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Soccer robot path planning based on the artificial potential field approach with simulated annealing

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SUMMARY
The paper presents research on the APF approach for solving the GNRON and local minima problems. The repulsive potential function is modified in order to solve the GNRON problem. A simulated annealing algorithm integrated into the APF has solved the local minimum problem. The improved APF is applied to the path-planning problem of soccer robots. The simulated experiments show the validity of this approach.

KEYWORDS: Path planning; Artificial potential field; Simulated annealing; GNRON problem

1. INTRODUCTION

Path planning is an important problem in the field of mobile robots. Its purpose is to find a collision-free path from the initial state, say, position and pose, to the goal state according to certain criteria in an environment full of obstacles. The main methods of path planning include the artificial potential field (APF) approach,[1–5] the grid approach,[6] genetic algorithms,[7] and so on. Among these methods, the APF approach is particularly attractive because of its mathematical elegance and simplicity. This study adopts the basic principle of the APF approach and applies it to path planning of soccer robots.

Soccer robot competitions are newly high technological activities that have developed over recent years. Path planning and collision avoidance are two important components in the competition. In the soccer robot environment, a "goal non-reachable with obstacles nearby" (GNRON) problem frequently occurs.[3] To overcome the GNRON problem, new repulsive potential functions have been provided by taking the relative distance between the robot and the goal position into consideration. Additionally, the simulated annealing technique is integrated with the APF approach to solve the local minima problem of the APF approach.

2. PATH PLANNING PROBLEM

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2.1. The Traditional APF Approach

Khatib first developed the application of artificial potential fields to path planning.[1] The basic principle of this approach is to construct attractive potential fields U_{att} around the goal to attract the robot and to construct repulsive potential fields U_{rep} around the obstacles to force the robot away. Consequently, a multiplex potential field U is formed with the above two potential fields reacting together. The attractive force, F_{att}, from the attractive potential field and the repulsive force, F_{rep}, from the repulsive potential fields drive the robot to its goal position as shown in Figure 1.

In mathematics, the task is to search the potential field function downhill to find a path avoiding collision from the initial position to the goal position. The attractive potential field function, the attractive force, the repulsive potential field function, the repulsive force, the multiplex potential field function and the composition of the forces are given by expressions (1)–(6), respectively.

$$U_{att}(X)=\frac{1}{2}k_a|X-X_{goal}|^2 \tag{1}$$

where k_a *is the constant of attractive potential field*, X is the position vector of the robot, and X_{goal} is the position vector of the goal.

$$F_{att}=-\nabla U_{att}=-k_a|X-X_{goal}| \tag{2}$$

$$U_{rep}(X)=\begin{cases}\frac{1}{2}k_r\left(\frac{1}{\rho(X,X_{obs})}-\frac{1}{\rho_0}\right)^2 & \text{if } \rho\le\rho_0\\ 0 & \text{if } \rho>\rho_0\end{cases} \tag{3}$$

where K_r is a constant repulsive potential field, and ρ_O represents the limited distance of the potential field influence, and $\rho(X, X_{obs})=|X-X_{obs}|$ is the distance to the obstacle.

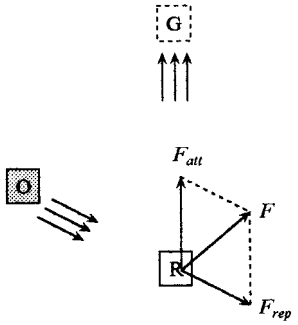


Fig. 1. Force in artificial potential fields.

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$$F_{rep} = -\nabla U_{rep}$$

$$= \begin{cases} k_r\left(\dfrac{1}{\rho(X, X_{obs})} - \dfrac{1}{\rho_0}\right) \dfrac{1}{\rho(X, X_{abs})^2} \nabla\rho(X, X_{obs}) & \text{if } \rho \le \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases} \quad (4)$$

$$U = U_{att} + U_{rep} \quad (5)$$

$$F = F_{att} + F_{rep} \quad (6)$$

2.2. The GNRON Problem

2.2.1. The Cause of the GNRON Problem. In most previous studies, the goal position is set relatively far away from obstacles. In these cases, the repulsive force due to obstacles is negligible, and the robot will be attracted to the goal position by the attractive force when the robot is near its goal position. However, in many real applications, the goal position may be quite close to an obstacle. Under these circumstances, when the robot approaches its goal, it approaches the obstacle as well. If the repulsive force is much larger than the attractive force the robot cannot reach its goal position due to the obstacle nearby.

Suppose the goal position of the robot is (0, 0), and the position of the obstacle is (1, 0) as shown in Figure 2. The GNRON problem can be analyzed as follows:

Let $k_a = 1$, $k_r = 1$ and $\rho_0 = 2$, then the attractive potential field function and the repulsive potential field function can be given by

$$U_{att} = \frac{1}{2}x^2$$

$$U_{rep}(X) = \begin{cases} \dfrac{1}{2}k_r\left(\dfrac{1}{|x-1|} - \dfrac{1}{2}\right)^2 & \text{if } |x-1| \le 2 \\ 0 & \text{if } |x-1| \le 2 \end{cases}$$

As shown in Figure 2, the robot should move to the goal position directly without considering the effect of the obstacle. In fact, the robot will be trapped at the minimum $x = -0.22$ where the composition of forces becomes zero (see Figure 3). The robot cannot reach the goal position, though there are no obstacles in its way. In short, the essential cause of the GNRON problem is that the goal position is not a minimum of the multiplex potential field function.

2.2.2. The Solving of the GNRON Problem. It has been found that if the repulsive potential field function

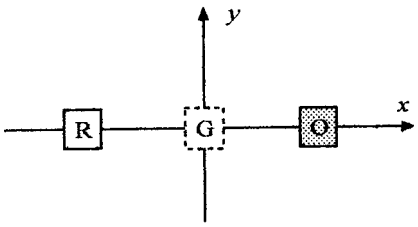


Fig. 2. The case of GNRON.

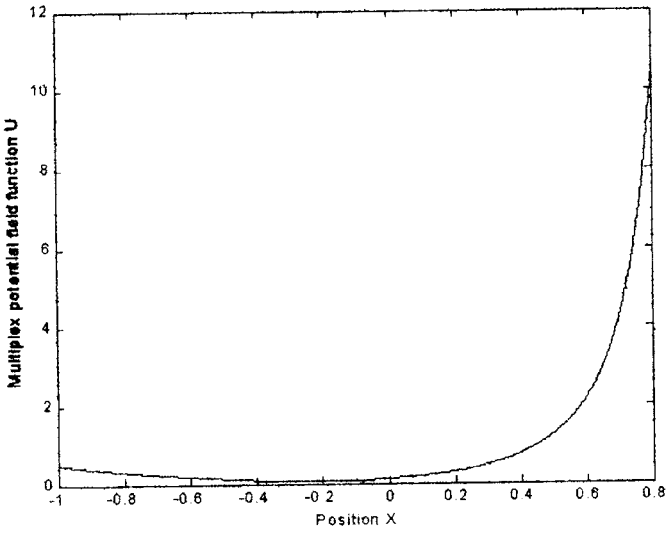


Fig. 3. The potential field function curve before modification.

approaches zero as the robot approaches the goal position, and the multiplex potential field function will be a global minimum when the robot reaches it. Therefore, a new repulsive potential field function, by taking the distance between the robot and goal into account,[3] is given by

$$U_{rep}(X) = \begin{cases} \dfrac{1}{2}k_r\left(\dfrac{1}{\rho(X, X_{obs})} - \dfrac{1}{\rho_0}\right)^2 \rho^2(X, X_{goal}) & \text{if } \rho \le \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases} \quad (7)$$

where $\rho(X, X_{goal}) = |X - X_{goal}|$

$$F_{rep} = -\nabla U_{rep}$$

$$= \begin{cases} k_r\left[\left(\dfrac{1}{\rho(X, X_{obs})} - \dfrac{1}{\rho_0}\right)\dfrac{\rho^2(X, X_{goal})}{\rho^2(X, X_{obs}}\nabla\rho(X, X_{obs}) \right. \\ \left. -\left(\dfrac{1}{\rho(X, X_{obs})} - \dfrac{1}{\rho_0}\right)^2 \rho(X, X_{goal})\nabla\rho(X, X_{goal})\right] & \text{if } \rho \le \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases} \quad (8)$$

In Figure 4, the minimum of the modified potential field function is $x = 0$, that is the goal position.

2.3. SA-APF Approach

There is a major problem in the APF approach, the formation of local minima can trap the robot before it reaches its goal position. The avoidance of the local minima has been an active research topic in the potential field path planning. The main classes of methods include: (i) The redefinition of the potential functions with no or a few local minima; and (ii) the utilization of effcient search techniques with the capability of escaping from the local minima. In this paper, the simulated annealing algorithm is adopted to solve the problem of the local minima, so it can be called the SA-APF approach.

The simulated annealing algorithm can simulate the annealing process of solid matter. It appears when the

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matter at a high temperature cools its energy decreases. If the cooling process is slow enough, the matter system will be balanced during the process. Then when it reaches a certain lower temperature, its energy will be minimal. Whereas, if the cooling process is fast, the matter can keep equal energy when a certain lower temperature is reached. The optimal method that simulates the annealing process is called Simulated Annealing (SA) algorithms. The steps of an SA algorithm are as follows:[5]

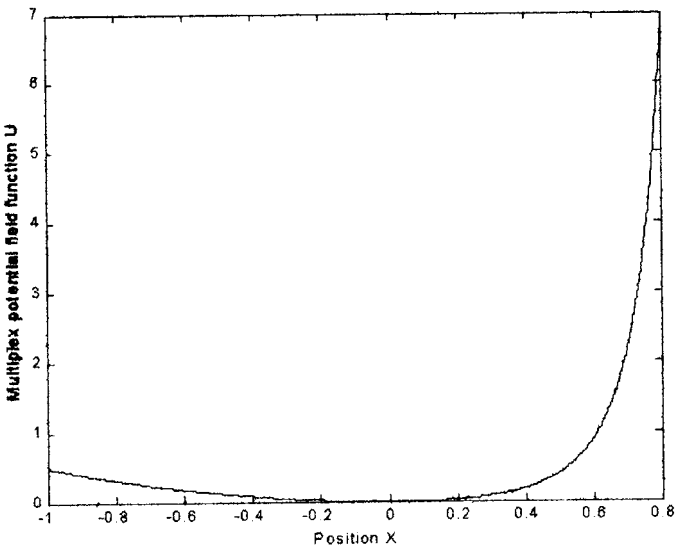


Fig. 4. The modified potential field function curve.

(i) Set initial state X and its initial temperature T_0 according to the annealing strategy.
(ii) Let $X'=X+\Delta X$ (where ΔX is a stochastic disturbance subject to a small uniform distribution), and compute $\Delta E=E(X')-E(X)$.
(iii) If $\Delta E<0$, then set X' new state; else, regard X' as new state according to the probability $P=\exp(-\Delta E/kT)$, where k is the Boltzmann constant. We can also choose a random number α between 0 and 1. If $P>\alpha$, set X' new state, else stay at X.
(iv) Repeat steps (ii) and (iii) until the balance state is obtained. Repeat the two steps a given number of times.
(v) Decrease T according to the annealing strategy in step (i). Repeat steps (ii)–(iv) until $T=0$ or the given temperature is obtained.

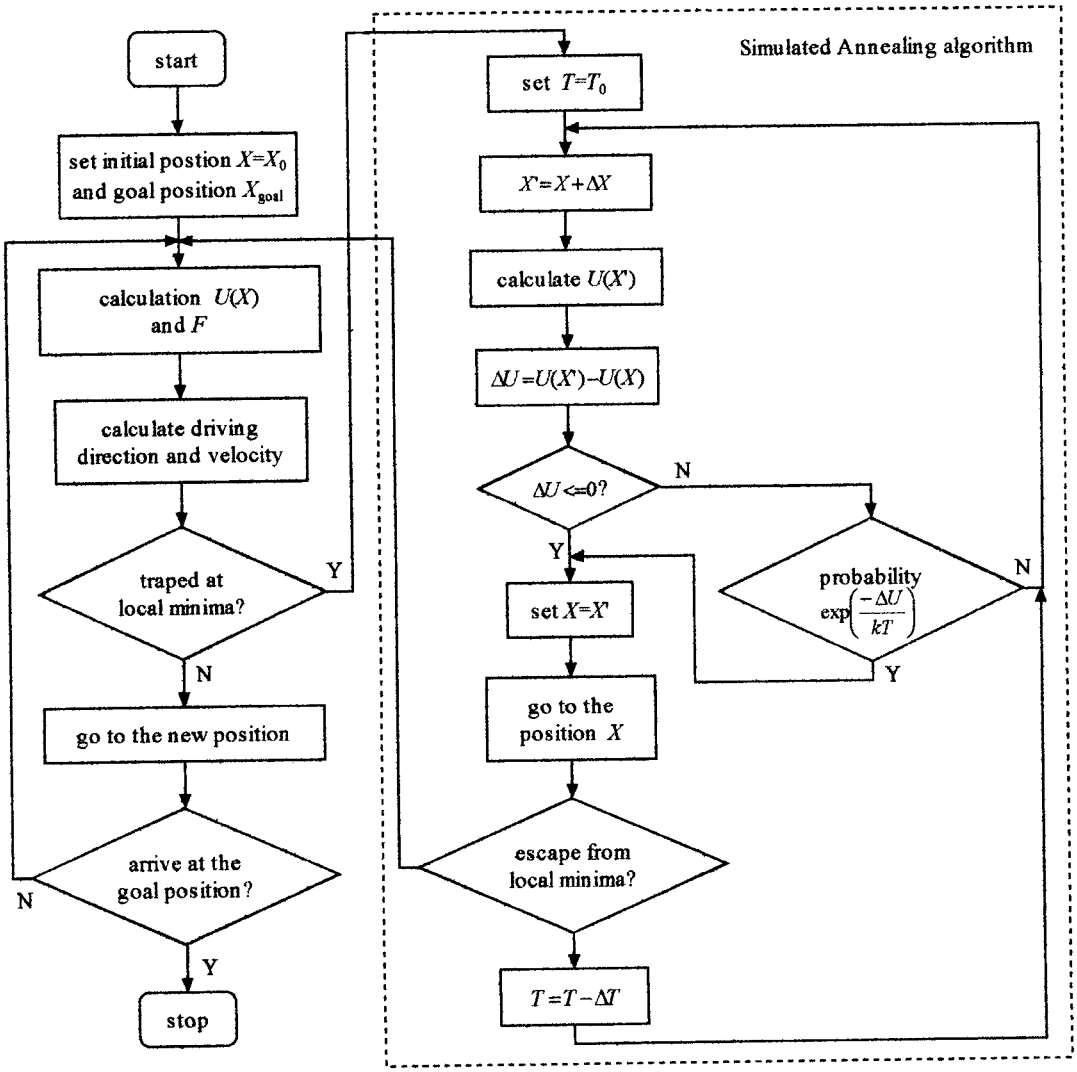


Fig. 5. Path planning algorithms.

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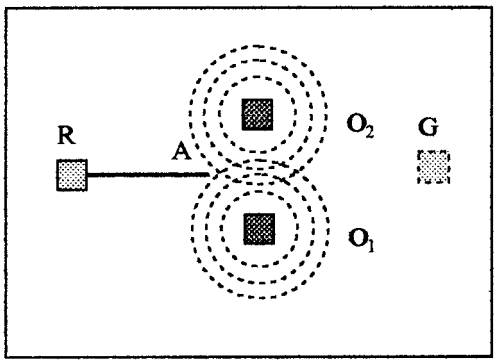


Fig. 6. The path of traditional APF.

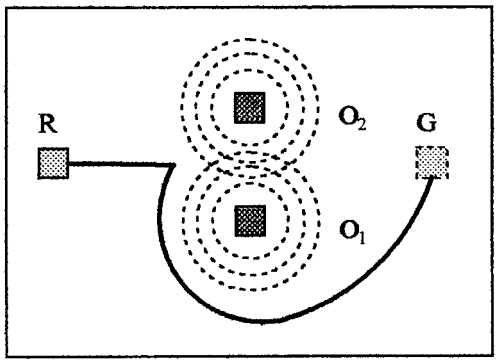


Fig. 7. The path of SA-APF.

From the above steps, when $\Delta E>0$, X' has the probability to be regarded as a new state to escape the local minimum. If T is higher, the probability is greater. In theory, the temperature decreases below $T(t)=T_0/1+\ln t$ $(t=1,2,3\cdots)$. We usually use $T(t)=\alpha T(t-1)$, where α is smaller than 1 but near to 1, the reference value is $0.85\leq\alpha\leq0.98$, t is the time variable.

Then, the path planning algorithms are shown in Figure 5.

To evaluate the performance of the proposed algorithms, two experiments were performed. One adopts the traditional artificial potential field approach, as shown in Figure 6, in which the robot is trapped at the local minimum A. The other adopts the improved SA-APF approach, as shown in Figure 7, in which the robot escapes from the local minima and reaches the goal position successfully.

4. CONCLUSION

This paper settles the main deficiency of the APF approach. To solve the GNRON problem of the soccer robot, new repulsive potential functions have been provided by taking the relative distance between the robot and the goal position into consideration. Additionally, the simulated annealing technique is integrated within the APF approach to solve the local minima problem. The results of simulations demonstrate its validity. The improved APF approach integrated with the SA algorithms is also suitable for path planning for other mobile robots.

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