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THE USE OF THE STEERING BEHAVIOURS METHOD IN ROBOT MOTION CONTROL

Potential applications for autonomous navigation of mobile robots include automatic driving, guiding the blind and disabled, exploring dangerous regions, transporting objects in factories or offices, collecting geographic information in unknown territories, such as unmanned exploration of a new planetary surface, etc.

Navigation strategies of mobile robots can be broadly divided into two categories: global trajectory planning and reactive navigation. In the first approach, a collision-free trajectory is designed to guide the robot to a given target through a known environment. But, the real world environment is subject to change over time. Thus, it is expected that an autonomous robot may encounter uncertain environmental situations, and reactive navigation capabilities are required. Especially during the initial exploration of an unknown environment to create a preliminary map of the environment, which can later be used to optimize the path. An autonomous robot must react to the surrounding situation in its immediate vicinity in such a way as to achieve the goal without colliding with obstacles.

This article discusses the application of the Steering Behaviours method in simulating natural robot movement. In modern computer graphics and animation, the concept of Steering Behaviours refers to a set of algorithms and methods used to create controlled behaviour for virtual objects. These algorithms allow for modelling various types of behaviour, such as flocking, obstacle avoidance, object following, and more. These behaviours allow virtual objects to exhibit intelligent and realistic movement in virtual environments.

In an attempt to simulate the process of avoiding obstacles when moving, a combination of basic reflex actions and higher-level logical decisions is implemented. It is shown that for reflexive navigation of autonomous mobile robots, the ability to reflexively avoid obstacles on only one side (left or right) is sufficient to avoid obstacles on both sides. The use of such a behavior model provides the basis for a compact representation of reflex behavior.

The goal is to first explore all the individual behaviors, moving from the truly simple to the more complex, and eventually combine and apply them to control robot motion.

Key words: *robot motion, robot contol, steering behaviours method, intelligent control*

Introduction. The main idea behind Steering Behaviours is to create controllable objects that can react to their environment as well as user actions. This is achieved by applying a set of algorithms based on principles of physics and mathematics that allow for modelling various types of behaviour.

One of the earliest and most well-known approaches to Steering Behaviours was proposed by Craig Reynolds in his paper “Steering Behaviours for Autonomous Characters” [1] in 1999. In this work, Reynolds introduced a set of simple algorithms that can be used to create controllable behaviours, such as following, flocking, evading, and more. Reynolds also suggested modelling the behaviour of virtual objects based on the principles observed in animal behaviour, such as birds and fish.

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Indeed, Steering Behaviours have found wide application in various fields, including computer games, virtual reality, robotics, and animation. They have also become an important component in research on animal and bird behaviour.

Methods. Within steering behaviours, several main types of control behaviors are distinguished, each corresponding to a specific task:

Seek behaviour: the agent moves towards a target located at a certain distance from it.

The Flee behaviour involves an agent moving away from a threat that is at a certain distance from it.

The formula for calculating the direction of movement is the same for the Flee behaviour as it is for the Seek behaviour, but with the inverse sign for the steering vector:

– the Collision Avoidance behaviour involves an agent avoiding collisions with other objects that are in its path.

– the Wander behaviour involves an agent moving in a random direction within a specified area. The formula for calculating the steering in this case also depends on the specific implementation.

– the Pursuit behaviour involves an agent moving towards a target that is also moving at a known speed.

In addition, within the framework of steering behaviours, additional rules are also used, such as speed and acceleration limits, direction control, and so on. These rules allow for obtaining more realistic and smooth movement of agents.

Since then, numerous other approaches to Steering Behaviours have been developed, including more complex algorithms based on artificial neural networks and genetic algorithms. Some of these approaches are presented in the works of K.V. Reddy's "Steering Behaviours for Autonomous Navigation" [2] and L.K. Erman's "Autonomous Steering Behaviours for Interactive Virtual Creatures" [3].

For instance, in one study published in the journal "Nature" [4], researchers utilized steering behaviours to study the behaviour of bird flocks. The study demonstrated that the behaviour of bird flocks can be explained by just a few simple rules, such as alignment and separation. By employing these rules in modelling using steering behaviours, the researchers were able to successfully replicate the behaviour of bird flocks in a realistic simulation.

In another study [5], published in the journal "Animal Behaviour," researchers utilized steering behaviours to study the migratory behaviour of sea turtles. By using various aspects of steering behaviours, such as target following and obstacle avoidance, the researchers created models of the migratory behaviour of sea turtles, which were successfully tested in the real world.

Indeed, Steering Behaviours are also used in studies of fish behaviour. In one study [6], published in the "Journal of Fish Biology," researchers employed steering behaviours to investigate the behaviour of fish in complex environments such as reefs and seagrass beds. By using these models, researchers can examine how changes in the environment impact fish behaviour and how they can adapt to new conditions.

Results. Pursuit Rule-based Imitation (PRBI) is a method in machine vision and robotics [7] that utilizes the principles of pursuit rule to create autonomous agents capable of imitating human movements and actions. It represents a comprehensive approach to modelling human behaviour and controlling robots in various scenarios.

The idea behind PRBI is that the movement of an object pursuing another object can be represented as a combination of the velocity vectors of the pursuer and the target object. The angle between these vectors determines the direction of the pursuer's movement.

The main idea of the method is that the movement of the pursuer can be represented as a combination of the velocity vectors of the pursuer and the pursued object. Thus, the velocity vector of the pursuer changes according to the velocity vector of the pursued object. The angle between the velocity vectors determines the direction of the pursuer's movement.

The formula for calculating the velocity vector of the pursuer in PRBI is as follows:

$$Vp = Vmax\,(Vt / \|Vt\| + k(Pt - Pp) / \|Pt - Pp\|) \quad (1)$$

where Vp – the velocity vector of the pursuer,
$Vmax$ – maximum speed of the pursuer,
Vt – the velocity vector of the pursued object,
$\|Vt\|$ – the magnitude of the velocity vector of the pursued object,
k – proportionality coefficient for controlling the scale of the pursuer's speed.
Pt – the position of the pursued object.
Pp – position of the pursuer.

This method is widely used in computer graphics and robotics, including obstacle avoidance and object tracking tasks. PRBI is also applied in scientific research studying the behaviour of animals, such as insects and fish, in their natural environment.

To create autonomous agents capable of replicating human movements, PRBI utilizes data from known human movements recorded in videos to train a motion model and control robots in real-time. During the training process, the model aims to minimize the difference between its own movement and the human movement represented in the video.

PRBI can be applied in various fields such as robotics, gaming industry, medicine, and technical design. For example, in robotics, PRBI can be used to create autonomous robots capable of replicating human movements and actions. In medicine, it can be used to develop systems that facilitate the rehabilitation of patients after a stroke. In the gaming industry, PRBI can be used to create realistic characters and scenes.

One of the main aspects of Steering behaviour is simulating obstacle avoidance. This is achieved using the "Avoidance" rule, which involves changing the object's direction of movement if it is too close to another object to avoid collision. To determine this, the vector from the object to the obstacle is calculated, and then the object's current direction of movement is rotated by a certain angle relative to this vector. The angle depends on the distance to the obstacle and is set using a function that provides a smooth transition from obstacle avoidance to straight-line movement when the object is far enough from the obstacle.

Formula for calculating the new direction of movement for an object based on the distance to the obstacle can be written as follows:

$$new_{direction} = direction + avoidance_{strength} * avoidance\_vector \quad (2)$$

where *direction* – the current direction of movement of an object
avoidance_strength – the coefficient that determines the magnitude of the avoidance angle
avoidance_vector – the vector that points from the object to the obstacle.

One example of applying the Steering behaviour method using the avoidance rule is a robot capable of moving around a room and avoiding obstacles in its path. In this case, the avoidance rule allows the robot to avoid collisions with other objects and move safely around the room [9].

The Steering behaviour method with the avoidance rule is an effective way to simulate natural behaviour of objects in a system, allowing them to avoid collisions with other objects and move safely in their environment. This method has found wide application in various fields, including robotics, computer games, and virtual reality.

The Steering behaviours method with the dispersion rule is one example of simulating natural behaviour in robotics and computer animation. It is used to describe the movement of objects that strive to evenly distribute themselves in space.

The main idea of the method is to create a dispersion effect of objects within a given area where they should be located. To achieve this, each object determines a direction vector pointing towards the central point of the area. Then, each object adds a random vector to its current velocity vector, which is directed in a random direction [10]. As a result, objects start moving in random directions, leading to a more uniform distribution of objects within the designated area.

Mathematically, the dispersion rule can be represented as follows:

$$steer = randomVector() * weight \tag{3}$$

where $randomVector()$ – random vector,
$weight$ – weight of a random vector.

An example of the application of the dispersion rule in robotics is a system used for robot distribution on a production line. In this case, the robots need to be evenly distributed along the line to avoid collisions and ensure efficient operation. To achieve this, each robot uses the dispersion rule to distribute its position along the line.

Additionally, the dispersion rule can be used to create realistic effects in computer animation, such as simulating the distribution of celestial objects in a galaxy.

Thus, the Steering Behaviours method with the dispersion rule is an effective tool for creating realistic and controllable movements of objects in various fields, including robotics and computer animation.

The Accumulative Imitation Rule (AIR) method is an algorithm used for solving optimization problems, based on the principle of evolutionary imitation in nature. In this method, each potential decision-maker (individual) has its own genome, which represents a set of parameters that can be tuned.

The idea of the method [11] is to create a population of decision-makers, each of which is randomly tuned based on a genetic algorithm, and then evaluate the effectiveness of everyone in solving the optimization problem. Then, the best decision-makers are selected to create a new population of decision-makers.

The accumulation rule involves each new individual inheriting genetic characteristics from the best decision-makers of the previous population, and these characteristics are added to its genome. This allows for the preservation of the best genetic traits and leads to a gradual improvement of the population of decision-makers.

When using the AIR method in robotics, the best decision-makers can be selected based on the effectiveness of their behavior during task execution, such as robot movement towards a target point. Then, these best decision-makers can be used to create new decision-makers whose genome will contain both the best characteristics of the best decision-makers from the previous population and randomly generated parameters.

An example of applying the formulas of the AIR method in robotics could be as follows: let's say a robot needs to learn how to deliver pizza to offices in different parts of the city. To achieve this, we can use the AIR method to train the robot to perform new tasks based on the genetic characteristics of the best decision-makers from the previous population. For example, at each iteration of the algorithm, we can select several best decision-makers from the previous population who can efficiently deliver pizza to different parts of the city and use their genetic characteristics to create a new robot.

Thus, the new robot will have the best genetic characteristics that will allow it to efficiently deliver pizza to offices in different parts of the city, even if it has not been specifically trained for this task.

The formula of the AIR method can be used to calculate the genetic characteristics of the new robot:

$$x\_i' = x\_i + \delta * \Sigma\_\{j = 1\}\^k\, w\_j\, (x\_j - x\_i) \quad (4)$$

where x_i – genetic characteristics of robot i in the previous population,

x_i' – the genetic characteristics of the new robot i in the current population,

δ – The coefficient that determines how strongly the new robot will depend on the genetic characteristics of the best performers.

w_j – The weight coefficient that determines how strongly the genetic characteristics of solver j affect the genetic characteristics of the new robot i.

The imitation method based on the clustering rule can help robots achieve optimal performance in task execution by efficiently tuning their control parameters.

The Imitation based on Divide and Conquer Rule method is a method [12] used for training robots to perform tasks that can be divided into smaller subtasks. This method is based on the principle of dividing the learning task into several simpler ones, performing each of them separately, and then combining the results to obtain the complete solution.

Mathematical formulas of the imitation method based on the divide and conquer rule can be described as follows:

Let T denote the training dataset, and let X and Y be the sets of input and output variables, respectively.

By dividing the training dataset T into several subsets T1, T2, ..., Tn, such that each subset Tj contains only those examples that have the same values for certain input variables Xj.

For each subset Tj, train a model Mj that takes input variables Xj and returns the corresponding values of output variables Yj.

By combining the models M1, M2, ..., Mn, we obtain the final model M, which takes input variables X and returns the corresponding values of output variables Y.

The imitation method based on the division rule in robotics can be used for:

– for industrial assembly tasks, a robot can be trained to perform individual steps of the process, such as picking up and moving parts, and then combine the results to achieve the complete assembly task.

– for automatic navigation tasks, a robot can be trained for various subtasks, such as path planning, obstacle avoidance, and target search, and then combine the results to achieve the navigation goal.

Conclusions. In conclusion, it can be noted that Steering Behaviours are a powerful tool for creating controlled behaviours in a virtual world. This method can be used to model the movements of real robots.

However, even though Steering Behaviours are a simple set of algorithms, their application can be challenging, especially when dealing with many objects or when using more complex algorithms. Therefore, developers should carefully choose and configure Steering Behaviours algorithms for specific tasks.

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РОБОТТАРДЫҢ ҚОЗҒАЛЫСЫН БАСҚАРУДА STEERING BEHAVIORS ӘДІСІН ҚОЛДАНУ

Мобильді роботтардың автономды навигациясының қолдану облысына автоматты жүргізу, зағиптар мен мүгедектерге жол көрсету, қауіпті аймақтарды зерттеу, зауыттарда немесе кеңселерде объектілерді тасымалдау, белгісіз аумақтарда географиялық ақпаратты жинау, мысалы, жаңа планеталық бетті ұшқышсыз зерттеу және т.б. жатуы мүмкін.

Мобильді роботтардың навигациялық стратегияларын екі санатқа бөлуге болады: жаһандық траекторияны жоспарлау және реактивті навигация. Бірінші тәсілде соқтығыссыз траектория роботты белгілі орта арқылы берілген нысанаға бағыттауға арналған. Бірақ, шынайы қоршаған орта уақыт өте өзгереді. Осылайша, автономды робот қоршаған ортаның белгісіз жағдайларына кездесуі мүмкін. Осы себепті реактивті навигация мүмкіндіктері қажет. Әсіресе белгісіз ортаны бастапқы барлау кезінде қоршаған ортаның алдын ала картасын жасау үшін, кейінірек жолды оңтайландыру үшін пайдалануға болады. Автономды робот өзінің жақын маңындағы кедергілерге соқтығыспай мақсатқа жетуі тиіс.

Мақалада роботтардың табиғи қозғалысын имитациялауда Steering Behaviors әдісін қолдану мәселелері қарастырылады. Қазіргі компьютерлік графика мен анимацияда Steering Behaviors («басқару мінез-құлқы») ұғымы виртуалды объектілердің әрекетін басқаруда қолданылатын алгоритмдер мен әдістер жиынтығын білдіреді. Бұл алгоритмдер әртүрлі мінез-құлықтарды модельдеуге мүмкіндік береді, мысалы, топтағы қозғалыс, кедергілерден жалтару, басқа объектілерді ұстану және т.б. Қозғалыс кезінде кедергілерді болдырмау процесін имитациялау әрекетінде негізгі рефлекторлық әрекеттер мен жоғары деңгейдегі логикалық шешімдердің комбинациясы жүзеге асырылады. Автономды мобильді роботтардың рефлексивті навигациясы үшін роботтың кедергіні бір (сол немесе оң) жағынан рефлексифті айналып өтуі кедергіні екі жағынан айналып өтуі жеткілікті екені көрсетіледі. Мұндай мінез-құлық моделін пайдалану рефлекторлық мінез-құлықты шағын түрде ұсынуға негіз болады.

Зерттеу мақсаты – алдымен қарапайымнан күрделіге қарай жылжып, барлық мінез-құлықтарды жеке дара зерттеу және соңында оларды робот қозғалысын басқару үшін біріктіру және қолдану.

Түйін сөздер: *робот қозғалысы, роботты басқару, steering behaviors әдісі, интеллектуалды басқару*

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ИСПОЛЬЗОВАНИЯ МЕТОДА STEERING BEHAVIORS В УПРАВЛЕНИИ ДВИЖЕНИЯМИ РОБОТОВ

Потенциальные области применения автономной навигации мобильных роботов включают автоматическое вождение, ориентирование слепых и инвалидов, исследование опасных регионов, транспортировку объектов на фабриках или в офисах, сбор географической информации на неизвестных территориях, например, беспилотное исследование новой поверхности планеты и т.д.

Навигационные стратегии мобильных роботов можно в общих чертах разделить на две категории: глобальное планирование траектории и реактивная навигация. В первом подходе траектория без столкновений предназначена для направления робота к заданной цели через известную среду. Но среда реального мира подвержена изменениям с течением времени. Таким образом, ожидается, что автономный робот может столкнуться с неопределенными ситуациями окружающей среды, и возможности реактивной навигации необходимы. Особенно во время первоначального исследования неизвестной среды для создания предварительной карты окружающей среды, которая впоследствии может быть использована для оптимизации пути. Автономный робот должен реагировать на окружающую ситуацию в непосредственной близости от него таким образом, чтобы достичь цели без столкновения с препятствиями.

В статье рассматриваются вопросы применения метода Steering Behaviors в имитации естественного движения роботов. В современной компьютерной графике и анимации понятие Steering Behaviors («поведение управления») относится к набору алгоритмов и методов, используемых для создания управляемого поведения виртуальных объектов. Эти алгоритмы позволяют моделировать различные виды поведения, такие как движение в стае, уклонение от препятствий, следование за другими объектами и т.д. В попытке имитировать процесс обхода препятствий при передвижении, реализована комбинация базовых рефлекторных действий и логических решений более высокого уровня. Показано, что для рефлексивной навигации автономных мобильных роботов способности рефлексивно избегать препятствий только с одной стороны (слева или справа) достаточно для обхода препятствий с обеих сторон. Использование такой модели поведения обеспечивает основу для компактного представления рефлекторного поведения.

Цель состоит в том, чтобы сначала исследовать все отдельные модели поведения, переходя от действительно простых к более сложным, и в конечном итоге объединить и применить их в управлении движениями роботов.

***Ключевые слова:** движение робота, управление роботом, метод steering behaviours, интеллектуальное управление.*