Obstacle Avoidance Techniques and Their Appropriateness for Imitating Ant Behaviour

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Abstract

There are various ways to implement obstacle avoidance. The report examines some of them. An obstacle avoidance methodology is chosen to imitate Ant behaviour. A combination of potential fields as used in a pheromone strategy and crash recovery seems to be an effective and realistic way to imitate ant behaviour.

Foreword

This report has been written as part of the Mobile Robots course at De Montfort University. The amount of citations is quite high. Since there was limited time left to refine this I rather kept it like this so the information about the different methods for obstacle avoidance is present and the reader knows where to look for in depth information about these methodologies by studying the suggested papers in the bibliography.

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Introduction

Obstacle avoidance is a largely researched field in behaviour based robotics. To gain understanding about obstacle avoidance some methods will be examined in this report. Since the change in the field of AI from the classical approach to the behaviour based approach it became much more important to deal with the environment in a real time manner. Obstacle avoidance is something which is of importance for almost all mobile robots.

Different techniques make use of information from the environment. Sometimes this information is sensed real-time sometimes it is based on inferences or planning and mapping techniques. The report will examine some methods to avoid obstacles. First it will describe reflexive systems with simple crash recovery furthermore solutions related to the subsumption architecture, potential fields methodology and solutions with fuzzy logic will be described. Also a hybrid methodology will be discussed. After that it will be discussed what methodologies are suitable for the imitation of ant behaviour.

Methods for Obstacle Avoidance

Several methods has been the developed to avoid obstacles. The possibilities largely depend on the amount of planning and the availability of sensors. Some robots are only equipped with bounce detectors [7], others deal with more complex sonar data [43]. Some methods for obstacle avoidance will be discussed in detail.

"A particular behaviour can be achieved with simple mechanisms without being explicitly encoded. It is suggested that enrichening the overall behaviour of an agent in such a way simplifies the creation of intelligent agents. [...] Obstacle avoidance [is] one particular kind of such a behaviour by an agent. We demonstrate that obstacle avoidance can be achieved on both a strategic level, caused by the intrinsic structure of the environment, and on a morphological level, caused by the properties of the agent's body. The underlying principles are studied on the example of local visual homing and an agent without sensorymotor coupling." [12]

2.1 Reflexive Control

When there is no representation of the environment except for the environment itself, what is often the case in modern behaviour based autonomous robots, there is no knowledge of the location of obstacles. When there is moreover a limited availability of sensors, e.g. proximity sensors, obstacle avoidance might be difficult to implement. When the robot crashes (hits an obstacle) this is usually detected, albeit just for a safety purpose. Based on a crash the robot might conclude that there is an obstacle at that location. It will recover (drive backwards) and tries a different strategy to continue its path. After a slight movement backwards it can choose a new direction, either at random, which is useful to exclude the possibility to enter an infinite loop, it can be partly random and partly based on the robot goals (e.g. goal location). When available it can use inferential data, like if there is a distinction between a front left crash and a front right crash it might be more effective to turn in the opposite direction to avoid the obstacle. On the other hand if there is no random part in this it can enter a loop when there are two obstacles, or one obstacle in a corner. That happens when it reaches the wall just right of the corner, moves backwards, adjusts its direction to the left and then hits the wall just left of the corner, goes back and adjusts to hit the original crash location and so on and so on. Even when another method of obstacle avoidance is implemented that tries to overcome crashes this recovery behavior can still be implemented to overcome failures.

"Reflex control is a method that guarantees collision avoidance with minimum nonessential influence on higher-level controls." [41]

"A promising approach to on-line automatic obstacle avoidance is the use of artificial potential functions. Potential functions are usually constructed about obstacles in task space, and gradients of these functions define virtual repulsive forces on a system to achieve collision avoidance. In most cases either these approaches do not consider actuator effort saturation, (and 'guarantee' collision avoidance only through the assumption of unlimited force and torque availability), or they invoke extremely conservative approximations. Reflex control is an obstacle avoidance method that is similar to potential functions in theory. However the reflex controller exhibits the following virtues: it does not suffer from unrealistic or overly restrictive assumptions on robot dynamics; it fits in control hierarchies and does not interfere with normal actions unless imminent danger is present; it guarantees collision avoidance (at least for static obstacles ; it does not suffer from excessive influence of obstacle repulsion fields; it can be computed rapidly on line; and it does not fail or slow down as environment complexity increases" [41]

"The reflex controller approves or disapproves higher-level commands, based on a rapid evaluation of a neighborhood of the robot's environment. This way, the reflex controller acts like a command filter that ideally is transparent, i.e., does not introduce any significant distortion of higher-level controls in all but emergency instances." [41]

2.2 Subsumption Architecture

The subsumption architecture is not really a way of avoiding obstacles. The subsumption architecture is build up of different layers where top layers subsume the activity of bottom layers. Usually the layer in the bottom provides some basic obstacle avoidance, usually of a reflexive type.

2.3 Edge Detection Method

"A more general and commonly employed method for obstacle avoidance is based on edge detection. In this method, the algorithm tries to determine the position of the vertical edges of the obstacle and consequently attempts to steer the robot around either edge. The line connecting the two edges is considered to represent one of the obstacle's boundaries. [...] A disadvantage with obstacle avoidance based on edge detecting is the need of the robot to stop in front of an obstacle in order to allow for a more accurate measurement. A further drawback of edge-detection methods is their sensitivity to sensor accuracy. Unfortunately, ultrasonic sensors, which are mostly used in mobile robot applications, offer many shortcomings in this respect: 1. Poor directionality that limits the accuracy in determination of the spatial position of an edge to 10-50 cm, depending on the distance to the obstacle and the angle between the obstacle surface and the acoustic beam.

2. Frequent misreadings that are caused by either ultrasonic noise from external sources or stray reflections from neighboring sensors ('crosstalk'). Misreadings cannot always be filtered out and they cause the algorithm to 'see' nonexisting edges.

3. Specular reflections which occur when the angle between the wave front and the normal to a smooth surface is too large. In this case the surface reflects the incoming ultra-sound waves away from the sensor, and the obstacle is either not detected at all, or (since only part of the surface is detected) 'seen' much smaller than it is in reality." [4]

In [5] a system based on Valentino Braitenberg's experiments of synthetic psychology was used to build two simple and compact vehicles. "Each capable of doing two different basic behaviors: the wall following (moving the vehicle at a constant distance from the wall on its left or right hand) and the obstacle avoidance (avoiding collision with obstacles during the path). Two different control systems have been developed and compared. The first system is controlled by an analogical circuit, whereas the second by a digital circuit. " [5]

2.4 Artificial Potential Fields

"The potential field method (PFM) is widely used for autonomous mobile robot obstacle avoidance due to its elegant mathematical analysis and simplicity. The basic concept of the potential field method is to fill the robot's workspace with an artificial potential field in which the robot is attracted to its goal position and is repulsed away from the obstacles. The robot is looked on as a moving particle, inside an artificial potential field that reflects the free and the collision space structures into the robot workspace. Such potential fields are generated by superposing an attractive potential that attracts the robot to the goal configuration, and a repulsive potential that repulses robot away from existing obstacles. The negative gradient of the generated global potential field is interpreted as artificial force acting on the robot that causes variations on its movement. PFM is well suited for both ultrasonic sensor and laser radar sensor, which is a great advantage. In the past decade, some new obstacle avoidance methods have been proposed based upon PFM." [1]

"There have been many proposed solutions for obstacle avoidance, among which a classical theory is APF algorithm in which the idea of attractive force and repulsive force are introduced. Compared with attractive force, repulsive force has smaller scope. It means that if the robot is too far from obstacles, repulsive force will vanish and has no effect on the result. As we know, artificial potential field just solves the problem of avoiding obstacles in local space, so it is known as local method. On the whole, APF deals with limited scene information, referring only the distance between robots and obstacles, and ignoring other important information such as velocity and angle. With further study, more and more scene information such as velocity, angle and acceleration is considered as factors of motion model." [25]

"In the traditional artificial potential field methods, an obstacle is considered as a point of highest potential, and a goal as a point of lowest potential. In the domain of robot path planning, a robot always moves from a high potential point to a low potential point. In general, these procedures involve the following basic steps:

- 1. Setting up a potential field function Φ which can be a function of distance D, such as: $\Phi = 1/D$,
- 2. Use of special algorithms to locate a minimum potential point,
- 3. Navigating a robot towards the minimum potential point arrived at, and,
- 4. The repetition of steps 2 and 3, until the robot reaches the goal position.

Traditional artificial potential field methods are efficient in identifying safe paths for robots. However, if an optimal path is required, it is needed to include the relevant optimization functions and associated constraints. The constraints invariably introduce complex computations, and the local minimum will be difficult to define and tackle." [37]

In [16] a new method, the vector field histogram method has been developed. It overcomes several drawbacks of the virtual force field method developed previously. By using the vector field histogram method it is possible to produce smooth non-oscillatory motion with less demands on the hardware.

The Virtual Force Field method is a derived method of PFM and it makes use of grids [1]. This method is described in [4].

The Vector Field Histogram method is based on the Virtual Force Field method and also looks for gaps in locally constructed polar histograms [1]. The vector field histogram methods is described in [3].

The potential fields method is applied in a great range of applications. It can be found in a planetary rover [11], another application about a vision based robot is described in [31].

2.5 Obstacle Avoidance with Fuzzy Logic

One way of modeling obstacles in the environment is by means of positive and negative fuzzy rules, or by positive rules on its own (larger complexity). An application of fuzzy control to a sonar-based obstacle avoidance mobile robot is described in [35]. Shang and Wang [32] use fuzzy reasoning to imitate human obstacle avoidance.

"A fuzzy obstacle avoidance controller [can be] designed for an autonomous vehicle. The controller is given the capability for obstacle avoidance by using negative fuzzy rules in conjunction with traditional positive ones. Negative fuzzy rules prescribe actions to be avoided rather than performed. A rule base of positive rules is specified by an expert for directing the vehicle to the target in the absence of obstacles, while a rule base of negative rules is experimentally determined from expert operation of the vehicle in the presence of obstacles. The consequents of the negative- rule system are codified into a chromosome, and this chromosome is evolved using an evolutionary algorithm. The resulting fuzzy system has far fewer rules than would be necessary for an obstacle avoidance controller using purely positive rules, while in addition retaining greater interpretability." [21] "For instance, let us decide that for the obstacle avoidance controller, the positive system inputs should be target direction and target distance, as these two quantities are indispensable information for steering toward a target. Similarly, we decide the negative system inputs should be obstacle direction and obstacle distance, as these quantities are indispensable for avoiding the obstacle. Also, we decide that the controller should have one output, steering direction. All angles will be relative to the current heading of the vehicle. For instance, a target direction of $\frac{\pi}{4}$ indicates the target lies 45 degrees to the left of the vehicle's current heading, whatever that heading may be. Similarly, a steering direction of $\frac{\pi}{8}$ indicates a 22.5 degrees right turn is taken by the vehicle, regardless of its present heading." [21]

2.6 A Hybrid solution

"Path planning is a key step in the control of mobile robot. And the quality of path influences the efficiency of mobile robot. So designing an efficient path planning algorithm is essential. Presently, there are many algorithms for path planning, such as Artificial Potential Field (APF), Fuzzy Logic (FL), Neural Networks (NN), Genetic Algorithm (GA), Ant Colony Optimization (ACO) and so on. However, these algorithms can't reach an ideal solution separately in complex dynamic environment. For example, APF usually gets into local minimum easily. Fuzzy logic offers a possibility to mimic expert human knowledge. However, when the input increases, the reasoning rules would expand rapidly, and the computation would mount up exponentially. Neural network has the capability to learn from existing knowledge, but the knowledge representation is very difficult. GA is an evolutionary algorithm, and able to resolve composition optimization problems. But it updates the good individuals entirely and doesn't have exploited the characteristics of the path solution space. ACO is fit for the combination optimization problems, such as path planning, but it can't be applied in dynamic environment. In real system, mobile robot always knows a lot of information about static obstacles in environment, so we can exploit the information to improve the algorithm efficiency. Therefore, mobile robot can plan the global route before moving. [Combining] the characteristics of ACO and APF [... a] path planning approach in dynamic environment that integrates the global planner and local planner [can be developed]. The basic idea is that, ACO is used to plan the global route based on static environment information, and then APF is utilized to program the local route. " [24]

This hybrid solution makes use of pheromone information obtained from ACO to prevent the robot from getting into a local minimum.

The combination of fuzzy controller, artificial neural network and genetic algorithm in 'Robust fuzzy and recurrent neural network motion control among dynamic obstacles for robot manipulators is suggested in [22].

Imitating Ant Behaviour

3.1 Ant Behaviour

"...in order to exchange information about which path should be followed, ants communicate with one another by means of pheromone (a chemical substance) trails. As ants move, a certain amount of pheromone is dropped on the ground, marking the path with a trail of this substance. The more ants follow a given trail, the more attractive this trail becomes to be followed by other ants. This process can be described as a loop of positive feedback, in which the probability that an ant chooses a path is proportional to the number of ants that have already passed by that path..." [40]

3.2 Obstacle Avoidance Techniques

Ants detect obstacles by touching them. Because of their embodiment they can often deal with obstacles. The ants might exploit their pheromone-technique just described. In which the path with an obstacle on it becomes less attractive. Since following a path with an obstacle on it takes more time for the ant to reach its destination it can follow that path at a lower frequency than an ant that chooses a more efficient path. The lower frequency results in less pheromone and less pheromone makes the path less likely to be chosen. The ants will take a more efficient path over time. Nevertheless when an ant hits an obstacle that is too hard to pass it can use the touch and recover solution proposed in last chapter.

The hybrid solution proposed in the previous chapter might also be useful for the imitation of ant behavior. It might give a behavior that looks quite identical to the ant behavior and therefore one can say that is good for imitation. Nevertheless from a cognitive perspective I am not sure if ants can have such a knowledge of their environment.

Conclusion and Recommendation

A lot of research has been undertaken and resulted in different solutions for obstacle avoidance. Which method to follow largely depends on the sensory data that is available and the internal knowledge representation. When one wants to imitate the behavior of ants it seems to be the best to exploit a hybrid solution. A solution that is based on both the imitation of the ant pheromone secretion strategy and a reflexive 'touch and recover' method to overcome local minimums.

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