Assignment 3.3 – Fuzzy Logic

SIT 788

1. Introduction

This report discusses the application of Fuzzy Logic for developing **Adaptive Cruise Control** application in the domain of **autonomous driving**. Cruise control offers assistive capabilities to a driver in navigating a car in terms of acceleration and braking automation. In the late 90's, fuzzy logic has been shown to have a tremendous impact and advantage over PID control systems in the domain of cruise control [2]. Adaptive cruise control is the next stage of cruise control which offers cruise control capabilities with corrective action capabilities based on obstacles around the vehicle.

2. Fuzzy Logic and Adaptive Cruise Control

The modern-day vehicles are equipped with multiple sensors like vehicle speed sensor, electronic control module, throttle actuators, distance sensors and the latest addition to these sensors are camera systems which provide these vehicles vision capabilities as well. These sensors open the doors to various levels of automation using control systems. Primitive automation techniques used proportional–integral–derivative (PID) control mechanism to introduce basic cruise control. These PID controllers work on the principle of optimal PID gains which are difficult and expensive to generalize for different types of vehicles [2]. This is where fuzzy logic controllers provide advantages over traditional control systems.

Advantages of using fuzzy inference systems are:

1. **Quick and cheap prototyping**: Because of intuition based rule mapping fuzzy systems, the **development is easier and faster**. Moreover, the traditional PID system suffer from the problem of **poor generalization** over different types of vehicles.
2. **Better performance on steep terrains**: Traditional controllers are ill equipped to handle steep ascent or descent of the vehicles, to tackle this they employ time-based downshifting or upshifting techniques, this **causes safety concern and an uncomfortable ride**. Because of non-binary control, fuzzy systems elegantly handle these issues and offer **better rider safety and comfort.**
3. **Efficient utilization of resources**: Fuzzy systems offer better fuel consumption and engine load management capabilities due to their multi-level output, this is mostly applicable in steep terrains where traditional controllers waste fuel because of improper downshifting and upshifting.
4. **Intelligent cruise control.**

3. System Design

Adaptive control is cruise control with additional intelligent corrective capabilities based on the obstacles ahead of the vehicle, it can operate in two modes:

1. When there are no obstacles in front of the vehicle (Native cruise control, velocity control mode).
2. When the sensor finds obstacles in front of the vehicle, here distance control mode is utilized (Adaptive cruise control).

Development of Adaptive cruise control requires following components [1]:

1. Automatic transmission vehicle

2. Throttle valve control system
3. Automatic braking control system
4. Distance Sensor

A popular design used in fuzzy inference systems for adaptive cruise control is Mamdani style inference system proposed in [4] which uses current speed and distance to the obstacle to yield goal speed. Based on this, [1] propose a fuzzy inference system for adaptive cruise control, which take two input variables: *distance error* and *relative speed.* Based on these inputs, an output command to adjust speed and braking is sent to the vehicle.

$$\text{dist}_{\text{error}} = \text{dist}_{\text{sensor}} - \text{dist}_{\text{set}} \qquad (1)$$

$$\text{Relative Speed} = V_{\text{obs}} - V_{\text{host}} \qquad (2)$$

The above equations define the input variables for the fuzzy inference system for adaptive cruise control. Equation (1) gives the difference in the distance of the obstacle and the vehicle as received from the distance sensor; equation (2) gives the relative speed difference based on which the system decides the amount throttle to apply. These rules are consolidated and represented as the system as shown in Fig 1. The middle block contains all the rules for this adaptive cruise control system (discussed in the next section).

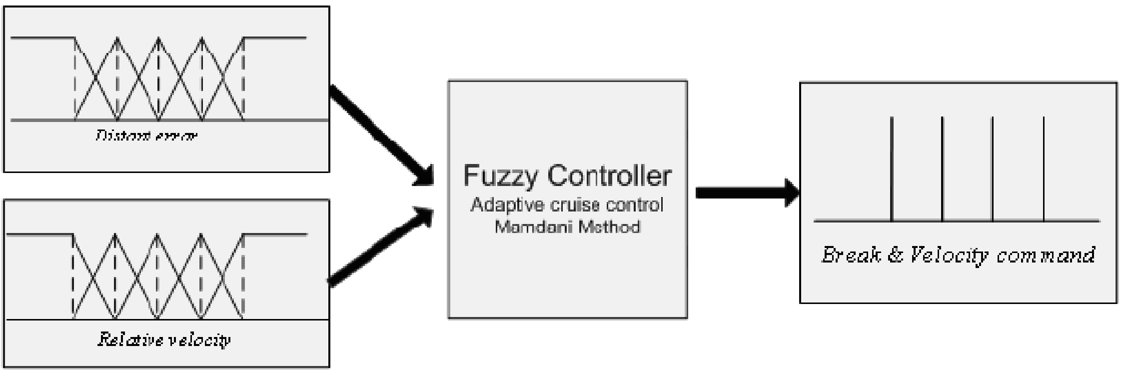


Fig 1: FIS adaptive cruise control system [1]

4. Rules for fuzzy inference system

This section explores the rules defined in a sample adaptive cruise control system as presented in [1]. These rules capture the general assumptions and common components considered while designing such systems using fuzzy inference systems. As shown in previous section, this fuzzy inference system uses two input variables. Both variables are associated with seven membership functions. The input variables take following values:

NL: negative large
NM: negative medium
NS: negative small
PS: positive small
PM: positive medium
PL: positive large
Z: zero

This shows the various fuzzy levels of the input variables, the real value of the output can be calculated by:

$$\text{Final Output} = \frac{\sum_{i=1}^{N} w_i Z_i}{\sum_{i=1}^{N} w_i}$$

$$\begin{aligned}
&\text{Where} \\
&\text{Final Output} &&= \text{Average of all outputs} \\
&w_i &&= \text{Weight of membership function of } Z_i \\
&Z_i &&= \text{output } i
\end{aligned}$$

This can be mapped to the output values in **Table 1**; shows how the combinations of seven membership function values result in the output values of the output command.

	Distance Error							
Relative Velocity		NL	NM	NS	Z	PS	PM	PL
	NL	NVL	NVL	NL	NM	NS	NS	Z
	NM	NVL	NL	NM	NM	NS	NS	Z
	NS	NL	NM	NS	NS	NS	Z	Z
	Z	NM	NS	Z	NS	Z	PS	PS
	PS	NM	Z	Z	Z	Z	PM	PL
	PM	NS	Z	Z	PS	PM	PL	PVL
	PL	NS	Z	Z	PS	PL	PVL	PVL

Table 1: Table denoting 49 total rules of the output command. [1]

The combinations of these inputs results in 49 total rules for the system and have nine singleton outputs:

NVL: negative very large

NL: negative large

NM: negative medium

NS: negative small

PS: positive small

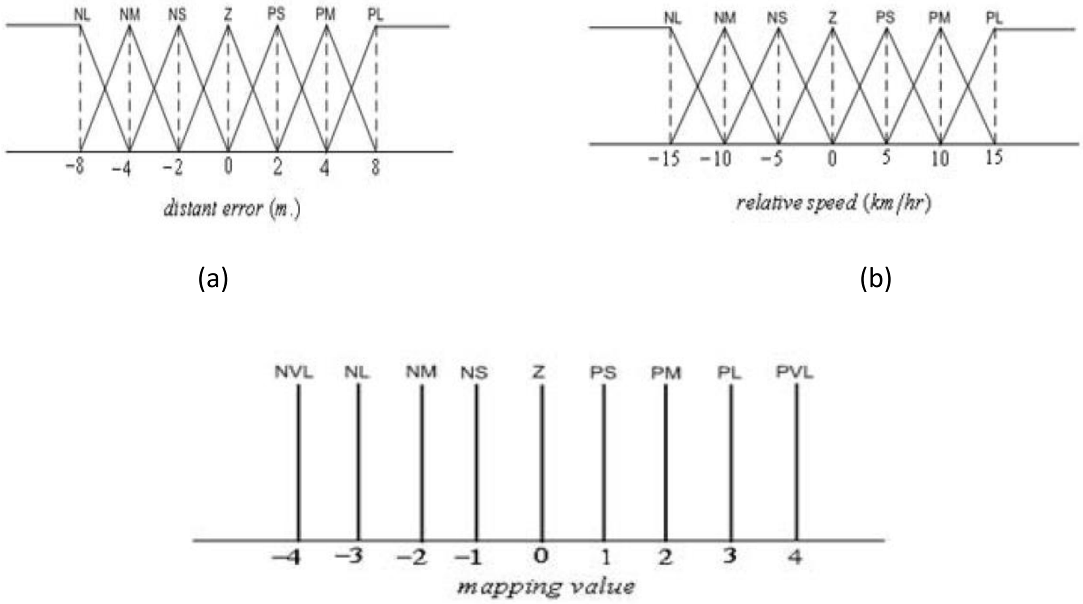
PM: positive medium

PL: positive large

PVL: positive very large

Z: zero

The negative output command means brake and positive command means velocity whereas zero means maintaining the current state.



(c)

Fig 2: a) Shows range of membership function of distance error. b) shows range of membership functions of relative velocity. c) shows membership function of output command.

Table 1 can be used to derive If-Then rule based on the input variables as follows:

> **If** *distant error* is positive large **and** *relative speed* is positive large,
>
> **then** output command is positive very large.

This translates to the command for the vehicle to achieve high velocity.

5. Conclusion

This paper argues the advantages of fuzzy inference systems based adaptive cruise control over traditional PID like systems. The paper also introduces a sample adaptive cruise control system and explains its system architecture and rules used in fuzzy inference system.

6. References

[1] Pananurak, W., Thanok, S. and Parnichkun, M., 2009, February. Adaptive cruise control for an intelligent vehicle. In *2008 IEEE International Conference on Robotics and Biomimetics* (pp. 1794-1799). IEEE.

[2] Shaout, A. and Jarrah, M.A., 1997. Cruise control technology review. *Computers & electrical engineering*, *23*(4), pp.259-271.

[3] Meng, Y., Mo, H., Zhao, X. and Le, F., 2021, July. Cruise Control for Autonomous Vehicles Based on Interval Type-2 Fuzzy Logic. In *2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence (DTPI)* (pp. 250-253). IEEE.

[4] Mamdani, E. H. ,1974. Application of fuzzy algorithms for control of simple dynamic plant. In *Proceedings of the Institution of Electrical Engineers* (Vol. 121, No. 12, pp. 1585–1588). IET.