

NASA-CR-200258

FINAL  
IN-63-012  
OCT  
11-23-92  
345-10

## ADAPTIVE CONTROL STRATEGIES FOR FLEXIBLE ROBOTIC ARM

FINAL REPORT

Principal Investigator: Dr. Jan T. Bialasiewicz  
University of Colorado at Denver  
Department of Electrical Engineering  
Campus Box 110  
P.O. Box 173364  
Denver, Colorado 80217-3364

Period covered by the report: July 15, 1992 to January 31, 1996

Grant Number: NAG-1-1444

## **1 ABSTRACT**

### **Adaptive Control Strategies for Flexible Robotic Arm**

The control problem of a flexible robotic arm has been investigated. The control strategies that have been developed have a wide application in approaching the general control problem of flexible space structures. The following control strategies have been developed and evaluated:

- Neural Self-Tuning Control Algorithm
- Neural-Network-Based Fuzzy Logic Control Algorithm
- Adaptive Pole Assignment Algorithm.

All of the above algorithms have been tested through computer simulation.

In addition, the hardware implementation of a computer control system that controls the tip position of a flexible arm clamped on a rigid hub mounted directly on the vertical shaft of a dc motor, has been developed.

An Adaptive Pole Assignment Algorithm has been applied to suppress vibrations of the described physical model of flexible robotic arm and has been successfully tested using this testbed.

## **2 SUMMARY OF THE PROJECT**

This research commenced on July 15, 1992 and has been supported by the Research Grant No. NAG-1-1444. Three Graduate Research Assistants have been working on the project at 1/3 time during its various phases. The results obtained have been discussed in three Master's Theses and two papers presented at international conferences and published in conference proceedings. One of the Graduate Research Assistants and the Principal Investigator have also presented a seminar at the NASA Langley Research Center.

At the beginning of this research, a neural network direct adaptive control schemes have been applied to control the tip position of a flexible robotic arm. However, satisfactory control performance was not attainable due to the inherent non-minimum phase characteristics of the flexible robotic arm system. Therefore, a neural self-tuning control (NSTC) algorithm has been developed and applied. This approach has shown promising results. Simulation results of the NSTC scheme and the conventional self-tuning control scheme have been used to examine performance factors such as control tracking mean square error, estimation mean square error, transient response, and steady-state response.

The results of this part of the research have been presented in reference [1] and have been reported in [2], a paper presented at the international conference Artificial Neural Networks in Engineering ANNIE '93.

In the second half of this research, two graduate students have been working under the supervision of the principal investigator. One of them has joined the project to develop the laboratory set-up, including hardware-software interface, to enable the evaluation and necessary modifications of the algorithms developed, as well as to develop, test, and modify other adaptive strategies. The other student, has been working on the adaptive neural network-based fuzzy logic control algorithms. It was originally intended to verify the results of his research using the laboratory setup. However, the delays in acquisition of all necessary hardware elements and in development of the necessary software, made this goal impossible within the time-frame of his thesis research. He finally tested his algorithms through computer simulation. The results of his research have been presented in reference [3] and have been reported in [4], a paper presented at the international conference Artificial Neural Networks in Engineering ANNIE '94.

Finally, the development of the laboratory model of flexible robotic arm computer control system has been completed by the third graduate student and he has successfully tested the adaptive pole assignment algorithm developed to suppress vibrations of the tip of a flexible arm. This laboratory setup, which besides a physical model of a flexible robotic arm and a computer with hardware-software interface includes analog optical position indicator, wide angle lens and LED source with high intensity output, has also been used to perform identification of the flexible manipulator. The identification was carried out using two methods: the Observer/Kalman Filter algorithm and the recursive least squares algorithm. The identified model was then used in the design of a dead-beat controller which was relatively successful in controlling the flexible manipulator. The results of this part of the research, including a detailed description of the laboratory setup, are presented in [5].

The abstracts of all referenced reports/publications are included in the Appendix.

### 3 REFERENCES

- [1] Ho, Long T., "Neural Self-Tuning Adaptive Control of Non-Minimum Phase System Developed for Flexible Robotic Arm", M.S. Thesis, Department of Electrical Engineering, University of Colorado at Denver, 1994.
- [2] Ho, Long T. and Jan T. Bialasiewicz, "Neural Self-Tuning Adaptive Control of Non-Minimum Phase System", in *Intelligent Engineering Systems Through Artificial Neural Networks*, Vol. 3, ASME Press, 1993, pp. 575-580.
- [3] Leung, Kam L., "Learning Fuzzy Logic Control System", M.S. Thesis, Department of Electrical Engineering, University of Colorado at Denver, 1994.
- [4] Leung, Kam L. and Jan T. Bialasiewicz, "Performance Evaluation of a Learning Fuzzy Logic Control System", in *Intelligent Engineering Systems Through Artificial Neural Networks*, Vol. 4, ASME Press, 1994, pp. 277-282.
- [5] Kebede Anteneh, "Identification and Control of a Flexible Robotic Arm Model", M.S. Thesis, Department of Electrical Engineering, University of Colorado at Denver, 1994.

## APPENDIX

### ABSTRACTS

Ho, Long T., "Neural Self-Tuning Adaptive Control of Non-Minimum Phase System Developed for Flexible Robotic Arm", M.S. Thesis, Department of Electrical Engineering, University of Colorado at Denver, 1994.

The motivation of this research came about when a neural network direct adaptive control schemes were applied to control the tip position of a flexible robotic arm. Satisfactory performance was not attainable due to the inherent non-minimum phase characteristics of the flexible robotic arm. Most of the existing neural network control algorithms are based on the direct method and exhibit very high sensitivity if not unstable closed loop behavior. Therefore, a neural self-tuning control (NSTC) algorithm has been developed and applied to this problem and showed promising results. Simulation results of the NSTC scheme and the conventional self-tuning control scheme are used to examine performance factors such as control tracking mean square error, estimation mean square error, transient response, and steady-state response.

Ho, Long T. and Jan T. Bialasiewicz, "Neural Self-Tuning Adaptive Control of Non-Minimum Phase System", in *Intelligent Engineering Systems Through Artificial Neural Networks*, Vol. 3, ASME Press, 1993, pp. 575-580.

A neural network adaptive control schemes have been applied to control a tip position of a flexible robotic arm. It has been shown that the neural self-tuning adaptive control algorithm has a very comparable performance to the conventional self-tuning control algorithm. Unlike other applications of neural networks, where thousands of iterations were required before the network can be maturely trained, in this application the neural network identification had a convergence rate comparable to that of the recursive least squares.

Leung, Kam L., "Learning Fuzzy Logic Control System", M.S. Thesis, Department of Electrical Engineering, University of Colorado at Denver, 1994.

The performance of the Learning Fuzzy Logic Control System (LFLCS), developed in this thesis, has been evaluated. The learning Fuzzy Logic Controller (LFLC) learns to control the motor by learning the set of teaching values that are generated by a classical PI controller. It is assumed that the classical PI controller is tuned to minimize the error of a position control system of the D.C. motor. The Learning Fuzzy Logic Controller developed in this thesis is a multi-input single-output network. Training of the LFLC is implemented off-line. Upon completion of the training process, the FLFC replaces the classical PI controller. In this thesis, a closed-loop position control system of a D.C. motor using the LFLC is implemented. The primary focus is on the learning capabilities of the LFLC. The learning includes symbolic representation of the Input Linguistic

Nodes set and the Output Linguistic Nodes set. In addition, we investigate the knowledge-based representation of the network. As part of the design process, we implement a digital computer simulation of the LFLCS. The computer simulation program is written in "C" language, and it is implemented in DOS platform. The LFLCS, designed in this thesis, has been developed on an IBM compatible 486-DX2 66 computer. First, the performance of the LFLC is evaluated by comparing the angular shaft position of the D.C. motor controlled by a conventional PI controller and that controlled by the LFLC. Second, the symbolic representation of the LFLC and the knowledge-based representation for the network are investigated by observing the parameters of the Fuzzy Logic membership functions and the links at each layer of the LFLC. While there are some limitations of application with this approach, the result of the simulation shows that the LFLC is able to control the angular shaft position of the D.C. motor. Furthermore, the LFLC has better performance in rise time, settling time and steady-state error than the conventional PI controller.

Leung, Kam L. and Jan T. Bialasiewicz, "Performance Evaluation of a Learning Fuzzy Logic Control System", in *Intelligent Engineering Systems Through Artificial Neural Networks*, Vol. 4, ASME Press, 1994, pp. 277-282.

The performance of a Fuzzy Logic Control System has been evaluated in this paper. In this system the fuzzy logic controller controls the shaft position of a D.C. motor. The teaching pattern is generated by the PID controller properly tuned to give the acceptable performance of the position control system of the D.C. motor.

Kebede Anteneh, "Identification and Control of a Flexible Robotic Arm Model", M.S. Thesis, Department of Electrical Engineering, University of Colorado at Denver, 1994.

The purpose of this thesis is to design a controller which can suppress vibrations of a physical model of flexible robotic arm. As part of the design, the identification of the flexible robotic arm model was carried out using the observer/Kalman filter identification and the recursive least squares algorithms. An adaptive pole placement controller is used to control the flexible robotic arm model. A gradient estimator is used to eliminate the possible bursting phenomena in the adaptive control system.