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A PURSUIT-EVASION GAME ALGORITHM BASED ON RAPID-RESPONSE VIRTUAL FORCE MODEL

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ABSTRACT

One-on-one pursuit evasion game is the ideal research project for optimal search of agent. Without primal information about circumstance and evasion, it is helpful of enlighten search model for suiting to evade game. Virtual Force Model is one of most common enlighten random model. But it will make a center vibration in balance circumstance. This paper presents a rapid response virtual force model, which will rapidly generate the enlighten information and also solve the problem of center vibration. The simulation shows that the Rapid Response Virtual Force Model can achieve the optimal search for agent.

Keywords: *Pursuit-Evasion Game, Optimal Search, Virtual Force Model, Random Walk Mobility Model*

1. INTRODUCTION

Along with the miniaturization of LSI, technologies such as SOC, AI, computer control and high efficiency cell promote the rapid development of the mobile detection sensor in the practical life and have been applied in the daily life to continuously improve our living environment and make our life better [1].

However, mobility agent perfectly solving practical problems is still one of the major difficulties for the scientific cycle at present. Researchers wish that the mobility agent might complete a large quantity of repetitive work, work under hazardous environment, toxic waste and nuclear pollution disposal, planet exploration, battlefield operations, mine clearance, reconnaissance, rescue and other work instead of human. Although mobility agent has been competent in single and simple problems within a limited scale, as the task becomes more and more complicated, the adaptive capacity of the mobility agent becomes lower and lower, or even zero. As a result, we still have to struggle to research the mobility agent [2].

The pursuit-evasion game of mobility agent is an ideal topic to research the optimal search of mobility agent. Optimal search is an emerging science for scholars to research the efficiency of the search strategy in various scientific applications. It is closely related to the statistical decision-making theory of statistics and the optimal theory of applied mathematics. One-to-one situation is the most fundamental in the pursuit-evasion game of mobility agent, in which confrontation and game between the pursuer and evader shall be especially considered, since such hostile game strategy shall be solved by the intelligent processing algorithm. Current researches on the pursuit-evasion game of mobility agent mostly base on the precondition that the pursuer has understood the environment and some prior information of the evader, which is a favorable condition for the search. For example, precondition of the search probability model is that the prior distribution characteristic of the evader in the environment to be searched has been understood. However, actually, in most situations neither pursuer nor evader has understood any prior information of the other. As a result, it is more valuable to research the one-to-one pursuit-evasion game of mobility agent without any understanding of the environment or prior information of the evader [3].

2. RELATED WORK

The optimal search problem of the pursuit-evasion game of mobility agent firstly took place in the search for the submarine by the search strategy in the World War Two. This theory focuses on how to design an intelligent search strategy to maximize the detection of the searched target or minimize the resource or time cost in searching the target. There are altogether five stages in the development of the optimal search. The first stage is the classical stage

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focusing on the optimized search of the static target. It mainly utilizes the probability statistic model to optimize the search of the static target by the searching force [4].

The second stage is the mathematical stage focusing on the establishment and research on the mathematical model of the optimal search from the perspective of the mathematical analysis. It transfers the searched target from the static target to the mobile target [5].

The third stage is the algorithm stage, in which the algorithm about intelligent search is researched and developed. It mainly applies the search force model in the search of the practical mobile target and forms the related intelligent algorithm [6].

The fourth stage is the dynamic stage, which mainly utilizes the probability distribution model of the target to predict the information of the evader to dynamically plan the pursuer resource [7].

The fifth stage is the modern research stage, which mainly combines various search strategies with the application platform to optimize the configuration of more mobility agents to realize more rapid and accurate search [8].

Since the application environment of the optimal search is very complicated, currently there is no any universal optimal search method for all circumstances. As a result, most search methods are carried out by enlightenment. Reference [9] utilizes "return rate" to enlighten the search to realize the optimal search of the UAV. Reference [10] adopts the Markov chain information as the enlightening information to control the search of the mobility agent. Reference [11] adopts the predicted target distribution probability as the enlightening information to control the search of the mobility agent. Reference [12] utilizes two considerations, namely, partial optimal and overall optimal to control the mobility agent.

It can be inferred from the above analysis that currently most researches utilize certain prior information of the evader and the environment to form the enlightening information to realize the optimal search. Actually, in most situations, such prior information such as battlefield environment is difficult to obtain. As a result, the optimal search without any prior information is necessary. Besides, energy limit on the mobility agent from the carrier shall also be considered to realize the search planning more rapidly with fewer requirements on the calculation. This article proposes a virtual force model on the rapid response to realize the enlightening optimal search for the unknown target in the unknown environment. Besides, this algorithm also reduces the calculation amount of search.

3. RAPID-RESPONSE VIRTUAL FORCE MODEL ALGORITHM

Virtual force model is the most common method in the search enlightenment. Its core concept is to convert various enlightening information to an acting force to control the mobility agent to search along the direction calculated by the enlightening information to obtain an enlightening optimal search algorithm. The following is the analysis of the mathematical model of this algorithm.

3.1 Detection Model

Detection sensor of the mobility agent is one of the aspects that the optimal search shall consider. Coverage area of the detection sensor is the information obtained by one mobile search from the monitored area. The most common detection model is the binary detection mode, whose formula is:

$$p_d = \begin{cases} 1, d \le d_t \\ 0, d_t \le d \end{cases} \quad (1)$$

p_d is the detection probability of the detection sensor of the mobility agent towards the object. When distance between the mobility agent and the object is less than d_t, the sensor is bound to detect the object, and when distance between the mobility agent and the target is over d_t, the target will no longer be detected.

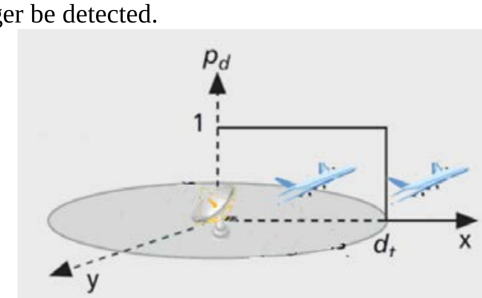

Figure 1: Detection Probability Model Of Mobility Agent

3.2 Virtual Force Model

Since this algorithm is for the unknown search environment where the information of the evader is also unknown, the enlightening virtual force model to be considered only contains the existing track information of the mobility agent. As a result, there are mainly two suitable kinds of virtual forces, one of which is the repulsion force. It is mainly for the

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area that has been detected by the mobility agent. Although the evader may also exist in such area, the probability is quite less than that in other undetected areas. The mobility agent shall be inclined to search the undetected area, so the undetected area generates a kind of attraction force to the mobility agent. Formula of the virtual force is shown in Formula 2:

$$F_{virtual} = \int_{search-area} F_{appeal} ds + \int_{search-area} F_{eclude} ds \quad (2)$$

As for the area that has been detected even earlier, the probability of evader is larger than that of the area that has been detected recently. Therefore, as the time goes on, the repulsion force of the detected area attenuates, and the rapid-response virtual force model algorithm utilizes the attenuating factor to rectify the repulsion force of the detected area. The formula is shown in Formula 3:

$$F_{eclude} = \frac{w}{Dist^2} \quad (3)$$

w is the attenuating factor and $Dist$ is the distance between the detected area and the mobility agent.

3.3 Center Shock Principle of Balanced Area

Since the mobility agent grasps no prior information of the search environment, overall trend of the attraction force to the mobility agent is moving to the search center, while the repulsion force model repulses the mobility agent from the center to the direction opposite to the track. However, once the mobility agent leaves the center, the attraction force of the undetected area will pull the mobility agent to the center again. In the event that there are only such repulsion force and attraction force, the mobility agent will shock in the center but cannot complete the search task. Potential field of shocking virtual force is shown in Fig. 2:

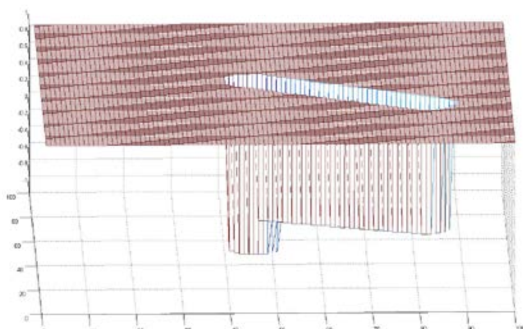

Figure 2: Potential Field Of Shocking Virtual Force

3.4 Algorithm Principle

Principle of the rapid-response virtual force model is that when calculating the overall information in the operation of the mobility agent, if there are more than one mobility agents in the search area, information exchange between mobility agents is necessary. This consumes the communication energy and increases the calculation amount of the mobility agent that it is quite intolerable for the application environment that requires much on the real-time property. As a result, reducing the calculation amount in each operation is one of the principal problems to be considered by such application environment.

Principle of the rapid response is that the mobility agent detects the area one by one from far to near to determine whether it has been detected. Once the undetected area reaches a certain threshold value, it stops the search and takes it as the final result of the attraction force but does not calculate the attraction force of the remaining part. This reduces the calculation amount without affecting the balance of the attraction force towards the center.

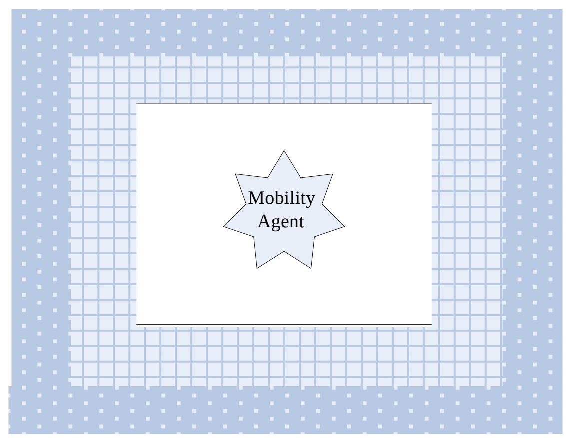

Figure 3: Rapid-Response Attraction Force Calculation Diagram

Different filling methods in Fig. 3 represents the times of attraction force calculation. The calculation follows the sequence from inside to outside until the calculated attraction force reaches the threshold value, and moves along the direction of the calculated virtual force.

After calculating the attraction force, it calculates the repulsion force as an adjusting factor to push the mobility agent to the direction opposite to the former track.

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4. EXPERIMENTAL RESULTS

To verify the search effect of the rapid-response virtual force model, this article utilizes the Monte Carlo Method to carry out the emulated verification of the search algorithm. Let us assume the search area as a [100000, 100000] area, assume the movement speed of the mobility agent as 3000, assume the maximum movement speed of the evader as 1000, assume the detection distance of the mobility agent as 5000, assume the mobility agent control model to be compared with the algorithm proposed by this article as the random walk mobility model, and assume any place within the search area as the place of the first appearance of the mobility agent and evader. Besides, to reduce the influence of the initialization to the minimum extent, let us assume that the mobility agent is firstly placed in the search area and the evader randomly appears later. Without prejudice to the generality, when the evader moves to the search boundary, emulated operation shall be carried out in the search area in the way of light refraction.

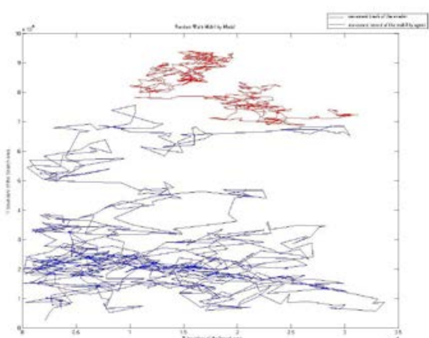
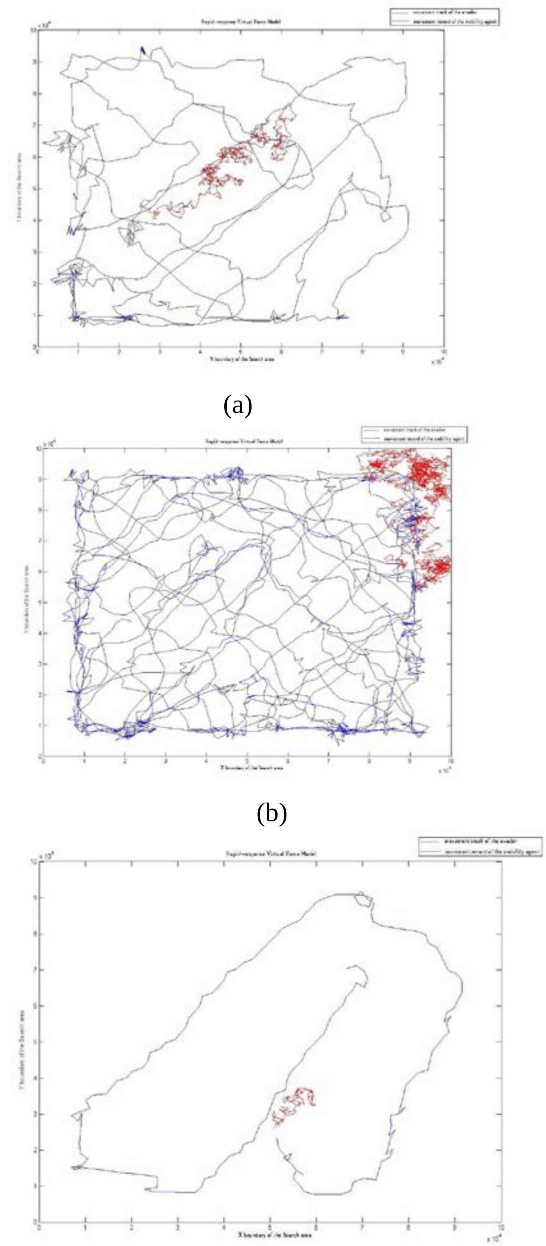


Figure 4: Emulated Search Of Random Walk Mobility Model

Fig. 4 is the emulation result of the random walk mobility model. Blue track is the movement record of the mobility agent. Red is the movement track of the evader. It can be seen from Fig. 4 that since there is no enlightening information, the mobility agent may repeatedly move within a small area, thus extending the final search time.



(a)

(b)

(c)

Figure 5: Emulated Search Of Rapid-Response Virtual Force Model

a, b, c in Fig. 5 represent the result of the three Monte Carlo emulation experiments. It can be seen from (a) and (b) that since the appearance time and movement of the evader are random, it is possible to search the target easily or for many times of attempts. Mobility agent in Fig. (b) costs longer time because the evader appears in the area that has been detected by the mobility agent in the past. It is also possible in the practice. It can be seen from Fig. (b) that the rapid-response virtual force model

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may control the mobility agent to move at a constant speed in the whole search space for a higher efficiency.

Fig. 6 shows search expectations of 10, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1,000 emulation experiments respectively calculated by the random walk mobility model and rapid-response virtual force model. These experiments are conducted without considering the initial condition. It can be seen from Fig. 6 that the search expectation of the random walk mobility model is between about 1,700 and 2,300 while that of the rapid-response virtual force model is between about 420 and 490, and the search time is greatly shorter than that of the random walk mobility model. Besides, search expectation of the random walk mobility model fluctuates largely at 25% around the center, while the fluctuation range of the rapid-response virtual force model is about 15% around the center. As a result, the stability of the rapid-response virtual force model is stronger than that of the random walk mobility model, indicating that the rapid-response virtual force model is quite effective in searching the randomly moving object and is able to stably search the evader.

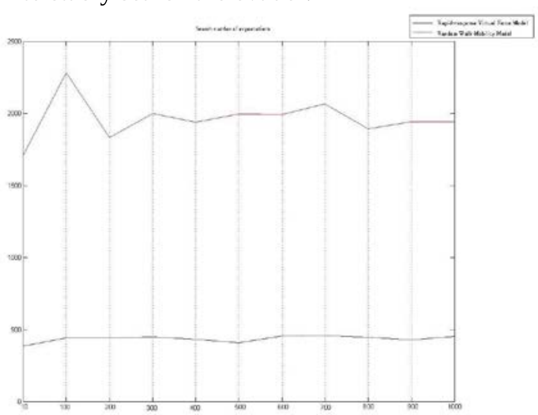

Figure 6: Emulated Search Expectation Result

It can be concluded from the above emulation experiment that the rapid-response virtual force model is able to more stably search the target. Due to the control by the enlightening information, the mobility agent may adopt the rapid-response virtual force model to better search the coverage area to detect the monitored area without the shock in some areas. Besides, since this algorithm begins to control the mobility agent to search the object after obtaining the required attraction force, its calculation and analysis amount is less than most virtual force models; therefore, this algorithm is advantageous in the intelligent calculation and analysis in the pursuit-evasion game and is able to elevate the utilization efficiency of the effective resource by the application environment.

5. CONCLUSION

As for the pursuit-evasion game of the evader whose prior information is unknown, this article proposes a virtual force calculation model on the rapid response, which calculates the attraction force from far to near around the mobility agent until the attraction force reaches the threshold, and controls the mobility agent to move along the direction of the calculated attraction force. Besides, it takes the existing track information as the repulsion force in the calculation to adjust the direction of the mobility agent. The enlightening information calculated by the algorithm only comes from the existing information of the mobility agent but needs no support from any other prior information. Besides, this algorithm adopts the rapid response characteristic to reduce the calculation amount to make it more applicable to the real-time application system that requires much on the calculation resource. The final emulation verifies the optimal search effect of the rapid-response virtual force model.

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