Takagi–Sugeno Fuzzy-PI Controller Hardware

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The intelligent system Field Programmable Gate Array (FPGA) is represented as Takagi--Sugeno Fuzzy-PI controller. The implementation uses a fully parallel strategy associated with a hybrid bit format scheme (fixed-point and floating-point). Two hardware designs are proposed; the first one uses a single clock cycle processing architecture, and the other uses a pipeline scheme. The bit accuracy was tested by simulation with a nonlinear control system of a robotic manipulator. The area, throughput, and dynamic power consumption of the implemented hardware are used to validate and compare the results of this proposal. The results achieved allow the use of the proposed hardware in applications with high-throughput, low-power, and ultra-low-latency requirements such as teleoperation of robot manipulators, tactile internet, or industry 4.0 automation, among others.

FPGA Hardware Takagi-Sugeno Fuzzy Fuzzy-PI

1. Introduction

Systems based on Fuzzy Logic (FL), have been used in many industrial and commercial applications such as robotics, automation, control, and classification problems. Unlike high data volume systems, such as Big Data and Mining of Massive Datasets (MMD) [1][2][3], one of the great advantages of Fuzzy Logic is its ability to work with incomplete or inaccurate information.

Intelligent systems based on production rules that use Fuzzy Logic in the inference process are called in the literature Fuzzy Systems (FS) [4]. Among the existing inference strategies, the most used, the Mamdani and the Takagi–Sugeno, are differentiated by the final stage of the inference process [5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20].

2. Development

The interest in the development of dedicated hardware implementing Fuzzy Systems has increased due to the demand for high-throughput, low-power, and ultra-low-latency control systems for emerging applications such as the tactile Internet [21][22], the Internet of Things (IoT), and Industry 4.0, where the problems associated with processing, power, latency, and miniaturization are fundamental. Robotic manipulators used on the tactile internet need a high-throughput and ultra-low-latency control system, and this can be achieved with dedicated hardware [21].

The development of dedicated hardware, in addition to speeding up parallel processing, makes it possible to operate with clocks adapted to low-power consumption [23][24][25][26][27][28][29]. The works presented in [30][31][32][33][34][35][36][37] propose implementations of FS on reconfigurable hardware (Field Programmable Gate Array—FPGA), showing the possibilities associated with the acceleration of fuzzy inference processes having a high degree of parallelization. Other works propose specific implementations of Fuzzy Control Systems (FCS) using the Fuzzy Mamdani Inference Machine (M-FIM) and the Takagi–Sugeno Fuzzy Inference Machine (TS-FIM) [5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20]. The works presented in [38][39][40] propose the Takagi–Sugeno hardware acceleration for other types of application fields.

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