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A collaborative assembly for low-voltage electrical apparatuses

Key words: Low-voltage electrical apparatus; Collaborative assembly; Artificial potential field based planning; Adaptive quantum genetic algorithm; Dynamic interaction

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Motivation

1. Low-voltage electrical apparatuses (LVEAs) have many workpieces and intricate geometric structures, and the assembly process is rigid and labor-intensive, and has little balance. The assembly process cannot readily adapt to changes in assembly situations. Thus, it is challenging to construct a collaborative assembly method for assembling LVEAs.

2. In the collaborative assembly of LVEAs, it is of paramount importance to realize the assembly planning and dynamic interaction of robots to improve the assembly efficiency. When changes occur in an assembly process, such as production shifts or robot failures, the robots can quickly adjust themselves to maintain the stability of the assembly process.

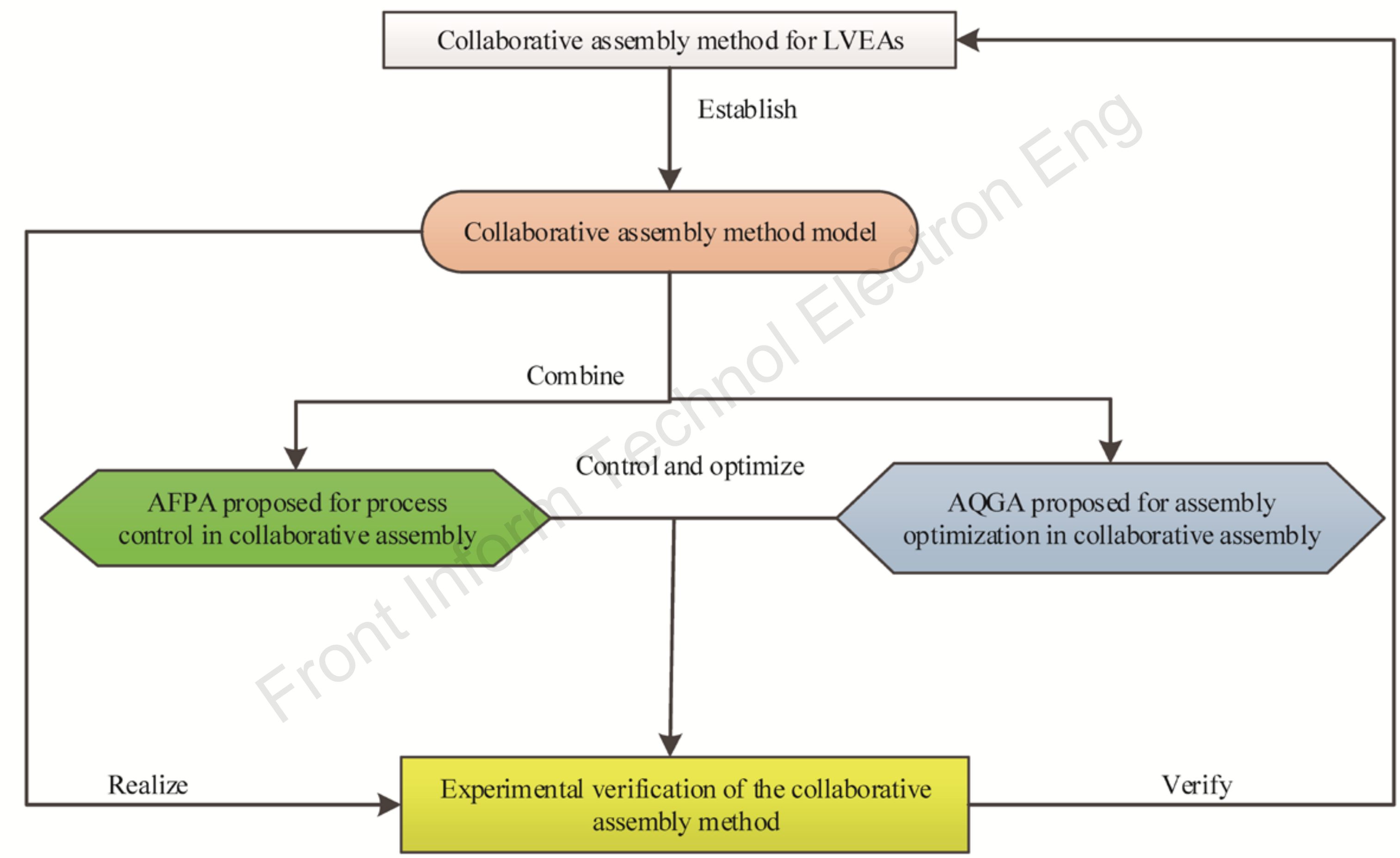
Main idea

1. Based on the requirements of collaborative assembly, a colored Petri net (CPN) model is proposed to analyze the performance of the interaction and self-government of robots in collaborative assembly.

2. In the collaborative assembly of LVEAs, an artificial potential field based planning algorithm (AFPA) is presented to realize the assembly planning and dynamic interaction of robots.

3. To optimize the assembling balance of LVEAs assembly, an adaptive quantum genetic algorithm (AQGA) is developed to optimize the assembly process.

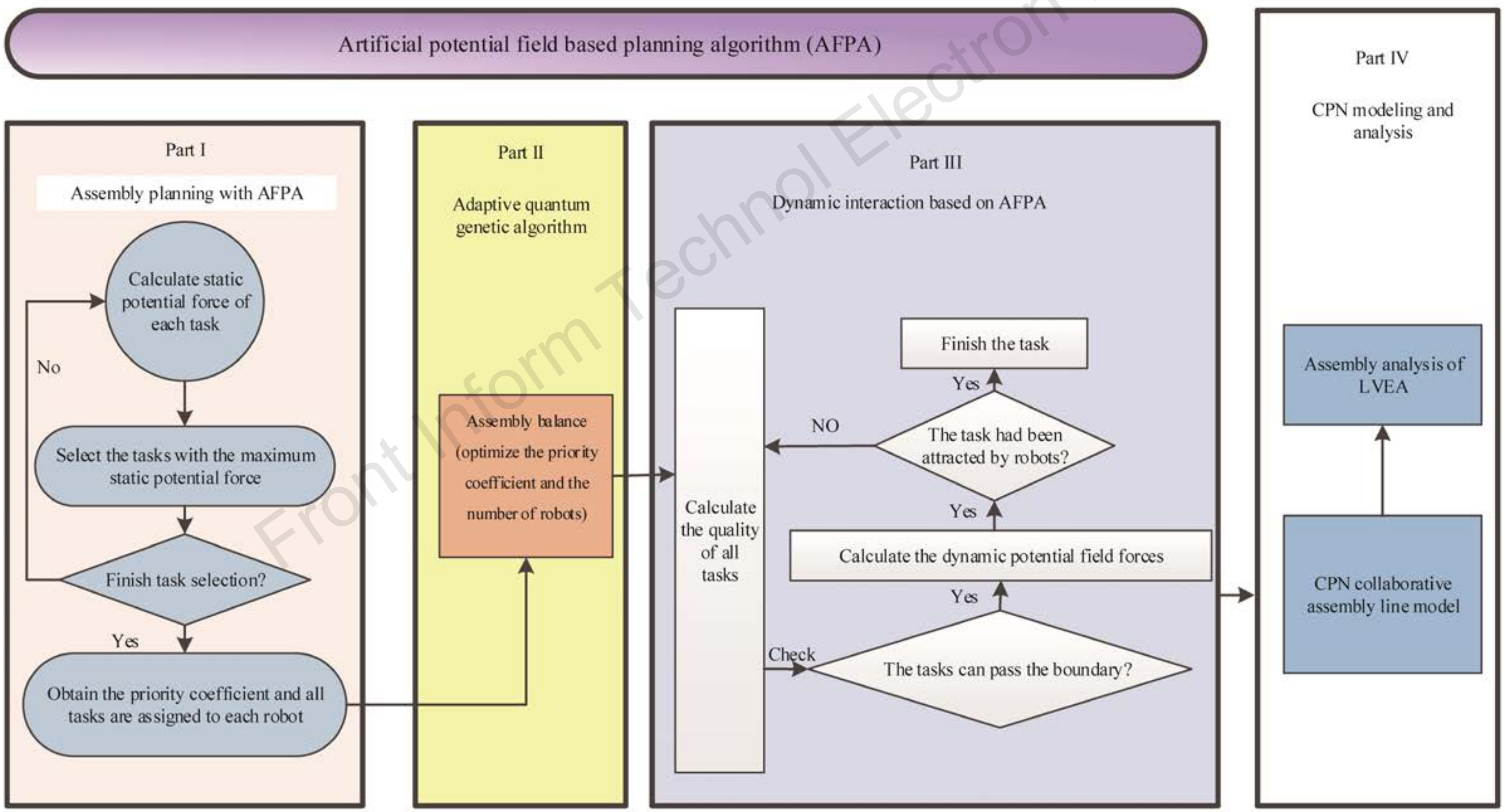
Framework



Main content of this paper

Method

1. To realize the collaborative assembly of LVEAs, assembly planning with AFPA is proposed to assign assembly tasks to robots dynamically, and an AQGA is proposed to optimize the assembling balance.



Architecture of the collaborative assembly methodology

Method

2. To evaluate the proposed collaborative assembly, four metrics LE, SI, Fitness, and Cmp are introduced. LE (Eq. (1)) reflects the efficiency of the assembly line; a smaller LE means a smaller number of robots required. SI (Eq. (2)) is the smoothness index of the assembly line; the smaller the SI, the less the workload difference between robots, and the more equally these workloads are distributed to robots. The multi-objective optimization fitness, Fitness (Eq. (3)), is introduced to evaluate the performance of AQGA. Cmp (Eq. (4)) is introduced to evaluate the compatibility of the assembly line.

$$\mathrm{LE} = \frac{1}{mC}\sum_{s=1}^{m}\mathrm{ST}_s, \quad (1)$$

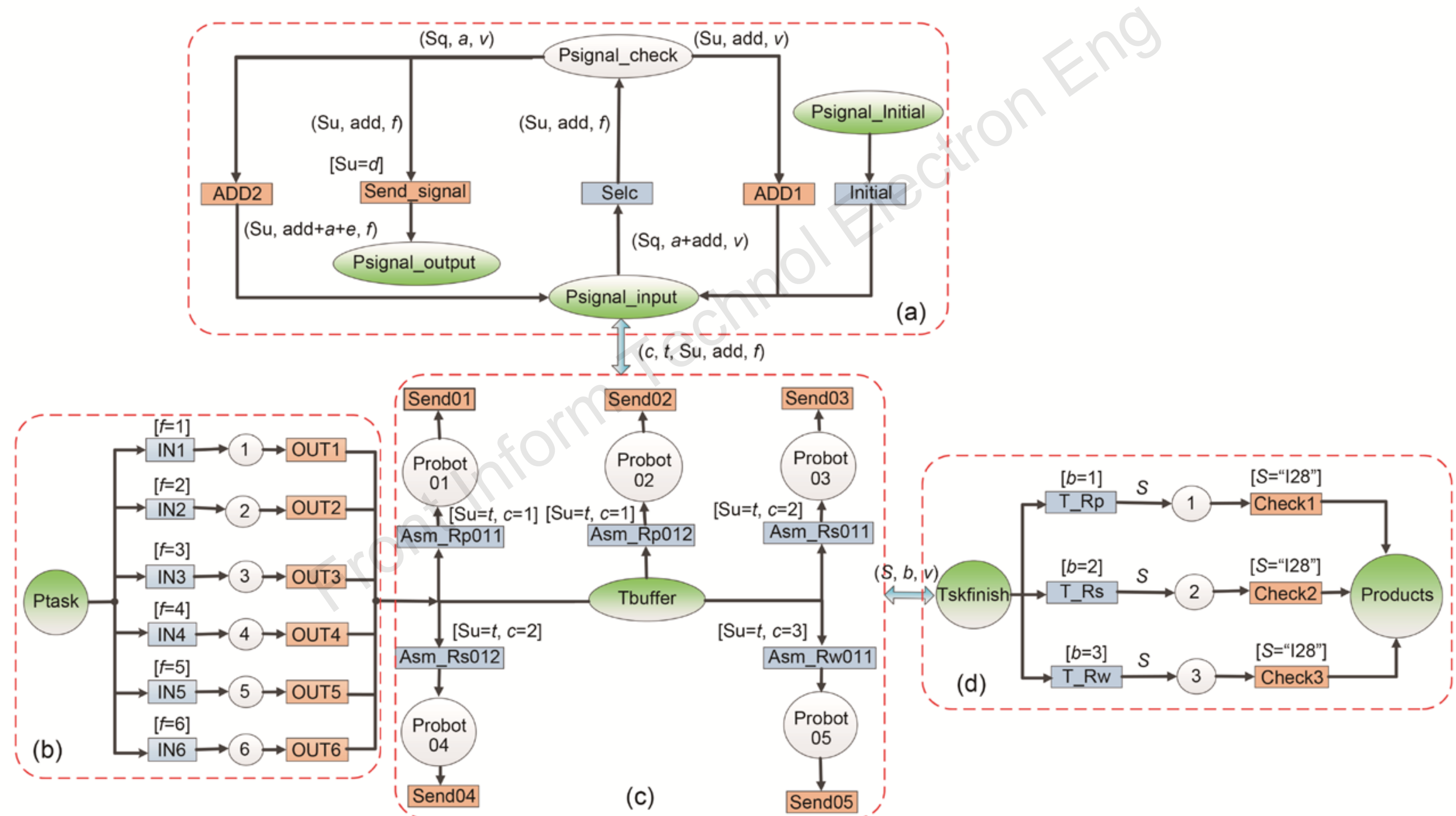
$$\mathrm{SI} = \sqrt{\frac{1}{m}\sum_{s=1}^{m}\left(\mathrm{ST}_{\max} - \mathrm{ST}_s\right)}, \quad (2)$$

$$\mathrm{Fitness} = \frac{100 - \mathrm{LE}}{100 - \mathrm{LE}_0} + 2\frac{\mathrm{SI}}{\mathrm{SI}_0}\frac{m}{C}, \quad (3)$$

$$\mathrm{Cmp} = \frac{S_r + 1}{S_p + 1}\frac{\mathrm{EL}_r + 1}{\mathrm{EL}_p + 1}\frac{\mathrm{SI}_r + 1}{\mathrm{SI}_p + 1}, \quad (4)$$

Method

3. To analyze the performance of the proposed collaborative assembly of an LVEA, the colored Petri net (CPN) modeling theory is applied to establish the assembly model.



CPN collaborative assembly model: (a) product and task detection unit; (b) task data unit; (c) assembly robot unit; (d) information processing unit

Major results

Table S15 Comparison between the collaborative assembly and basic assembly lines

Theoretical cycle, C_t	Compared parameter	Value			
		One-sided linear assembly, simulated annealing	Double-sided linear assembly, tabu search	U-shaped assembly, genetic algorithm	Collaborative assembly, AFPA-AQGA
70	SI	1	2.2361	3.74	0.49
	LE	0.33	0.35	0.29	0.74
	S	12	12	9	5
90	SI	1.41	26.7067	2.45	0.23–0.31
	LE	0.33	0.2574	0.3	0.82–0.84
	S	9	12	9	4
120	SI	1.18	64.3623	1.29	0.35–0.43
	LE	0.33	0.1986	0.22	0.76–0.79
	S	9	12	6	3
150	SI	1.2	0	1.41	0.24
	LE	0.32	0.3067	0.27	0.89
	S	5	6	6	3

Conclusions

1. Through the construction of the CPN collaborative assembly model, the self-government of robots was analyzed in the collaborative assembly. The simulation results showed that the robots had good performance to avoid assembly confliction in the collaborative assembly and good self-government ability to improve the passive fault tolerance of the assembly process.

2. AQGA applied to balance the collaborative assembly had better convergence performance than the compared algorithms GA, GASA, RQGA, and QGA. With the optimization of AQGA, the Fitness, LE, SI, and *S* values obtained were better than those optimized with the compared algorithms. Hence, AQGA had better performance in collaborative assembly balance.

Conclusions

3. AFPA was proposed to perform assembly planning and dynamic interaction of the collaborative assembly. The simulation results showed that in the application of AFPA, the collaborative assembly method could achieve assembly planning and dynamic interaction in the LVEA assembly. Compared with the traditional assembly line, the collaborative assembly method achieved better LE, SI, *S*, and Cmp.