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Adaptive Self-Tuning Path Control System for an Autonomous Mobile Robot

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1 Introduction

In the last decade researchers have developed special interest in autonomous mobile robots for application in industry as means of transport, inspection, and operation [2]. Higher operation levels, such as self-location methods, vision, and path planning, rely on the tracking and regulation capabilities of the motion control module which performs position control and the stabilization of the motion of the autonomous mobile robot about a time indexed trajectory. This path control problem implies control design for nonlinear time varying multivariable systems. One approach of solving this kind of control problems is using adaptive methods for the control system design. The adaptive part of the control system copes with the time variance and for the underlying control problem methods for nonlinear systems can be applied. Several successful applications of adaptive control schemes have been published [1] whereas in nonlinear systems literature few experiments, implementations, and applications on real systems have been reported.

2 System Definition

In control of nonholonomic systems, where non-integrable velocity constraints apply, a number of general models are defined. In [2] a special class of nonholonomic systems called unicycle type systems is presented. Consider this class of kinematic model $\dot{\tilde{x}} = v\cos(\tilde{\psi})$, $\dot{\tilde{y}} = v\sin(\tilde{\psi})$, $\dot{\tilde{\psi}} = \omega$ for the wheeled mobile robot B21 where the triplet $z = (\tilde{x}, \tilde{y}, \tilde{\psi})^T$ describes the position, $\tilde{x}$ and $\tilde{y}$, and orientation $\tilde{\psi}$ of the robot with respect to a fixed frame in the movement plane. The input vector is composed by the translational velocity v and the angular velocity ω. The path control problem is defined as the stabilization of the autonomous mobile robot about a time indexed trajectory. This time indexed trajectory, i.e. the reference path, is calculated taking into account the dynamics of the mobile robot B21 and using as input spline parameters computing a geometric collision free path from the starting point S to the goal point G. The reference path is defined by the reference translational velocity v_r and the reference angular velocity ω_r. Together with the physical initial conditions of the robot $x_r(0)$, $y_r(0)$, and $\psi_r(0)$ the reference path is defined in the movement plane. A feedback law has to be designed, such that the deviation $x = (e_x, e_y, e_\psi)^T$ from the reference path tends to zero, i.e. $\lim_{t\to\infty} x = 0$. From this a nonlinear time varying multivariable state space model for the deviation is computed.

3 Control System

To design a feedback law for the obtained system satisfying the above mentioned conditions of global asymptotical stability implies dealing with a nonlinear time varying multivariable system. A suitable design method for time varying systems with changing operation points is the adaptive control. In this case the concept of adaptive self-tuning regulators as referred to in [1] is used to design the control structure. The control system is composed of two loops. The inner loop is a feedback control structure with the process and the controller. The outer loop is the parameter adjustment loop. The values of the parameters are updated and the controller parameters are obtained from the solution of a design problem using these updated parameters. This general structure is applied to the actual path control problem. From the reference path and the corresponding reference initial conditions the reference input velocities v_r and ω_r are computed. In our case we consider the time varying signals v_r and ψ_r defined by the reference path as the process parameters. They are sampled at 16 Hz where the sampling method is chosen to be sample and hold. In this way the time varying process parameters are transformed into known time invariant parameters v_{rk} and ψ_{rk} for every sampling period. Then an on-line solution to the design problem for the system with time invariant parameters has to be computed. In this case the pole assignment method referred to in [3] is chosen.

4 Control Design

The underlying control problem of the adaptive self-tuning controller consists in designing on-line at every iteration a feedback law. The control design is performed in continuous time and the feedback law $u_k(t)$ is obtained for every iteration k. If the time invariant system were in the canonical form for multivariable systems the pole assignment method for designing a globally asymptotically stabilizing feedback law could be easily applied [3]. As that system is not in the canonical form a nonlinear transformation $\tau_k(x)$ that transforms it into a canonical form must be calculated for every iteration k.
If the transformed coordinates are denoted by x^* the transformation is given by $x^* = \tau_k(x)$ and is calculated following [3] as

$$\tau_k(x) = \begin{pmatrix} -\sin(\psi_{rk} + e_\psi)e_x + \cos(\psi_{rk} + e_\psi)e_y \\ v_{rk}\sin(e_\psi) \\ \cos(\psi_{rk} + e_\psi)e_x + \sin(\psi_{rk} + e_\psi)e_y \end{pmatrix}.$$

Transforming the time invariant system the control law $u_k(t)$ is calculated in the original coordinates as $u_k(t)^T = (\tilde{\omega}_k(t)\tilde{v}_k(t))$ and applied to the process during every sampling period. The pole assignment method to design the contol law is now easily applied to the closed-loop system. Although we cannot infer that the whole control system is globally asymptotically stable experimental results demonstrate the excellent behaviour of the designed control system.

5 Experimental Results

The designed control system is implemented on the autonomous mobile robot B21 manufactured by Real World Interface. Figure 1 shows an experimental result where the robot starts at an initial point which lies 40 cm in each direction beside the starting location S of the reference path and it has an orientation error of π. The reference path is composed by a circle segment, a very narrow edge, a smooth curve, and a straight line. The robot eliminates the initial error and tracks the reference path. As it can be observed very narrow edges which imply high rotational accelerations are tracked by the path control module. The resulting path is very smooth and the controller even manages narrow curves where high rotational accelerations have to be performed.

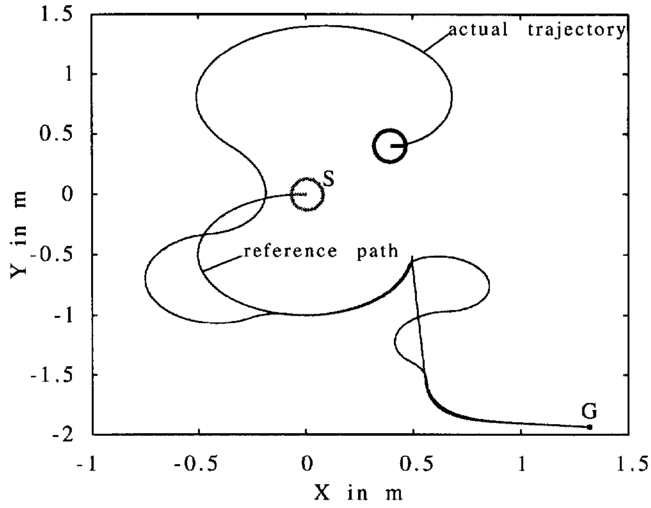

Figure 1: Reference and actual trajectory of the robot. The robot starts with an initial error of 0.4 m in x and y direction and an orientation error of π.

6 Conclusions

In the present paper we have considered the path control problem for the autonomous mobile robot B21. In particular we have defined the reference paths as time indexed functions. The error between the actual position and the reference path is described by a nonlinear time varying multivariable state space model. We have proposed an adaptive self-tuning control system taking into account the properties of the obtained state space model. We have concentrated especially on the control design block. For every iteration of the outer control loop a nonlinear transformation of the state space system into a canonical form must be carried out. Afterwards we use the pole assignment method to design a controller. We have implemented the designed control system on the real platform B21. Several experiments have been carried out where it has been demonstrated that the system requirements are fulfilled. The closed-loop system accurately follows the reference path. As expected, initial disturbances are eliminated and the reference path is caught up. Even reference paths with very high dynamics are followed accurately by the closed-loop system after the transient oscillations and no tracking error remains.

References

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