FUZZY CONTROL OF A SPEED LIMITER

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Abstract

Future regulations by the European Community (EC) require a speed control for the limitation of truck speeds on the European roads. Today's speed limiters consist of an adaptive PID-controller. However, the resulting truck behaviour is not satisfactory compared to an experienced driver. Therefore, the human experience has to be used to improve the design.

Some fundamental aspects for the development of a Fuzzy-Logic-Controller (FLC) for limiting the truck speed are presented in the paper. Simulations of a controller with one and two input variables are shown. It turns out that a FLC can be interpreted as a highly nonlinear control. The resulting control law will be discussed.

1 Introduction

Legal regulations by the European Community [5] require that from the October 1, 1994 every newly released truck has to be equipped with a device that limits the maximum vehicle speed to $85km/h$. Such a speed limiter has a similar function like a cruise control. It is important to note however, that it does not allow the vehicle speed to be raised above the upper limit of $85km/h$.

Today's speed limiters are based on adaptive PID control laws. It shows, however that experienced drivers can still outperform those devices with respect to ride smoothness and efficiency. The reason for this is that there are several system properties which are quite difficult to handle with conventional control strategies, e.g.

- very large variations of system parameters due to changing truck loads,
- highly nonlinear engine and drive train behaviour,
- strong disturbances due to road topology as well as air resistance forces and wind influences.

The intention to incorporate drivers' experience into the control law leads to the idea of using a *Fuzzy-Logic-Controller (FLC)* for this problem. The fuzzy logic approach to include human reasoning and experience in control systems has been successfully applied in a wide variety of technical products, see e.g. Zimmermann [4]. The basic theory of fuzzy sets and fuzzy logic is presented by Zadeh [3], Lee [1].

In the following sections of the paper some fundamental aspects for the development of a Fuzzy-Logic-Controller for controlling and limiting truck speed are presented.

2 Speed Control Devices and the Simulation Environment

The devices that are already available in a truck and can that can be utilized to realize a speed control are (1) a control unit, (2) the fuel injection pump, and (3) a servomotor. The control unit usually consists of a micro controller which executes the programs for the Anti-Lock-Braking-System as well as for the Traction-Control-System. For the latter the controller has access to a servomotor which is connected with the fuel injection pump for controlling the engine torque. The system can be used to download yet another program to the micro controller, in order to use the servomotor also for speed control. Figure 1 illustrates the functional relationship between the fuel injection pump, the accelerator pedal and the servomotor. The elongated hole ensures that the servomotor will never be able to move the external lever of the fuel injection pump further towards full load than the driver allows to. The spring coupling enables the speed limiter to reduce the driver's

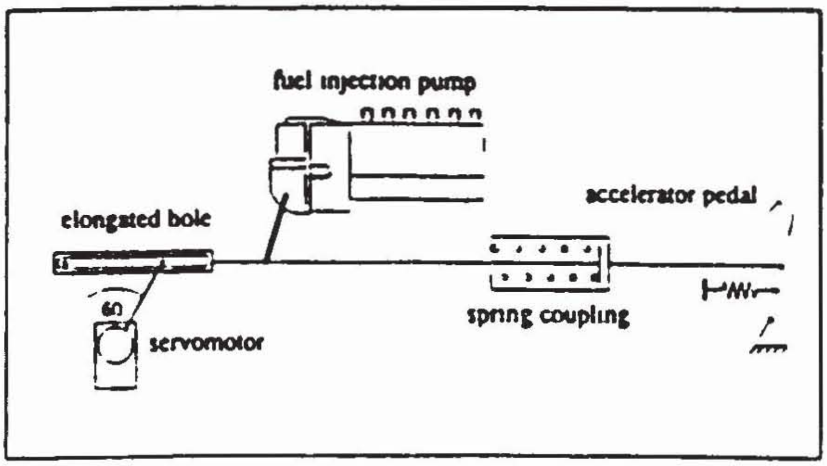

Figure 1 Functional relationship between fuel injection pump, accelerator pedal, and servomotor

setpoint when the vehicle speed exceeds the desired or maximum permitted speed The simulation of the truck behaviour is based on a model that can be executed in real-time on a single Motorola 68040 processor The FLC can be linked to an existing simulation program implemented in C In the FLC subroutine only integer values are used in order to facilitate an implementation on a micro controller in the real vehicle Due to the real time capabilities of the simulation it was possible to run the experiments in a hardware-in-the-loop setup, in which the real servomotor is controlled by the FLC subroutine directly

3 Definition of the Design Parameters

A FLC consists of the following functional blocks for which design parameters have to be chosen according to the application

1. **Fuzzification Interface:** The fuzzification interface measures the input variables, transforms the incoming values into descrete numbers, and provides the fuzzification of the crisp input data into linguistic fuzzy data
2. **Knowledge Base:** The knowledge base not only contains information about the system that has to be controlled but also information about the targeted behaviour of the complete system. It consists of a *data base* and a *rule base*
   - The data base provides the definitions necessary to realize the linguistic control rules and the fuzzy data manipulation
   - The rule base describes the control objectives by a set of linguistic control rules
3. **Decision Making Logic:** This function is the kernel of a FLC It emulates sensitive decision making by using fuzzy logic
4. **Defuzzification Interface:** This interface accomplishes the defuzzifaction by forming a *crisp control action* out of *fuzzy control actions* Furthermore it retransforms the discrete output data into continuous values

For the design of a FLC it is recommendable to construct a simple control algorithm in the beginning As soon as the simulation is functioning it is fairly simple to enhance and to modify the basic controller construct

3.1 Fuzzification Interface

As a fuzzifier (fuzzification operator), a *crisp data - fuzzy singleton transformation* was chosen This fuzzification method is easy to implement and it shows to be sufficient for the application under investigation

The first controller version has been designed with

- the deviation (*deltav*) of the vehicle speed from the desired speed (*vset*) as input variable,
- the servomotor speed as output.

In the second controller version the vehicle acceleration has been added as second input variable. This leads to a controller with a two dimensional input space and a one dimensional output space.

$$Output = f(Input1, Input2)$$

The discretization was done according to the possible range of all variables. This can be done in a very arbitrary fashion. However, when it comes to an application in a real system the individual ranges of each variable should be resoluted as highly as possible with the micro processor being used in order to minimize rounding errors during division operations.

3.2 The Knowledge Base

Linear membership functions are the most suitable type of membership functions for technical applications, Omron [6]. Hence, triangular shaped membership functions have been chosen uniformly. As an example, the very coarsely partitioned linguistic variable *deltav* of the first controller is depicted in figure 2a. The plot shows the *degree of membership (DOM)* of the speed deviation *deltav* to the linguistic variables dv_N1 for negative, dv_OK for admissible, and dv_P1 for positive deviation, respectively

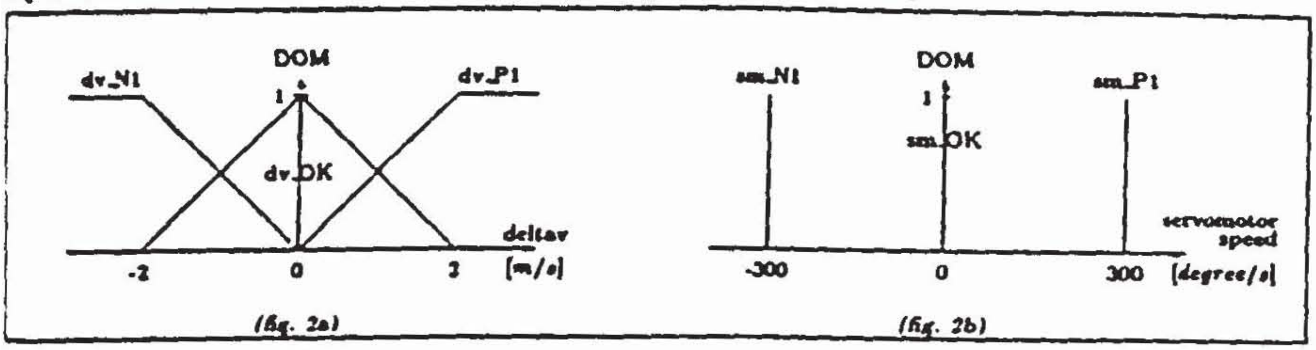

Figure 2: Partitioning of *deltav* (a) and *servomotor speed* (b) in the first single input controller.

A simple rule type which infers from the process state to a output decision has been applied. More sophisticated rule types like predictive rules have not been used in this examination. In the simple case of the first controller with one linguistic input variable -partitioned into three linguistic values- a complete rule base is given by:

Rule #1: IF *deltav*=dv_N1 THEN *servomotor speed*=sm_P1

Rule #2: IF *deltav*=dv_OK THEN *servomotor speed*=sm_OK

Rule #3: IF *deltav*=dv_P1 THEN *servomotor speed*=sm_N1

where sm_N1, sm_OK, and sm_P1 are linguistic values for negative, zero, and positive servomotor speed, respectively (see figure 2b).

3.3 The Decision Making Logic

The *Larsen Product Operator* has been chosen as the fuzzy inference mechanism. Hence, the output of the IF-part of a linguistic rule is simply multiplied with the membership function of the addressed linguistic value of the output variable of this rule.

3.4 The Fuzzification Interface

According to results obtained by Omron [6] it is sufficient for technical applications to represent the linguistic values of the linguistic output variables by fuzzy singletons. Thus, the membership functions of these linguistic values are single points, assigning a degree of membership of one to the chosen crisp values. This is illustrated in figure 2b.

Controller With One Input Variable

For all the following simulations a parameter set that describes a vehicle with a mass of 11.5 tons and an engine version of 170 hp has been used. For the examination of the robustness of the final controller, parameter variations have been conducted. The simulations started usually from 80km/h and vset was defined at 85km/h according to the future EC regulations.

Figure 3 shows the result of the first simulation. The truck speed approaches vset from below but it overshoots and oscillates continuously around vset due to a hefty control action of the FLC. Another possibility to depict

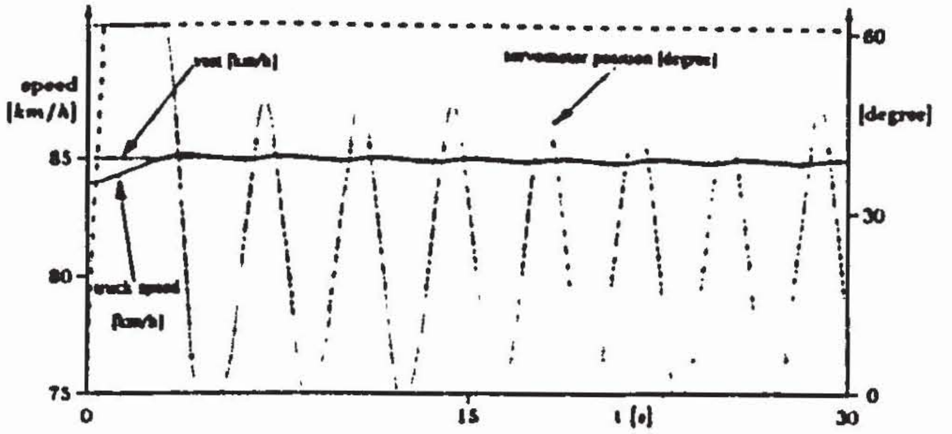

Figure 3: Oscillating system behaviour caused by the control actions of the first FLC

the system behaviour is to plot the vehicle speed against the fuel injection pump lever position. The plot in figure 4 shows a limit cycle behaviour which indicates the nonlinear character of the system. The following

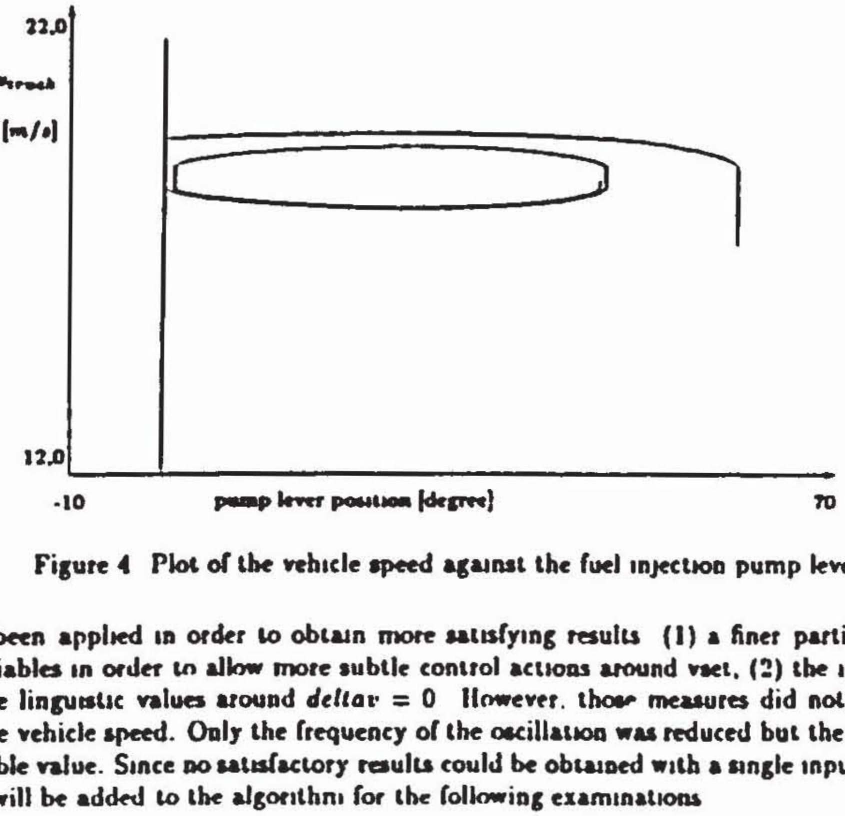

Figure 4: Plot of the vehicle speed against the fuel injection pump lever

methods have been applied in order to obtain more satisfying results: (1) a finer partitioning of the input and output variables in order to allow more subtle control actions around vset, (2) the introduction of zones of silence in the linguistic values around *deltav* = 0. However, those measures did not yield a more stable behaviour of the vehicle speed. Only the frequency of the oscillation was reduced but the amplitude remained at an inadmissible value. Since no satisfactory results could be obtained with a single input controller, another input variable will be added to the algorithm for the following examinations.

5 Controller With Two Input Variables

As a second input variable the derivation of the vehicle speed has been chosen. By extending the input space to a two dimensional space it is now possible to derive more sophisticated linguistic control rules. Now, not only one process variable will be examined in the IF part of a rule but moreover a combination of two process variables is used to come to more appropriate decisions. This also increases the number of rules required to obtain a complete rule set. Thus, it is also feasible to introduce a finer partitioning of the output variable with linguistic values.

The first experiment shows a very promising result. Figure 5 exhibits how the truck speed is approaching vset from below. As soon as the truck speed comes into the sensitive range of the controller the amount of injected fuel is being reduced and the vehicle speed reaches vset without overshoot. The problems, however, that are arising with this controller are easy to detect. Due to its radical strategy to hold vset at any circumstances heavy control action will be triggered by any kind of disturbance such as noisy signals from the speed observing

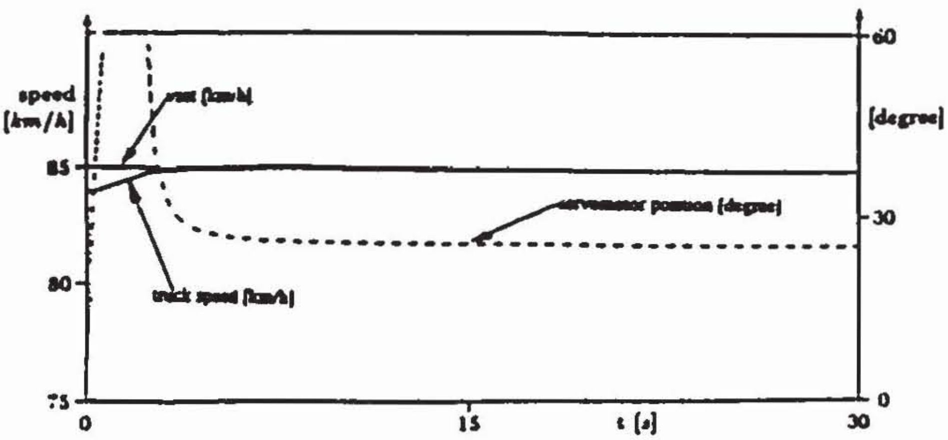

Figure 5: Picture perfect speed control of the first FLC with two input variables.

sensors, road bumps or wind forces. Therefore, the controller has to be made more capable of dealing with real world conditions.

6 Improving Disturbance Behaviour

This section will be restricted to treating with disturbances from the external environment only. The disturbances are represented by alternating slopes with $20m$ length and an inclination of $\pm 0.5 degrees$ which the vehicle has to pass after reaching vset.

Figure 6 depicts a fairly rough ride of the truck during the simulation caused by the strong reactions of the initial controller to the uneven road.

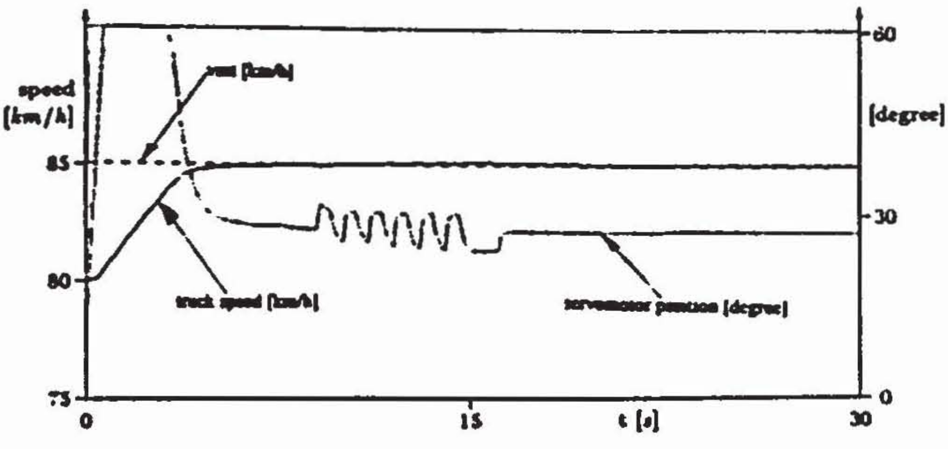

Figure 6: Aggressive behaviour of the FLC during disturbances impacting on the vehicle.

Principally, there are several possibilities to reduce the sensitivity of a FLC in a certain area or around the desired system state: (1) Another input variable, given by the integration of the vehicle speed, can be used, (2) the linguistic input variables as well as the output variables can be partitioned in a finer fashion around the desired state in order to obtain more subtle control actions in this area, (3) the linguistic rules around the desired system state can be formulated more "softly" which means that even if for example a deviation from vset occurs, the controller should only react very slowly, (4) the firing strength of the rules that are dealing with all small deviations from vset can be reduced, thereby decreasing the control action.

Using a trial and error strategy a controller was developed that shows a much smoother behaviour, figure 7, of the vehicle during the disturbances compared to the ride illustrated in figure 6. The trade-off for less aggressive control behaviour is a slightly slower approach of the truck speed toward vset in the beginning. However, as it will be shown later, this behaviour is still superior to a conventional PID controller.

7 Comparison: FLC – Conventional PID Controller

The PID controller used for comparison corresponds to commercial speed limiter controllers used by many truck manufacturers. During the comparison, four different parameter sets, representing four different vehicles, have

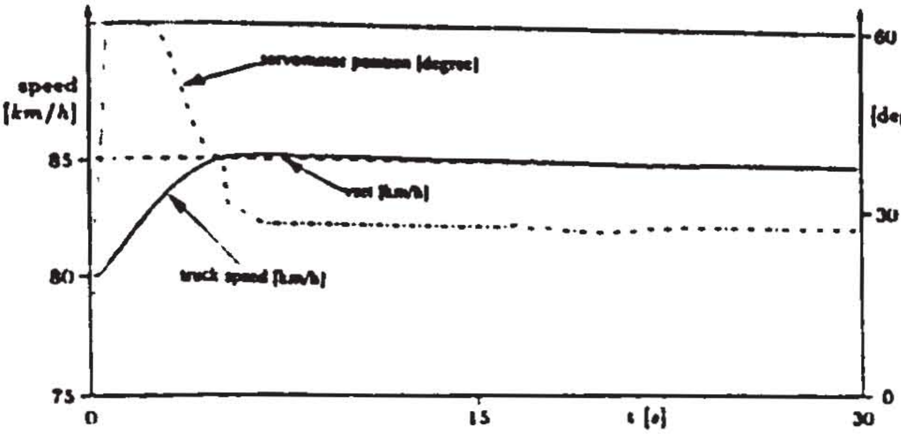

Figure 7 Smooth ride of the vehicle despite external disturbances

been loaded without modification of the controllers Two of the four situations shall be presented vicariously As it is the most difficult task for a truck speed controller to react in an appropriate fashion to a fast change in the inclination of the road, a situation will be shown where the vehicle, after reaching vset, will first go up a slope with $+3 degrees$ inclination, then go down a slope with the same steepness which is followed by a plain road.

The first parameter set describes a truck with the mass of 35 tons and an engine version with 490 hp. Figure 8 shows the performance of the FLC, whereas the behaviour of the conventional PID controller is shown in figure 9 The superior performance of the FLC is salient in this situation The PID controller is way more sluggish in its reponse to deviations in the truck speed from vset

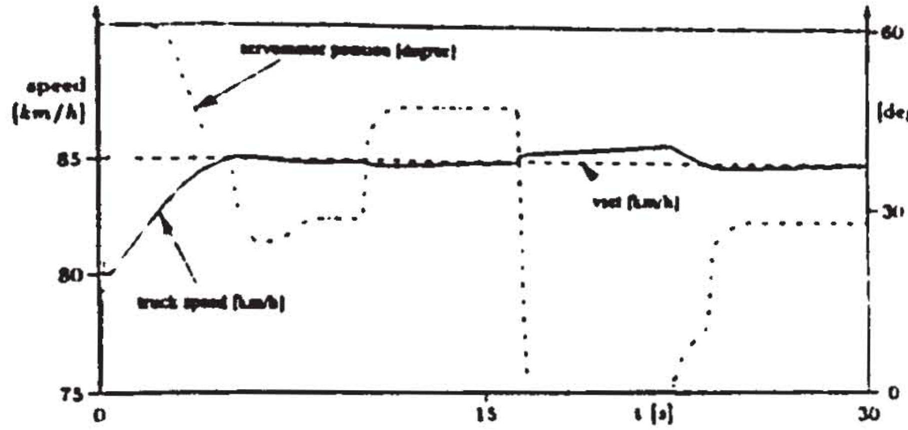

Figure 8 Performance of the FLC, truck with 35 tons, 490 hp

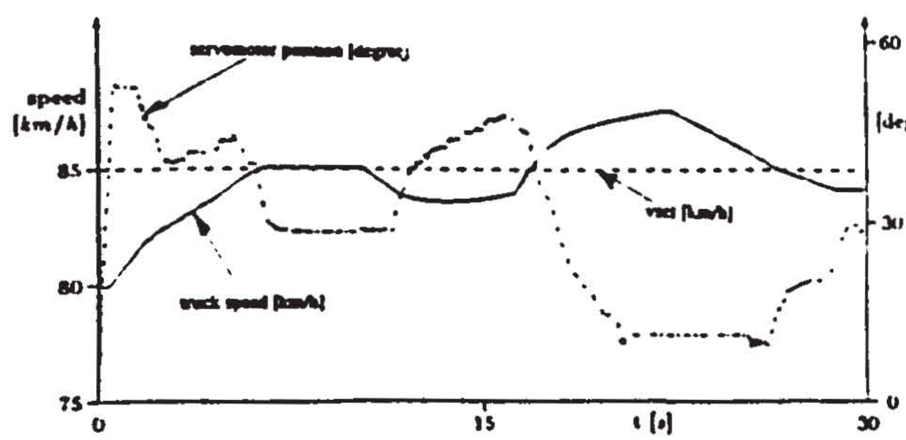

Figure 9: Performance of the PID controller, truck with: 35 tons, 490 hp

The second parameter set defines a vehicle with the mass of 6 tons, equipped with a 170 hp engine The FLC controlled ride is depicted in figure 10, the PID controlled ride can be seen in figure 11 Again, the PID controller is no match for the FLC due to the sluggishness of the PID control.

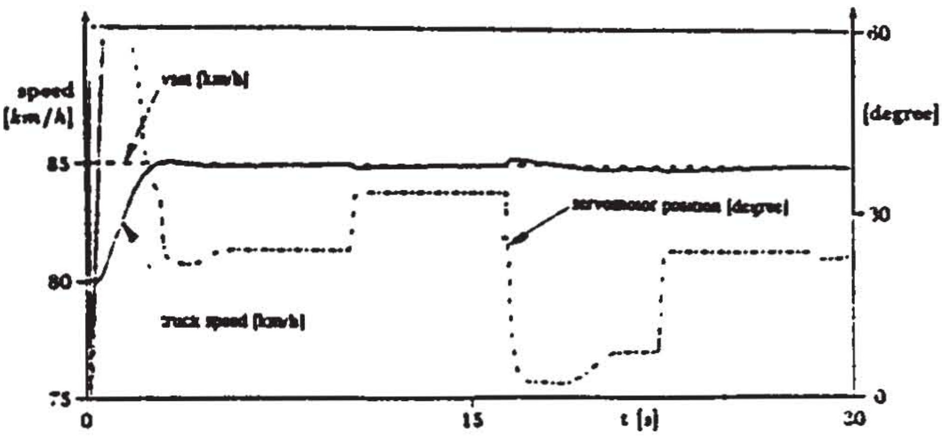

Figure 10: Performance of the FLC; truck with: 6 tons, 170 hp.

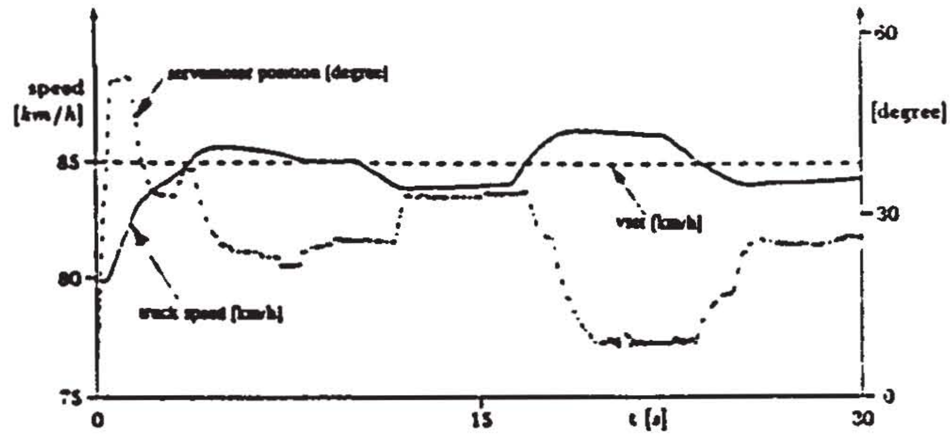

Figure 11: Performance of the PID controller; truck with: 6 tons, 170 hp.

As a result it can be noted that although the PID controller has been developed to match a variety of different vehicles, the FLC shows a much better performance, albeit its development for a single parameter set only.

8 The Nonlinear Characteristic of a FLC

The fuzzy logic control law that was developed represents a static relationship between the output variable and the two input variables. Its behaviour can therefore be visualized by plotting the nonlinear characteristic, figure 12. This visualization reveals that fuzzy logic can be used as a tool for designing complicated nonlinear

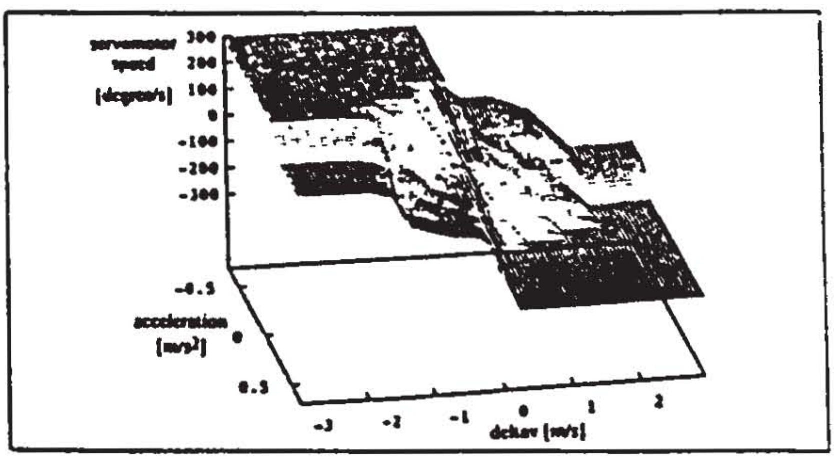

Figure 12: Nonlinear characteristic of the FLC.

control laws without using mathematical system models. The control law follows from decision rules that can be formulated in a more or less intuitive way. Fuzzy logic therefore provides a promising approach to the design of controllers for technical systems with complicated structure

9 Conclusion

A Fuzzy-Logic-Controller for speed limiters used in trucks was developed and its performance was compared to conventional PID controllers The results have been presented in the predecessing sections. In summary the following advantages of fuzzy logic can be enumerated, Thurm [2]

- The controller can be designed without a mathematical model of the system in a quasi intuitive process
- It is possible to specify the control behaviour via the linguistic control rules
- The FLC shows a significantly higher robustness than a PID controller
- The development process can be conducted in a very short time span
- Additional input or output variables can be added to the algorithm without bothering about mathematical complexity.
- Fuzzy logic is a promising tool to derive nonlinear control laws for complex systems

However, there are also some disadvantages to be pointed out·

- A large number of design parameters has to be specified without a formal methodology.
- There is no mathematical proof for the stability of a FLC controlled system available yet
- If the rules cannot be generated theoretically they have to be derived from expert knowledge This knowledge has to be quantifiable for successful implementation

In the view of the promising results it would be of interest to investigate further into the following problems

- The use of more input variables, as for instance the current vehicle load, in order to derive more sophisticated control rules
- Hardware solutions like fuzzy logic processors that are capable of processing large rule sets
- Implemention of a parallel fuzzy process as an adaptive controller which optimizes the initial fuzzy process according to its current performance.

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