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A path planning method using adaptive polymorphic ant colony algorithm for smart wheelchairs

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ABSTRACT

In many cases, users of smart wheelchairs have difficulties with daily maneuvering tasks and would benefit from an automated navigation system. With multi-colony division and cooperation mechanism, the polymorphic ant colony algorithm is helpful to solve optimal path planning problems by greatly improving search and convergence speed. In this paper, a path planning method for smart wheelchairs is proposed based on the adaptive polymorphic ant colony algorithm. To avoid ant colony from getting into local optimum in the process of reaching a solution, the adaptive state transition strategy and the adaptive information updating strategy were employed in the polymorphic ant colony algorithm to guarantee the relative importance of pheromone intensity and desirability. Subsequently, the search ant maintains the randomness for the search of the global optimal solution, and then the deadlock problem is solved by means of the direction determination method that improves the global search ability of the algorithm. The target path planning and obstacle path planning are respectively carried out by using the adaptive polymorphic ant colony algorithm. Experimental results indicate that the proposed method provides better performance than the improved ant colony algorithm and the polymorphic ant colony algorithm. Furthermore, the efficiency of finding an optimum solution is higher than the average polymorphic ant colony algorithm. The proposed method, which achieves superior performance in path planning for smart wheelchairs, is even racing ahead of other state-of-the-art solutions. In addition, this study reveals the feasibility of using it as an effective and feasible planning path tool for future healthcare systems.

1. Introduction

Smart wheelchairs give people with disabilities not only mobility but also the necessary help and support to handle daily living activities. The smart wheelchair combines a variety of research fields, such as machine vision [1], robot navigation and positioning [2], pattern recognition [3], multi-sensor fusion [4] and human-machine interface [5]. Especially in automatic navigation, accurate path planning results will greatly improve the performance of a smart wheelchair [6]. It is desirable to use reliable path planning methods to enhance awareness of the status of contemporary smart wheelchair technology, and ultimately increase the functional mobility and productivity of users. Intelligent optimization algorithms, which are simple, efficient and adaptive, have been introduced to solve path planning problems, especially in infrastructures and facilities for healthcare [7–9]. Ant colony optimization is an intelligent search algorithm developed by Marco Dorigo's doctoral thesis from a long-term observation of ant colony foraging behaviors [10]. Different from other path planning techniques, for instance, heuristic search or potential fields, it is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. Hence ant colony algorithm has widely used in transportation, logistics and distribution, network analysis, pipeline and other fields in recent years [11,12].

At present, a large number of scholars are doing applied research on the ant colony algorithm. For instance, Xia et al. studied the issues of dynamic nature, instability and multi QoS property restrictions of Web service in the process of services combinatorial

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optimization, and proposed a multiple pheromone dynamically updated ant colony algorithm [13]. Sheng et al. proposed a credible service discovery method based on the improved ant colony algorithm for the service discovery problems in the unstructured P2P networks [14]. Luo et al. proposed an improved ant colony algorithm based on dynamic node planning for the problem of selection of optimal measuring points for analog circuit [15]. Shan et al. employed the ant colony algorithm to the smart wheelchair path planning method to solve the problems of local optimal in the path search process for the smart wheelchair [16]. Mohamed et al. proposed multi-division vehicle routing problems based on the hybrid ant colony algorithm by combining local search and basic ant colony algorithm [17]. Although the ant colony algorithm is widely used, and reflects good search features during the path optimization, it has shortcomings of likeliness to fall into local optimum and long search time, etc [18,19].

In traditional ant colony algorithms, the paths are gradually explored by ants and the search efficiency of the algorithms is low. To solve this problem, many scholars put forward some improved methods to cope with such problem. Yao et al. put forward the adaptive parallel ant colony algorithm [20]. With the aid of this method, it can determine the optimal combination of parameters depending on the search stage to avoid stagnation to a certain extent. Hu et al. applied dynamic calls and the rule of increase of pheromone on the optimal path into the basic ant colony algorithm, and proposed the optimal path model with a number of path quality constraints [21]. Du et al. designed the improved polymorphic ant colony algorithm based on the secondary annealing mechanism according to the advantages of the polymorphic ant colony algorithm and the simulated annealing algorithm, allowing the pheromone release to reflect the path quality better than before [22]. Li et al. introduced the roulette method to the state transition rule, and classified the search into local search and global search. By doing so, it avoid the algorithm from falling into local optimum [23]. Yang et al. proposed the improved ant colony algorithm by combining group intelligence and local search, effectively solving the multi-dimensional problem in the traveling salesman problems [24].

Containing a variety of ant colonies and pheromones, the polymorphic ant colony algorithm combines local search and global search, allowing the searching speed and convergence speed to be greatly improved [25–27]. In this paper, an adaptive polymorphic ant colony algorithm is proposed to solve the path planning problem in smart wheelchairs. The search ant makes state transition according to the pseudo-random rule, and combines the state transition strategy and the adaptive parallel strategy of the search ant during the search to get the adaptive state transition strategy and the adaptive information strategy to avoid the algorithm from falling into local optimum. By employing the direction determining method, the deadlock problem was properly addressed and the increased efficiency of global search in a complex environment is achieved. The adaptive polymorphic ant colony algorithm proposed is applied separately to the target path and obstacle path planning experiments, and the experimental results are compared with the results obtained from the improved ant colony algorithm and the general polymorphic ant colony algorithm. The comparison shows, that the adaptive algorithm in this paper is better to implement the path planning for smart wheelchairs with fewer iterations and higher search efficiency.

2. Polymorphic ant colony algorithm

The multi-colony ant colony is introduced into the polymorphic ant colony algorithm based on the basic ant colony algorithm, which includes scouts, search and worker ants. Scouts take the path node of each wheelchair as the center and leave the investigation elements during the investigation, so that search ants may make a choice when they arrive at the path node. Scouts and search ants work in the polymorphic ant colony and perform tasks as follows:

Scouts: The scouts (quantity: m) are placed separately on the path nodes of the wheelchairs (quantity: n), and each scout investigates the path nodes of the other wheelchair (quantity: $n-1$), taking the path node of the wheelchair as the center, and combines the result of the investigation with the existing information to constitute the investigation element referred to as $s[i][j]$ and marked on the path from the path node i to the path node j. $s[i][j]$ ($i, j = 1, 2, \ldots, n-1, i \neq j$) is calculated by the following formula:

$$s[i][j] = \begin{cases} \dfrac{d_{ij}^{\min}}{d_{ij}}, & \text{path node } j \text{ is in the selectable range of the path node } i \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where d_{ij} the total path of the selected ant; $d_{ij}^{\min}$ is the minimum distance to the other $n-1$ path nodes when taking the wheelchair path node i as the center.

Based on this result, the information amount on each path at the initial time is set firstly as follows:

$$\tau_{ij}(0) = \begin{cases} C \cdot s[i][j], & s[i][j] \neq 0 \\ \dfrac{C \cdot d_{ij}^{\min}}{d_{ij}^{\max}}, & \text{otherwise} \end{cases} \tag{2}$$

where $d_{ij}^{\max}$ is the maximum distance to the other $n-1$ path nodes when taking the path node i as the center. C is the information amount on each path at the initial time.

Search ant: the adaptive transition probability $p_{ij}^{k}(t)$ of ant k ($k = 1, 2, \ldots, m$) from the path node i to the path node j in the search process is calculated as follows:

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{\tau_{ij}(t)^{\alpha} \cdot \eta_{ij}(t)^{\beta}}{\sum\limits_{h \notin tabu_k} \tau_{ih}(t)^{\alpha} \cdot \eta_{ih}(t)^{\beta}}, & j \notin tabu_k \text{ and } s[i][j] \neq 0 \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where $\tau_{ij}(t)$ is the information amount on the path (i, j) at the time t; $\eta_{ij}(t)$ is the heuristic function, and its expression is $\eta_{ij}(t) = \frac{1}{d_{ij}}$; α is the information heuristic factor, representing the relative importance of the path; β is the desired heuristic factor, representing the relative importance of the visibility; $tabu_k$ is the taboo collection, and t is the amount of evolution generation.

After all the ants complete a cycle, the pheromone on each path is updated as the following formula:

$$\tau_{ij}(t+1) = \begin{cases} \rho \cdot \tau_{ij}(t) + (1-\rho) \cdot \Delta\tau_{ij}(t), & s[i][j] \neq 0 \\ \rho \cdot \tau_{ij}(t), & \text{otherwise} \end{cases} \tag{4}$$

Where ρ is the pheromone evaporation factor, $1-\rho$ is the pheromone residual factor; in order to prevent the unlimited accumulation of information, the value range of ρ is $P \subset [0, 1)$; $\Delta\tau_{ij}(t)$ is the amount of information released by all the ants on the path (i, j) in this cycle, and $\Delta\tau_{ij}(t) = \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t)$.

$\Delta\tau_{ij}^{k}(t)$ is the amount of information released by ant k on the path (i, j) in this cycle, and its formula is as follows:

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \dfrac{Q \cdot (d_{ij}^{\min}/d_{ij})}{L_k}, & \text{ant } k \text{ goes through} (i, j) \text{ and } s[i][j] \neq 0 \\ 0, & \text{otherwise} \end{cases} \tag{5}$$