

algorithm,algpseudocode

Algorithm 2: ControlledLISTENMode Optimization Algorithm

[1]

Input: Objective function $f(x)$, bounds $[lb, ub]$, dimension D , number of agents N , iterations T **Output:** Best solution x^* , $f(x^*)$

Initialize roles: Initiators, Duelists, Controllers, Sentinels based on ratio;

Initialize positions $X_i \sim U(lb, ub)$ for $i = 1 \dots N$;Evaluate fitness $F_i = f(X_i)$ and set global best $x^* = \arg \min F_i$;**for** iteration $t = 1$ to T **do**

Compute population standard deviation and step scale;

 Compute progress factor $p = t/T$ and Lévy probability $\rho = 0.2 - 0.1p$; Initialize hotspot list $H = \emptyset$; **foreach** Initiator i **do** Compute adaptive step $\sigma = \sigma_1 \cdot \text{step_scale} \cdot (0.3 + 0.7(1 - p))$; **if** $\text{rand}() < \rho$ **then** $\text{step} \leftarrow 0.8 \cdot \text{LevyFlight}(\beta)$; **else** $\text{step} \leftarrow \sigma \cdot \mathcal{N}(0, I)$; **end** $X_i \leftarrow \text{clip}(X_i + \text{step})$; Add X_i to hotspots H ; **end** Evaluate $f(h)$ for each $h \in H$; Select top-k best hotspots as target set T_H ; **foreach** Duelist d **do** Select random target $t \in T_H$; Compute $lf = \text{LevyFlight}(\beta)$; $\text{step} \leftarrow \sigma_2(t - X_d) + 0.5\beta \cdot lf$; $X_d \leftarrow \text{clip}(X_d + \text{step})$; **end** **foreach** Controller c **do** Determine active set $A = \text{initiators} \cup \text{duelists}$; **if** $|A| > 0$ **then** Select $k \propto (1 - p)$ samples from A ; $\text{centroid} \leftarrow \frac{1}{k} \sum X_i, \forall i \in A$; **else** $\text{centroid} \leftarrow \text{random agent}$; **end** $\text{step} \leftarrow \eta(\text{centroid} - X_c) + 0.1\mathcal{N}(0, I)$; $X_c \leftarrow \text{clip}(X_c + \text{step})$; **end** **if** Controller(s) exist **then** $C_{\text{mean}} = \text{mean of controller positions}$ **end** **foreach** Sentinel s **do** **if** global best x^* exists **then** $\text{step} \leftarrow \lambda(x^* - X_s) + 0.2(C_{\text{mean}} - X_s)$; $X_s \leftarrow \text{clip}(X_s + \text{step})$; **end** **if** $\text{rand}() < 0.05$ **then** $X_s \leftarrow \text{clip}(X_s + 0.02\mathcal{N}(0, I))$; **end** **end** **if** variance $< 10^{-3}$ **then**

Randomly reinitialize one sentinel;

end

/* Evaluate and Archive Elites

 Evaluate all $F_i = f(X_i)$; Update global best $x^*, f(x^*)$;

Store top-5 elites in archive;

end**return** $x^*, f(x^*)$

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