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A MULTI-INPUT FEEDBACK CONTROL ALGORITHM FOR FORMATION CONTROL

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ABSTRACT

Aiming at the multiple robots formation control problem, this paper presents a solution for the paralyzed deadlock and decision conflict in the formation system. It introduces the randomized-generating function and variable repulsive force feedback control algorithm, combines the leader-follower and the artificial potential field approach and defines the distance, velocity vector and the virtual force as the inputs and outputs of the feedback control system. The two-wheel differential robot physical platform is designed on PC with the 2000series DSP chip. And the simulation results and mobile robots entity test demonstrate the validity of the proposed method.

Key words: *Multi-Input Feedback Control, Random Generating Function, Variable Repulsive Force, System Conflict*

1. INTRODUCTION

Robot team formation has been one of the main difficulties in the field of multi-robot system research. Missions like spatial search require solving the problem of multi-robot proceeding under uncertain circumstances in scheduled formations, which is called formation control[1-2]. Formation control is a kind of control technique [3] that controls multiple robots to maintain in a certain formation as well as to adapt to the environment on the way to their destinations. So far the main multi-robot cooperation algorithms are tracking method [4], behavioral method [5] [6], virtual structure [7] and artificial potential field [8] [9]. Document 10 describes the design of a virtual robot tracking cooperation method based on mobile reference points. Document 12 presents a flexible feedback linearization algorithm and an optimal approximate target algorithm to build the control law and solve the obstacle-avoidance problem of non-holonomic constraint robot cooperation.

This article combines the tracking method and the method of artificial potential field, and defines the virtual force between the tracking robot and the virtual robot and between the neighbor robots and the obstacle based on distance and velocity component. And it also designs a randomized-generating function method and variable repulsive force feedback control method to increase the system stability.

2. MULTI-ROBOT COOPERATION ALGORITHM DESIGN BASED ON MULTIPLE INPUT FEEDBACK CONTROL

2.1 Design of Distance and Velocity Component Feedback Cooperation Algorithm

This article mainly studies the group control algorithm of the tracking robots: through establishing the attractive force and repulsive force equations between the tracking robots and the leading robot and between the obstacle and the corresponding neighbor robots based on the distance and velocity feedback, the article calculates the "resultant force" exerted on the tracking robots and derive the desired velocities of the robots at the next moment and control their movements in this way.

Definition of the neighbor robot: suppose in two-dimension space there are N robots of the same properties within the robot swarm, and the neighbor robot j ($j \in N$) of tracking robot i ($i \in N$) is the robot meeting the condition $\|d_{ij}\| < P$. $\|d_{ij}\|$ is the distance between robots and P is the threshold value of the distance.

Define the attractive force of tracking robot and virtual robot:

$$F_{iR} = I_1 \cdot \|d_{iR}\| + \mu \cdot (v_R - v_{iR}) \tag{1}$$

where I_1 is a positive scalar parameter, $\|d_{iR}\|$ is the distance between tracking robot i and the corresponding virtual robot, μ is the weight, v_R is the desired speed component of tracking robot i in the direction of its virtual robot and v_{iR} is the actual speed component of tracking robot i in the direction of its virtual robot.

Define the attractive/repulsive force between tracking robot i and the neighbor robot j:

$$F_{ij} = I_2 \cdot \left\| d_{ij} - L \right\| - \rho \cdot \left(v_{ij} - v_{ji} \right) \qquad (2)$$

where I_2 is a positive scalar parameter, $\left\| d_{ij} \right\|$ is the actual velocity of robot i in the direction of robot j, L is the optimal distance between robots, ρ is the weight, v_{ij} is the actual velocity component of robot i in the direction of robot j which is set as the positive direction and v_{ji} is the actual velocity component of robot j in the direction of robot i. The force between robots appears to be attractive when $d_{ij} > L$, and appears to be repulsive when $d_{ij} < L$.

Define the repulsive force between tracking robot i and the obstacle:

$$F_{ik} = I_3 / \left\| L - d_{ik} \right\| + \sigma \cdot v_{ik} \qquad (3)$$

where I_3 is a positive parameter, d_{ik} is the distance between the robots and the obstacle, σ is the weight and v_{ik} is the velocity component of tracking robot i in the direction of the obstacle.

The resultant force exerted on tracking robot i obtained from (1), (2) and (3) is:

$$F_i = F_{iR} + \sum_{j=0}^{n} F_{ij} - \sum_{k=0}^{m} F_{ik} \qquad (4)$$

2.2 Mobile Robot Track Control Based on Virtual "Resultant Force"

Take the example of WMRs two-wheel differential driving robot, and suppose the rigid robot body moves on a horizontal plane and the friction type between the wheels and the ground is coulomb friction, and the robot's center of gravity is at its geometric center. According to the resultant force F_i exerted on tracking robot i, we obtain from the dynamic equations that:

$$v_i(t+\Delta t) = \frac{F_i \cdot \cos(\beta_i - \theta_i)}{M_i} \cdot \Delta t + v_i(t) \qquad (5)$$

$$\omega_i(t+\Delta t) = \frac{F_i \cdot \cos(\beta_i - \theta_i) \cdot L}{I_i} \cdot \Delta t + \omega_i(t) \qquad (6)$$

where $v_i(t+\Delta t)$ and $\omega_i(t+\Delta t)$ are the linear velocity and the angular velocity of robot i at moment $t+\Delta t$, F_i is the resultant force exerted on robot I, M_i is the mass of robot, θ_i is the azimuth angle of robot i, β_i is the angle between the resultant force F_i of robot i and the global coordinate system, L is the distance between the center of the robot driving wheels and robot's center of mass and I_i is the moment of inertia of robot i.

Obtained from WMRs dynamic equations that:

$$v_i(t) = \frac{v_R(t) + v_L(t)}{2} \qquad (7)$$

$$\omega_i(t) = \frac{v_R(t) - v_L(t)}{D} \qquad (8)$$

where $v_R(t)$ and $v_L(t)$ are the speeds of the left wheel and the right wheel of robot i at moment t respectively and D is the distance between the wheels.

From equations (5), (6), (7) and (8), we can derive the velocity controlling quantities of both the left and right wheels at moment $t+\Delta t$ according to the resultant force exerted on robot i at moment t, and control the track of mobile robot in this way.

3. SOLUTION TO CONFLICTS OF GROUP ROBOT SYSTEM BASED ON RANDOM FUNCTION AND VARIABLE REPULSIVE FORCE

There is another important issue in the research field of group robot system, which is solving system conflicts. There are variable patterns of the conflicts in group robot system. Task conflict, path conflict and space conflict are among the major ones. The conflicts in group robot system can easily bring disorder to the system and may seriously degrade the overall performance of the system.

3.1 Deadlock Problem

When deadlock situations occur among robots or between the robots and the obstacle, which means the resultant force F_i stays at zero, we introduce the random disturbance operator to apply random virtual force to the robot, and thus help the robot break away from the deadlock situation. Define the random disturbance operator as:

$$F_i^{\gamma} = \tau \cdot g(i) \qquad (9)$$

where τ is a positive scalar parameter and $g(i)$ is a randomizer.

3.2 Decisional Conflict

To avoid decisional conflicts among the

tracking robots or between the robots and the obstacle, the article introduces the method of feedback control according to variable repulsive force based on the cooperation algorithms above except for control strategies like obstacle priority or ID priority. Suppose the resultant force exerted on robot i is F_t^{ip} at moment τ, and the resultant force exerted on robot i is F_{t+1}^{ip} at moment $t+1$. If $F_{t+1}^{ip} > F_t^{ip}$, which means the repulsive force is still increasing after cooperative controlling, we introduce negative feedback proportional control factor:

$$F_i = F_{t+1}^{ip} + F_{t+1}^{id} + kp \cdot (F_{t+1}^{ip} - F_t^{ip}) \qquad (10)$$

where F_{t+1}^{id} is the attractive force exerted on robot i at moment $t+1$ and kp is the proportional control factor.

4. COOPERATION ALGORITHM SIMULATION AND EXPERIMENT

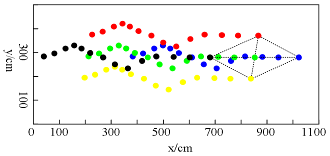
4.1 Introduction of Experimental Platform

In this experiment system, the experiment platform consists of 3 two-wheel differential driving mobile agents. The upper computer is built with VC and is mainly used to receive wireless contact information and obstacle distance information, and it derives motion control information of the agent by real time calculation. The lower computer use 2000 series DSP chip from TI Corporation as its master controller unit to collect ultrasonic wave information and encoder information, and the agent's wheels' motion can be controlled under the commands from the lower computer.

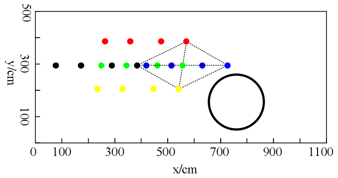
In the experiment: safe size of robot is 30*30*20cm, maximum speed allowed is 0.5m/s, maximum acceleration allowed is $1.5 m/s^2$, threshold value of the distance between neighbor robots is P=2.1m, positive parameters $I_1 = I_2 = I_3 = 0.15$, weight $\mu = \rho = \sigma = 0.05$, the optimum distance between robots is L=40cm and the communication cycle between robots is 20Hz which means data exchanges among robots and the controlling quantity of the next moment is derived every 50ms.

4.2 Simulation Experiment

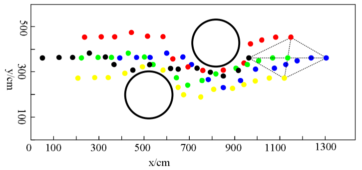
In the simulation experiment, we took the example of the quadrilateral formation of 5 tracking robots and designed an experiment of formation maintenance and obstacle avoidance. Fig.1 (a) shows the tracking robots maintains the formation and moves at the same time. Fig.1 (b), (c) shows the tracking robots maintains the formation before and after encountering an obstacle.



a. Formation Maintaining



b. Proceeding Before The Obstacle



c. Multi-Obstacle Avoiding And Formation Maintaining

Figure 1 Multi-Robot Motion Track

In the figure, Black and colored dots represent robots, and the dashed lines stands for quadrilateral formation and the black circle means the obstacles. During the movement, the robots keep a certain safe distance with the obstacle and can adjust and maintain the formation after the avoidance.

4.3 Robot entity Experiment

This article designs a triangle formation among 3 agents. In the experiment, we placed a 30*40cm object as an obstacle. And during the experiment we achieved the completion of proceeding, obstacle avoiding and formation maintaining of the 3 tracking robots. Tab.1 shows the cooperative control errors of robot 1, robot 2 and robot 3 respectively. And we define the tracking error as $e = \sqrt{(\Delta x)^2 + (\Delta y)^2}$.

Table 1: Robot tracking errors

Time/s	E1/mm	E2/mm	E3/mm
10	52.8	53.6	51.4
20	50.1	51.9	49.6
30	49.7	49.2	50.4
40	55.3	56.2	52.8
50	58.4	56.5	53.2
60	54.3	53.7	51.5
70	52.1	51.7	50.4
80	50.9	49.6	49.8

In the table, E1, E2 and E3 represent the tracking errors of robot 1, robot 2 and robot 3 respectively. We can see that at the 30th second the obstacle avoidance committed by robot 1 and robot 2 caused by the obstacle's repulsive force, increased the tracking error. And the formation maintenance committed by robot 3 caused by the attractive force from robot 1 and robot 2, increased the tracking error either. After the robots left the obstacle, the formation turned back to triangle and the tracking error decreased to 50mm, and thus the formation maintenance and obstacle avoidance are achieved.

5. CONCLUSION

To solve the problem of multi-robot cooperation, this article combines the tracking algorithm and artificial potential field, and defines the virtual force between the tracking robot and virtual robot and between neighbor robots and the obstacle based on distance and velocity component. And the article introduces methods like random function and variable repulsive force feedback control to solve deadlock and decisional conflict in multi-robot cooperation system. Through simulation and entity experiment, the article proves the stability and effectiveness of the multi-robot cooperative control algorithms mentioned above.

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