Research on attack and defence control of martial arts arena robot based on kinodynamics

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Abstract
In the research of intelligent mobile robot, autonomous mobility is a very key problem. It is very important to accurately and quickly respond to the surrounding environment, avoid obstacles in the process of moving in real time and move to the destination without interruption. Most of the existing path planning and obstacle avoidance algorithms do not consider the kinematic and geometric constraints of the robot parameters, there will be physical feasibility and versatility problems in the actual robot application; the existing martial arts challenge arena robot attack and defence control strategy, mainly rely on experience and try, accuracy and flexibility and other aspects are inadequate. In view of this, this article proposes a dynamic model based on virtual force, and applies it to the martial arts challenge arena robot, develops a set of attack and defence control strategy of martial arts challenge arena robot, completes the simulation experiment and the actual robot experiment, analyse the experimental results, and puts forward the improvement scheme. The experimental results show that the motion model proposed in this article can help the robot to complete the obstacle avoidance planning task, and the attack and defence control model based on the motion modelling can effectively improve the obstacle avoidance efficiency and attack and defence intensity of the martial arts challenge arena robot, and enhance the competitiveness of its confrontation.

Keywords
Martial arts arena robot, kinodynamics, obstacle avoidance planning, offensive and defensive strategy

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Introduction
Robot is a kind of programmable and multi-functional operating machine or a special system which can be used to change and programmable actions in order to perform different tasks. The task and goal of robot is to help human to finish the work better or to work under the condition of complex terrain and unsuitable environment. With more and more attention paid to the development of robotics at home and abroad, robotics has been recognized as one of the high-tech technologies with far-reaching influence and important significance for the future development of emerging industries. With the development and promotion of Internet technology, Internet of things technology and other high-tech, robot technology is rapidly expanding from traditional industrial and manufacturing fields to medical, education, service, entertainment, exploration, rescue and other fields. Researchers are also constantly in-depth research and development of robot systems for different fields.

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factory automation production, monitoring system, quality control system, disaster resistance and medical assistance. Many researchers have also proposed different ideas and methods for the offensive and defensive strategies of the robots. Zhao Baosen et al. used eight infrared sensor detection modules to detect the distance between the robot and the other robot and the position on the platform to realize the robot positioning. Li Wei carried out the feasibility analysis of the invisible design from the aspects of sensor principle analysis, material selection and structural design. Li Weiguo and others elaborated on the offensive strategy and precautions of the martial arts robot. Li Zhiling and others combined the sensor with the infrared sensor to improve the efficiency of the target search to enhance the robot’s response capability. Zhou Xiulong and others, Xu Ge, Shen Xinfeng, Sun Xuri and others also elaborated their ideas on the overall design and offensive and defensive control strategies of martial arts. However, the existing tactical and tactical control strategies for martial arts and cymbals are mainly based on experience and experiment. By controlling the forward and backward movement of the robot, and rotating the pre-set distance and angle to the left and right, the accuracy and flexibility are insufficient.

In this article, a robot based on differential motion of such a motion structure is taken as an example to present a virtual force-based path planning and obstacle avoidance control model. This model only needs to be detected by the robot’s own sensor and analysed by the central processing module to develop the motion trajectory in real time, without the complicated steps such as map modelling, so it can be better applied to low cost and simpler. Then the model algorithm is applied to the actual martial arts robot, and the offensive and defensive control model of the martial arts robot is constructed. Based on this, the attack and defence control strategy are improved, and the attack and defence integration are realized in its movement. Finally, simulation experiments, robot obstacle avoidance experiments and robot confrontation experiments are carried out to verify the correctness and effectiveness of the model and strategy.

**Structure and system design of robot in martial arts challenge arena**

**Overall structure of the robot**

The developed martial arts platform robot adopts differential drive wheel structure, the whole is square structure, the chassis size is 240 mm × 240 mm, the weight is about 3.8 kg, the metal casing, the whole body is black, and there are multiple infrared ranging and infrared photoelectricity around, switch sensor, driven with four wheels. After the information collected by the sensor is transmitted to the central processing module, after analysis and calculation, the motor drive module issues an instruction to control the rotation of the motor, thereby controlling the movement of the robot. The central processing module acts as the ‘brain’ of the robot, analysing and controlling the actions of the entire robot. The sensor, as the ‘eye’ of the robot, gets environmental information from the surroundings. The robot is equipped with eight infrared ranging sensors, every 45°, where the No. 1 sensor is located at the centre of the front of the robot. At the same time, there are four infrared photoelectric switch sensors installed at the front and rear of the robot. There are two during the movement of the robot, the infrared distance sensor detects the distance between the obstacle and the robot, and the infrared photoelectric switch sensor detects the edge of the platform.

**Kinematic modelling and analysis of robot**

**Dynamic modelling**

It can be seen from Newton’s law of motion that the state of motion of an object changes due to the action of a force. The actual power of the robot comes from the torque of the motor, which drives the wheel to rotate. In order to model the dynamics of motion, the virtual force \( F_A \) is introduced, that is, the virtual force \( F_A \) is assumed to act on a certain point on the robot, which is the only driving force of the robot. The robot changes its motion state under its action. \( F_A \) is an imaginary force. It is virtual and does not exist in real. First of all, we use it to model the motion dynamics, and get the motion equation, in order to get the angular velocity and linear velocity needed by the robot at a certain
time point; then, through the relationship between the geometric configuration of the robot and the actual motion, we can get the required wheel speed, so as to change the required motion state of the robot into the actual control that can be realized in reality. Figure 1 shows the motion dynamics model of the martial arts robot.

Among them, \( W \) coordinate system is the global coordinate system, \( R \) coordinate system is the robot coordinate system; \( G \) is the centre of gravity of the robot, \( C \) is the centre point of two wheels, \( F_A \) is the virtual force resultant force, \( a \) is the virtual force action point, \( V \) is the linear speed in the \( x \)-axis direction in \( R \) coordinate system, \( \omega \) is the robot angular speed; \( R \) is the robot wheel radius, \( V_L \) is the left wheel linear speed of the robot, \( V_R \) is the right wheel linear speed of the robot, \( D \) is the two wheels linear speed, the distance from the centre point to the wheel, \( h \) is the distance from the centre of gravity \( g \) of the robot to the virtual force action point, \( s \) is the distance from the centre of gravity \( g \) of the robot to the centre point \( C \) of the two wheels; \( \theta \) is the angle between the virtual force \( F_A \) and the \( X \)-axis in the \( R \) coordinate system, and \( \Phi \) is the angle between the \( w \) coordinate system and the \( X \)-axis in the \( R \) coordinate system.

Let the robot move under the action of the virtual force \( F_A \), apply dynamic equation as follows

\[
\begin{align*}
\sum F &= ma \\
\sum M &= I_G \Omega
\end{align*}
\]

(1)

It can get

\[
\begin{align*}
(I_{zz} + ms^2)\omega - 2msv\omega + \frac{2bd^2}{r} \omega &= F(h - s)\sin \theta \\
mv + ms\omega^2 + \frac{2b}{r}v &= F\cos \theta
\end{align*}
\]

(2)

The parameters in the equation are: \( F_A \) has a modulus of \( F \), the mass of the robot is \( m \), the moment of inertia around the vertical axis is \( I_{zz} \), and the viscous friction coefficient is \( b \). \( s \) is small enough, \( k_i = m/I_{zz} \), and simplify equation (2) to linear differential equation:

\[
\begin{align*}
v &= \frac{1}{mr}(-2bv) + \frac{1}{m}F \cos \theta \\
\omega &= \frac{d^2}{mr}(-2bk_\omega) + \frac{1}{m}FK_i h \sin \theta
\end{align*}
\]

(3)

Let \( \mathbf{x} = (v, w)^T, \mathbf{u} = (F\cos \theta, F\sin \theta)^T \), and get the state space equation \( \mathbf{x} = \mathbf{Ax} + \mathbf{Bu} \)

\[
\begin{bmatrix}
-2b/mr & 0 \\
0 & -2bd^2/rI_{zz}
\end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} + \begin{bmatrix} 1/m & 0 \\
0 & h/I_{zz}
\end{bmatrix} \begin{bmatrix} F \cos \theta \\ F\sin \theta \end{bmatrix}
\]

(4)

This state space equation gives the motion of the robot under the action of the virtual force \( F_A \).

**Analysis of parameter sensitivity**

In order to facilitate the analysis, since the rotation of 90° is a very common and representative behaviour in robot path planning, the analysis is performed by taking the robot to rotate 90° as an example.

It can be seen from Figure 2 that when \( b \) is small, the curve oscillates very much; as \( b \) gradually increases, the curve also gradually becomes smoother, and the larger \( b \) is, the longer it takes for the angle \( \Phi \) to change from 0° to 90°. This conclusion can be obtained from an intuitive analysis: increasing the viscous friction coefficient \( b \) means increasing the energy lost by friction during the movement of the robot, which makes the system more stable, but the movement also changes more slowly.

**Modelling of virtual force**

The power of \( F_A \) as an illusion is combined by many forces. As shown in Figure 3, let \( g \) be the target point of the robot movement, \( o \) is the obstacle encountered during the robot movement, the attraction point of the target point \( g \) to the robot is \( F_g \), and the obstacle \( o \) is the repulsion of the robot to \( F_o \). If there are multiple target points, there will be multiple gravitational forces \( F_{gk}(k = 1, 2, 3...); \) if there are multiple obstacles, there will be multiple repulsive forces \( F_{ok}(k = 1, 2, 3, ...); \), using the physics analysis method of force to synthesize the force, the final virtual force \( F_A \) can be obtained. In this way, by the combined action of gravity and repulsion, a resultant force is obtained to guide the movement of the robot.

In the actual environment, when moving the robot to the target point, it will encounter obstacles with different shapes. Some obstacles are small, and a single sensor can be detected. The robot will be connected to the centre of the sensor and the robot. The repulsion of the line direction is \( F_o \), while some obstacles are larger and will be detected by multiple sensors at the same time. As shown in Figure 4, an obstacle is detected by three sensors at the same time. The robot will receive three repulsive forces, and the direction of each repulsion. For each sensor and the robot centre point connection direction; in some cases, the robot will receive the repulsion of multiple obstacles at the same time, and each obstacle may be detected by multiple sensors at the same time, so the situation more complicated. In either case, the force of each \( F_{gk} \) and \( F_{ok} \) on the robot can be the final virtual resultant \( F_A \).

**Attack and defence control strategy of robot in martial arts challenge arena**

**Overall confrontation strategy**

In order to make up for the shortcomings of the existing offensive and defensive control strategies of martial arts robots, improve the scientific, effective and stable control of offensive and defensive control, combined with the sports mechanics and virtual force modelling given in the
previous chapters, improve their offensive and defensive control strategies. The flow chart of the overall attack and defence control strategy of the martial arts platform is shown in Figure 5. After the confrontation began, the robot randomly walked around the ring to find the enemy. Once the enemy is discovered, first adjust the attitude of the robot to face the enemy, and then execute the core attack and defence strategy composed of the defensive strategy and the offensive strategy. After reaching the imaginary target point, the maximum speed is pushed to the enemy robot to step down. During the entire confrontation process, real-time edge detection is performed by interruption to prevent the robot from falling off.

**Figure 2.** Instantaneous response of $\phi$ at different $b$ values.

**Figure 3.** Model of virtual force.

**Figure 4.** Schematic diagrams of virtual force.
Defensive strategy

During the robot martial arts competition, the relative positions of the robots are constantly changing. The infrared distance measuring sensor installed on the robot can detect the distance of the robot from the enemy robot in real time. Using the virtual force modelling method, it is possible to obtain the repulsive force $F_{oi}$ of the enemy robot to our robot, and to obtain the virtual force $F_A$ that ultimately acts on the robot, the key is to obtain the attraction point $F_g$ of the target point to the robot. Figure 6 shows the relative position of the robot under two extreme conditions. The left picture shows the robots face to face, and the right picture shows the diagonal of the chassis of our robot facing the enemy robot.

Attack strategy

The robot’s attack strategy is based on its defensive strategy. When the defensive strategy is executed, the preparation phase of the attack strategy has actually completed.

Experimental results and analysis

Simulation experiment of turning 90°

The 90° rotation is very common and representative in robot path planning tasks. Therefore, in order to verify the
correctness of the motion dynamics modelling in this article, MATLAB is used to simulate the trajectory of the robot rotating 90° under continuous motion. Although the general specifications of the martial arts robots have been stipulated in the competition rules of the martial arts competition, the robot parameters are still different. Therefore, when the MATLAB simulation experiment is performed to verify the motion dynamics modelling, the robots mentioned at the beginning of this chapter are not used. The actual geometric parameters, but the standardization of the parameters, can verify the versatility of the model, but also simplify the calculation. After standardizing the robot geometry parameters, we simulated the robot’s movement trajectory by changing the four key parameters $b$, $k_i$, $h$, and $F$. First, the parameters are normalized, let $m = r = d = 1$; then, through the stability condition and the parameter sensitivity analysis, we can get a set of approximate optimal parameters of equation: $b = 0.975$, $k_i = 0.95$, $h = 0.58$, $F = 1.05$. Using this set of parameters, when the robot encounters obstacles in continuous motion, the movement of the obstacle is directly rotated by 90° as shown in Figure 8.

It shows that when the robot uses the optimal parameters, the movement trajectory rotated by 90° in the case of continuous motion is relatively smooth, and the path planning task is well completed. Keep three of the four parameters $b$, $k_i$, $h$, $F$ unchanged, only change one of them, and then get four moving axes of the robot rotated 90°. It can be seen that the movement trajectories of the robots in the four images are different, and they are different from the trajectory map of the robot under the approximate optimal parameters: some rotation is rapid, the trajectory is not smooth enough; some are slow to rotate, and the response is not sensitive enough. Some even swayed very badly, and the trajectory was very strange. But no matter what kind of
parameters, whether the trajectory performance is excellent, the robot can complete the path planning task of ‘rotating 90°’ and finally reach the target point. It shows that the motion dynamics model described in this article has stability and correctness.

Simulation experiment of virtual force

Using the actual data used in the experiment: $D = 0.12$, $l_0 = 1$, $C = 48$, $G_1 = 400$, $\sigma_1 = -2$, $G_2 = 10$, $\sigma_2 = 1.2$, we can get

$$\begin{align*}
F_{gk} &= 48, l_{gk} > 1 \\
F_{gk} &= 400 \frac{0.12}{l_{gk}^2}, 0 < l_{gk} \leq l_0 \\
F_{gk} &= 0, l_{gk} = 0
\end{align*}$$

$$F_{oi} = 10 \frac{0.12}{l_{oi}^{1.2}}, l_{oi} > 0$$

The virtual force $F_g$ and $F_o$ are simulated in MATLAB, and the results are shown in Figure 9.

Figure 8. The moving track of robot rotating 90° under different parameters. (a) The trajectory of robot turning 90 degrees with approximate optimal parameters. (b) $b = 2, k_i = 0.9, h = 0.58, F = 1.05$. (c) $b = 0.975, k_i = 2, h = 0.58, F = 1.05$. (d) $b = 0.975, k_i = 0.95, h = 1, F = 1.05$.

Figure 9. Relationship between virtual force and distance.

As shown in Figure 9, the attractive force $F_g$ of the target point to the robot gradually increases as the distance between the two increases. When the distance exceeds 1 m, the $F_g$ does not increase any more, keeping 48 N unchanged; the repulsion of the obstacle to the robot $F_o$, the distance between the two gradually increases and decreases.
Obstacle avoidance experiment of robot

In real life, due to the wide variety of obstacles, the obstacle avoidance behaviours adopted are also very different. In view of this obstacle avoidance behaviour design, compared with other methods, it does not need to model the environment, and can be used as a supplement to the sensor to collect information, realizing the real-time and practicality of the obstacle avoidance of the mobile robot. Therefore, the coordination of the relationship between the various behaviours has become a key point in realizing this theory. Based on the analysis and understanding of the obstacles, the obstacle avoidance behaviour is roughly divided into four types: direct behaviour, direct obstacle avoidance behaviour, wall walking behaviour and emergency obstacle avoidance behaviour, so as to complete the obstacle avoidance process of the whole robot. The flow chart of the entire obstacle avoidance of the mobile robot is shown in Figure 10.

As shown in Figure 11, the obstacle avoidance test of the mobile robot in a complex environment is simulated in the laboratory. Although the experimental environment is not simple, it is not a professional complex environment. However, in order to reflect the complexity, we also made a special design for the whole process.

**Conclusion**

This article introduces the overall structure, circuit system and hardware components of the martial arts robot. Taking the robot with differential structure of such motion structure as an example, a dynamic force modelling method based on virtual force is proposed. Combined with motion dynamics modelling and virtual force modelling, the robot motion controller is constructed. This article expounds the confrontation strategy of martial arts robots, and uses motion modelling to formulate a complete set of robot martial arts competitions, and puts forward the offensive and defensive control strategy of martial arts. The final experimental results verify the correctness and practicability of motion dynamics modelling, virtual force modelling and offensive and defensive control strategies, and provide
a new idea for robot obstacle avoidance planning and martial arts robot confrontation strategy.

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