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DOCTORAL DISSERTATION ABSTRACT

APPLICATION OF THE DIFFERENTIAL GAME THEORY IN OPTIMAL ADAPTIVE CONTROL MOTION OF A WHEELED MOBILE ROBOT

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Abstract:

This dissertation documents the results of research on the application of the theory of differential games in the control of nonlinear systems, on the example of a wheeled mobile robot (WMR). This dissertation fits into the development of innovative engineering solutions in the area of research on optimal solutions in mechatronic systems, which include WMR.

Its purpose is to demonstrate the usefulness of the theory of differential games, and reinforcement learning techniques, especially techniques known as neural dynamic programming, in the optimal control of mechatronic systems.

In the first part of the dissertation, a non-linear dynamics model is described and a classic method of testing the stability of nonlinear systems is presented - the direct method of Lapunov. Next, neural networks, the problem of optimal control resulting from the Bellman optimality principle, the actor-critic structure, the concept of dissipativity and the associated input-output stability are described. This approach to the stability of a dynamic object leads to the determine of a H_∞ control that minimizes the L_2 gain of the analyzed system i.e. γ^* for finite energy signals. This problem is solved in a two-person zero-sum differential game, which is a minmax problem, and its solution is to find a solution to the Hamilton-Jacobi-Issac equation.

In the next chapter, dynamic objects were presented. They were used to verify the adopted theoretical assumptions regarding the application of the theory of zero-sum differential games in the control of a linear object such as the WMR drive module and a non-linear object such as a WMR.

The following chapters of the dissertation concern the synthesis of optimal control using the theory of zero-sum differential games with respect to the drive module. In this case, the determination of the optimal control in the presence of worst case disturbances comes to solving the Riccati equation.

In the case of WMR, the optimal solution is approximated using the actor-critic structure. In addition, it was assumed that WMR performs the task of tracking control and the task of stabilization - simple behavioral behavior of drive-to-goal . In order to assess the verification of the input-output stability, the H_∞ control condition was verified in numerical tests by adding a parametric disturbance system understood as a change of friction of motion to the mathematical model of the robot. The determined minimum γ gain confirmed the fulfillment of the condition, i.e. $\gamma^* \leq \gamma$, which confirms with a simulation an input-output stability.

The last part of the thesis contains the results of verification tests of suboptimal control in changing working conditions. The verification of the optimal control of the drive module in the presence of the worst case disturbances is described. Due to the difficulty of measuring its size, it was assessed on the basis of the mathematical model of the drive module. On this basis,

it was assessed that the gain $\gamma^* \leq \gamma$ condition is met, which is a verification confirmation of the input-output stability of the optimal control system that has been verified.

The rest of the verification regards the tracking control task and the stabilization task for WMR. Verification associated with WMR is divided into two parts. The first concerns control with the use of a differential zero-sum game, in which the procedure of adapting the weight of the critic approximating the solution of the HJI equation was carried out. The second is due to the need to check the H_∞ control condition. In this case, the WMR is affected by disturbances resulting from the change of the ground on which the robot moves.

Their values are difficult to measure, therefore, to check the condition, the estimation resulting from the control difference for WMR motion with and without disturbances was used. On this basis, the control condition $\gamma^* \leq \gamma$, was estimated, which allows to draw conclusions regarding the stability of the input-output type and the resistance of the designed system to changing operating conditions.

The obtained solutions are an extension of the problem of optimal control (from the point of view of the synthesis of the input-output control system), taking into account the weakening of the influence of variable working conditions and other disturbances on the assumed MRK motion. Moreover, the correctness of the adopted analytical and simulation solutions in experimental research was confirmed, which confirms the thesis of this dissertation.