

## Fuzzy Sensing and Control for a Truck

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### Abstract

*This paper discusses the effects of the sensor-data resolution on the I/O characteristics of a digital fuzzy logic controller used for backing-up a truck. It is shown that it is possible to smooth these characteristics by dithering the sensor data before quantization.*

### 1. Introduction

Surprisingly even to the *fuzzy logic* (FL) founder Zadeh, [1], *fuzzy logic control* (FLC) is today the most important and visible side of the FL theory, [2].

Fuzzy logic control provides a very convenient non-analytic solution to many practical control problems that may be too complicated to be solved by the classical analytic control based on a high resolution I/O function  $OUTPUT = F(INPUT)$  as illustrated in Fig. 1, [3].

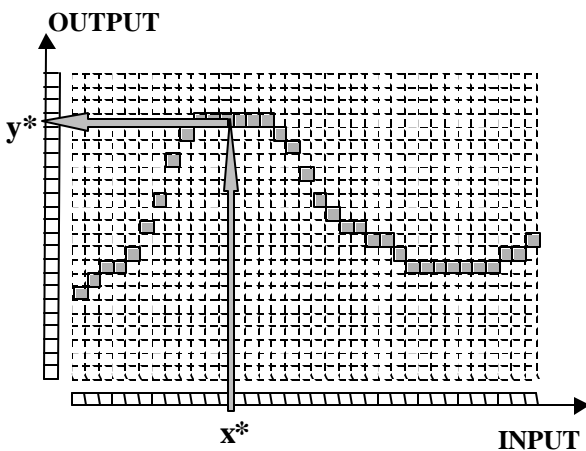


Fig. 1. Classic control implements a high-resolution I/O mapping relationship

As shown in Fig. 2, a FLC consists of three major components: input interface, inference mechanism, and output interface.

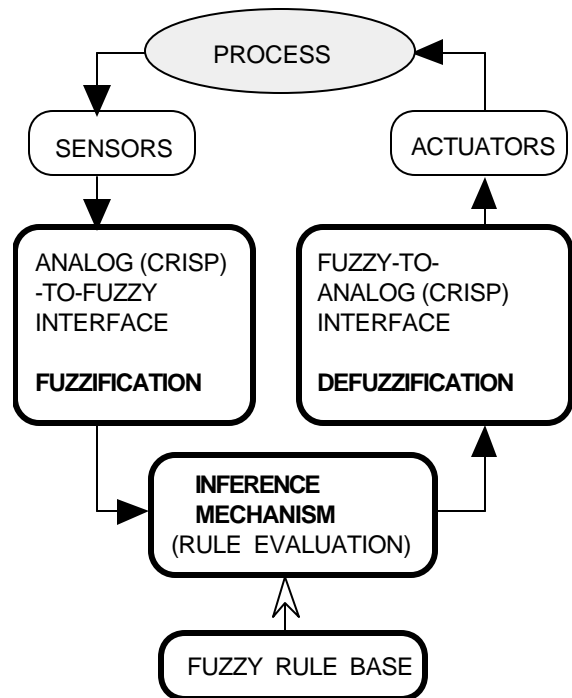


Fig. 2. The structure of a fuzzy logic controller

The control algorithm is based on very low-resolution I/O mapping, as shown in Fig. 3, allowing to describe the controller's behavior with simple "if-then" control rules able to incorporate empirical knowledge. In many applications, this leads to a simpler solution in less design time. FLCs have found many practical applications in the context of complex ill-defined processes that can be controlled by skilled human operators: water quality control, automatic

train operation control, nuclear reactor control, automobile transmission control, etc, [4]-[8]

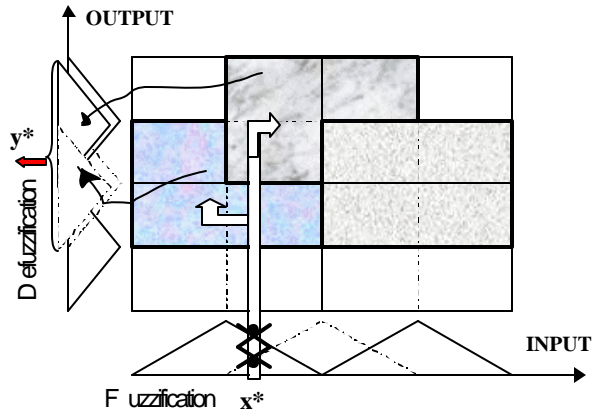


Fig. 3. Very low-resolution -resolution I/O mapping used in the fuzzy logic control

The overlapping of the fuzzy domains and their linear membership functions will eventually allow to achieve a rather high-resolution I/O function between crisp input and output variables. This has led a common wisdom tenet which considers that FLCs are supposed to make do with uncertain data coming from low-resolution and imprecise sensors. It is the objective of this paper is to challenge this tenet.

The paper studies the effects of the input sensor-data resolution on the I/O characteristics of the digital FLC for backing-up a four wheel truck. Simulation experiments have shown that the low resolution of the sensor data results in a rough quantization of the controller's I/O characteristic. It is also shown that it is possible to considerably smooth the I/O characteristic of a digital FLC by dithering the sensor data before quantization.

## 2. Fuzzy logic control for backing-up a four wheel truck

The problem, illustrated in Fig. 4, is to back up a four-wheel truck into a docking station from any initial position that has enough clearance from the docking station.

The 2D position and orientation of the truck is defined by the  $(x, y)$  coordinates position of the rear center of the truck and by its angle  $j$  with the horizontal. The front wheels are for steering while the back wheels are only for driving. The steering angle  $q$  is the control variable. The goal is to make the truck arrive at the loading dock at a right angle and to align the rear center of the truck with the center of the docking station.

The FLC has two input variables: the truck angle  $j$  and the  $x$  position. We assume that enough clearance between the truck and the loading dock so we could ignore the  $y$ -position coordinate. The output variable is the steering angle  $q$ . The variable ranges are as follows:  $-50 < x < 50$ ,  $-90^\circ < j < 270^\circ$ ,  $-45^\circ < q < 45^\circ$ . Positive values of  $q$  represent counter-clockwise rotations of the steering wheel.

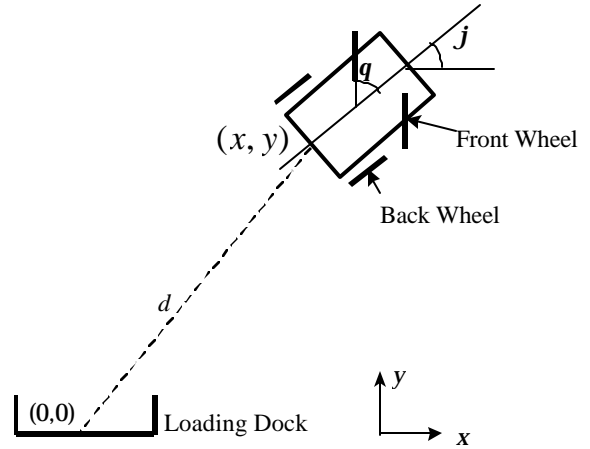


Fig. 4. The parameters of the truck backing-up problem

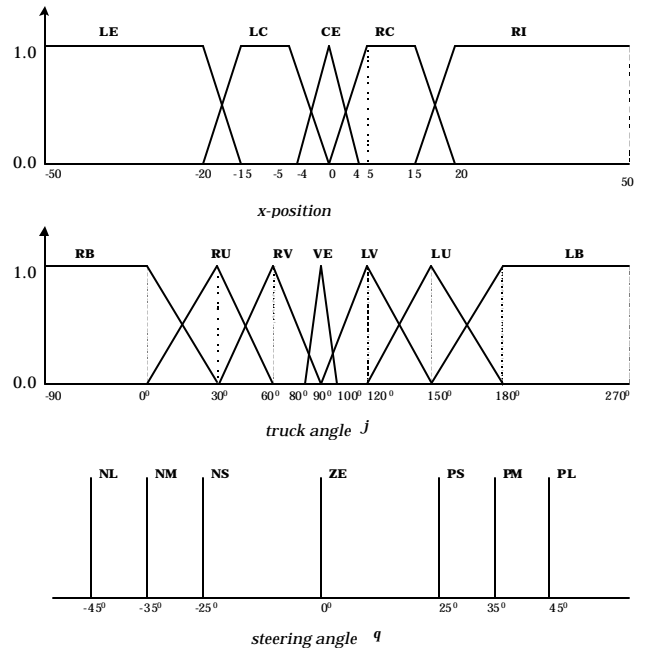


Fig. 5. Membership functions for the truck backer-upper FLC

The domains of  $x$  and  $j$  are partitioned in five and respectively seven overlapping triangular fuzzy membership



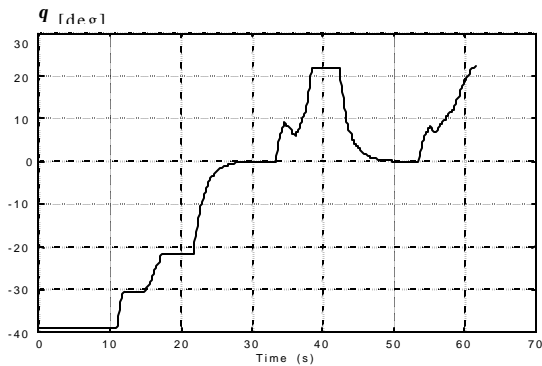


Fig. 8. Time diagrams of digital FLC's output during a docking experiment when input variables are analog and respectively quantized with a 4-bit bit resolution

A dithered quantizer has to be followed by a low-pass filter in order to calculate the statistical mean value of the sequence of digital data. Fig. 9 and Fig. 10 illustrate two possible architectures of a dithered digital FLC. In the first case, a low-pass filter is placed immediately after input quantizer. In the second case the low-pass filters are placed at the FLC output.

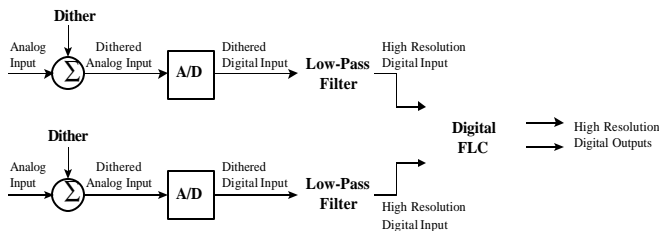


Fig. 9. Dithered digital FLC architecture with low-pass filters placed immediately after the input A/D converters

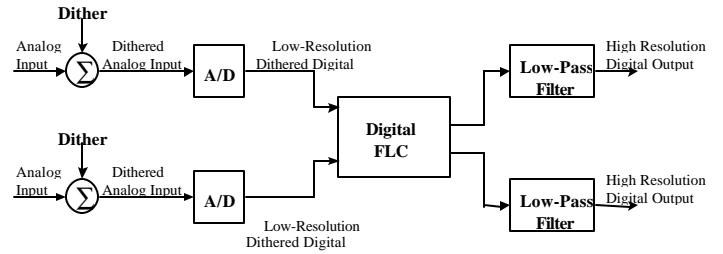


Fig. 10. Dithered digital FLC architecture with low-pass filters placed at the FLC's outputs

We have used the second implementation as it offers a better performance because a final low-pass filter can also smooth the non-linearity caused by the *min-max* composition rules of the FLC.

Experimental results have confirmed the beneficial role dithering plays in the reduction of the quantization error of the digital FLC. Fig. 11 shows the time diagram for the steering angle  $q$  controlled by a dithered digital FLC's with 4-bit input A/D converters and a 20-unit moving average low-pass filter at the FLC's output while running the same docking experiment as that illustrated in Fig. 4.

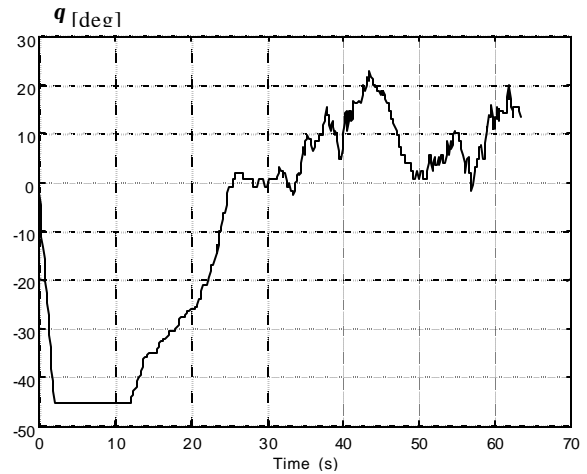


Fig. 11. Time diagram of dithered digital FLC's output during a docking experiment when 4-bit A/D converters are used to quantize the dithered inputs and a low-pass filter is placed at the FLC's output

Fig. 12 and Fig. 13 show the input/output characteristics of the FLC with analog input and respectively of a digital FLC with dithered 4bit quantized inputs and a low-pass filter is placed at the FLC's output. These results confirm the overall good performance of the digital FLC with dithered inputs.

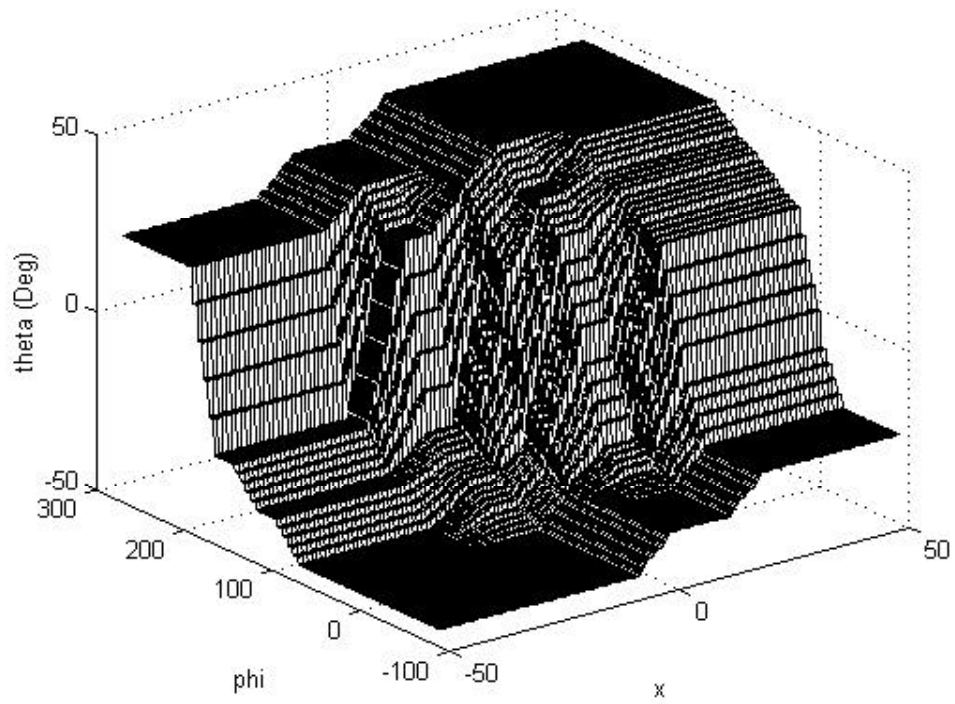


Fig. 12. The I/O characteristics of the analog FLC for backing-up the truck

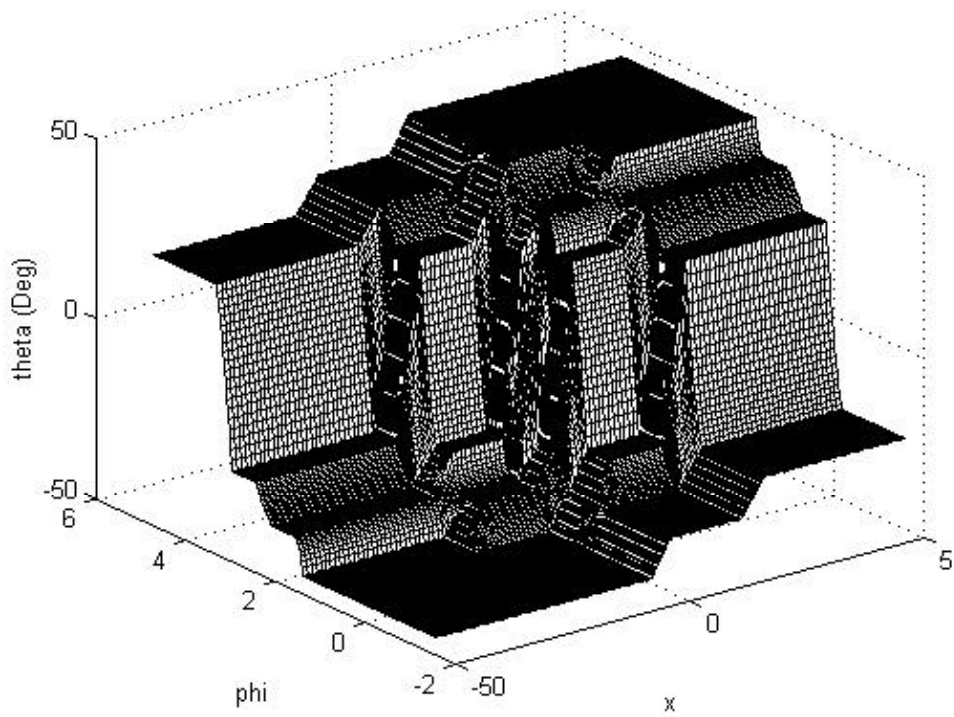


Fig. 13. The I/O characteristics of the digital FLC with dithered 4-bit quantized inputs

Fig. 14 shows comparatively the trails of a truck docking under the control of (a) an analog FLC, (b) a digital FLC using 4-bit A/D converters for the input data, and (c) a dithered digital FLC using 4-bit A/D converters and a 20-unit moving average low-pass filter at the controller's output. Trail (a) and (c) both end at the loading dock (0,0), while the trail (b) does not reach the dock in the end.

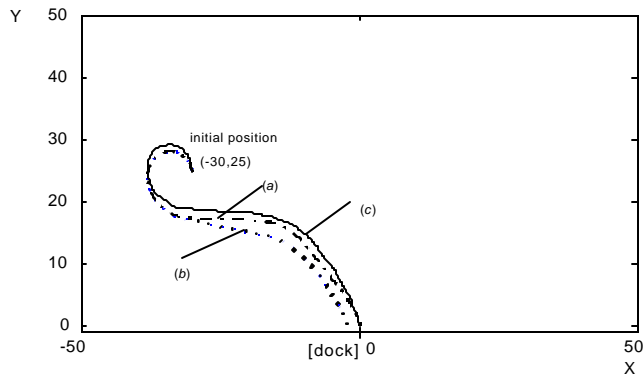


Fig. 14. Truck trails for different FLC architectures: (a) analog ; (b) digital without dithering; (c) digital with uniform dithering and 20-unit moving average filter

## 5. Conclusion

A low resolution of the input data in a digital FLC results in a low resolution of the controller's characteristics. However, dithering can significantly improve the resolution of a digital FLC beyond the initial resolution of the A/D converters used for the input data.

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