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A new moving target interception algorithm for mobile robots based on sub-goal forecasting and an improved scout ant algorithm

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ABSTRACT

It is difficult to make a robot intercept a moving target, whose trajectory and speed are unknown and dynamically changing, in a comparatively short distance when the environment contains complex objects. This paper presents a new moving target interception algorithm in which the robot can intercept such a target by following many short straight line trajectories. In the algorithm, an intercept point is first forecasted assuming that the robot and the target both move along straight line trajectories. The robot rapidly plans a navigation path to this projected intercept point by using the new ant algorithm. The robot walks along the planned path while continuously monitoring the target. When the robot detects that the target has moved to a new grid it will re-forecast the intercept point and re-plan the navigation path. This process will be repeated until the robot has intercepted the moving target. The simulation results have shown that the algorithm is very effective and can successfully intercept a moving target while moving along a relatively short path no matter whether the environment has complex obstacles or not and the actual trajectory of the moving target is a straight line or a complex curve.

1. Introduction

Tracking or interception of moving targets using mobile robots is a fundamentally important issue in robotics. Various types of applications, e.g., soccer robotics, automated guidance systems, and autonomous surveillance where the target may be any moving object and/or human (friend or enemy), may benefit from this field. As a result, this topic has attracted remarkable attention from many researchers, and many interesting research results have been obtained [1–19]. However, in many real applications the trajectory and speed of the moving targets are generally unknown and dynamically changing. In addition, the work place of the robot may have some complex obstacles. In such a situation, how to enable the robot to intercept the target along a comparatively short path is a difficult issue that has not been adequately solved. This paper presents an effective solution to solve this problem.

There have been many achievements on target tracking for mobile robots. The method of target tracking based on fuzzy logic [1–7] is one of the most common approaches. In [1,2], the authors present a new adaptive motion control algorithm that combines a grey-theory-based position prediction method with a look-ahead fuzzy logic control for the autonomous mobile target tracking task. In [3], a real-time fuzzy target tracking control scheme for autonomous mobile robots is designed by using infrared sensors, and it utilizes the fuzzy sliding-mode control scheme to realize related tracking behavior. Some scholars implement target tracking for multi-robot cooperation using fuzzy logic controllers in a game theoretic framework [7]. It is well known that the fuzzy control methods have some advantages such as the characteristic of intelligence and the ability to more easily simulate and incorporate human experience. But they also have flaws. For instance, proper fuzzy control rules have to be built by tracing the fuzzy control relations of the system. If the dynamic performance of the moving target is time-variant, the fuzzy control rules which are built beforehand may become improper. In some complex circumstances, more fuzzy rules are required to tackle extra dimensions in the spatiotemporal domain so that the process of fuzzy inference is time-consuming, which subsequently influences the real-time performance of tracking. Moreover, it is hard to obtain the optimal solution due to the indeterminacy of the fuzzy control.

The potential field method is particularly attractive because of its elegant mathematical analysis and simplicity. Therefore it is widely used in the field of autonomous mobile robot path planning. In recent years, this kind of method has been applied to the problem of target tracking by some scholars [8,9]. In [8], a new potential field method is proposed for motion planning of mobile robots in a dynamic environment where the target and the obstacles are moving. In [9], the author uses the potential field method

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for velocity planning for a mobile robot to track a moving target. The potential field method for motion planning of mobile robots in stationary environments has some notable disadvantages, and these problems still exist and may become more serious when the targets and obstacles are moving. For example, the robot can be trapped easily into local minima, and oscillation and deadlock may occur.

The method of target tracking based on geometry is another kind of effective approach [10]. The method in [10] is based on geometric rules combined with the kinematics equations of the robot and the moving target. The robot can track the moving target along a short path using this method. But if more complex obstacles exist in the environment, the method's implementation will become more difficult.

Visual methods and strategies are another family of methods widely used for target tracking [11–16]. For example, simulating the pursuit of a moving target using a robot based on artificial vision is considered in [11]. In [12], the authors deal with the problem of intercepting a moving target by a non-holonomic mobile robot using visual feedback. A real-time object tracking and collision avoidance method is presented in [13] for mobile robot navigation in indoor environments using stereo vision and a laser sensor, where stereo vision is used to identify the target and to calculate its relative distance from the mobile robot and the laser finder is used to avoid collision with surrounding objects. The algorithms based on artificial vision are quite efficient. However, they may suffer from two problems: on one hand, it is difficult for these algorithms to satisfy the real time requirement in practice as they need to deal with a huge amount of data collected by the camera, which is a time-consuming process. On the other hand, there is one prerequisite for these algorithms that the moving target must stay within the camera scope, which requires real-time camera calibration. Otherwise, the navigation algorithm could fail.

There are other methods for moving target tracking such as roadmap-based motion planning [17]. In [19], authors propose an efficient grid-based distance-propagating dynamic system for real-time robot path planning in dynamic environments, which incorporates safety margins around obstacles using local penalty functions. The path through which the robot travels minimizes the sum of the current known distance to a target and the cumulative local penalty functions along the path. The algorithm is similar to D* but does not maintain a sorted queue of points to update. All these methods have achieved good results.

The methods above try to solve the problem of moving target tracking in different ways and have varying results. But, there still exist some problems to be resolved in different degrees. For example, in some algorithms the robot just tracks along the actual trajectory of the moving target, so it is difficult to intercept the target rapidly. Some algorithms are unfit for highly maneuverable targets whose paths are unknown to the robot or for environments which have many complex obstacles. There are also some algorithms that cannot satisfy the requirement of real-time. Thus, continuous research is needed to find a satisfactory solution.

In this paper we present a new moving target interception algorithm from a new point of view – a very fast local path planning algorithm that allows the global path to be recomputed whenever a change in the target's trajectory is detected. With our algorithm, the robot can rapidly intercept the moving target along a relatively short path in an environment containing many complex obstacles and in which the target may move with unknown and dynamically changing speed and trajectory. The main idea of our algorithm is that the robot computes the speed, orientation and linear trajectory of the moving target after the target moves one grid, and the intercept point, which is regarded as the navigational sub-goal of the robot, will be forecasted based on the assumption that the moving target and the robot move with linear trajectories during a short period of time. Then the robot rapidly plans a navigation path by using the new ant algorithm. The robot continuously monitors the target while it is moving along the planned path. Once the trajectory or speed of moving target is found to change, the robot will re-forecast the intercept point and re-plan the navigation path. This process will be repeated until the robot has intercepted the moving target. The process is dynamic, and it approximates the dynamically changing trajectory of the moving target by many short linear trajectories. The simulation results show that by our algorithm the robot can successfully intercept the moving target along a relatively short path in an environment with many complex obstacles.

One key point of our algorithm is that the local path planning algorithm for the robot must be fast so as to meet the requirement of real time. There are already many successful algorithms for path planning, such as the traditional artificial potential field algorithm and the A* and D* algorithms [20–23]. In recent years, some scholars also adopted the ant colony optimization (ACO) algorithm [24] or improved ACO algorithm in robot path planning [25–27]. Although many achievements have been made through such investigations, there still exist some deficiencies. For example, the artificial potential field algorithm and A* algorithms easily fall into local optimizations, and the ACO algorithm has the default of stagnation, etc. To solve these problems we have proposed a new quickly convergent path planning algorithm for mobile robots based on the scout ants birth-death optimization (SABO) [28] and multi-scout ants' cooperation (MSAC) [29]. The MSAC algorithm solves the problem of robot collision avoidance with moving obstacles. Moreover, it is very fast, planning optimal paths in just 0.03 s using an ordinary PC in complex environments with 200×200 grids. Because of its rapid convergence and environmental adaptability, the MSAC algorithm is used in our target interception method.

2. Description of environment

Let *AS* be the robot's 2-D working field, in which are distributed a finite number of static obstacles $Sb_1, Sb_2, \ldots, Sb_n$. Let *AS* be discretized into a grid of M points labeled by an index g_i, each point being either a free space or a barrier space (i.e., occupied by an obstacle). The target and the robot may occupy any free space. We define $OS = \{O_1, O_2, \ldots, O_m\}, \quad (m \geq n)$ to be the set of grids occupied by obstacles. Let $d(g_i, g_j)$ denote the Euclidean distance between two grids g_i and g_j. Let $BR(g_i)$ be the set of grid points which are adjacent neighbors to point g_i. $W(g_k) = \{g | g \in BR(g_k), g \notin OS\}$ is the set of free spaces in $BR(g_k)$.

Establish a Cartesian coordinate system $\sum_0$ which takes the upper left corner of *AS* as the origin. The robot, moving target and each grid in *AS* has its own definite coordinate. We denote the coordinates of the robot and the moving target at a certain time as $R(x_R(t), y_R(t))$ and $G(x_G(t), y_G(t))$ or, abbreviated, as $R(x_R, y_R)$ and $G(x_G, y_G)$.

It is assumed that there are only one robot and one moving target in *AS*. The speed of the robot and the moving target are denoted as V_R and V_G respectively. V_R is constant and known. On the other hand, both the trajectory and speed of the moving target are unknown to the robot and are allowed to change dynamically. In this paper, we assume $V_R > V_G$ in order to make sure that the moving target can be intercepted successfully.

At the beginning, the robot may not know where the target is and may need to locate the target, for example by random walking. Once the target is detected, the current position of the robot and the moving target are regarded as their starting points, which are denoted by R_{begin} and G_{begin} respectively, and the process of interception is carried out.