Research on Task Scheduling of Cyber Physical System of Coal Preparation Plant Based on Dynamic Alliance

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Abstract — **Effective production scheduling strategy is the premise to ensure the safety of coal preparation plant, this paper studies production scheduling strategies in CPS. Combined with coal preparation plant production process, the partial order theory is used to establish the CPS model of coal preparation plant. Dynamic alliance method was applied in task scheduling of the CPS. A task scheduling algorithm for the CPS of coal preparation plant was proposed based on an improved particle swarm optimization algorithm. In the algorithm, the discrete particle swarm optimization algorithm is used for global optimization, and a tabu search algorithm is adopted for local search, so as to obtain the globally optimal solution. The simulation results show that the improved algorithm improves the convergent rate and precision of task scheduling and average utilization of processor.**

Keywords - coal preparation plant; cyber physical system; partial order; task scheduling; dynamic alliance; particle swarm optimization

I. INTRODUCTION

Considering various kinds of coal preparation plant equipments and complex production processes, it remains one of the important issues for coal preparation plants to use cyber information to improve production efficiency and safety. The use of mineral internet of things technology [1] resolves the share of information in different systems of intelligent mines, and meanwhile realizes distributed perception based on Internet , but not yet the intelligent perception control. Cyber physical system is an efficient integration between physical system and information system, which offers a novel solution for intelligent resolution and automatic undertaking assignment with regard to coal preparation plants.

At present, the research on the CPS is still in its infancy. Hot topics about CPS in Literature [1] are summarized .Through analysis, literature [2] thinks CPS aimed for the coal mine design and development of specific application has the feasibility and credibility. First, the CPS is applied to the coal mine production system, and combined with the CPS and complex environment of the coal mine, the paper builds the CPS model of coal mine, but the CPS model cannot be directly applied in coal preparation plant. Coal preparation plant production system is a typical application of loosely coupled system, so the CPS shall be the large heterogeneous distributed real-time system[2]. In this paper, regarding the characteristics of production in coal preparation plant, multi Agent technology is adopted to establish the model of the CPS for coal preparation plant.

The key problem for the CPS of coal preparation plant is how to efficiently process task scheduling so as to ensure the reliability and real-time performance of system. In view of the multiple tasks scheduling of heterogeneous real-time systems, reference[3] study the initial tumble clusters of tasks, control processor load, task duplication scheduling, so it reduces the time complexity of the algorithm and improves the success rate of task scheduling. References [4] use heuristic search algorithm, in terms of maximum residual bandwidth processor as an index for task allocation, to make the balance of the load of each processor far as possible, and uses the degradation mechanism to improve the soft real-time task scheduling success ratio. In reference [6] by introducing table scheduling technology, it improves Particle Swarm Optimization algorithm (PSO), and shortens the scheduling length and running time of multiprocessor task scheduling. The above algorithms in terms of task scheduling success rate or the system load balance are to some extent improved, but only limited in one area of its specific field.

PSO is a kind of search algorithm based on population, which can be applied to large scale parallel multiprocessor systems, and to loosely coupled distributed systems [5].As a result, PSO algorithm can be used in coal preparation plant CPS task scheduling. Based on the analysis of coal preparation plant CPS task scheduling demand, and the introduction of dynamic alliance model, and combined with Tabu Search (Tabu Search, TS) algorithm, this paper improves the Discrete PSO (DPSO) algorithm, improved PSO algorithm based on dynamic alliance is proposed to solve the CPS task scheduling problems of coal preparation plant. The experimental results show that the algorithm regarding the aspects of convergence speed, convergence precision and task scheduling system processor utilization is upgraded.

II. CPS TASKSCHEDULING MODEL OF COAL PREPARATION PLANT

A. *CPS model of coal preparation plant*

CPS is a complex system, on the basis of environmental awareness, through the organic combination of computing, communication and control technology and the depth of cooperation, which realizes the interaction of the physical world and information world, and provides such services as

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real-time sensing, dynamic control and information feedback [6]. The analysis of the model can better recognizes the CPS behavior of coal preparation plant, and at the same time, through the model driven design can improve the design automation, and reduce the error in the process of essence [1].System model requires that the information world can interact with the physical environment. Therefore, when modeling, it must emphasize autonomy and interaction of the system.

Multi-agent System (Multi-Agents System, MAS), composed of multiple intelligences, is a loose coupling problem solving network. Agent has the intelligence of the System, and can independently finish their own tasks, and it can interact and cooperate with the other Agents. So this article uses the Agent (Agent) technology for the CPS modeling of coal preparation plant.

The xinglongzhuang coal preparation plant technological process is shown in Fig.1. This paper takes xinglongzhuang coal preparation plant as the research object, and according to the theory of partial order, establishes the CPS model of coal preparation plant, as shown in figure 2, in the figure, each intersection module achieves loose coupling partial order structure.

Production process of coal preparation plant is fixed continuous process, so the knowledge sharing mode and process direction are in the same way. The communication content from the information network towards the physical network is the control command, whereas communication content from the physical network to the direction of the information network is the physical environment information perceived by the sensors. Each production workshop has a management Agent which is in charge of the device node in the area. Due to complicate production system of coal preparation plant, this article mainly aims at , in the process between the raw coal to the product coal, modeling between moving sieve workshop and the main washing workshop, so the model contains 1 and 2 management Agents. All kinds of sensors distributed on the production equipment and other infrastructure agent can real-time percept of various parameters of the physical environment of coal preparation plant, including jig material level and beds, air volume of jig for the wind system and the amount of water in water supply system, transportation equipment status, product ash and moisture, etc. Multiplexer sensors sum up the physical environment formation perceived by sensors, and the servers are responsible for semantic interpretation. Each server uses a distributed algorithm for relevant calculations of the processed sensor data, and to provide decision support for operating station, so as to realize the real-time intelligent control of the physical environment [7] .When the physical environment of coal preparation plant changes, the CPS can find itself an adaptive adjustment and meet the production demands[8] .

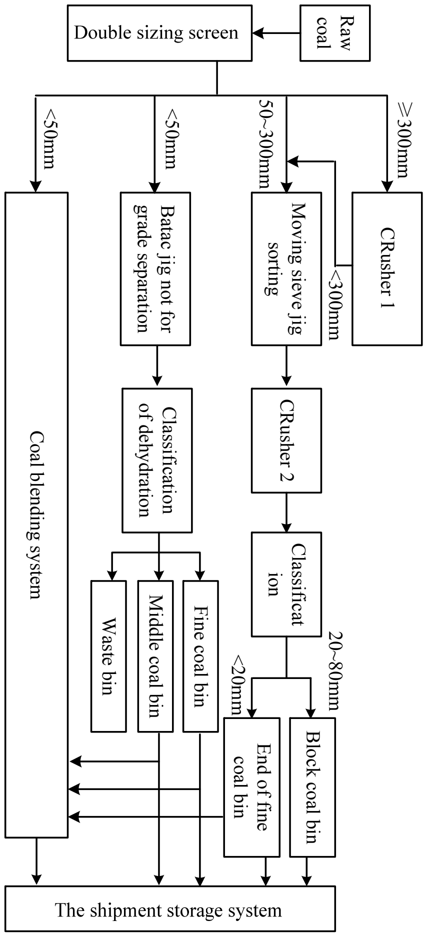

Figure 1. Technological process of coal preparation plant

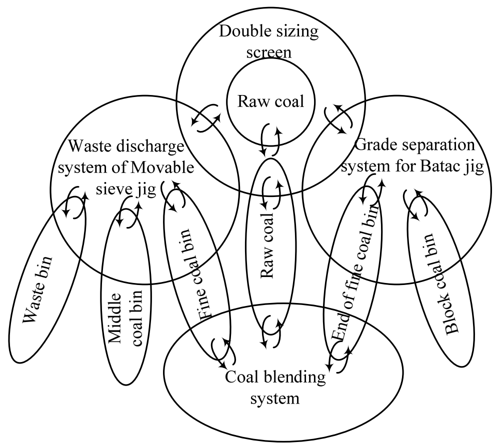

Figure 2. CPS model of coal preparation plant

When an Agent receives the task in the system, and then this task is sent to management Agent of this Agent area. After management Agent checks regional condition of Agents, it chooses the appropriate combination of processors for task scheduling.

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B. Coal preparation plant Dynamic Alliance

Dynamic Alliance (DA) refers to a number of complementary enterprises to form a temporary coalition so as to complete a task efficiently [9].This paper introduces dynamic alliance into the process of CPS task scheduling. Because of the complexity of the CPS of coal preparation plant, this paper, when establishing the dynamic alliance model of coal preparation plant, is first of all, to simplify the system processors and tasks. Assumptions: ①each processor performance does not change over time; ②tasks are independent between each other; ③ignore the system energy consumption on the evaluation of the fitness function.

It is assumed that the information physical system of coal preparation plant totals M processors and N independent tasks to deal with. Known processor matrix is for $p=\left[p_1, p_2, \cdots, p_j, \cdots, p_M\right]$, the processor power matrix is for $p=[\rho_1,\rho_2,\cdots,\rho_j,\cdots,\rho_M]$, among which ρ_j indicates the j processor's processing capacity. The greater the ρ_j is , the stronger the processor's capacity is .Set if a standard processor capacity value is 1. If task matrix is $T=\left[\tau_1, \tau_2, \cdots, \tau_i, \cdots, \tau_N\right]$, τ_i is for the task number i .The task of T of the processing time of the matrix on the standard processor is $C=[C_1,C_2,\cdots,C_i,\cdots,C_N]$, and C_i shows the processing time of the task of number i on the standard processor. The matrix of execution time of all the tasks on the processors

$$E_{\text{ext}}=\left[e_{11}, \cdots, e_{1M}, e_{21}, \cdots, e_{2M}, \cdots, e_{N1}, \cdots, e_{NM}\right] \tag{1}$$

among which e_{ij} is the estimated execution time of task on the processor of p_j, and $e_{ij}=C_i/\rho_j$.

Execution time of p_j is the sum of all execution time of all tasks distributed on the processors, that is,

$$R\left(p_j\right)=\sum_{i=1}^{n} C_i/\rho_j \tag{2}$$

In the equation: n is the number of tasks assigned to the processor p_j

The time for finishing this task is

$$S=\max_{j=1}^{m}(R(p_j)) \tag{3}$$

In the equation: m is the number of processors in the Combination of dynamic alliance.

The total time of processor completion is the sum of time to finish tasks of each processor, it is

$$E=\sum_{j=1}^{m} R(p_j) \tag{4}$$

A good scheduling plan is to make sure the completion time for task is as short as possible, besides that, it also ensures system processor utilization on average[9]. The processor utilization is equal to the sum of task completion time on the processor divided by maximum effective units of time[6]. According to this definition, average utilization of the system processor is expressed as

$$U_{\text{ave}}=\frac{\sum_{j=1}^{m}\left(\frac{R(p_j)}{S}\right)}{m} \tag{5}$$

To simplify equation (4), it gets

$$U_{\text{ave}}=\frac{E}{mS} \tag{6}$$

Set $z=\left[z_1, z_2, \cdots, z_M\right]$ as a union of plan, Coal preparation plant CPS dynamic alliance model can be abstracted as multi-object optimization problem:

$$Minimize(E)$$

$$Maxmize(U_{ave})$$

$$Minimize(m),\ m=\sum_{j=1}^{M} z_j$$

$$s.t\ 1 \le m \le M$$

Among which,

$$z_j=\begin{cases}1, & p_j \text{ added into dynamic alliance}\\ 0, & p_j \text{ not added into dynamic alliance}\end{cases}$$

III. TASK SCHEDULING ALGORITHM OF CPS COAL PREPARATION PLANT

Choosing DPSO algorithm for the CPS task scheduling of coal preparation plant, and according to the shortcoming of DPSO algorithm in late period which is inclined to fall into local optimum, this paper introduces TS in the late algorithm to improve the algorithm, that is, the current optimal solution of DPSO as the initial feasible solution of TS algorithm, using TS algorithm for local search, and finally finding the optimal solution in a general manner. In this article, this algorithm is named as the improved DPSO algorithm based on dynamic alliance.

A. Particle position description and fitness functions structure

Among discrete particle swarms, the particle is strings composed of 0 and 1. Assume that the particle number is D, and the matrix of the particles position is X, $X=\left[X_1, X_2, \cdots X_d, \cdots X_D\right]$, among which, $X_d=[x_{d1}, x_{d2}, \cdots, x_{dj}, \cdots x_{DM}]$, indicating a plan of dynamic alliance.

Because of S relating to E , U_{ave} , so this article is only for evaluation of S .Ignore the system energy consumption and define the fitness functions as

$$F\left(X_d\right)=w_1 S\left(X_d\right)+w_2 M\left(X_d\right) \tag{7}$$

In the equation, $S\left(X_d\right)$, $M\left(X_d\right)$ are respectively S -value of particle X_d and particles representing union membership numbers as M - value, and S is calculated by the algorithm of the earliest completion time of task allocation; W_1 , W_2 are respectively the weight of $S(X_d)$, $M(X_d)$ in fitness functions, $W_1 + W_2 = 1$,in this paper, $W_1 = 0.6$, $W_2 = 0.4$.

B. Particle position and velocity update

Particle position matrix X is expressed as the state matrix of dynamic alliance. In PSO algorithm, the particle velocity is expressed as change quantity which is the next position of particle relative to that of the previous position, therefore define particle velocity matrix in DPSO algorithm as $V = [V_1, V_2, \cdots V_d \cdots, V_D]$.

Among which $V_d = [v_{d1}, v_{d2}, \cdots, v_{dj}, \cdots v_{DM}]$, $v_{dj} \in \{1,2,3\}$, representing the particle X_d 's movement speed. Among, v_j represents updating formula of the particle velocity of speed matrix as

$$V_d^k = \frac{1}{2} ceil(w * V_d^{k-1} + c_{11} * rand * (p_{\mathrm{dbest}} - X_d^{k-1}) + c_{21} * rand * (g_{\mathrm{best}} - X_d^{k-1})) \tag{8}$$

In the equation, k as iterations, d as the particle number; V_d^k as the speed matrix of number k iteration medium particle, w as the inertial factor, c_{11} , c_{21} for learning factors, $rand$ for random number uniformly distributed between 0 and 1, p_{dbest} for current optimal solution of particle X_d , g_{best} for the current optimal solution in a general manner, X_d^{k-1} for the position of the particle X_d in the iteration.

Updating formula for particle location as

$$x_{dj}^k = \begin{cases} x_{dj}^{k-1} & v_{dj}^k = 2 \\ x_{dj}^k & v_{dj}^k \neq 2 \end{cases} \tag{9}$$

In the equation, x_{dj}^k is expressed as the number j dimension values of the number d particle position in the number k iteration.

C. Improved PSO task scheduling algorithm

Inertia weight in PSO algorithm is used to balance global convergence and convergence speed, and the larger w is beneficial to global search, whereas the smaller one is advantageous to the local search[10] .In this article, set $w = 1$, $c_{11} = c_{21} = 1.41$. Due to improve PSO algorithm, so this article adopts DPSO algorithm in the early stage and adopts TS algorithm in the late period, which determines to set running conditions of TS algorithm. This paper takes the relative change rate of the current optimal value as the initial condition of TS algorithm.

The followings are task scheduling processes for the improved PSO algorithm.

1) Particle initial position of random initialization is X (alliance) and historical best position of each particle is p_{dbest} , and tabu table is initialized to be null.

2) The current optimal solution is g_{best}

3) To judge if it is satisfied with initial conditions of TS algorithm, if satisfied, to execute step 7, otherwise step 4.

4) Evaluate the fitness of each particle.

5) Update p_{dbest} and g_{best} . For each particle, comparing $F(X_d)$ with p_{dbest} , if $F(X_d)$ is superior to p_{dbest} , $F(X_d)$ should be used to replace the individual optimal value p_{dbest} .Comparing individual optimal value p_{dbest} and g_{best} , if individual optimal value is more superior, it should replace g_{best} .

6) In accordance with equation(8) and (9) update Particle velocity $V_d{}^k$ and position $x_{dj}{}^k$, and execute step 3.

7) To judge whether to meet the termination criterion, if met, output g_{best} , and end the algorithm, or generate a number of current neighborhood solutions, and choose the candidate solutions.

8) determine whether to meet contempt rules, if satisfied, use particles which are corresponded to the solutions satisfied with contempt rules to replace the particles earliest put in the taboo table, update g_{best} , and execute step 7, otherwise to determine the taboo attributes of candidate solutions ,take the best candidate solutions which are not taboos as g_{best} , use particles corresponding to the solution to replace the particles earliest put in the taboo table, and execute step 7.

The followings are calculation algorithms for $F(X_d)$ and U_{ave} .

1) Calculate the value of $M(X_d)$ that particles are corresponding to.

2) Take out a task from the beginning of task sequence, and calculate the estimated finish time of the task on each processor

3) Compare all estimated finish time, and take the minimum value.

4) To process tasks by assigning to corresponding processors which are taken out as the minimum value, and save the earliest start time of the next task on the processors, and delete the task.

5) To judge if the task is completed, if completed, execute step 6, otherwise step 2.

6) According to the results of distribution to calculate the value of $S(X_d)$ and E.

7) According to $M(X_d)$, $S(X_d)$, E ,calculate $F(X_d)$ and U_{ave} .

IV. THE SIMULATION AND THE RESULT ANALYSIS

This article uses Matlab for algorithm simulation. Assumes that the number of system processors $M = 10$, number of tasks $N = 100$,and the number of iterations $K = 300$. Processor power matrix obeys randomly uniform distribution of 0.5~1.5, the estimated execution time of the task on standard processors obeys randomly uniform distribution of 1~10, the number of particles $D = 40$, and number of neighborhood solutions $l_1 = M*(M-1)/2$.

Figure 3 shows in the iterative process, the changes of current optimal value, and Fig.4 shows the relative change rate of current optimal value in the process of iteration relative to that of the previous iteration.

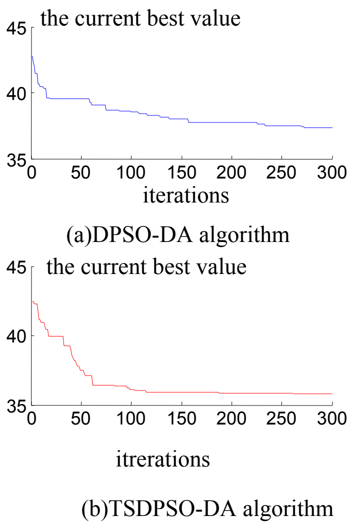

Figure3. iterative processes of the two algorithms

Figure 5 shows the processor utilization on average among the Earliest completion Time (Earliest Finish Time, EFT) algorithm, the DPSO and TSDPSO - DA - DA algorithm under the condition of different tasks, and the results are the average value after performing this algorithm for five times. Obviously, if the result is smaller when the task number divides the processor, the processor average utilization rate is higher; after adding TS algorithm, the processor average utilization rate is further improved.

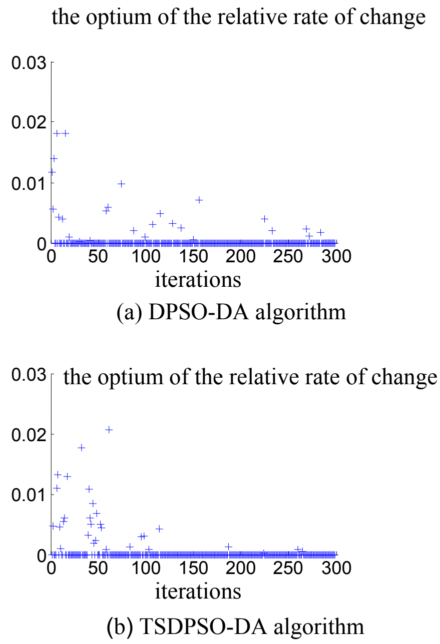

Figure 4. The change rate of optimal values of two Algorithms

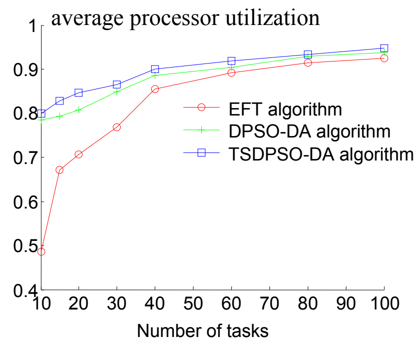

Figure 5. CPS model of coal preparation plant

V. CONCLUSIONS

This paper introduces the CPS in coal preparation plant automation system, and builds the model of coal preparation plant CPS based on multiple Agents; According to task scheduling problems of the model, TSPSO-DA algorithm is proposed. Simulation results show that, compared with algorithms of EFT and DPSO–DA, this algorithm has significant advantages in the aspects of the average system processor utilization, convergence speed and the precision which can effectively solve the CPS task scheduling problem of coal preparation plant.

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