PID, Fuzzy and Model Predictive Control Applied to a Practical Nonlinear Plant

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ABSTRACT
For the cooling system of a mobile machine with \( m \) control variables and with \( n \leq m \) correction variables different control strategies have been investigated in order to minimize power to save energy and to reduce fan noise with sufficient cooling. The plant is nonlinear and not identified. Three different kinds of controllers have been investigated in several variations, i.e. fuzzy control, PI(D) and model predictive control (MPC). 14 different criteria have been used for evaluation. In many respects a linear controller with fuzzy prediction proved best, in particular the prediction model can handle nonlinear properties of the plant. A problem of advanced control schemes with unidentified plants is the difficulty to prove stability.

KEYWORDS
Construction Machine, Defuzzification, Fan Control, Fan Noise, Feedforward, Fuzzy Control, Fuzzification, Mamdani, Model Predictive Control, MPC, Nonlinear System, PI Control, PID Control

INTRODUCTION
Beside classic PI and PID controllers today a lot of other controller concepts are known. Some of them, i.e. fuzzy controllers and model predictive controllers, which can be implemented in present embedded electronic control units without reaching the limit of computational power are used in a specific example application. This example application is the cooling system of a dumper, a construction machine which can be considered as a motorized wheelbarrow. The cooling controller does not act directly upon engine control, indirect effects, e.g. a reaction of the engine controller to overheating due to insufficient cooling, are possible. The controlled plant is not linear. Mathematically spoken the plant is the relation between the demanded fan power as plant input and the resulting temperatures of coolant, lubricant, hydraulic oil and inlet air under different working conditions as plant output (Figure 1). Such plants are typical situations in which control is implemented without identification of the system, i.e. without mathematical modeling. Identification is not impossible with nonlinear systems, but the effort is large and the resulting accuracy often disappointing (Ogata, 2009 and other textbooks). There is a lot of requirements, so a controller has to react quickly to disturbances or changing setpoints and the controlled variable should stay close to its setpoint. Not everything which is mathematically possible is also reasonable from a practical point of view, so beyond formal requirements other requirements concerning the industrial usability of a controller need

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to be considered, these requirements might be in practice more crucial for the choice of a controller than its mathematical properties.

The PI(D), fuzzy and predictive controllers have been investigated in different scenarios on a validated laboratory model of the plant including the original embedded control unit of the machine. In this setup all controllers have been subject to the same conditions showing weakness and strength of each controller. A long catalogue of different criteria to evaluate the different properties of controllers is proposed, the reader might modify the catalogue due to his application. Based on this set of criteria a ranking of controllers is proposed. Finally a generalization to other problems is given.

**BACKGROUND**

**PID Control**

The probably oldest kind of linear controllers is a proportional controller (P controller) which generates a control action $u(t)$ proportional to the error $e(t)$, i.e. the deviation of the controlled variable from the reference. To eliminate the permanent remaining error $e(t \rightarrow \infty)$ of a proportional control an integrator can be switched in parallel to the proportional controller, this combination is a PI controller. In order to accelerate the response of the controller an additional differentiator can be switched in parallel to
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