Real-time Adaptive Learning and Control System

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Project Objective:

The objective of this project is to develop a real-time adaptive learning and control system based on the latest Intel's DE2i-150 board. Specifically, the team needs to develop a novel adaptive dynamic programing (ADP) architecture originally proposed in [1, 2, 3] based on the DE2i-150 board to demonstrate its real-time learning, control, and optimization capability. This project requires: (1) hardware and embedded system design, (2) software simulation and modeling, (3) software-hardware co-design, and (4) system integration and demonstration.

Motivations and Justifications:

Development of intelligent systems and discovering mechanisms for intelligent behavior is one of the most exciting research areas in science and engineering. With the recent development of brain research and modern technologies, scientists and engineers will hopefully find efficient ways to build brain-like complex systems that are highly robust, adaptive, and fault tolerant to uncertain environments. However, although scientists and engineers have successfully borrowed some ideas from biological intelligent systems, for instance, the designing of the insect-inspired robots, there is still no clear picture about how to design the truly brain-like general-purpose intelligent machines. One of the essential challenges is how to develop general models, algorithms, and architectures to be able to adaptively learn and accumulate knowledge, make predictions in an uncertain and unstructured environment, and adjust actions to maximize some kind of utility function over time to achieve goals (goal-oriented behaviors). While there are significant amount of efforts to tackle this challenge from the software oriented perspective, there is a critical need to develop real-time intelligent systems based on the massively parallel processing power of today's hardware technology. This project aims to explore this direction by designing a promising computational intelligence approach, a new ADP architecture, into the latest Intel's DE2i-150 board.

Design Approach:

The design approach requires to take advantage of the on-board CPU processor and the FPGA resources for the task. Specifically, our new ADP architecture requires the implementation of three neural network architectures [2]: one reference network, one critic network, and one action network. All could be implemented based on multi-layer perceptron (MLP) with backpropagation method.

During this project period, the team needs to implement all three neural networks with MLP into the DE2i-150 board, and demonstrate its online model-free learning and control capability based on popular control benchmarks such as the inverted pendulum. The team also needs to compare the real-time control performance of their design with the Matlab-based control approach which has currently been implemented in our lab (a virtual reality implementation of our current control approach can be found at YouTube:

http://www.youtube.com/watch?v=0eZEDBz6ki0&feature=youtu.be

Required skills:

1. Strong in mathematics, especially with differentiation equations, matrix operation, stochastic analysis, and gradients calculation;

2. Proficient in FPGA and embedded system design. Note: the whole system needs to be implemented into the Intel DE2i-150 board. Therefore, the team must have strong design background and experience with FPGA/Embedded system design and software-hardware co-design.

3. Familiar with neural network algorithm. The key algorithm is a multi-layer perceptron (MLP) neural network. The team must understand every single step of the neural network computation, and can write both Matlab code and FPGA design for the neural network MLP.

4. Strong background in control: the benchmark that needs to demonstrate the final design will be a popular control system, the inverted pendulum system. The team need understand how to control the balance of this system;

5. Strong hardware and system design and integration skills: The final system needs to integrate both the Intel DE2i-150 board and a physical inverted pendulum. The team needs to be able to finish the design and debug the integrated overall system.

6. Familiar with Matlab modeling and simulation. The hardware design performance needs to be compared with the Matlab simulation for the same benchmark. Therefore, in addition to the hardware system design, the team needs to be able to simulate the whole system in Matlab environment as well.

7. Good communication skills, team work, and responsible. This project has specific timelines and milestones that need to be met throughout the project period. Therefore, it is very important that the team can work effectively according to the timeline, document their progress, and write in-progress reports. The team will also need to interact with the graduate students for this project.

References:

[1] He, Self-Adaptive Systems for Machine Intelligence, ISBN: 978-0-470-34396-8, Wiley, 2011.

[2] H. He, Z. Ni, and J. Fu, “A Three-network Architecture for On-line Learning and Optimization based on Adaptive Dynamic Programming,” Neurocomputing, vol. 78, issue 1, pp. 3-13, 2012
[3] Z. Ni, H. He, and J. Wen, "Adaptive Learning in Tracking Control Based on the Dual Critic Network Design, IEEE Trans. Neural Networks and Learning Systems, 2013.