Reconfigurable Hardware Accelerator for Intelligent Software Agents

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Abstract:

Programs for contemporary industrial control systems are designed using Object Oriented methods and software agents. It is required that the system should reach its objectives even when unexpected events occur in an uncertain environment. There is need for a high-level information representation such that a predictable behavior can be achieved in a uniform way for all agents. A fuzzy automaton-based approach offers clear benefits for developing agents of reconfigurable architecture.

Some of the most difficult problems in industrial process control innovation are as follows: how can new knowledge be introduced to the system, how can the system activate stored domain knowledge in an autonomous way, how can the knowledge be validated (or recognized as invalid), and how can the system recover if the new activated knowledge (or the currently active knowledge) is not suitable to handle the current situation of the plant. A fuzzy automaton can implement new knowledge by means of the states of the goal path of an event-driven, sequential control algorithm while providing an effective approximation method to model continuous and discrete signals in a single theoretical framework. With respect to problem that how can the knowledge be validated (or recognized as invalid) we propose that knowledge validation will be achieved by quantifying the degree of deviation from the nominal operating conditions due to unexpected events caused by either abrupt, or gradual changes in the system, or in the environment of the system. With respect to problem of fault detection, identification and recovery, the evaluation of the state transitions between the states of a large system will be done by focusing only on clusters of relevant states along the goal path. A reconfigurable virtual fuzzy automaton will be used to model those clusters of states.

It has been proposed in previous papers that the Hybrid Fuzzy-Boolean Finite State Machine (HFB FSM) can be used to address these problems by modeling the relevant section of the state graph and the current status of the plant. It provides for intelligent decision making at the supervisory level [1][2].

The supervisory controller (SC) needs to configure the HFB FSM for each of those particular state clusters to model that segment of the control algorithm along with the plant. Then using the inputs provided by the SC from the plant the HFB FSM devises the next state in the goal path to detect the presence of a potential fault and advises the SC whether a recovery is possible from the fault (if any). Since the configurations of the critical state clusters keep changing along the goal path the SC needs to reconfigure the HFB-FSM for every state cluster of concern. In previous work a software approach using fuzzy logic enabled software agents has been proposed [4]. In this paper the design of a reconfigurable state transition algorithm and a reconfigurable inference engine will be discussed for a hardware accelerator of a reconfigurable HFB-FSM [3]. The hardware is developed using VHDL and FPGAs.

With the extended HFB-FSM, the conditions for the fuzzy state transitions can be given in terms of fuzzy inputs, two-valued (digital inputs) and analog inputs with threshold (i.e., two-valued inputs, essentially). The value of each fuzzy input variable is converted to a set of two-valued (Boolean) variables using a Fuzzy-to-Boolean mapping algorithm (B algorithm) [1]. The actual mapping of any fuzzy input value to a unique set of Boolean variables is fundamental to determine the next state of the HFB FSM. Since each new instance of the HFB FSM model (as the ontological control process moves along the goal path) requires a new mapping scheme, a reconfigurable implementation of the B algorithm is of great importance to the design of a hardware accelerator for the HFB-FSM.

In the B algorithm, the Mean of Maxima (MOM) defuzzification method along with a set of non-overlapping Boolean sub-intervals covering the Universal Space for the fuzzy variable are used for the Fuzzy-to-Boolean mapping. The boundaries of those sub-intervals play a major role in determining the state transitions. By introducing parameters to define the Boolean sub-intervals without changing the Universal Space the state transition conditions can be reconfigured.

For fuzzy inference computations, fuzzy outputs are obtained using the composite linguistic model [1] that belongs to the current fuzzy state. Using parameterized components, a great degree of versatility with respect to the number of fuzzy inputs, the resolution of the degree of membership of each fuzzy input, the granularity of the universal set and the auto-sizing of the FAM matrices can be achieved. Computations on the fuzzy union and intersection operations are done incrementally as the inputs are being sampled.

The detailed implementation of the design is written in VHDL and is mapped to a FPGA. The design has been validated using ModelSim along with a simulation program of the HFB FSM Model developed earlier in the Intelligent Fuzzy Controllers Laboratory at Western Michigan University. The full paper will discuss the detailed hardware design and the simulation results.

References

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