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Improved dynamic grey wolf optimizer

Key words: Swarm intelligence; Grey wolf optimizer; Dynamic grey wolf optimizer; Optimization experiment

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Part 1

Standard grey wolf optimizer (GWO)

1.1 Algorithm model

A pyramid model of four levels is proposed to simulate the hunting behavior of the grey wolf (Fig. 1), where wolf α is the highest leader, wolf β is second only to wolf α, and wolf δ is second to wolf β. Wolf ω is the lowest-ranking wolf in the grey wolf optimizer (GWO), often referred to as the search wolf, and the hunting behavior is done mainly by wolf ω in GWO. The schematics of encircling behavior, attacking prey, and searching for prey are shown in Figs. 2-4.

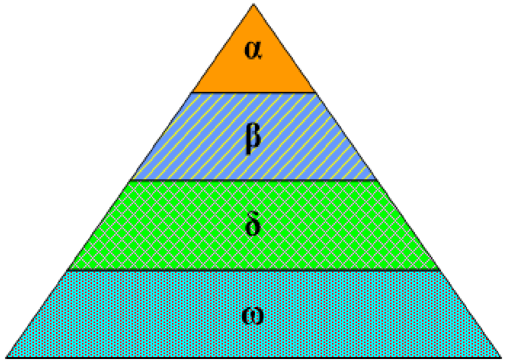

Fig. 1 Pyramid model of four levels

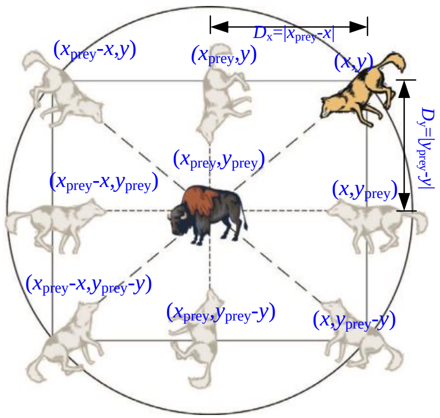

Fig. 2 Schematic of 2D encircling behavior

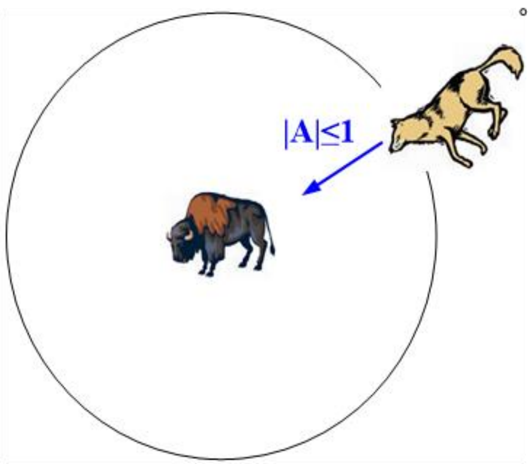

Fig. 3 Attacking prey

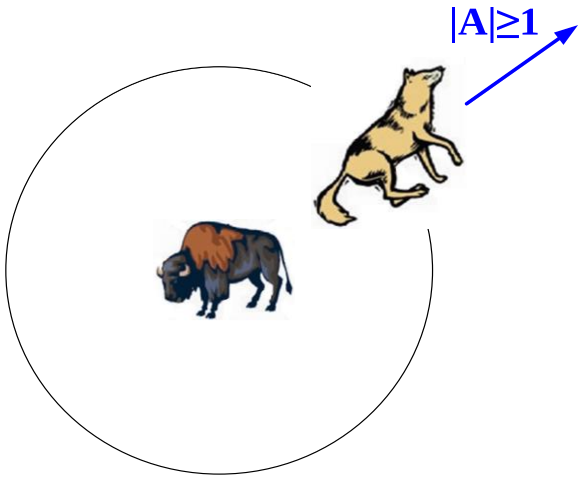

Fig. 4 Searching for prey

1.2 Static grey wolf optimizer

- The position of the search wolf is updated as follows:

$$D_\alpha = |C_1 \cdot X_\alpha - X(t)|$$

$$D_\beta = |C_2 \cdot X_\beta - X(t)|$$

$$D_\delta = |C_3 \cdot X_\delta - X(t)|$$

$$X_1(t+1) = X_\alpha - A_1 \cdot D_\alpha$$

$$X_2(t+1) = X_\beta - A_2 \cdot D_\beta$$

$$X_3(t+1) = X_\delta - A_3 \cdot D_\delta$$

$$X(t+1) = \frac{X_1(t+1) + X_2(t+1) + X_3(t+1)}{3}$$

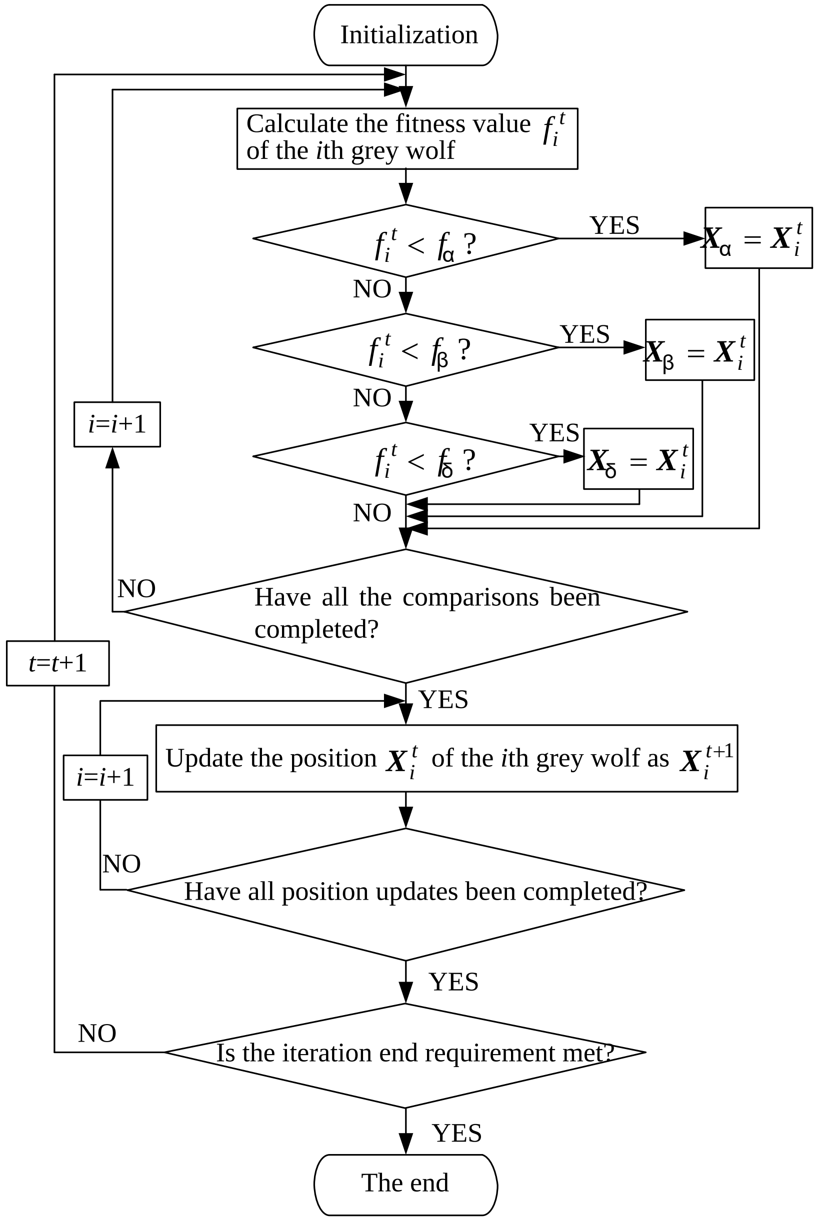

Fig. 5 Flow chart of the static GWO

Part 2

Dynamic GWO

2.1 First dynamic GWO

The features of DGWO1 are as follows:

(1) The position updating of each search wolf does not need to wait for other search wolves.

(2) $\boldsymbol{X}_{\alpha}$, $\boldsymbol{X}_{\beta}$, and $\boldsymbol{X}_{\delta}$ may be different for each search wolf in position updating.

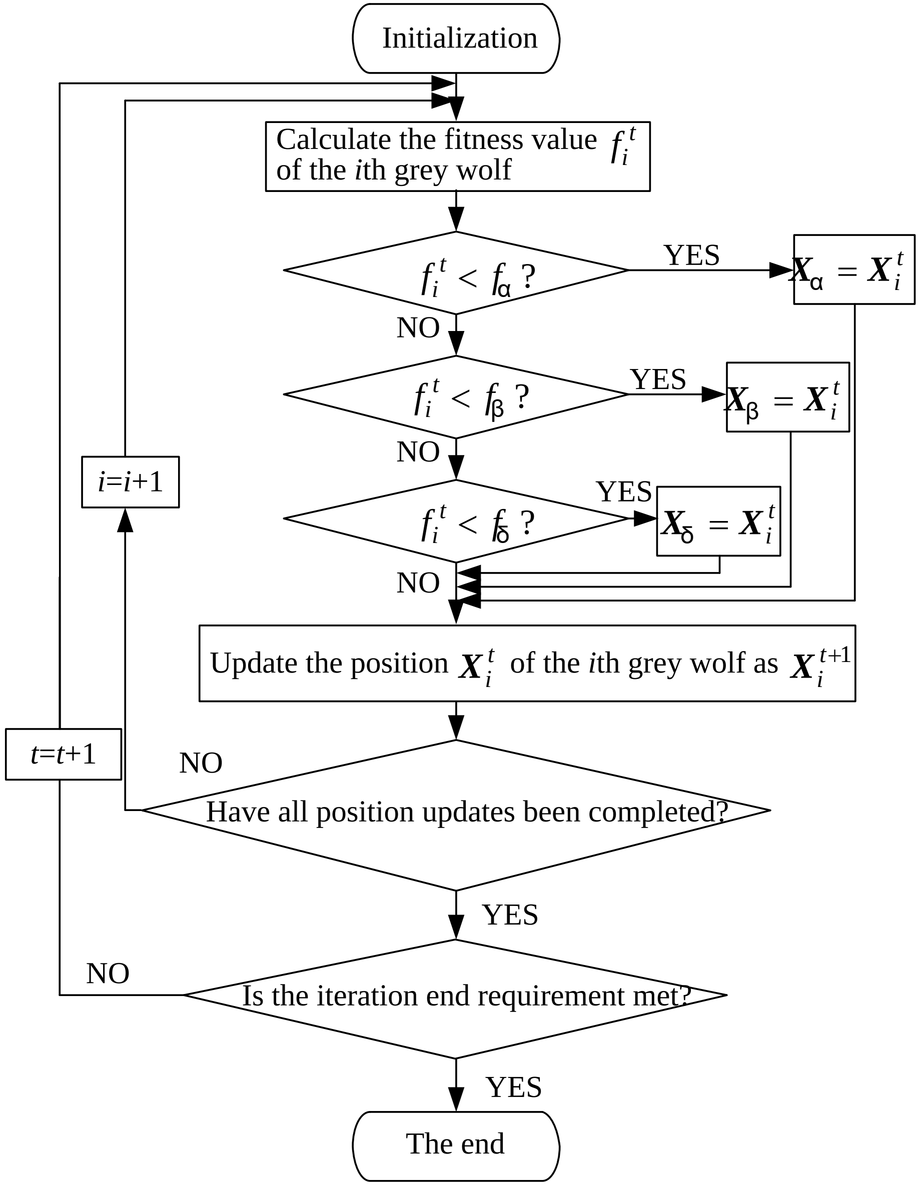

Fig. 6 Flow chart of the first dynamic GWO

Dynamic GWO

2.2 Second dynamic GWO

The difference between DGWO2 and DGWO1 is that the values of $\boldsymbol{X}_\alpha$, $\boldsymbol{X}_\beta$, and $\boldsymbol{X}_\delta$ for the position updating of the i^{th} search wolf in DGWO1 are those obtained after comparing the i^{th} search wolf and wolves α, β, and δ, whereas the values of $\boldsymbol{X}_\alpha$, $\boldsymbol{X}_\beta$, and $\boldsymbol{X}_\delta$ for the position updating of the i^{th} search wolf in DGWO2 are those obtained after comparing the $(i-1)^{\text{th}}$ search wolf and wolves α, β, and δ.

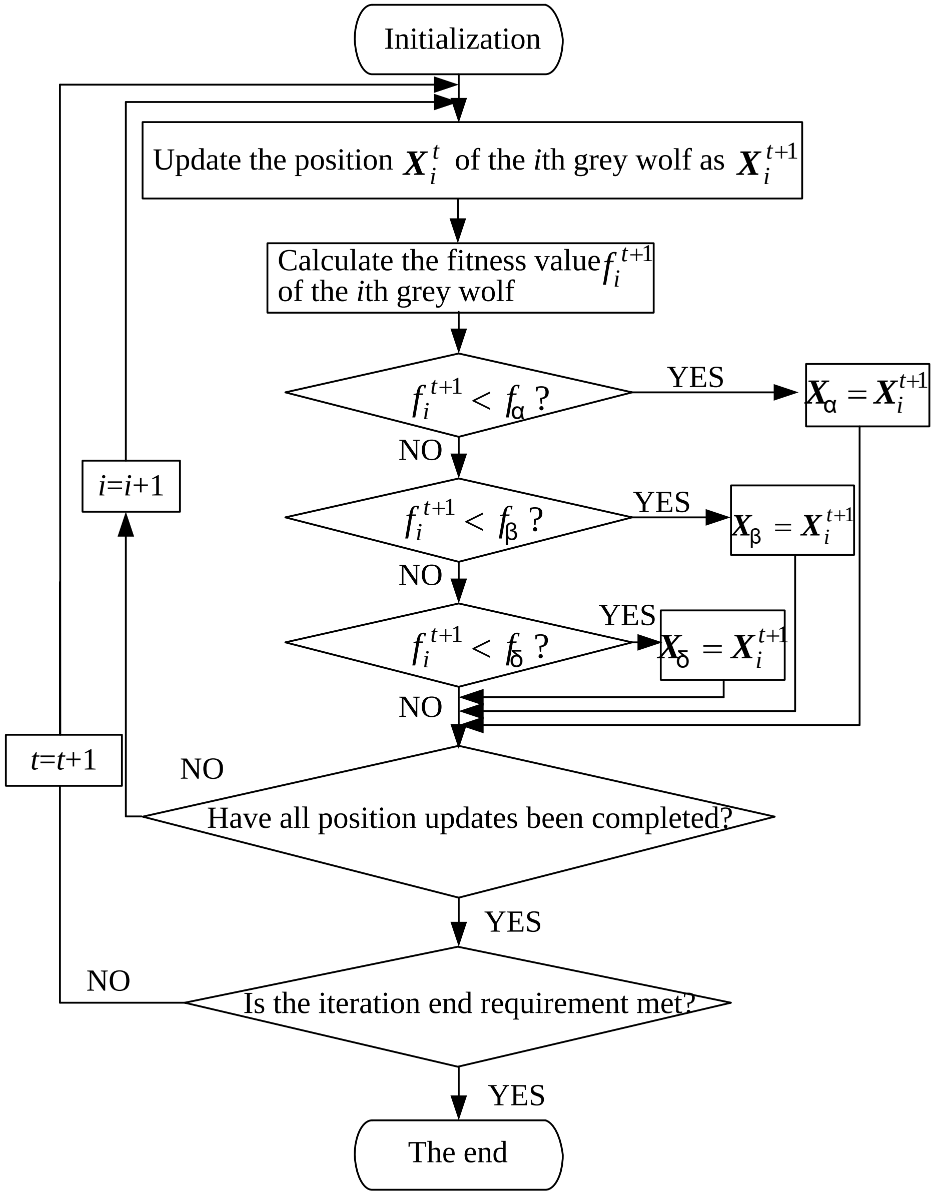

Fig. 7 Flow chart of the second dynamic GWO

2.3 Experimental test

Table 1 Introduction of CEC2014 test functions

Category	No.	Function description	Range	Dimension	f_{min}
Unimodal functions	Fun1	Rotated high conditioned elliptic function	[−100, 100]D	30	100
	Fun2	Rotated bent cigar function	[−100, 100]D	30	200
	Fun3	Rotated discus function	[−100, 100]D	30	300
Simple multimodal functions	Fun4	Shifted and rotated Rosenbrock's function	[−100, 100]D	30	400
	Fun5	Shifted and rotated Ackley's function	[−100, 100]D	30	500
	Fun6	Shifted and rotated Weierstrass function	[−100, 100]D	30	600
	Fun7	Shifted and rotated Griewank's function	[−100, 100]D	30	700
	Fun8	Shifted Rastrigin's function	[−100, 100]D	30	800
	Fun9	Shifted and rotated Rastrigin's function	[−100, 100]D	30	900
	Fun10	Shifted Schwefel's function	[−100, 100]D	30	1000
	Fun11	Shifted and rotated Schwefel's function	[−100, 100]D	30	1100
	Fun12	Shifted and rotated Katsuura's function	[−100, 100]D	30	1200
	Fun13	Shifted and rotated happy cat function	[−100, 100]D	30	1300
	Fun14	Shifted and rotated HGBat function	[−100, 100]D	30	1400
	Fun15	Shifted and rotated expanded Griewank's plus	[−100, 100]D	30	1500
	Fun16	Shifted and rotated expanded Scaffer's F6 function	[−100, 100]D	30	1600
Hybrid functions	Fun17	Hybrid function 1 (N=3)	[−100, 100]D	30	1700
	Fun18	Hybrid function 2 (N=3)	[−100, 100]D	30	1800
	Fun19	Hybrid function 3 (N=4)	[−100, 100]D	30	1900
	Fun20	Hybrid function 4 (N=4)	[−100, 100]D	30	2000
	Fun21	Hybrid function 5 (N=5)	[−100, 100]D	30	2100
	Fun22	Hybrid function 6 (N=5)	[−100, 100]D	30	2200
Composition functions	Fun23	Composition function 1 (N=5)	[−100, 100]D	30	2300
	Fun24	Composition function 2 (N=3)	[−100, 100]D	30	2400
	Fun25	Composition function 3 (N=3)	[−100, 100]D	30	2500
	Fun26	Composition function 4 (N=5)	[−100, 100]D	30	2600
	Fun27	Composition function 5 (N=5)	[−100, 100]D	30	2700
	Fun28	Composition function 6 (N=5)	[−100, 100]D	30	2800
	Fun29	Composition function 7 (N=3)	[−100, 100]D	30	2900
	Fun30	Composition function 8 (N=3)	[−100, 100]D	30	3000

Dynamic GWO

Table 2 The results of GWO, DGWO1, and DGWO2

No.	Algorithm	E_{ave}	E_{min}	E_{max}	STD	T_{ave} (s)
	GWO	7.7348E+07	1.7351E+07	2.2245E+08	5.4443E+07	0.620 000 00
Fun1	DGWO1	6.9518E+07	1.0246E+07	1.6806E+08	4.3795E+07	0.634 266 67
	DGWO2	9.7561E+07	3.0570E+07	3.6159E+08	6.4678E+07	0.708 833 33
	GWO	1.7374E+09	3.2964E+08	7.1383E+09	1.5693E+09	0.576 000 00
Fun2	DGWO1	9.3054E+08	8.2950E+07	3.0748E+09	7.1292E+08	0.608 600 00
	DGWO2	1.5497E+09	1.3502E+08	4.5133E+09	1.1434E+09	0.647 700 00
	GWO	4.4154E+04	2.1225E+04	7.2421E+04	1.2688E+04	0.580 500 00
Fun3	DGWO1	4.2716E+04	1.1950E+04	6.7400E+04	1.1629E+04	0.600 133 33
	DGWO2	4.2887E+04	1.9757E+04	5.6139E+04	9.3738E+03	0.636 700 00
	GWO	272.776 001	111.389 438	991.139 518	161.183 792	0.606 066 67
Fun4	DGWO1	249.367 799	138.746 704	389.764 796	63.725 696 6	0.598 933 33
	DGWO2	269.071 525	135.750 025	468.485 451	77.771 601	0.653 233 33
	GWO	21.048 390 7	20.954 732 4	21.119 694 2	0.046 445 16	0.598 133 33
Fun5	DGWO1	21.073 439 0	20.923 770 9	21.168 280 9	0.059 163 18	0.616 200 00
	DGWO2	21.052 303 0	20.930 537 3	21.150 743 5	0.049 953 19	0.671 100 00
	GWO	16.138 581 7	7.719 749 90	22.520 341 4	2.720 183 57	2.186 666 67
Fun6	DGWO1	13.345 383 1	7.793 407 07	18.014 303 4	2.856 747 81	2.193 333 33
	DGWO2	16.046 175 9	10.906 464 3	22.160 307 9	3.139 867 85	2.371 666 67
	GWO	18.677 730 1	2.290 059 49	50.470 529 5	12.598 917 0	0.608 166 67
Fun7	DGWO1	12.119 935 7	4.077 443 55	46.909 334 9	9.887 208 00	0.624 766 67
	DGWO2	16.724 520 7	3.442 175 71	42.524 885 9	11.370 005 4	0.706 066 67
	GWO	84.128 305 8	51.135 448 8	119.946 435	18.667 089 5	0.568 033 33
Fun8	DGWO1	83.216 554 1	45.237 634 3	183.901 163	29.200 958 1	0.586 800 00
	DGWO2	96.119 267 6	46.227 783 2	157.915 940	25.803 891 5	0.678 100 00
	GWO	101.913 738	53.687 965 8	174.292 255	28.048 629 9	0.591 533 33
Fun9	DGWO1	107.711 217	66.619 405 0	247.011 399	45.636 299 6	0.610 900 00
	DGWO2	104.673 026	76.026 141 4	155.802 704	20.196 713 9	0.670 200 00
	GWO	2882.950 67	1876.128 08	5506.288 99	742.515 951	0.641 900 00
Fun10	DGWO1	2295.958 83	1188.735 45	3673.702 85	608.441 075	0.665 166 67
	DGWO2	2786.682 12	1750.041 73	4119.279 84	627.442 287	0.768 700 00
	GWO	3663.280 72	2142.506 64	7202.166 16	1288.925 83	0.662 566 67
Fun11	DGWO1	3563.578 79	1985.361 06	7227.054 04	1103.213 96	0.685 666 67
	DGWO2	3337.252 81	2283.152 95	5862.003 51	687.189 136	0.821 766 67
	GWO	2.985 698 07	0.328 392 73	3.822 384 31	0.768 025 50	0.860 966 67
Fun12	DGWO1	2.412 137 13	0.175 209 87	3.783 569 46	1.195 294 87	0.896 033 33
	DGWO2	2.803 669 40	0.261 362 94	3.990 728 62	0.988 940 55	1.053 166 67
	GWO	0.536 126 93	0.345 703 55	1.501 063 15	0.198 913 68	0.574 966 67
Fun13	DGWO1	0.494 892 44	0.332 262 18	0.894 971 50	0.111 282 74	0.596 166 67
	DGWO2	0.524 429 99	0.306 659 44	0.806 768 69	0.123 578 13	0.704 866 67
	GWO	4.809 309 63	0.204 567 04	24.518 411 7	6.343 336 27	0.576 400 00
Fun14	DGWO1	1.056 274 75	0.227 968 90	10.467 584 7	1.863 233 08	0.601 733 33
	DGWO2	2.506 442 19	0.226 079 42	12.361 006 2	3.795 511 21	0.700 600 00
	GWO	315.635 614	6.875 791 12	4741.164 01	991.317 380	0.594 800 00
Fun15	DGWO1	48.509 007	15.957 130 1	349.030 677	75.821 151 9	0.615 533 33
	DGWO2	191.716 911	11.706 372 4	1988.790 37	480.383 755	0.730 166 67
	GWO	12.158 315	11.088 895 5	13.068 278 0	0.610 878 21	0.600 533 33
Fun16	DGWO1	11.736 275 3	9.903 901 14	12.840 498 9	0.781 347 39	0.622 533 33
	DGWO2	11.936 781 4	10.277 638 8	12.809 454 2	0.598 443 99	0.747 300 00
	GWO	2.8962E+06	2.7577E+05	1.4475E+07	3.0274E+06	0.629 633 33
Fun17	DGWO1	2.2905E+06	1.8796E+05	7.6651E+06	1.9662E+06	0.648 833 33
	DGWO2	2.7561E+06	1.6183E+05	1.1978E+07	3.0029E+06	0.773 766 67

To be continued

Table 2

No.	Algorithm	E_{ave}	E_{min}	E_{max}	STD	T_{ave} (s)
	GWO	1.3223E+07	8.5780E+03	7.5837E+07	1.9894E+07	0.593 100 00
Fun18	DGWO1	8.4606E+06	1.0638E+04	6.2757E+07	1.8511E+07	0.618 433 33
	DGWO2	1.3929E+07	9.4177E+02	1.0145E+08	2.6621E+07	0.743 300 00
	GWO	50.6284625	12.306 446 8	92.794 2614	26.651 3327	0.917 233 33
Fun19	DGWO1	32.8742287	12.792 560 1	76.307 1264	20.998 6305	0.937 533 33
	DGWO2	45.0406580	16.218 304 2	88.189 0767	26.065 4346	1.122 966 67
	GWO	2.9684E+04	1.4239E+04	7.3322E+04	1.4796E+04	0.597 400 00
Fun20	DGWO1	3.2474E+04	3.3878E+03	8.8334E+04	2.0072E+04	0.615 100 00
	DGWO2	3.4576E+04	8.8262E+03	9.5146E+04	2.2123E+04	0.741 200 00
	GWO	9.2300E+05	2.8342E+04	1.0654E+07	1.8986E+06	0.620 233 33
Fun21	DGWO1	8.2583E+05	7.6834E+04	1.0495E+07	1.8703E+06	0.640 833 33
	DGWO2	1.5589E+06	1.1307E+05	1.0072E+07	2.2829E+06	0.752 633 33
	GWO	427.903 188	84.751 731	1144.203 63	215.941 522	0.652 233 33
Fun22	DGWO1	348.052 763	58.330 618	604.669 184	153.379 408	0.670 466 67
	DGWO2	457.596 281	44.498 0107	1018.284 01	246.024 009	0.755 133 33
	GWO	338.382 543	325.772 425	360.410 310	9.336 105 09	0.934 933 33
Fun23	DGWO1	337.020 531	325.456 587	365.686 879	11.214 597 4	0.951 666 67
	DGWO2	339.492 910	326.283 158	371.444 432	12.179 159 5	1.128 633 33
	GWO	200.056 117	200.033 488	200.109 925	0.019 251 47	0.821 700 00
Fun24	DGWO1	200.085 139	200.050 013	200.141 596	0.024 645 05	0.848 333 33
	DGWO2	200.034 313	200.021 036	200.064 168	0.011 843 02	0.971 133 33
	GWO	212.157 269	200	220.079 676	5.512 285 26	0.890 933 33
Fun25	DGWO1	212.741 401	200	220.619 928	5.162 735 19	0.911 066 67
	DGWO2	214.008 045	200	222.217 401	4.026 295 09	0.996 566 67
	GWO	127.378 859	100.325 550	200.281 093	44.634 295 8	2.609 166 67
Fun26	DGWO1	140.398 082	100.348 975	200.382 863	49.631 866 5	2.629 900 00
	DGWO2	160.293 829	100.291 873	200.558 498	49.610 911 6	2.952 700 00
	GWO	645.187 725	428.495 181	871.723 890	137.250 692	2.574 866 67
Fun27	DGWO1	617.996 603	420.905 577	812.234 452	126.461 387	2.592 800 00
	DGWO2	727.147 534	409.297 087	926.558 827	115.610 516	2.866 166 67
	GWO	1168.927 28	887.657 395	2205.104 65	299.722 556	1.058 233 33
Fun28	DGWO1	1083.662 76	856.961 974	1535.041 87	169.773 424	1.079 166 67
	DGWO2	1127.608 03	880.408 681	1800.382 09	251.710 203	1.172 133 33
	GWO	1.4705E+06	6.1953E+03	1.8575E+07	3.9090E+06	1.183 700 00
Fun29	DGWO1	5.6260E+04	6.1817E+03	4.0440E+05	9.2709E+04	1.199 200 00
	DGWO2	2.1456E+06	5.6005E+03	1.3420E+07	3.8727E+06	1.252 666 67
	GWO	7.0658E+04	9.2651E+03	2.9369E+05	5.5296E+04	0.884 600 00
Fun30	DGWO1	6.2713E+04	1.7721E+04	1.4785E+05	3.5613E+04	0.907 200 00
	DGWO2	6.7740E+04	1.3471E+04	1.5801E+05	3.4178E+04	0.960 800 00

Dynamic GWO

- From Table 2, comparing DGWO1 with GWO, there are 24 functions whose average DGWO1 errors E_{ave} are superior to the GWO errors, 17 functions whose minimum DGWO1 errors are better than the GWO errors, 21 functions whose maximum DGWO1 errors are lower than the GWO errors, and 20 functions whose DGWO1 average standard deviations are less than the GWO average standard deviations. All of these numbers are more than half of 30, which shows that the overall optimization capability of DGWO1 is better than that of GWO.

- Comparing DGWO2 with GWO, there are 17 average errors, 17 minimum errors, 20 maximum errors, and 19 standard deviations of DGWO2, which are superior to the counterparts of GWO. These numbers are also more than half of 30, which shows that the overall optimization ability of DGWO2 is better than that of GWO.

Dynamic GWO

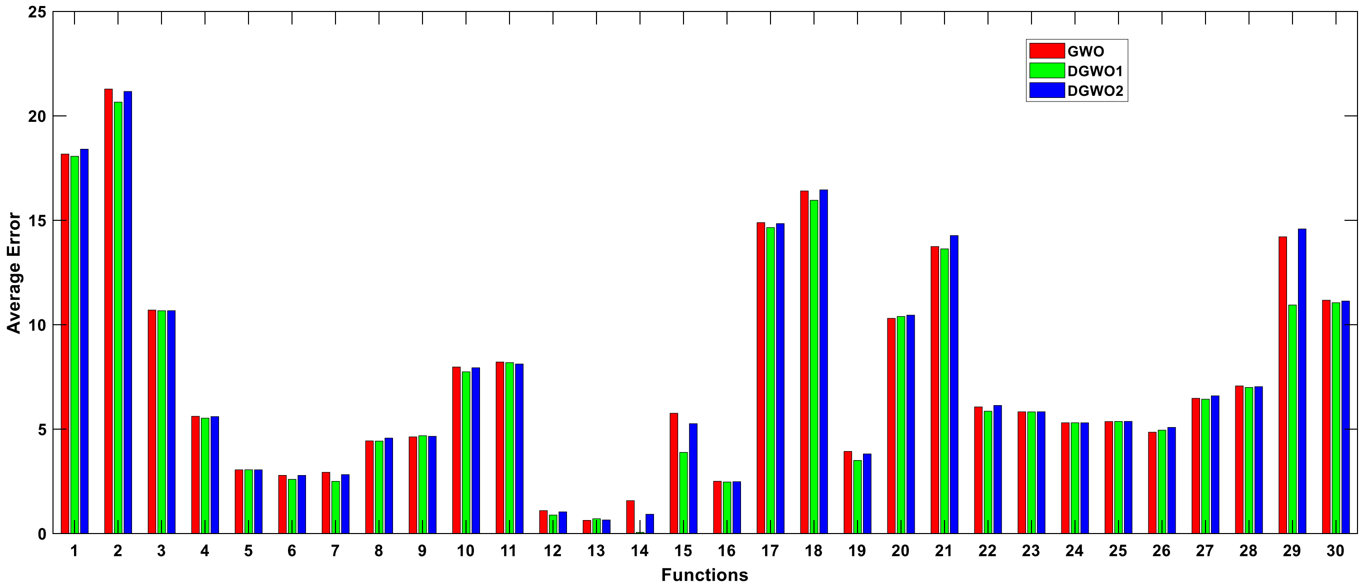

Fig. 8 The average errors (in log) of GWO, DGWO1, and DGWO2

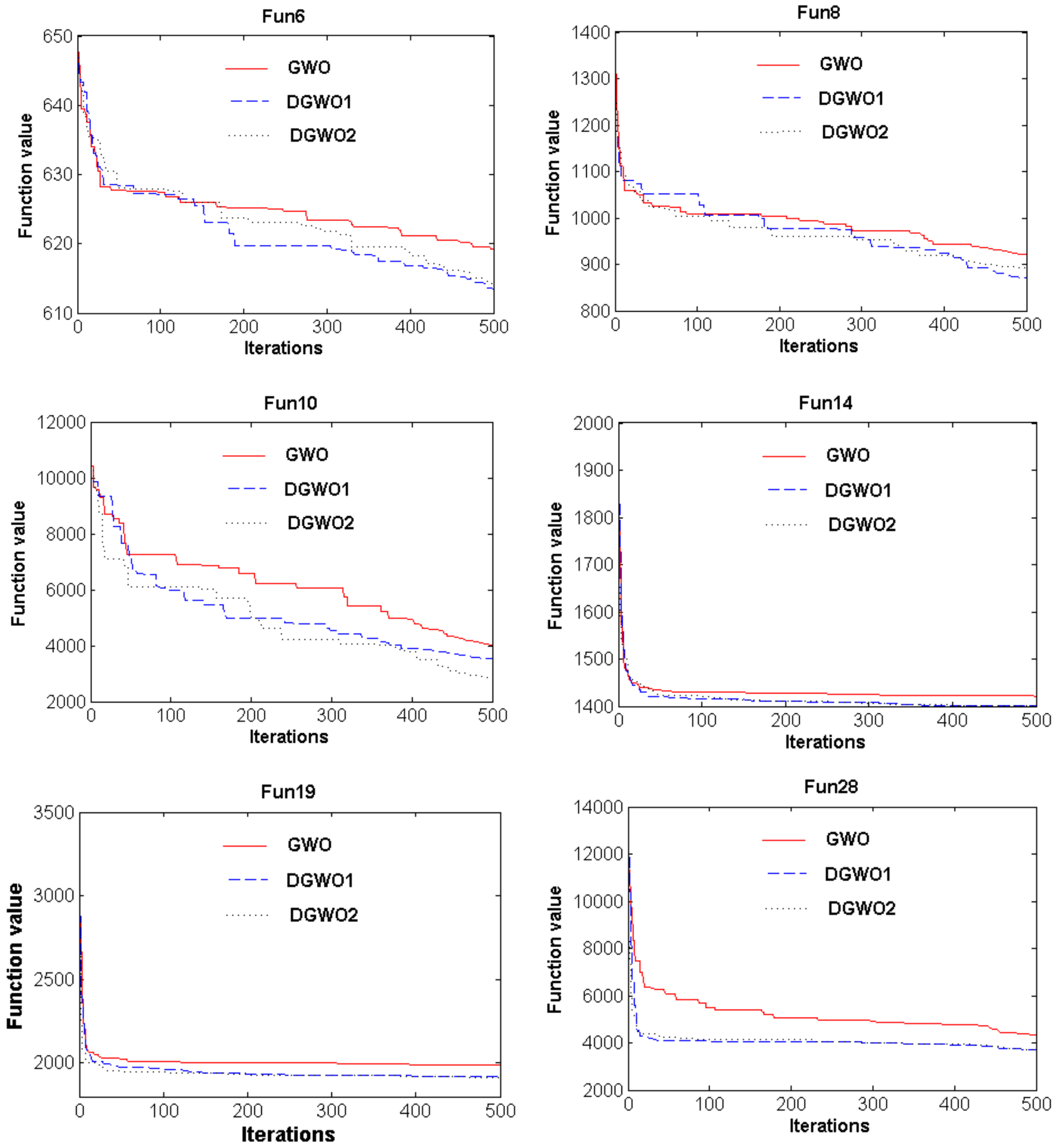

Fig. 9 Convergence graphs of some functions

Part 3

Improved strategies with dynamic GWOs

3.1 Improved strategies with dynamic GWOs

In MR-GWO, if the improvements over GWO are shifted to the first dynamic GWO, the novel improved algorithm would be called DMR-GWO1, and if the improvements are shifted to the second dynamic GWO, the novel improved algorithm will be called DMR-GWO2. Similarly, there are Dβ-GWO1, Dβ-GWO2, DGWO-EPD1, and DGWO-EPD2.

Because there are many algorithms studied, to reduce the length of the table header, the further shorthand notations of each algorithm are listed in Table 3.

Table 3 Shorthand notations for each algorithm

Algorithm	Shorthand notation	Algorithm	Shorthand notation	Algorithm	Shorthand notation
GWO	A1	DMR-GWO1	DA21	Dβ-GWO2	DA32
DGWO1	DA11	DMR-GWO2	DA22	GWO-EPD	A4
DGWO2	DA12	β-GWO	A3	DGWO-EPD1	DA41
MR-GWO	A2	Dβ-GWO1	DA31	DGWO-EPD2	DA42

Improved dynamic GWO

3.2 Experimental results

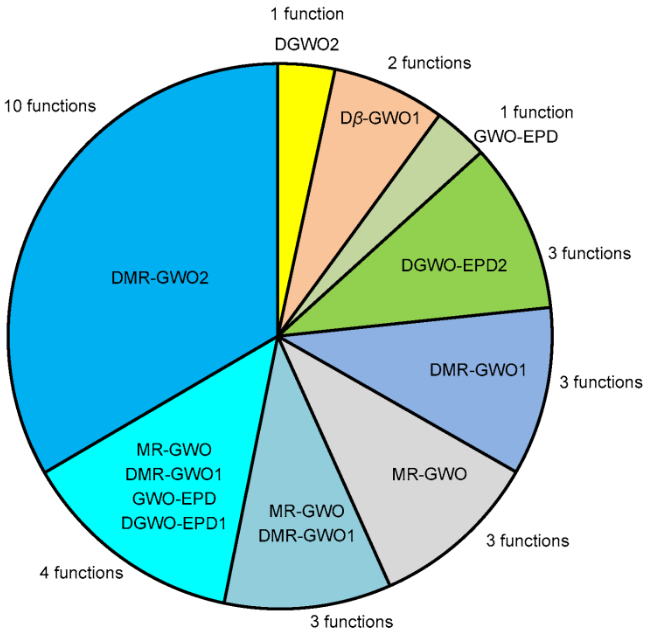

Fig. 10 The distribution of the optimal results

Table 4 Results of the improved dynamic GWO algorithms

No.	A1	DA11	DA12	A2	DA21	DA22	A3	DA31	DA32	A4	DA41	DA42	DE
1	7.73E7	6.95E7	9.76E7	3.06E7	3.21E7	**2.57E7**	7.58E7	6.69E7	6.94E7	3.84E7	3.32E7	2.88E7	2.25E9
2	1.74E9	9.31E8	1.55E9	4.27E7	4.55E7	**8.65E6**	1.98E9	1.37E9	1.89E9	3.52E7	3.43E7	1.24E7	9.8E10
3	4.42E4	4.27E4	4.29E4	2.33E4	**2.29E4**	2.72E4	4.08E4	4.53E4	4.49E4	2.89E4	2.97E4	2.94E4	1.31E7
4	272.776	249.368	269.072	180.607	177.784	**143.461**	271.894	247.689	246.676	179.890	191.136	158.569	2.34E4
5	21.0484	21.0734	21.0523	**20.8545**	20.8944	21.0569	21.0617	21.0696	21.0536	21.0072	20.9860	21.0342	21.02
6	16.1386	13.3454	16.0462	20.2130	20.3455	**12.4589**	15.5060	14.4338	16.9081	17.0944	17.0788	14.9227	47.38
7	18.6777	12.1199	16.7245	1.430 85	1.406 07	1.15631	14.0324	11.1091	17.1134	1.281 39	1.290 83	**1.135 52**	972.63
8	84.1283	83.2166	96.1193	127.920	117.273	**76.6245**	82.9077	76.9432	87.9166	99.1351	99.2870	82.7748	404.46
9	101.914	107.711	104.673	161.362	137.883	89.3886	107.246	**87.9287**	109.793	114.559	102.408	99.4011	379.73
10	2882.95	2295.96	2786.68	3013.81	3015.27	**1996.75**	2705.92	2595.62	2877.46	2445.56	2586.64	3082.61	8.80E3
11	3663.28	3563.58	**3337.25**	3940.57	3875.21	4198.12	3775.18	3864.90	3509.92	3725.07	3498.25	3972.42	9.23E3
12	2.985 70	2.412 14	2.803 67	0.967 26	**0.865 71**	3.099 84	2.703 58	2.920 33	2.900 51	1.497 86	1.619 34	3.162 16	1.77
13	0.536 13	0.494 89	0.524 43	0.603 78	0.591 79	0.487 58	0.523 87	**0.452 91**	0.506 52	0.524 00	0.529 57	0.498 75	10.41
14	4.809 31	1.056 27	2.506 44	**0.297 54**	0.307 99	0.528 20	3.016 27	1.472 55	1.939 91	0.463 28	0.448 06	0.569 11	370.28
15	315.636	48.5090	191.717	20.3668	18.8064	**13.7993**	43.5207	98.1012	49.1236	18.4611	18.7740	16.8452	6.34E5
16	12.1583	11.7363	11.9368	**11.6643**	11.7568	12.0493	11.9108	12.0953	11.9483	12.0532	11.8940	12.2230	13.98
17	2.90E6	2.29E6	2.76E6	2.37E6	2.35E6	1.64E6	3.29E6	1.74E6	2.24E6	2.22E6	1.79E6	**1.38E6**	9.48E8
18	1.32E7	8.46E6	1.39E7	4.15E4	5.92E4	**2.52E4**	8.91E6	7.77E6	1.40E7	6.34E4	5.47E4	4.83E4	1.5E10
19	50.6285	32.8742	45.0407	22.1325	17.9416	**16.3372**	42.9697	50.7686	40.5305	19.8551	18.3296	17.1595	824.69
20	2.97E4	3.25E4	3.46E4	1.39E4	1.99E4	1.31E4	2.52E4	2.69E4	2.49E4	9.50E3	1.40E4	**1.25E4**	2.75E9
21	9.23E5	8.26E5	1.56E6	5.41E5	**4.78E5**	4.80E5	1.39E6	1.76E6	1.82E6	5.26E5	5.21E5	5.74E5	1.97E9
22	427.903	348.053	457.596	524.016	486.510	**347.260**	408.625	440.924	391.068	451.570	405.747	391.186	4.40E6
23	338.383	337.021	339.493	**200**	**200**	325.372	335.603	333.485	336.847	**200**	**200**	327.142	215.43
24	200.056	200.085	200.034	**200**	**200**	200.014	200.059	200.081	200.036	200.085	200.083	200.078	202.78
25	212.157	212.741	214.008	**200**	**200**	208.481	212.604	212.012	213.120	**200**	**200**	211.450	200.23
26	127.379	140.398	160.294	130.466	123.823	147.046	120.525	137.029	161.487	**120.468**	120.512	127.169	200.00
27	645.188	617.997	727.148	**200**	**200**	409.710	669.900	646.451	697.768	**200**	**200**	617.280	216.28
28	1168.93	1083.66	1127.61	**200**	**200**	1059.13	1181.14	1012.48	1176.88	**200**	**200**	978.382	219.08
29	1.47E6	5.63E4	2.15E6	**200**	**200**	1.57E4	6.50E5	7.84E5	9.63E5	1.65E5	2.25E5	1.08E6	1.79E7
30	7.07E4	6.27E4	6.77E4	**200**	**200**	3.10E4	6.71E4	4.88E4	5.32E4	4.57E4	3.77E4	2.70E4	1.20E6

The bold data are the best results of all algorithms

Improved dynamic GWO

Definition 1 For a problem, the algorithm rank is determined by the average value and the median value obtained after the maximum number of iterations. When there are many problems, the rank value of each algorithm is calculated by

$$\text{Rank value} = \sum_{i=1}^{n} \text{rank1}_i + \sum_{i=1}^{n} \text{rank2}_i \qquad (1)$$

Table 5 Rank value results of the algorithms

Algorithm	Rank value	Rank
GWO	3.82E+09	10
DGWO1	2.47E+09	8
DGWO2	4.09E+09	12
MR-GWO	1.83E+08	6
DMR-GWO1	1.48E+08	4
DMR-GWO2	7.21E+07	1
β-GWO	3.43E+09	9
Dβ-GWO1	2.21E+09	7
Dβ-GWO2	4.08E+09	11
GWO-EPD	1.55E+08	5
DGWO-EPD1	1.42E+08	3
DGWO-EPD2	1.02E+08	2
DE	2.41E+11	13

According to the ranking results in Table 6, the best rank belongs to DMR-GWO2, the second best is DGWO-EPD2, and the third and fourth best are DGWO-EPD1 and DMR-GWO1, respectively. The first four algorithms are based on the dynamic GWOs, which to some extent proves that the improvement based on the dynamic GWO algorithms is notable.

Part 4

Conclusions

Conclusions

Based on the structure analysis of the standard GWO, two dynamic GWOs, DGWO1 and DGWO2, are proposed by changing the structure of the algorithm. The advantage of DGWO1 and DGWO2 is that the new positions of the three leading wolves can be used in time for the position updating of the search wolf.

The difference between DGWO1 and DGWO2 is as follows: in DGWO1, the position updating of the search wolf is done after the comparison between the current search wolf itself and the three leading wolves, but in DGWO2, the position updating of the search wolf is done after the comparison between the previous search wolf and the three leading wolves.

Finally, the dynamic structure is applied to other improved GWO algorithms to obtain the corresponding improved dynamic GWO algorithms. It is also proved by these experiments that most of the improved algorithms based on the dynamic GWO structures are more effective than those based on the static GWO structure. It is also shown that DMR-GWO2 has the best performance in the 30 standard test experiments based on the rank value.