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AUTOMATIC DESIGN OF FUZZY CONTROLLER FOR ROTARY INVERTED PENDULUM WITH SUCCESS-HISTORY ADAPTIVE GENETIC ALGORITHM[1]

Digest of paper[2]

Vladimir Stanovov, Shakhnaz Akhmedova, Eugene Semenkin

Reshetnev Siberian State University of Science and Technology
e-mails: vladimirstanovov@yandex.ru, shahnaz@inbox.ru, eugenesemenkin@yandex.ru
Russian Federation

Abstract: In this paper an adaptive genetic algorithm for fuzzy controller design is proposed. The problem of rotary inverted pendulum stabilization and swing-up sequence is considered. The genetic algorithm is used to determine the structure of the fuzzy rule base, which is then used to control the pendulum. The experiments on a model show that the success-history adaptive genetic algorithm is capable of automatic search for an optimal rule base with no prior expert knowledge about the system dynamics.
Key words: Fuzzy control, rotary inverted pendulum, genetic algorithm, parameter adaptation.

1. INTRODUCTION

Modern dynamic control system design community typically relies on human expert knowledge and well-developed mathematical methods to create control mechanisms. Although this approach is usually efficient, it requires large amount of work performed by high-level specialists, which is not always possible. Therefore, development of automated design mechanisms, which would be able to create efficient control mechanisms, satisfying the requirements with minimal expert knowledge involvement is an important area of research.

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The fuzzy logic-based control mechanisms are well known for their flexibility, relatively clear structure and high efficiency when applied to various types of control problems [1, 2]. The genetic fuzzy systems are often applied to solve data analysis problems, as well as controller design problems.

The rotary inverted pendulum (RIP) controller design problem [4] is often considered as a benchmark problem, due to its important properties, such as nonlinearity, non-minimum phase and instability, which make it highly challenging to control. In this study the success-history based adaptive genetic algorithm (GA) is applied to the Mamdani type [5] fuzzy controller automatic design, where the goal is to find an optimal rule base configuration. The rest of the paper is organized as follows: section 2 describes the RIP system and parameters, section 3 contains the genetic algorithm and rule base, section 4 describes the experiments and results, and section 5 concludes the paper.

2. ROTARY INVERTED PENDULUM AND GENETIC ALGORITHM

The inverted pendulum systems are well known and often used for experimenting with control system design. The rotary inverted pendulum is one of the types of inverted pendulum systems, where the pendulum is mounted on the output arm, which is driven by a servo motor. The position of the pendulum and arm are measured by encoders. The input to the system is the servo motor direction and voltage control signal. In this study, the model described in [4] is used for experiments. The state variables of the RIP system are angular positions and velocities of the arm and the pendulum.

Figure 1 shows the RIP and its main parameters. The modeling was performed with step size of $h = 0.01$ and time $T_{max} = 10$ seconds. During modeling, the number of revolutions of arm and pendulum was also measured.

The fuzzy rule based controller used in this study had four input linguistic variables according to the RIP system state variables, and the output variable, i.e. the control voltage. The input variables fuzzy terms had similar structure: one fuzzy term in the middle, and two expanding terms on each side.

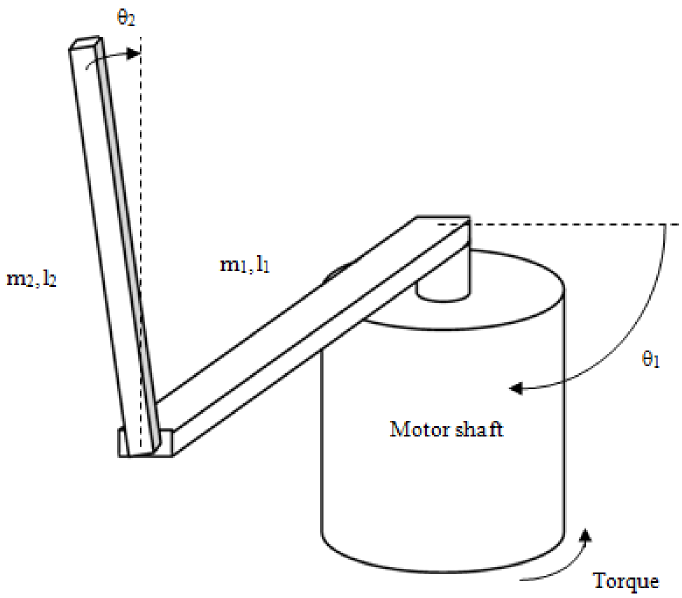

Fig. 1. Rotary inverted pendulum

As long as each variable had 5 fuzzy terms, the full rule base had 5^4 rules. The goal of the genetic algorithm was to determine the output term number for each rule. For the output variable there were 14 fuzzy terms to allow more accurate control.

The genetic algorithm chromosome consisted of 625 integer values from 0 to 13, so that the search space size was 14^{625}. The GA used tournament selection with tournament size of 2, uniform crossover with rate *Cr*, and mutation with probability *Mr*. For crossover one of the individuals was the *i*-th individual in the population and the second was chosen by selection. The newly generated individual replaced the old *i*-th individual only if its fitness was at least as good as current individual's fitness.

The success-history adaptation (SHA) mechanism was adapted from SHADE algorithm [6] and adjusted the probability of crossover *Cr* and mutation *Mr*. The mutation probability changed in range [0, 0.008] and crossover probability in range [0, 1].

4. EXPERIMENTAL SETUP AND RESULTS

As long as the goal of the control was to set the pendulum to the upright position and the arm to the predefined zero position, the fitness calculation was based on the total difference between the desired and actual positions of the pendulum and the arm, as well as their angular velocity. Each state variable in fitness calculation was weighted by its range.

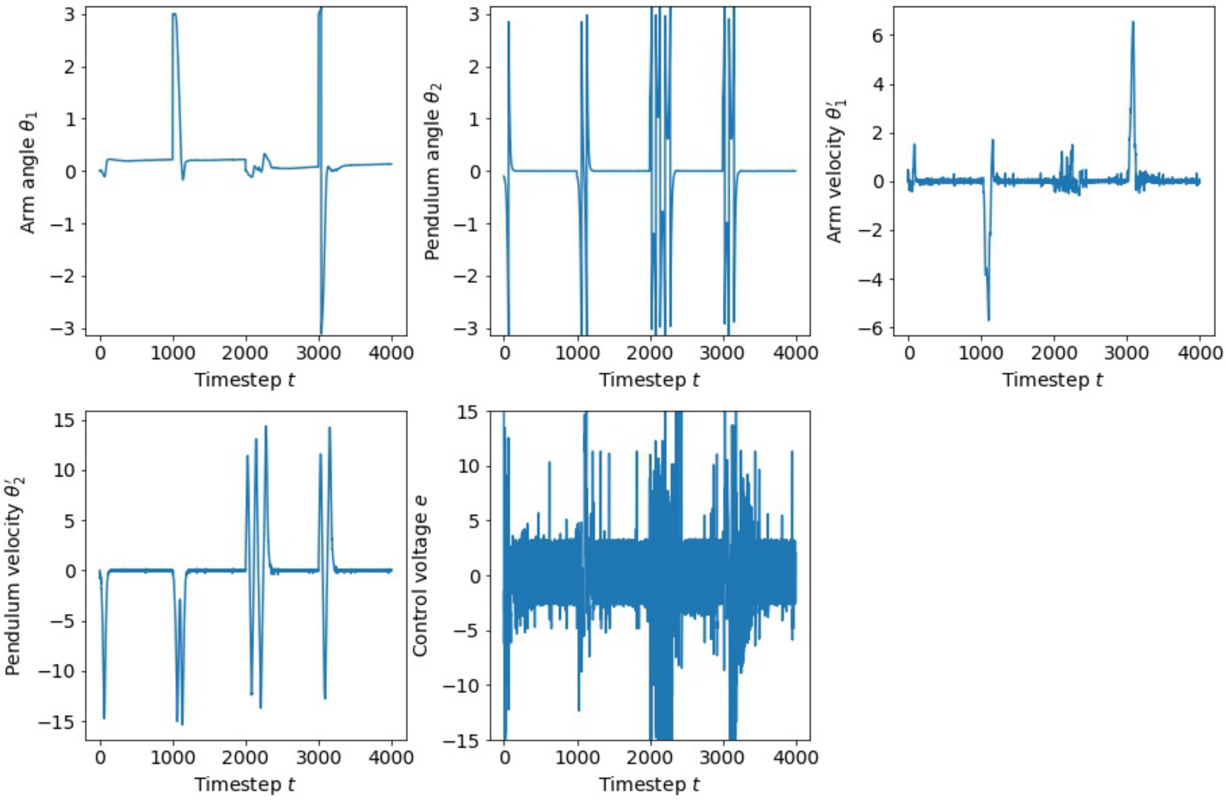

Fig. 3. Designed control mechanism operation, fitness = 14.7937

As long as fitness calculation involved fuzzy inference procedure, the Mamdani procedure was used for inference. The controller design consisted of four steps, with different starting points of the arm and pendulum. The learning process was divided in four parts, the maximum number of generations was set to 1200, and each 300 generations new starting point was added to the control goal. This allowed the fuzzy controller to be trained in step-by-step manner with gradual problem complexity increasing. The population size was set to 200 individuals.

The experiment in figure 3 demonstrates that the automatically designed fuzzy controllers are capable of stabilizing the system within just a few iterations. Also, the designed swing-up sequence appears to be relatively simple, i.e. the fuzzy controller requires several steps to bring the pendulum in the upright position and then hold it until the end of the control sequence. The arm velocity and pendulum velocity stay within limits during the whole control period.

From the 30 performed experiments, 12 were successful, i.e. after 1200 generations the best designed controller was capable of reaching the control goal. Other controllers either failed to generate swing-up sequence or failed to stabilize the arm position or pendulum position.

5. CONCLUSION

In this study the success-history based adaptive genetic algorithm was developed to automatically generate fuzzy rule bases for the rotary inverted pendulum problem. The experiment has shown that the automatic design of complex fuzzy controllers is not only possible, but also could be highly efficient, as the proposed approach was able to generate the swing-up sequences for a highly non-linear and unstable system.

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