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Integrated particle swarm optimization algorithm based obstacle avoidance control design for home service robot ☆

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A B S T R A C T

This paper presents a new particle swarm optimization (PSO) algorithm, called the PSO-IAC algorithm, to resolve the goal of reaching with the obstacle avoidance problem for a 6-DOF manipulator of the home service robot. The proposed PSO-IAC algorithm integrates the improved adaptive inertia weight and the constriction factor with the standard PSO. Both the free-space and obstacle avoidance states are established for evaluations in computer simulations and real-time experiments. The performance comparisons of the PSO-IAC algorithm with respect to the existing inertia weighted PSO (PSO-W), constriction factor based PSO (PSO-C), constriction factor and inertia weighted PSO (PSO-CW), and adaptive inertia weighted PSO (PSO-A) algorithms are examined. Simulation results indicate that the PSO-IAC algorithm provides the fastest convergence capability. Finally, the proposed control scheme can make the manipulator of the home service robot arrive at the goal position with and without obstacles in all real-time experiments.

1. Introduction

Robot arms are quite important executive tools for home service robots in carrying out their services at home. A robot arm must be able to reach the target position precisely. In order to arrive at the goal point, the rotations of the end effector and each link are calculated by inverse kinematics [1]. Ref. [2] proposed a biomimetic approach to figure out inverse kinematics such that the end-effector of an anthropomorphic robot arm can be correctly located. Nearchou [3] introduced a modified genetic algorithm for solving the inverse kinematics problem. A recurrent neural network [4] was applied to solve the kinematic control problem of collaborative redundant manipulators.

Essentially, inverse kinematics are used to determine the rotating angle of each joint without considering collision with obstacles. Being collision free becomes an important issue for robotic arms in planning the trajectory movements. A concept of neural networks based on Q-learning [5] was carried out to address the problem of obstacle avoidance with a robot arm. Ref. [6] presents a dual neural network approach to deal with the collision-free inverse kinematics problem. Application of the adaptive fuzzy algorithm to solve inverse kinematics and obstacle avoidance problems with redundant manipulators was examined in [7]. A flexible fuzzy logic control [8] was proposed to overcome the collision avoidance problems with manipulator robots in complex environments.

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Chyan and Ponnambalam [9] used hybrid Particle Swarm Optimization (PSO) to conquer the static obstacle avoidance problem of the 5-DOF robot manipulator in a 2-D environment. Over the last decade, many studies have proposed different types of PSO algorithms to overcome various engineering problems such as a new constraint-handling mechanism concept [10] applied to constrained particle swarm optimization to solve engineering problems. A PSO-based optimal tuning strategy was proposed by Nery et al. [11], which utilizes a basic PSO concept to solve complex constrained mixed-integer nonlinear optimization problems, and was applied to constrained multivariable predictive controller (MPC) algorithms with model uncertainty. A PSO method [12] apply to solve optimization problem about defense against SYN flooding attacks. Advanced Particle Swarm Optimization (APSO) and Fully Informed Particle Swarm Optimization (FIPS) algorithms [13] were proposed to improve optimization of the tool path planning in 5-axis flank milling, which successfully resulted in fewer machining errors. Ref. [14] proposed utilize PSO method apply to efficient spatial domain based on image hiding scheme. Vasumathi and Moorthi [15] suggested a hybrid adaptive Neural Network–Particle Swarm Optimization (ANN–PSO) algorithm for the harmonic estimation problem and some other PSOs [16,17] to handle global optimization problems. This paper presents a novel PSO method applied to resolve the obstacle avoidance and angle planning problems of a 6-DOF robotic arm for the home service robot in 3-D spatial circumstances. The PSO algorithm is a population-based optimization search algorithm that was first introduced by [18] in 1995. The advantages of PSO include rapid convergence speed, lower parameter setting, and dynamic environment capability. The concept of PSO is to simulate bird flocking behavior, assuming there is some food in an area, but such food is unknown to the birds. However, the birds can get information about the distance from the food, and then they can find food close by. These birds are assumed to be the particles in the PSO algorithm; each particle represents a solution, and the quality of the solution is determined by the corresponding fitness value. The particle with the highest fitness value is a leader in the group. The leader will release its position message to other particles in the group. The velocity and position updating rules of each particle are described in [18],

$$V_i(t+1) = V_i(t) + c_1 \cdot rand_1 \cdot (pbest_i - X_i(t)) + c_2 \cdot rand_2 \cdot (gbest_i - X_i(t)) \tag{1}$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{2}$$

where $V_i(t)$ is the current velocity of particle i at iteration t, c_1 and c_2 are two positive constants called acceleration coefficients, $rand_1$ and $rand_2$ are two independent random numbers distributed in the range of $[0, 1]$, $X_i(t)$ is the current position of particle i at iteration t, $pbest_i$ is the best previous position of particle i at iteration t, and $gbest_i$ is the best previous position among all the particles at iteration t.

The major contributions of this paper are as follows: (1) a new artificial algorithm is presented to resolve the goal reaching with obstacle avoidance problem for a 6-DOF manipulator of the home service robot; (2) the proposed PSO-IAC algorithm applies the integration of the constriction factor and improved adaptive inertia weight to the standard PSO to increase the obstacle avoidance control system convergence velocity; (3) the practical effectiveness of an obstacle avoidance control scheme is demonstrated by experiments of the free-space and obstacle avoidance states for the home service robot.

The rest of this paper is organized as follows. Section 2 introduces the hardware configuration of the 6-DOF robotic arm of the home service robot and the forward kinematic analysis. Section 3 examines the various PSOs, for example, inertia weighted PSO (PSO-W), constriction factor based PSO (PSO-C), constriction factor and inertia weighted PSO (PSO-CW), and adaptive inertia weighted PSO (PSO-A), and presents a novel PSO algorithm, the PSO-IAC. In Section 4, computer simulations and real-time experiments are utilized to demonstrate the performance of the proposed PSO-IAC in comparison with PSO-W, PSO-C, PSO-CW, and PSO-A. Finally, Section 5 draws some conclusions.

2. Kinematic analysis of 6-DOF robotic arm

This section introduces the hardware mechanism of robots and gives the calculation of the kinematics based on the Denavit–Hartenberg (D–H) parameters [19] obtained from the relevant hardware parameters. The home service robot used in this study is called May and was implemented in the aiRobots laboratory. She is shown in Fig. 1. This subsection focuses on the hardware configuration of her arms. First, the materials in May's skeleton are aluminum alloy (Al) and magnesium (Mg). All servo motors used for the mobile chassis, robotic neck, arms, and fingers were made by the ROBOTIS company, including RX-28, RX-64, and EX-106+. The mechanism of the 6-DOF robotic arm is shown in Fig. 2, with 2-DOF on the shoulder, 2-DOF on the elbow, and 2-DOF on the wrist. In order to provide a large enough torque on the shoulder joint, each DOF of the shoulder has in fact two EX-106+ motors.

The coordinate system for 6-DOF robotic arm of the home service robot is established by using D–H convention. Fig. 3 depicts the coordinate system of the right 6-DOF robotic arm. With this coordinate system, four parameters of each joint, known as D–H parameters, are defined in Table 1. The range of EX-106+ motor is 250° and that of RX-64 is 300°. Fig. 4 illustrates the range and actual values (d_i and a_i) of the right 6-DOF robotic arm.

The above-mentioned information reveals that the position of the end-effector can be calculated via the forward kinematic method. According to the D–H convention, the coordinate transformation matrices for each link are obtained as follows.