TS Control – The Link between Fuzzy Control and Classical Control Theory

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Abstract. Fuzzy controller can be approximated or generalized respectively by replacing the fuzzy sets in the rule conclusions by real numbers or functions. Such a controller is called a TS controller and can be seen as a classical gain scheduling controller. Therefore, TS control can be interpreted as fuzzy and classical control as well. Besides this, for this type of control during the last years there were methods developed, that make it interesting for practical applications.

The objective of this paper is the introduction of TS control and the discussion of its position at the border between fuzzy and classical control, but also the presentation of suitable methods, approaches and fields of application for this controller type.

1. Introduction

Takagi-Sugeno control was introduced by T. Takagi and M. Sugeno in the middle of the 80s as an additional version of fuzzy control. In principle, it is nothing else but gain scheduling control, which is well known in control theory since decades. But in the following years, in the field of fuzzy control this controller type received intensive research activities, and since the end of the 90s a controller design method was developed, that makes TS control very interesting for practical applications. On the one hand, this state space based method can thoroughly be seen as a classical approach, but on the other hand, a TS controller can also be interpreted as a generalized fuzzy controller, and therefore it can be said, that TS control is a link between fuzzy control and classical control theory.

This paper starts with a short description of the conventional fuzzy controller. This gives the basis to discuss conventional fuzzy control and to point out the special position and advantages of TS control later. In the rest of the paper, TS control with its analysis and design methods is introduced in detail (further details see [5]).
2. Fuzzy control

Let the starting point be a conventional fuzzy controller for temperature control with the temperature \( x \) as input and the actuating variable \( y \) as controller output, given by the fuzzy rules

\[
R_1 : \quad \text{IF } x \text{ IS cold THEN } y \text{ IS big} \tag{1}
\]

\[
R_2 : \quad \text{IF } x \text{ IS hot THEN } y \text{ IS small} \tag{2}
\]

The vague expressions \textit{cold, hot, big, and small} are defined by the fuzzy sets of Figure 1.

![Diagram](image)

**Figure 1.** Black Forest test.

With a measured temperature \( x_k \) at time \( t = t_k \) the two fuzzy rules are activated according to the membership degree of \( x_k \) to the fuzzy sets \textit{cold} and \textit{hot}. The membership degree is equivalent to the value of the respective membership function at \( x = x_k \). In the example of Figure 1 \( x_k \) belongs more to the set \textit{hot} of the hot temperatures than to the set \textit{cold} of the cold temperatures. Following from that, rule No. 2 is stronger activated than rule No. 1, and the output fuzzy set \textit{small} of the second rule is higher weighted in the overall fuzzy set. This output fuzzy set of the entire controller is the set of all possible output values for the input value \( x_k \), and it is computed by association of all differently activated output fuzzy sets of all rules.

Then, one value \( y_k \) of this controller output fuzzy set has to be determined by the so-called defuzzification. This value will be the controller response to the input value \( x_k \). Normally, for defuzzification the center-of-gravity method is used, that means, the \( y \) coordinate of the center of gravity of the fuzzy set is used as defuzzification result.