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Discrete neural dynamic programming in wheeled mobile robot control

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ABSTRACT

In this paper we propose a discrete algorithm for a tracking control of a two-wheeled mobile robot (WMR), using an advanced Adaptive Critic Design (ACD). We used Dual-Heuristic Programming (DHP) algorithm, that consists of two parametric structures implemented as Neural Networks (NNs): an actor and a critic, both realized in a form of Random Vector Functional Link (RVFL) NNs. In the proposed algorithm the control system consists of the DHP adaptive critic, a PD controller and a supervisory term, derived from the Lyapunov stability theorem. The supervisory term guaranties a stable realization of a tracking movement in a learning phase of the adaptive critic structure and robustness in face of disturbances. The discrete tracking control algorithm works online, uses the WMR model for a state prediction and does not require a preliminary learning. Verification has been conducted to illustrate the performance of the proposed control algorithm, by a series of experiments on the WMR Pioneer 2-DX.

1. Introduction

The WMRs are used for complex transport or inspection tasks, where presence of human operator is economically unjustified or can cause unnecessary danger for the life. From mathematical point of view, the WMRs are non-holonomic objects described by nonlinear dynamic equations, what results in problems with the synthesis of stable control algorithms.

In recent years we can observe intensive development of effective artificial intelligence (AI) methods, as NNs [1], fuzzy logic, or reinforcement learning (RL) algorithms [2–9] in synthesis of the complex nonlinear control algorithms.

In the presented article the discrete tracking control algorithm, with Neural Dynamic Programming (NDP) algorithm in a form of the advanced model-based ACD in DHP [2,4,6–8] configuration is proposed. The ACD algorithm consists of two structures realized in a form of RVFL NN [1]: the actor approximates the optimal control law and implements current control policy, the critic rates quality of the control signal by approximation of the derivative of the value function with respect to the states and passes feedback to the actor, which accordingly changes its policy. The presented discrete control algorithm does not require the preliminary learning, works online and uses the WMR model for the state prediction in DHP structure. Stability of the control system is achieved by the additional supervisory control element derived from the Lyapunov stability theory [10], which guarantees stability in the ACD NNs learning phase and robustness in a face of disturbances. Verification of the proposed control algorithm was realized on the WMR Pioneer 2-DX.

The results of the researches presented in the article continue authors earlier works related to synthesis of the WMR tracking control algorithms using NNs [1], fuzzy logic or RL methods [3–5]. The paper is organized as follows: Section 1 is a short introduction into the tracking control of the WMR problem, Section 2 presents the discrete model of the WMR dynamics with executive systems dynamics involved. Section 3 contains the synthesis of the discrete tracking control

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algorithm of actor-critic architecture. Section 4 contains the stability analysis, in Section 5 results of the verification experiments realized on the WMR Pioneer 2-DX are presented. Section 6 summarizes the research project.

2. The wheeled mobile robot dynamics

We analyzed the movement of the non-holonomic WMR (with third, free rolling castor wheel), in the *xy* plane [1]. The WMR is schematically shown in Fig. 1.

In the mathematical model of the WMR we include the Maggie's dynamics equations [1,11] of the WMR and dynamical properties of the driving systems [12] composed of DC motors with permanent magnets, coupled with gears with ratio r_g and precise position encoders. We assumed the generalized coordinates vector of the WMR as

$$q = \left[\alpha^T, \dot{\alpha}^T\right]^T, \tag{1}$$

where $\alpha = [\alpha_i]^T$, α_i is an angle of a self-turn of the driver wheels, $i = 1,2$. The dynamics of the WMR is given by

$$M_R\ddot{q} + C_R(\dot{q})\dot{q} + F_R(\dot{q}) + \tau_{Rd} = \tau_R, \tag{2}$$

where M_R is the inertia matrix of the WMR, $C_R(\dot{q})$ is the Coriolis/centrifugal matrix, $F_R(\dot{q})$ is the friction vector, τ_{Rd} is the vector of bounded disturbances including unmodeled dynamics, and τ_R represents the vector of control signals including the wheel-driving moments. The DC electric motors dynamics can be written as

$$J_M\ddot{\varphi}_M + \left(B_M + \frac{K_M K_b}{R}\right)I \cdot \dot{\varphi}_M = \frac{K_M}{R}u_M - r\tau_L, \tag{3}$$

where the vector $\varphi_M = [\varphi_{M1}, \varphi_{M2}]^T$ contains angles of the self-turn of the DC motor shaft, J_M is the inertia matrix of the rotor and the gear, $J_M = (J_r + J_g)I$, B_M denotes friction of the gear, K_M is the motor torque constant, K_b is the back-EMF constant, R is the rotor resistance, r is the matrix of ratios, $r = I \cdot r_g$, τ_L is the load vector and u_M is the control vector containing motors voltages, $u_M = [V_1, V_2]^T$.

Using relation $\alpha = r\varphi_M$, where $r_g < 1$, taking into account the dynamics of the DC motors (3), we can write the dynamical equations of the WMR (2), in the form

$$(r^{-1}J_M + rM_R)\ddot{q} + rC_R(\dot{q})\dot{q} + \left[r^{-1}\left(B_M + \frac{K_M K_b}{R}\right)I + rF_R(\dot{q})\right]\dot{q} + r\tau_{Rd} = \frac{K_M}{R}u_M, \tag{4}$$

and in the shorter form

$$M\ddot{q} + C(\dot{q})\dot{q} + F(\dot{q}) + \tau_d = u, \tag{5}$$

where matrices M, $C(\dot{q})$ and vector $F(\dot{q})$ result from the WMR Maggie's dynamics equations and dynamical properties of the driving systems, τ_d denotes the vector of bounded disturbances, and u is a vector of control signals, $u = ru_M$. Using the Euler Derivative approximation and the state vector in a form $z = [z_1, z_2]^T$, where $z_1 = [\alpha_i]T$, $z_2 = [\dot{\alpha}_i]^T$, $i = 1,2$, we obtain the discrete notation of the WMR dynamics in the form

$$\begin{aligned} z_{1k+1} &= z_{1k} + z_{2k}h, \\ z_{2k+1} &= -M^{-1}[C(z_{2k})z_{2k} + F(z_{2k}) + \tau_d - u_k]h + z_{2k}, \end{aligned} \tag{6}$$

where k is an index of iteration steps and h is a time discretization parameter. The tracking control problem is defined as generating the control law, that minimizes tracking errors e_k assumed in the form

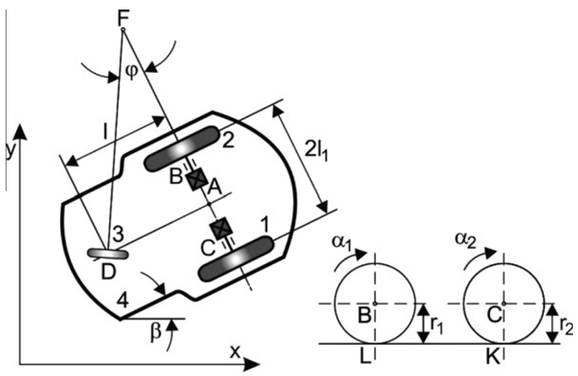

Fig. 1. Schematic diagram of the WMR.