Design of a Force Reflection Controller for Telerobot Systems using Neural Network and Fuzzy Logic

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(Received: 16 February 1995; in final form: 21 July 1995)

Category: (3) Teleoperation, and (5) Intelligent systems / Intelligent control / Fuzzy control.

Abstract. This paper presents a new method for selecting the force-reflection gain in a position-force type bilateral teleoperation system. The force-reflection gain greatly affects the task performance of a teleoperation system; too small gain results in poor task performance while too large gain results in system instability. The maximum boundary of the gain guaranteeing the stability greatly depends upon characteristics of the elements in the system such as: a master arm which is combined with the human operator’s hand and the environments with which the slave arm contacts. In normal practice, it is, therefore, very difficult to determine such maximum boundary of the gain. To overcome this difficulty, this paper proposes a force-reflection gain selecting algorithm based on artificial neural network and fuzzy logic. The method estimates characteristics of the master arm and the environments by using neural networks and, then, determines the force-reflection gain from the estimated characteristics by using fuzzy logic. In order to show the effectiveness of the proposed algorithm, a series of experiments are conducted under various conditions of teleoperation using a laboratory-made telerobot system.

Key words. Telerobot, force-reflection gain, neural network, fuzzy logic.

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List of Symbols

- \( E: \) average system error
- \( F_h: \) forces from the human operator
- \( F_m: \) forces applied to the master arm, \((F_m = F_h + F_r)\)
- \( F_r: \) reflected force, \((F_r = k_f \times F_S)\)
- \( F_S: \) contact force
- \( f_j(:)\): activation function for the \( j \)th node
- \( g_k, g_m, g_z: \) scaling factors for \( k_f^*, m, \) and \( z, \) respectively
- \( K_i: \) fuzzy subsets for \( \tilde{k}_f^* \)
- \( k_f: \) force-reflection gain
- \( k_f(t): \) force-reflection gain at time \( t \)
- \( k_f^*: \) inferred force-reflection gain (output of the fuzzy gain selector)
- \( k_f^*(t): \) inferred force-reflection gain at time \( t \)
- \( \tilde{k}_f^*: \) fuzzy variable for \( \tilde{k}_f^* \)
- \( M_i: \) fuzzy subsets for \( \tilde{m} \)
- \( M_0: \) DC gain of the master arm
- \( m: \) output of the NN1
- \( \tilde{m}: \) fuzzy variable for \( m \)
- \( net_j: \) net input to the \( j \)th node
- \( o_i: \) output of the \( i \)th node
- \( S_0: \) DC gain of the slave arm
- \( t_m: \) target output of the \( m \)th node in the output layer
- \( w_{ji}: \) weight between \( j \)th node and \( i \)th node
- \( X_m: \) position of the master arm
- \( X_S: \) position of the slave arm
- \( Z_e0: \) DC gain of the environment
- \( Z_i: \) fuzzy subsets for \( \tilde{z} \)
- \( z: \) output of the NN2
- \( \tilde{z}: \) fuzzy variable for \( z \)
- \( \alpha, \beta: \) weighting factors for the decision maker
- \( \alpha_w: \) momentum rate
- \( \delta_j: \) partial derivative of error, \( E, \) with respect to \( net_j \)
- \( \eta: \) learning rate
- \( \mu_K(\tilde{k}_f^*): \) membership function for the final output of the fuzzy rule
- \( \mu_{K_i}(\tilde{k}_f^*): \) membership function for the output of the \( i \)th rule
- \( \Pi: \) decision function of the decision maker

1. Introduction

The technology of teleoperation essentially applies to various operations in hostile environments such as nuclear facilities, undersea or space where human can hardly work. Due to its diverse work capabilities, the manipulation devices have