 2.876E+01 +
F22	1.000E+02 ± 1.525E-02	1.000E+02 ± 4.060E-02 +	3.027E+02 ± 8.436E+01 +	3.888E+02 ± 1.181E+02 +
F23	4.157E+02 ± 1.555E+01	**4.113E+02 ± 1.536E+01** −	5.310E+02 ± 3.988E+01 +	5.035E+02 ± 3.233E+01 +
F24	4.735E+02 ± 1.452E+01	4.738E+02 ± 1.458E+01 ≈	5.791E+02 ± 3.661E+01 +	5.715E+02 ± 2.405E+01 +
F25	3.873E+02 ± 2.454E+00	3.871E+02 ± 2.262E+00 ≈	5.235E+02 ± 3.617E+01 +	5.290E+02 ± 4.507E+01 +
F26	1.476E+03 ± 4.442E+02	1.365E+03 ± 5.930E+02 ≈	2.537E+03 ± 7.018E+02 +	2.206E+03 ± 8.242E+02 +
F27	**5.180E+02 ± 1.354E+01**	5.218E+02 ± 1.440E+01 ≈	6.188E+02 ± 3.091E+01 +	5.269E+02 ± 3.616E+01 ≈
F28	3.614E+02 ± 4.767E+01	3.871E+02 ± 4.326E+01 +	6.325E+02 ± 7.868E+01 +	6.323E+02 ± 8.293E+01 +
F29	**5.965E+02 ± 7.869E+01**	6.539E+02 ± 9.960E+01 +	1.005E+03 ± 1.440E+02 +	8.018E+02 ± 1.651E+02 +
F30	1.346E+05 ± 1.151E+05	5.325E+05 ± 5.060E+05 +	6.895E+06 ± 5.630E+06 +	2.463E+06 ± 2.175E+06 +
	+/ ≈ /−	14/15/1	30/0/0	30/0/0
	HGSA	GLPSO	IMODE	SIS
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
F1	2.840E+03 ± 2.594E+03 ≈	1.021E+04 ± 4.648E+04 ≈	**9.104E-03 ± 1.751E-03** −	4.006E+03 ± 4.457E+03 ≈
F2	2.099E+06 ± 1.053E+07 −	1.296E+20 ± 9.254E+20 +	3.014E+01 ± 1.801E+02 −	**1.049E-04 ± 5.491E-05** −
F3	4.483E+04 ± 3.635E+03 +	2.444E+04 ± 2.347E+04 +	**1.920E-07 ± 5.003E-09** −	2.973E+03 ± 1.693E+04 −
F4	1.191E+02 ± 2.162E+00 +	5.113E+02 ± 2.489E+01 +	**1.146E+01 ± 2.175E+01** −	7.895E+01 ± 3.875E+01 +
F5	1.512E+02 ± 1.378E+01 +	5.660E+02 ± 1.923E+01 +	9.258E+01 ± 2.002E+01 +	1.000E+02 ± 2.696E+01 +
F6	8.907E+00 ± 5.917E+00 +	6.002E+02 ± 8.388E-02 +	9.787E+00 ± 2.669E+00 +	**2.548E+00 ± 2.507E+00** −
F7	**4.026E+01 ± 2.373E+00** −	8.244E+02 ± 2.205E+01 +	1.580E+02 ± 2.741E+01 +	1.374E+02 ± 2.497E+01 +
F8	1.042E+02 ± 8.634E+00 +	8.700E+02 ± 1.622E+01 +	9.049E+01 ± 1.327E+01 +	9.834E+01 ± 2.217E+01 +
F9	**0.000E+00 ± 0.000E+00** −	1.294E+03 ± 3.297E+02 +	1.078E+03 ± 3.404E+02 +	2.761E+01 ± 6.264E+01 +
F10	3.183E+03 ± 4.953E+02 +	3.479E+03 ± 4.621E+02 +	2.589E+03 ± 4.650E+02 +	3.249E+03 ± 6.333E+02 +
F11	9.613E+01 ± 2.995E+01 ≈	1.556E+03 ± 5.338E+02 +	1.320E+02 ± 4.943E+01 +	1.462E+02 ± 5.379E+01 +
F12	1.352E+05 ± 7.134E+04 ≈	2.435E+06 ± 2.049E+06 +	**1.224E+03 ± 3.897E+02** −	7.465E+05 ± 7.161E+05 +
F13	**1.246E+04 ± 5.262E+03** −	2.306E+04 ± 4.393E+04 −	2.449E+02 ± 1.043E+02 −	8.048E+04 ± 5.943E+04 +
F14	7.247E+03 ± 5.060E+03 +	1.526E+05 ± 3.494E+05 +	**1.373E+02 ± 4.446E+01** −	4.630E+03 ± 4.918E+03 +
F15	7.404E+02 ± 5.807E+02 −	4.771E+03 ± 4.049E+03 −	**1.098E+02 ± 4.257E+01** −	4.189E+06 ± 2.952E+07 +
F16	1.153E+03 ± 1.854E+02 +	2.632E+03 ± 2.853E+02 +	6.631E+02 ± 2.031E+02 +	7.098E+02 ± 2.971E+02 +
F17	1.044E+03 ± 1.917E+02 +	2.125E+03 ± 2.061E+02 +	1.901E+02 ± 8.919E+01 +	2.344E+02 ± 1.084E+02 +
F18	6.117E+04 ± 1.949E+04 +	7.314E+05 ± 1.344E+06 +	**8.212E+01 ± 2.599E+01** −	1.444E+05 ± 9.140E+04 +
F19	2.867E+03 ± 1.178E+03 ≈	8.744E+03 ± 7.691E+03 +	**2.208E+02 ± 7.484E+01** −	1.307E+05 ± 6.491E+04 +
F20	9.078E+02 ± 1.924E+02 +	2.414E+03 ± 1.702E+02 +	**1.354E+02 ± 7.375E+01** −	4.455E+02 ± 1.828E+02 +
F21	3.209E+02 ± 3.573E+01 +	2.374E+03 ± 1.868E+01 +	**1.012E+02 ± 1.717E+00** −	2.948E+02 ± 2.174E+01 +
F22	1.911E+02 ± 6.503E+02 −	3.061E+03 ± 1.399E+03 +	4.556E+02 ± 2.966E+01 +	**1.004E+02 ± 1.014E+00** −
F23	4.731E+02 ± 1.288E+02 +	2.729E+03 ± 2.025E+01 +	5.735E+02 ± 9.761E+01 +	4.431E+02 ± 2.524E+01 +
F24	5.182E+02 ± 3.940E+01 +	2.918E+03 ± 2.833E+01 +	**7.249E+01 ± 2.508E+01** −	5.074E+02 ± 2.449E+01 +
F25	3.917E+02 ± 8.681E+00 +	2.897E+03 ± 1.353E+01 +	3.914E+02 ± 1.343E+01 +	**3.875E+02 ± 5.082E+00** −
F26	**2.529E+02 ± 5.041E+01** −	4.688E+03 ± 2.828E+02 +	2.843E+02 ± 3.673E+01 −	1.659E+03 ± 6.587E+02 +
F27	5.552E+02 ± 2.297E+01 +	3.240E+03 ± 1.425E+01 +	5.466E+02 ± 1.178E+01 +	5.199E+02 ± 1.646E+01 ≈
F28	**3.097E+02 ± 2.705E+01** −	3.232E+03 ± 3.025E+01 +	3.299E+02 ± 5.577E+01 −	3.553E+02 ± 5.973E+01 −
F29	1.197E+03 ± 2.137E+02 +	3.780E+03 ± 2.189E+02 +	6.863E+02 ± 9.191E+01 +	7.706E+02 ± 1.609E+02 +
F30	7.428E+03 ± 1.724E+03 −	5.818E+04 ± 4.673E+04 −	**3.213E+03 ± 7.184E+02** −	5.221E+05 ± 3.810E+05 +
	17/4/9	26/1/3	14/0/16	27/1/2

Table 3 Experimental results of MCWFS and other state-of-the-art competitors on 30 CEC2017 benchmark functions($D = 50$).

FUN	MCWFS	CWFS	WFS	CCWFSSE
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
F1	7.205E+03 ± 6.452E+03	8.669E+03 ± 7.373E+03 ≈	1.672E+09 ± 5.857E+08 +	1.942E+10 ± 5.136E+09 +
F2	1.042E+13 ± 5.386E+13	2.150E+16 ± 7.511E+16 +	1.000E+30 ± 2.843E+14 +	1.312E+56 ± 8.683E+56 +
F3	6.751E+00 ± 2.415E+00	4.125E+01 ± 3.341E+01 +	3.396E+04 ± 5.752E+03 +	9.037E+04 ± 2.249E+04 +
F4	1.223E+02 ± 4.548E+01	1.254E+02 ± 4.691E+01 ≈	4.725E+02 ± 1.192E+02 +	1.754E+03 ± 7.056E+02 +
F5	**1.359E+02 ± 2.768E+01**	1.370E+02 ± 2.619E+01 ≈	2.754E+02 ± 4.782E+01 +	3.918E+02 ± 5.646E+01 +
F6	**1.002E+01 ± 4.584E+00**	1.177E+01 ± 4.660E+00 +	3.170E+01 ± 8.117E+00 +	4.741E+01 ± 8.644E+00 +
F7	2.039E+02 ± 3.239E+01	2.005E+02 ± 2.800E+01 ≈	4.310E+02 ± 6.070E+01 +	6.105E+02 ± 5.956E+01 +
F8	**1.313E+02 ± 2.112E+01**	1.372E+02 ± 1.930E+01 +	2.727E+02 ± 4.181E+01 +	3.998E+02 ± 5.991E+01 +
F9	9.700E+02 ± 9.093E+02	1.482E+03 ± 1.698E+03 ≈	7.835E+03 ± 4.195E+03 +	1.756E+04 ± 4.961E+03 +
F10	**4.212E+03 ± 6.525E+02**	4.334E+03 ± 5.383E+02 ≈	8.582E+03 ± 1.036E+03 +	9.398E+03 ± 1.141E+03 +
F11	1.777E+02 ± 4.343E+01	1.930E+02 ± 4.615E+01 +	6.736E+02 ± 1.194E+02 +	1.626E+03 ± 5.505E+02 +
F12	1.825E+06 ± 1.263E+06	6.919E+06 ± 3.808E+06 +	3.315E+08 ± 1.775E+08 +	7.324E+08 ± 5.045E+08 +
F13	3.598E+04 ± 1.595E+04	5.887E+04 ± 2.707E+04 +	3.384E+06 ± 3.226E+06 +	2.071E+07 ± 3.420E+07 +
F14	6.352E+02 ± 3.988E+02	7.476E+03 ± 7.940E+03 +	1.115E+05 ± 9.378E+04 +	1.712E+05 ± 1.228E+05 +
F15	1.116E+04 ± 6.935E+03	2.497E+04 ± 1.375E+04 +	9.225E+05 ± 1.021E+06 +	7.547E+06 ± 1.023E+07 +
F16	**7.773E+02 ± 1.845E+02**	7.741E+02 ± 1.964E+02 ≈	1.793E+03 ± 4.811E+02 +	1.778E+03 ± 4.387E+02 +
F17	**6.670E+02 ± 1.544E+02**	6.738E+02 ± 1.624E+02 ≈	1.285E+03 ± 2.466E+02 +	1.568E+03 ± 3.121E+02 +
F18	5.694E+04 ± 2.707E+04	1.061E+05 ± 4.855E+04 +	1.601E+06 ± 9.382E+05 +	2.081E+06 ± 1.858E+06 +
F19	1.878E+04 ± 1.938E+04	1.155E+05 ± 1.312E+05 +	1.954E+06 ± 1.403E+06 +	8.660E+06 ± 6.988E+06 +
F20	**5.289E+02 ± 1.657E+02**	5.441E+02 ± 1.425E+02 ≈	9.669E+02 ± 2.346E+02 +	1.062E+03 ± 3.004E+02 +
F21	**3.270E+02 ± 2.243E+01**	3.285E+02 ± 2.300E+01 ≈	4.730E+02 ± 4.939E+01 +	5.669E+02 ± 6.852E+01 +
F22	3.798E+03 ± 1.929E+03	4.398E+03 ± 1.578E+03 +	8.180E+03 ± 2.080E+03 +	8.978E+03 ± 1.800E+03 +
F23	5.698E+02 ± 3.489E+01	**5.638E+02 ± 3.345E+01** ≈	8.064E+02 ± 6.412E+01 +	9.066E+02 ± 6.912E+01 +
F24	**6.266E+02 ± 2.781E+01**	6.393E+02 ± 2.831E+01 +	8.493E+02 ± 7.058E+01 +	9.807E+02 ± 7.553E+01 +
F25	5.056E+02 ± 2.809E+01	5.088E+02 ± 2.813E+01 ≈	9.038E+02 ± 9.022E+01 +	2.292E+03 ± 5.480E+02 +
F26	2.619E+03 ± 4.509E+02	2.560E+03 ± 4.872E+02 ≈	4.742E+03 ± 5.017E+02 +	5.946E+03 ± 9.692E+02 +
F27	**6.206E+02 ± 5.209E+01**	6.284E+02 ± 4.279E+01 ≈	1.069E+03 ± 1.120E+02 +	1.068E+03 ± 1.051E+02 +
F28	**4.695E+02 ± 1.786E+01**	4.769E+02 ± 2.196E+01 +	1.260E+03 ± 3.099E+02 +	2.366E+03 ± 8.532E+02 +
F29	**9.624E+02 ± 2.068E+02**	9.637E+02 ± 1.787E+02 ≈	1.981E+03 ± 3.938E+02 +	2.108E+03 ± 4.416E+02 +
F30	1.219E+07 ± 3.024E+06	2.138E+07 ± 5.050E+06 +	1.995E+08 ± 3.754E+07 +	1.360E+08 ± 4.529E+07 +
	+/ ≈ /−	15/15/0	30/0/0	29/1/0
	HGSA	GLPSO	IMODE	SIS
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
F1	7.945E+02 ± 1.126E+03 −	6.138E+06 ± 4.045E+07 −	**1.582E-02 ± 1.369E-03** −	8.183E+03 ± 9.204E+03 ≈
F2	**2.450E+10 ± 1.017E+11** −	7.731E+52 ± 5.483E+53 +	7.030E+31 ± 4.278E+32 +	1.621E+11 ± 9.369E+11 −
F3	1.180E+05 ± 9.609E+03 +	7.827E+04 ± 1.101E+04 +	9.578E-07 ± 4.812E-08 −	**5.334E+02 ± 3.616E+03** −
F4	1.958E+02 ± 4.010E+01 +	8.643E+02 ± 2.489E+02 +	**3.217E+01 ± 4.497E+01** −	1.495E+02 ± 5.303E+01 +
F5	2.676E+02 ± 2.086E+01 +	3.566E+02 ± 4.186E+01 +	2.860E+02 ± 3.159E+01 +	2.105E+02 ± 3.573E+01 +
F6	2.362E+01 ± 4.438E+00 +	1.472E+01 ± 2.961E+00 +	3.473E+01 ± 5.506E+00 +	1.333E+01 ± 6.169E+00 +
F7	**7.097E+01 ± 4.077E+00** −	3.677E+02 ± 8.170E+01 +	5.130E+02 ± 8.630E+01 +	2.922E+02 ± 5.105E+01 +
F8	2.918E+02 ± 1.598E+01 +	3.620E+02 ± 3.855E+01 +	2.975E+02 ± 3.953E+01 +	2.078E+02 ± 4.089E+01 +
F9	**1.133E+01 ± 8.092E+01** −	1.488E+03 ± 1.104E+03 +	8.924E+03 ± 1.547E+03 +	1.200E+03 ± 1.265E+03 ≈
F10	5.747E+03 ± 5.409E+02 +	1.231E+04 ± 4.412E+02 +	5.237E+03 ± 8.165E+02 +	5.759E+03 ± 9.321E+02 +
F11	**1.262E+02 ± 1.365E+01** −	7.270E+02 ± 6.007E+02 +	2.316E+02 ± 6.981E+01 +	2.178E+02 ± 5.622E+01 +
F12	8.335E+05 ± 3.786E+05 −	1.251E+08 ± 3.145E+08 +	**1.945E+03 ± 4.818E+02** −	4.103E+06 ± 2.433E+06 +
F13	5.693E+02 ± 6.422E+02 −	2.880E+06 ± 1.276E+07 −	**4.710E+02 ± 1.460E+02** −	9.495E+04 ± 5.083E+04 +
F14	2.290E+04 ± 1.295E+04 +	2.809E+05 ± 4.382E+05 +	**2.460E+02 ± 6.591E+01** −	2.314E+04 ± 2.189E+04 +
F15	7.845E+03 ± 1.809E+03 −	6.184E+03 ± 6.436E+03 −	**3.103E+02 ± 8.744E+01** −	4.429E+04 ± 2.259E+04 +
F16	1.828E+03 ± 3.078E+02 +	2.785E+03 ± 4.031E+02 +	1.574E+03 ± 4.701E+02 +	1.205E+03 ± 3.327E+02 +
F17	1.670E+03 ± 3.126E+02 +	1.505E+03 ± 2.726E+02 +	1.473E+03 ± 2.667E+02 +	1.055E+03 ± 2.801E+02 +
F18	1.815E+05 ± 6.846E+04 +	3.868E+06 ± 4.309E+06 +	**1.847E+02 ± 6.384E+01** −	1.761E+05 ± 1.180E+05 +
F19	1.423E+04 ± 3.369E+03 ≈	6.479E+04 ± 3.813E+05 −	**1.575E+02 ± 1.079E+02** −	1.615E+05 ± 6.041E+04 +
F20	1.315E+03 ± 3.138E+02 +	1.313E+03 ± 3.192E+02 +	9.405E+02 ± 1.953E+02 +	9.206E+02 ± 2.736E+02 +
F21	4.561E+02 ± 2.685E+01 +	5.756E+02 ± 2.577E+01 +	4.955E+02 ± 4.050E+01 +	3.976E+02 ± 3.886E+01 +
F22	7.902E+03 ± 5.240E+02 +	1.122E+04 ± 3.842E+03 +	3.181E+03 ± 2.542E+03 ≈	**2.615E+03 ± 3.111E+03** −
F23	1.071E+03 ± 1.984E+02 +	9.861E+02 ± 4.881E+01 +	8.985E+02 ± 8.012E+01 +	6.345E+02 ± 4.494E+01 +
F24	8.866E+02 ± 4.943E+01 +	1.055E+03 ± 4.607E+01 +	1.109E+03 ± 9.811E+01 +	6.835E+02 ± 4.188E+01 +
F25	5.813E+02 ± 1.508E+01 +	9.207E+02 ± 1.121E+02 +	5.253E+02 ± 3.955E+01 +	5.290E+02 ± 3.078E+01 +
F26	**3.000E+02 ± 7.309E-13** −	5.958E+03 ± 6.938E+02 +	4.199E+03 ± 2.184E+03 +	3.165E+03 ± 6.271E+02 +
F27	1.401E+03 ± 2.816E+02 +	1.419E+03 ± 1.126E+02 +	1.113E+03 ± 1.038E+02 +	6.357E+02 ± 4.946E+01 +
F28	5.023E+02 ± 2.131E+01 +	1.207E+03 ± 2.199E+02 +	4.866E+02 ± 2.083E+01 +	4.809E+02 ± 2.401E+01 +
F29	1.706E+03 ± 2.733E+02 +	2.037E+03 ± 4.919E+02 +	1.967E+03 ± 3.468E+02 +	1.260E+03 ± 2.851E+02 +
F30	1.340E+06 ± 9.704E+04 −	1.236E+07 ± 6.858E+06 ≈	**6.001E+05 ± 3.584E+04** −	1.990E+07 ± 5.743E+06 +
	19/1/10	25/1/4	19/1/10	25/2/3

Table 4 Experimental results of MCWFS and other state-of-the-art competitors on 30 CEC2017 benchmark functions($D = 100$).

FUN	MCWFS	CWFS	WFS	CCWFSSE
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
F1	9.079E+04 ± 3.076E+04	3.520E+05 ± 1.236E+05 +	3.904E+09 ± 1.440E+09 +	1.002E+11 ± 1.541E+10 +
F2	9.912E+29 ± 6.301E+28	1.000E+30 ± 2.843E+14 ≈	1.000E+30 ± 2.843E+14 ≈	2.172E+134 ± 9.319E+134 +
F3	4.310E+02 ± 2.126E+02	8.376E+03 ± 5.342E+03 +	1.118E+05 ± 1.208E+04 +	3.196E+05 ± 4.439E+04 +
F4	2.744E+02 ± 4.414E+01	2.777E+02 ± 5.115E+01 ≈	8.701E+02 ± 1.063E+02 +	1.470E+04 ± 3.758E+03 +
F5	**4.220E+02 ± 6.341E+01**	4.233E+02 ± 5.457E+01 ≈	5.664E+02 ± 8.519E+01 +	1.118E+03 ± 1.568E+02 +
F6	3.158E+01 ± 6.911E+00	3.229E+01 ± 5.655E+00 ≈	**2.766E+01 ± 7.590E+00** −	7.418E+01 ± 6.454E+00 +
F7	6.018E+02 ± 7.489E+01	6.307E+02 ± 6.311E+01 +	1.191E+03 ± 1.388E+02 +	1.885E+03 ± 1.190E+02 +
F8	**4.317E+02 ± 4.378E+01**	4.320E+02 ± 5.088E+01 ≈	5.921E+02 ± 9.029E+01 +	1.148E+03 ± 1.311E+02 +
F9	1.439E+04 ± 4.346E+03	1.499E+04 ± 3.903E+03 ≈	**1.137E+04 ± 4.462E+03** −	5.917E+04 ± 1.150E+04 +
F10	**1.085E+04 ± 1.209E+03**	1.088E+04 ± 1.049E+03 ≈	1.926E+04 ± 1.661E+03 +	2.345E+04 ± 1.935E+03 +
F11	**1.097E+03 ± 1.496E+02**	1.369E+03 ± 2.231E+02 +	4.568E+03 ± 7.797E+02 +	5.075E+04 ± 1.548E+04 +
F12	5.396E+06 ± 2.719E+06	3.556E+07 ± 1.635E+07 +	1.296E+09 ± 2.863E+08 +	1.489E+10 ± 5.978E+09 +
F13	3.290E+04 ± 1.222E+04	4.294E+04 ± 1.487E+04 +	7.821E+06 ± 4.666E+06 +	3.910E+08 ± 3.305E+08 +
F14	1.553E+04 ± 1.106E+04	1.020E+05 ± 5.229E+04 +	2.035E+06 ± 8.195E+05 +	4.016E+06 ± 2.171E+06 +
F15	2.122E+04 ± 9.397E+03	3.683E+04 ± 1.153E+04 +	1.915E+06 ± 1.674E+06 +	2.630E+07 ± 3.875E+07 +
F16	**2.215E+03 ± 5.415E+02**	2.300E+03 ± 5.128E+02 ≈	4.491E+03 ± 5.926E+02 +	5.969E+03 ± 7.565E+02 +
F17	**1.678E+03 ± 2.978E+02**	1.706E+03 ± 2.870E+02 ≈	2.907E+03 ± 4.913E+02 +	3.923E+03 ± 4.686E+02 +
F18	9.682E+04 ± 2.948E+04	2.764E+05 ± 9.560E+04 +	2.467E+06 ± 1.219E+06 +	6.512E+06 ± 3.903E+06 +
F19	3.636E+04 ± 2.885E+04	3.162E+05 ± 2.461E+05 +	6.476E+06 ± 3.870E+06 +	6.217E+07 ± 4.405E+07 +
F20	**1.672E+03 ± 3.059E+02**	1.693E+03 ± 3.065E+02 ≈	2.899E+03 ± 4.790E+02 +	3.573E+03 ± 7.335E+02 +
F21	**6.718E+02 ± 5.199E+01**	6.753E+02 ± 4.953E+01 ≈	8.649E+02 ± 9.716E+01 +	1.376E+03 ± 1.292E+02 +
F22	**1.241E+04 ± 2.144E+03**	1.250E+04 ± 1.418E+03 ≈	2.067E+04 ± 1.341E+03 +	2.400E+04 ± 1.940E+03 +
F23	**1.042E+03 ± 6.883E+01**	1.055E+03 ± 7.595E+01 ≈	1.500E+03 ± 1.437E+02 +	2.034E+03 ± 1.810E+02 +
F24	1.408E+03 ± 1.027E+02	1.398E+03 ± 1.001E+02 ≈	2.000E+03 ± 1.707E+02 +	3.258E+03 ± 3.051E+02 +
F25	7.644E+02 ± 6.390E+01	7.876E+02 ± 7.420E+01 +	1.672E+03 ± 1.093E+02 +	7.339E+03 ± 1.146E+03 +
F26	7.710E+03 ± 1.332E+03	7.848E+03 ± 7.649E+02 ≈	1.096E+04 ± 1.097E+03 +	2.212E+04 ± 2.042E+03 +
F27	7.840E+02 ± 7.186E+01	**7.727E+02 ± 6.977E+01** ≈	1.421E+03 ± 1.312E+02 +	2.029E+03 ± 2.089E+02 +
F28	5.889E+02 ± 3.752E+01	6.167E+02 ± 4.565E+01 +	2.151E+03 ± 3.566E+02 +	1.223E+04 ± 1.708E+03 +
F29	**3.126E+03 ± 3.699E+02**	3.250E+03 ± 4.345E+02 ≈	5.322E+03 ± 6.490E+02 +	7.943E+03 ± 1.342E+03 +
F30	1.385E+06 ± 6.549E+05	8.467E+06 ± 3.451E+06 +	2.988E+08 ± 7.818E+07 +	6.956E+08 ± 3.184E+08 +
	+/ ≈ /−	13/17/0	27/1/2	30/0/0
	HGSA	GLPSO	IMODE	SIS
	ERROR ± STD	ERROR ± STD	ERROR ± STD	ERROR ± STD
F1	3.707E+03 ± 3.211E+03 −	9.755E+04 ± 1.848E+05 +	**1.191E+03 ± 6.482E+03** −	1.480E+04 ± 1.630E+04 −
F2	1.945E+45 ± 1.373E+46 +	1.611E+77 ± 1.151E+78 +	1.457E+149 ± 7.035E+149 +	**3.816E+12 ± 2.228E+13** −
F3	2.744E+05 ± 1.552E+04 +	1.492E+05 ± 4.428E+04 +	**7.044E-05 ± 1.808E-06** −	8.880E+03 ± 1.727E+04 +
F4	2.736E+02 ± 3.846E+01 ≈	3.081E+02 ± 5.051E+01 +	**9.713E+01 ± 9.964E+01** −	2.660E+02 ± 3.578E+01 ≈
F5	7.287E+02 ± 3.137E+01 +	4.946E+02 ± 6.658E+01 +	1.020E+03 ± 6.795E+01 +	5.378E+02 ± 7.798E+01 +
F6	3.113E+01 ± 2.947E+00 ≈	1.438E+02 ± 3.827E+02 +	6.204E+01 ± 3.806E+00 +	3.981E+01 ± 5.921E+00 +
F7	**1.518E+02 ± 8.209E+00** −	7.417E+02 ± 8.550E+01 +	2.224E+03 ± 3.693E+02 +	7.612E+02 ± 1.023E+02 +
F8	7.954E+02 ± 3.085E+01 +	4.766E+02 ± 5.894E+01 +	1.091E+03 ± 8.806E+01 +	5.472E+02 ± 6.862E+01 +
F9	2.081E+03 ± 7.172E+02 −	8.940E+04 ± 3.517E+03 +	3.208E+04 ± 3.575E+03 +	1.821E+04 ± 4.802E+03 +
F10	1.225E+04 ± 8.714E+02 +	1.119E+04 ± 1.167E+03 +	1.215E+04 ± 1.112E+03 +	1.251E+04 ± 1.204E+03 +
F11	4.394E+03 ± 1.405E+03 +	3.231E+04 ± 1.353E+04 +	1.314E+03 ± 2.440E+02 +	1.274E+03 ± 2.290E+02 +
F12	1.329E+06 ± 4.346E+05 −	3.595E+07 ± 1.746E+07 +	**7.326E+05 ± 5.202E+06** −	9.407E+06 ± 5.109E+06 +
F13	3.031E+03 ± 2.063E+03 −	2.420E+04 ± 1.928E+04 −	**6.909E+02 ± 1.708E+02** −	6.211E+04 ± 2.374E+04 +
F14	2.037E+05 ± 3.621E+04 +	3.769E+06 ± 3.642E+06 +	**5.123E+02 ± 1.019E+02** −	8.382E+04 ± 4.756E+04 +
F15	8.601E+02 ± 6.547E+02 −	5.793E+04 ± 4.997E+03 +	**2.775E+02 ± 6.783E+01** −	5.064E+04 ± 1.976E+04 +
F16	4.904E+03 ± 5.010E+02 +	4.085E+03 ± 7.461E+02 +	4.390E+03 ± 9.865E+02 +	3.092E+03 ± 5.939E+02 +
F17	3.203E+03 ± 3.943E+02 +	3.391E+03 ± 4.840E+02 +	4.026E+03 ± 5.945E+02 +	2.297E+03 ± 4.945E+02 +
F18	2.813E+05 ± 5.077E+04 +	4.552E+06 ± 4.224E+06 +	**2.739E+02 ± 7.621E+01** −	2.365E+05 ± 7.763E+04 +
F19	1.226E+03 ± 9.443E+02 −	5.520E+04 ± 5.474E+03 +	**7.536E+02 ± 9.661E+02** −	3.784E+05 ± 1.087E+05 +
F20	3.891E+03 ± 3.827E+02 +	2.877E+03 ± 5.376E+02 +	2.990E+03 ± 4.537E+02 +	2.659E+03 ± 5.464E+02 +
F21	9.193E+02 ± 4.243E+01 +	6.739E+02 ± 5.677E+01 +	1.412E+03 ± 1.034E+02 +	7.639E+02 ± 9.062E+01 +
F22	1.694E+04 ± 8.212E+02 +	1.252E+04 ± 1.109E+03 +	1.370E+04 ± 1.268E+03 +	1.365E+04 ± 3.627E+03 +
F23	3.091E+03 ± 2.906E+02 +	2.129E+03 ± 4.525E+01 +	2.005E+03 ± 1.524E+02 +	1.182E+03 ± 9.514E+01 +
F24	**1.264E+03 ± 7.487E+01** −	1.475E+03 ± 6.757E+01 +	2.602E+03 ± 3.364E+02 +	1.447E+03 ± 8.889E+01 +
F25	8.390E+02 ± 5.914E+01 +	8.454E+02 ± 5.749E+01 +	**7.159E+02 ± 4.740E+01** −	7.855E+02 ± 7.441E+01 +
F26	**5.524E+02 ± 1.803E+03** −	8.555E+03 ± 5.981E+02 +	1.295E+04 ± 2.007E+03 +	8.871E+03 ± 9.829E+02 +
F27	1.453E+03 ± 2.107E+02 +	8.547E+02 ± 5.908E+01 +	1.610E+03 ± 2.545E+02 +	8.012E+02 ± 5.647E+01 +
F28	6.247E+02 ± 2.500E+01 +	6.658E+02 ± 4.056E+01 +	**4.962E+02 ± 8.375E+01** −	6.211E+02 ± 5.294E+01 +
F29	4.462E+03 ± 3.878E+02 +	3.396E+03 ± 5.700E+02 +	4.714E+03 ± 6.889E+02 +	3.541E+03 ± 5.921E+02 +
F30	**9.267E+03 ± 2.152E+03** −	1.418E+06 ± 9.161E+04 +	9.596E+03 ± 6.335E+03 −	2.421E+06 ± 1.030E+06 +
	18/2/10	29/0/1	18/0/12	27/1/2