DESIGN AND DEVELOPMENT OF INTELLIGENT SYSTEMS: PID AND FUZZY LOGIC CONTROL OF TELEOPERATION SYSTEMS

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Abstract

The research work at the Robotics and Automation Laboratory (R&A Lab) at Florida International University (FIU) has concentrated on the development of a number of key technologies to enhance remote operations at nuclear facilities by utilizing intelligent systems. For this purpose, current projects concentrate on fault-tolerant systems, design of an omni-directional platform, intelligent control, and telesensation systems. As an example of this ongoing work, this paper specifically presents the recent work on teleoperation systems. A human/machine remote control system often referred to as "teleoperation" has been developed to assist the operator to perform complex and uncertain tasks in hazardous environments such as nuclear reactors, space and under-water operations. Many features have been added to the system such that it is capable to provide the operator with the sensational feelings of the remote site as if he/she were at the remote site. The first phase of the project has been completed. It produced a 1-Degree-of-Freedom (DOF) Force-Reflecting Manual Controller (FRMC) testbed and a Graphical User Interface (GUI) which interfaces the controller to a computer. This testbed has been developed to demonstrate the basic principles of a force-reflecting teleoperation system. Two control methods including conventional PID method and newly developed fuzzy logic algorithm have been tested and analyzed. The next phase is to develop a 3-DOF FRMC with an implementation of a Virtual Reality (VR) Unit as an additional feature. The system will be able to provide the operator with a 3-D environment visual feedback and virtual object manipulation. Thus, the performance, efficiency, and productivity will be greatly improved.

Introduction

The research work at FIU's Robotics and Automation Laboratory currently addresses the following problems:

- Development of fault-tolerant systems
  - Developed a unique fault tolerance measure

- Designed fault-tolerant controllers
- Initial experimental tests on fault-tolerant controllers

- Omni-Directional Platform Design
  - Unique design to provide high maneuverability in cluttered environments
  - Provision for fault tolerance
  - Phase I Prototype Construction
  - Test-bed for lab experiments
  - Availability for nuclear reactor tests

- Intelligent System Controller Design
  - Sensor Fusion
  - Modular Controller Design
  - Graphical Intelligent Controller Software

- Development of Telesensation Technologies
  - Force-Reflecting Manual Controller Design
  - One-Axis Test-bed
  - Interface Software Development
  - Three-Axis System Design and Construction

The technologies under development directly target facility dismantlement, inspection and maintenance tasks in nuclear facilities, and dismantlement and decommisioning (D&D) operations. However, their generic nature makes is extremely attractive for use in other facilities, which are dedicated to energy production. This paper specifically reviews the development of a 1-DOF force-reflecting manual controller which is an important component of a teleoperation system.

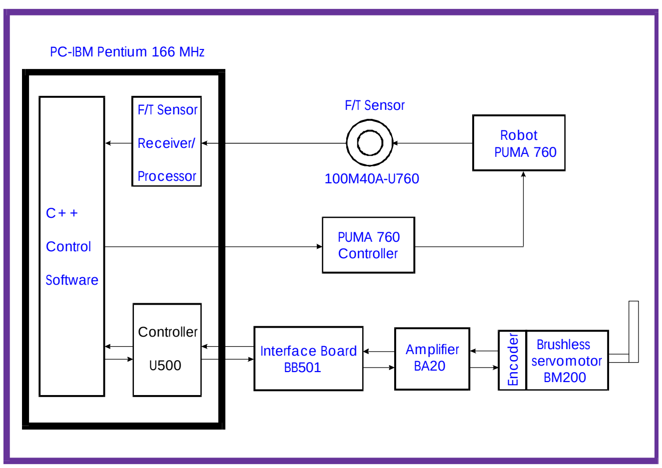

Figure 1. Block Diagram Representation of the Force-Reflecting Manual Controller Testbed

Teleoperation systems have become increasingly utilized in many applications in recent years. For instance, the system is used to conduct inspections, maintenance and general repair tasks in nuclear facilities [1, 2]. In under water operations, the operator guides the remote system to explore the area or to search for the clues that cause the old ship to be sunk. The successful of the system in performing these tasks has called for a better and more sophisticate system. Such an advanced system is defined as telesensation system.

The word “telesensation” has been used to describe telecommunication systems such as teleconferencing where people from different remote locations in the real world are able to hold a meeting or work cooperatively in the same artificial world. Such a system combines the use of computer vision, computer graphics, virtual reality (VR) and telecommunications [3, 4]. This word is applied in the robotics field in the sense that the system integrates the use of VR unit in addition to the advanced human-machine interface. Thus, the overall telesensation system will provide the operator with better coordination of human and the remote system [5]. As a result, the efficiency, reliability, and safety of the system are greatly improved.

Currently, the Robotics and Automation Laboratory at Florida International University is developing a telesensation system. The system will ultimately include a Force-Reflecting Manual Controller (FRMC), a user-friendly Graphical User Interface (GUI), a VR unit, and a sensor-based manipulator. Presently, the 1-DOF FRMC testbed has been developed to demonstrate the basic principles of a force-reflecting teleoperation system. The system characteristics and the results of the control algorithm, which include PID and fuzzy logic controllers, are described in the following sections.

Figure 2. Experimental Setup of the Force-Reflecting
Manual Controller Prototype

1-DOF FRMC System Characteristics and Experiment Setup

The 1-DOF FRMC prototype is a direct-drive system and capable to provide a maximum of force reflection of 5 lb. The update rate of the system is approximately 0.002 second or 500 Hz. Figure 1 shows the schematic setup of a 1-DOF FRMC testbed whereas Figure 2 shows the system components and the actual experimental setup in the R&A Lab [6].

In order to prevent any damage of the system from an unexpected response, a mathematical model has been derived to use as a tool to predict the system output, and also test various control algorithms on the computer quickly. Exciting the system with a known input, and observing its output, system identification of the system has been performed to obtain a mathematical model. Although a number of higher-order systems were considered initially, a 2nd-order model has been selected to represent the system. For this purpose, MATHLAB software package has been utilized. It is shown that the following transfer function represents the manual controller dynamics quite well:

$$G(s) = \frac{0.0296s + 0.042}{s^2 + 1.8944s + 0.8950}$$

The validation process of this model has been verified. The details of the system identification process and the model validation are explained in detail in [7].

Fuzzy Logic Controller and Conventional PID Controller

The fuzzy controller consists of a set of user-supplied rules of which the inputs and outputs are both fuzzy values. All control rules are used in parallel, and the recommended actions are combined according to the fuzzy control rules, which are weighted by the degree of satisfaction of the antecedent. To investigate the performance of a fuzzy logic controller on the 1-DOF FRMC testbed, the control algorithm has been developed and experimentally tested. Different gains have been used to experiment in an attempt to find the suitable gain for this 1-DOF FRMC prototype. In this section, only the experimental results are presented. The control algorithm and the user-supplied rules are described in [7, 8].

Figures 3 and 4 show the actual system response of the 1-DOF FRMC testbed under the fuzzy logic controller with various base values (see [8] for definition of base value).

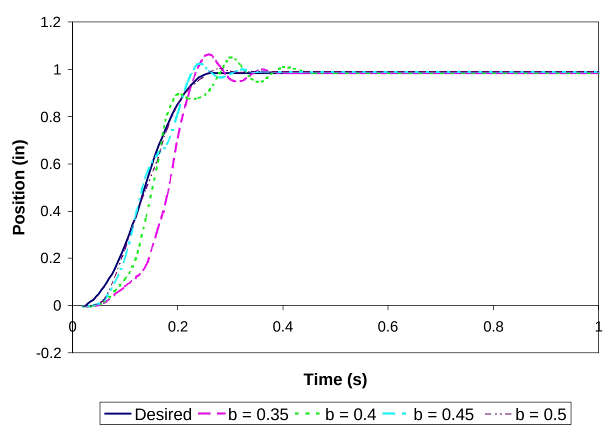

Figure 3. Actual System Response with Base Values between 0.35 to 0.5

As can be seen from the above figures, different base values produce different system responses. Thus, with the fuzzy logic controller, as is the case with most controllers, the selection of the system gains is one of the most important factors that determines the performance of the system. In the case of the 1-DOF FRMC, the most appropriate base value is 0.5 for the look-up table created for this system (See [8] for the definition of look-up table). Note that the results obtained above were for the case that the operator held the joystick with a loose grip.

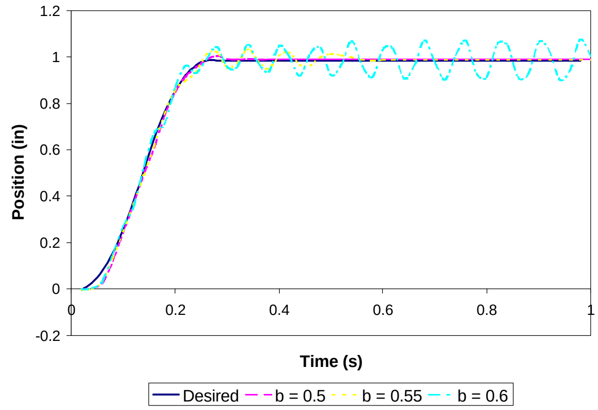

Figure 4. Actual System Response with Base Values between 0.5 to 0.6

A soft grip uses lower gains while a firm grip uses higher gains in order to provide a force-reflection sensation. As for the 1-DOF FRMC, the experiments show that for the stable region of the soft grip, the base value is in the range of 0.35-0.55; whereas for the firm grasp, the base value can be as much as 0.8-1.0. If the base value falls below the above values, poor performance results, and the higher base value causes the system to be unstable.

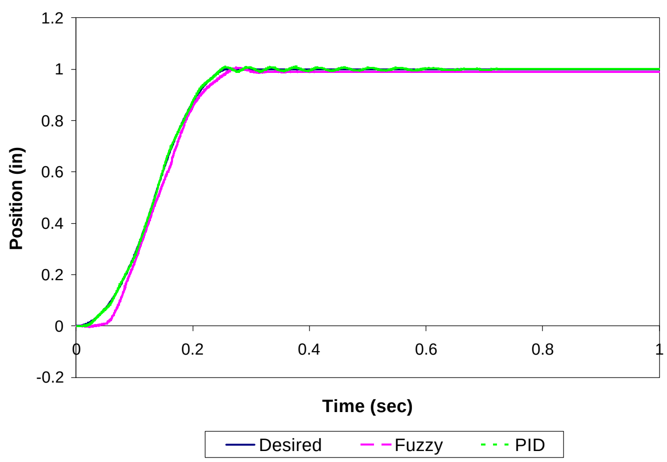

Figure 5. System Responses to PID and Fuzzy Logic Controllers

A comparison of the system response between PID controller and fuzzy logic controller is shown in Figure 5. The system parameters used in this experiment are set as K_P = 10, K_I = 28,000, and K_D = 40,000, and the base value (b) for fuzzy logic controller is selected as 0.5.

As seen in Figure 5, both controllers follow the desired path quite well. The differences are that PID shows an overshoot and transient oscillations but has no steady-state error, whereas the fuzzy logic controller produces no oscillations, but it displays steady-state error and can not catch up with the desired path at the beginning as well as PID. Therefore, the choice of selecting a controller between the PID and fuzzy logic approaches will depend largely on the operator and the requirements of the tasks since each has its benefits and drawbacks. However, for the purpose of force-reflecting manual controller application, where a very high precision is not required due to the limitations on human perception, the performance of both controllers are judged to be acceptable.

Future Work

The future work of this project includes the development of a 3-DOF version of FRMC and the addition of a VR unit. The design alternatives of the 3-DOF version are proposed in [8]. The conceptual design is in the form of a parallel configuration where it utilizes a direct drive setup which eliminates the need of intermediate transmission elements such as gears or belts. As a result, it has zero backlash and virtually no friction. Several VR units have been surveyed in order to identify a suitable system for the telesensation project. The survey is published in [5].

Conclusions

Research and development work at FIU's Robotics and Automation Laboratory has been introduced briefly. These concentrate on developing intelligent systems for use in robotics, mobile platforms, as well as in intelligent automobiles. Specifically, in this paper, design and development of a 1-DOF FRMC prototype has been reviewed. System identification of this prototype, and two controllers tested on this system have been introduced. The mathematical model is identified and verified where it is used as a tool to simulate the system output produced in response to designed controllers. As for the control methods used in the experiment, the results show that the fuzzy logic controller can be used to control the remote system as successfully as the conventional PID controller.

References

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