DEVELOPMENT AND SIMULATION OF AN ERGONOMIC CONTROL SYSTEM FOR A LARGE CONSTRUCTION MANIPULATOR

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ABSTRACT

This paper discusses the development and implementation of a new ergonomic manual control system for a large construction manipulator. The manipulator consists of a 22 ton rough terrain hydraulic crane with a multifunction manipulator attachment. The combined device gives a single operator hydraulic control over eight independent joint axes allowing for dextrous positioning of large sections of pipe or steel. The application for the machine is in industrial construction as found in the building of chemical plants, power facilities, and other process industries. This study discusses how the new ergonomic control system was developed and how a computer graphics model of this pipe manipulator was used to test this system. Implementation of the new system on the actual machine is also discussed.

INTRODUCTION

The unmodified pipe manipulator (as shown in Figure 1) is controlled by manually operating eight separate control levers (one for each joint axis). The function of each control lever is shown in Figure 2. The control panel is located in a basket at the end of the crane boom. A single operator controls the crane and the manipulator attachment to pick up and maneuver sections of pipe. When tested in the field, this control system proved to be cumbersome and the machine was not well accepted. To replace this system, a more ergonomic controller called the "ergostick" was developed. This device consists of two arms which give the operator full control over the machine's eight axes. Furthermore, the ergostick motions correspond exactly to the motions of the manipulator making operation very intuitive. In addition to this better means of manual control, the operator is also provided with various kinematic functions. These functions involve computer control of the joint axes resulting in straight line motions in any desired direction.

To support ergostick development, a computer graphics simulator of the pipe manipulator was created. The simulator consists of a high powered graphics workstation and a 3D simulation software package which provides a real-time 3D shaded-image model of the manipulator. The graphics simulator was and is being used to test the ergostick systems and to perform construction simulations. This testing allows us to evaluate various designs (based on ergonomic issues and mechanical reliability), and to test enhancements (e.g., computer assisted control) before implementing them on the actual machine. Figure 3 illustrates how the ergostick system interacts with both the simulator and the manipulator. The components in this system are discussed in following sections.

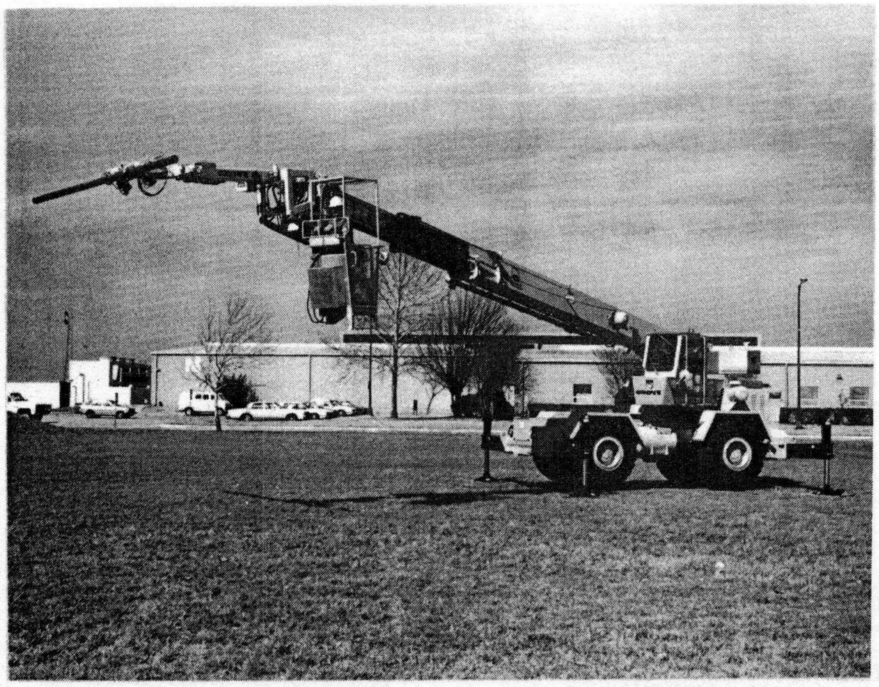

Figure 1
Grove Pipe Manipulator

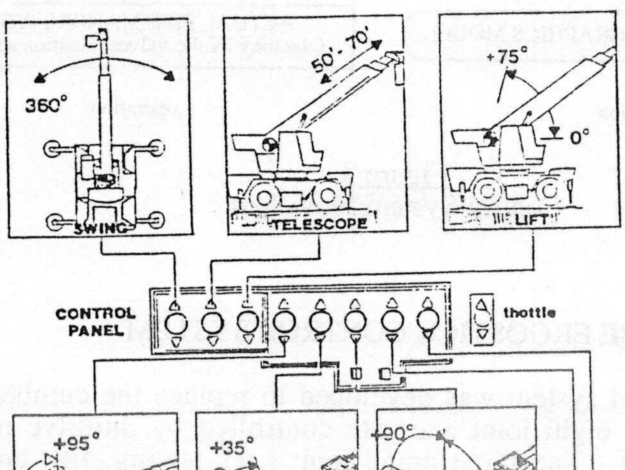

Figure 2
Pipe Manipulator Joint Axes

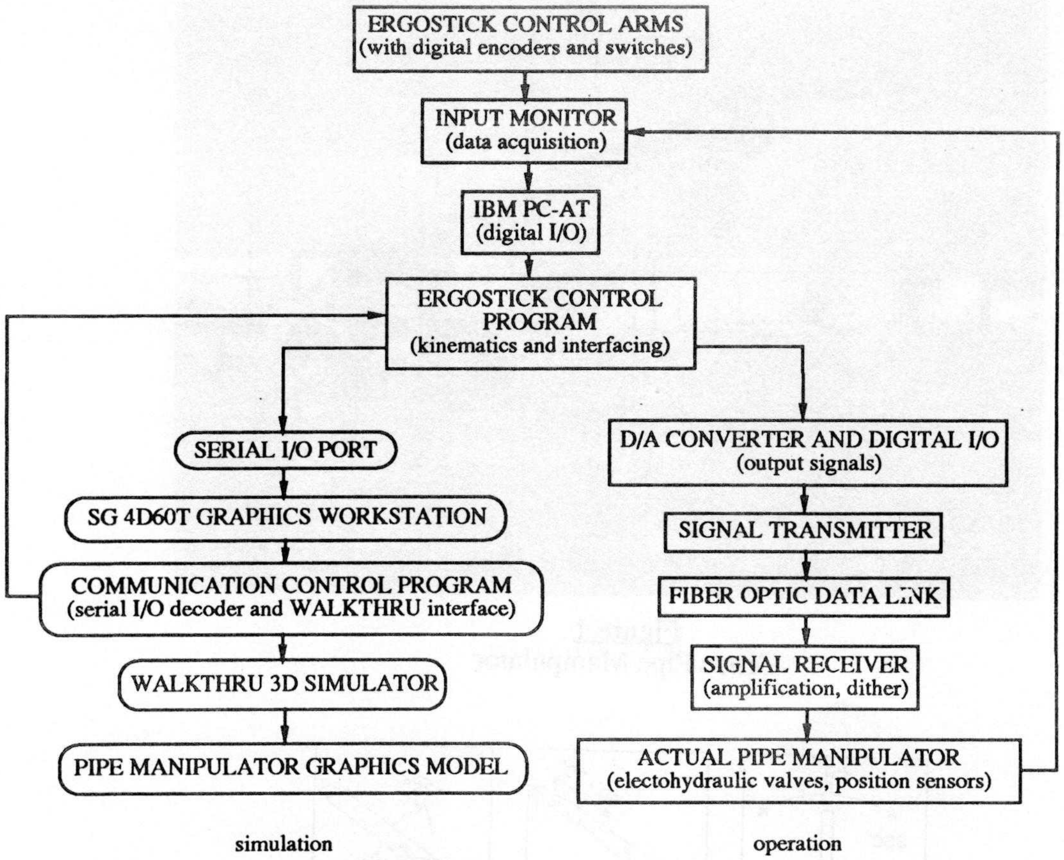

Figure 3
Control System Flowchart

THE ERGOSTICK CONTROL SYSTEM

The ergostick control system was developed to replace the cumbersome manual control levers. Here, the eight joint axes are controlled by intuitive motions of the operator's arms and wrist. The three crane joint axes (swing, lift, and extend) are controlled with the left arm and the manipulator attachment axes (lift, extend, rotate, pivot, and roll) are controlled with the right arm and wrist. The movements of the ergostick arms correspond exactly to the movements of the pipe manipulator. For example, to have the crane boom lift, the operator simply lifts his left arm, or to have the pipe pivot, the operator simply curls his right wrist. Furthermore, the ergostick provide proportional rate control so that the axis being operated moves faster the further the ergostick function is deflected. An important feature is that many axes can be operated simultaneously -- this was difficult with the eight separate control levers. In addition to controlling the joint axis motions, the operator can also control a variety of other functions through switches located on the hand grips. These switches control other features on the crane including opening and closing the jaws, a creep speed mode which allows for fine positioning, and a horn for safety reasons. The result is an intuitive, non-distracting control system which gives an operator command over all functions of the machine. The prototype of the ergostick device is shown (in actual operation) in Figure 4.

Figure 4
Ergostick Control Station

In addition to improved manual control, various kinematic functions are also made available to the operator. These functions include cartesian (straight line) motion and pipe axis motion. They are activated by switches on the ergostick hand grips and are controlled by three independent motions of the left arm. The cartesian motion allows the operator to move in directions corresponding to the directions in his environment (pipe racks are typically rectangular), whereas with the old system he could only operate in directions provided by the individual joints. The pipe axis motion function allows the operator to literally point a straight piece of pipe towards its destination and have motion ensue along that direction. Both of these functions require simultaneous control of all eight of the joint axes in the manipulator. Furthermore, the rates at which each joint is to be driven is prescribed by kinematic relationships, and computer assisted control is required. Also necessary is a continuous knowledge of the position of the axes as this affects the equations involved.

The hardware makeup of the ergostick controller consists rotary and sliding mechanical components providing the motions corresponding to those of the manipulator, digital encoders and switches for monitoring the operator's inputs, electrical circuitry to monitor and manage the encoder data, and a small computer (IBM PC-AT) with a control program to process the information and generate control signals. Figure 3 illustrates how these signals can be used to control the actual manipulator or the computer graphics simulator. In the case of actual operation, the signals are in the form of voltages supplied to a transmitting box (MRC-1 made by OEM Controls) located on the ergostick station. The transmitter communicates these signals serially to a receiving box on the crane via an electrically isolated fiber optic data link (a future generation system could employ a cableless radio link). Here, the signals are amplified and conditioned to stroke the electrohydraulic valves on the manipulator. One of the conditioning features is a constant "dither" which keeps the valve spools constantly vibrating to reduce sticking and surging of the valves thereby providing smother more accurate control. Also located on the crane are digital position sensors which monitor the motion of the axes. This information is relayed back to the control program for use in the kinematic functions.

THE COMPUTER GRAPHICS MODEL

In order to test the ergostick prototype, a 3-D computer graphics model of the Pipe Manipulator was created. The system chosen for our model was WALKTHRU (developed by Bechtel) running on a Silicon Graphics IRIS 4D 60GT workstation. This workstation is very powerful (the processor runs at 12 million instructions per second) and it allows real-time simulation with 3D shaded models. WALKTHRU is a simulation system which allows the user to interact with 3-D geometry. The pipe manipulator model running with WALKTHRU (see Figure 5) provides a realistic simulation of actual machine operation. Construction tasks can be performed and visualized in real-time. Important features of the program include real time shaded image motion, on-line interference checking, and recording capabilities. The on-line shading and interference are invaluable for simulation purposes. These features allow easy visualization of the geometry and let the user know when objects are about to collide. The recording capabilities are also useful allowing the user to store simulation data for later playback or for simulation analysis.

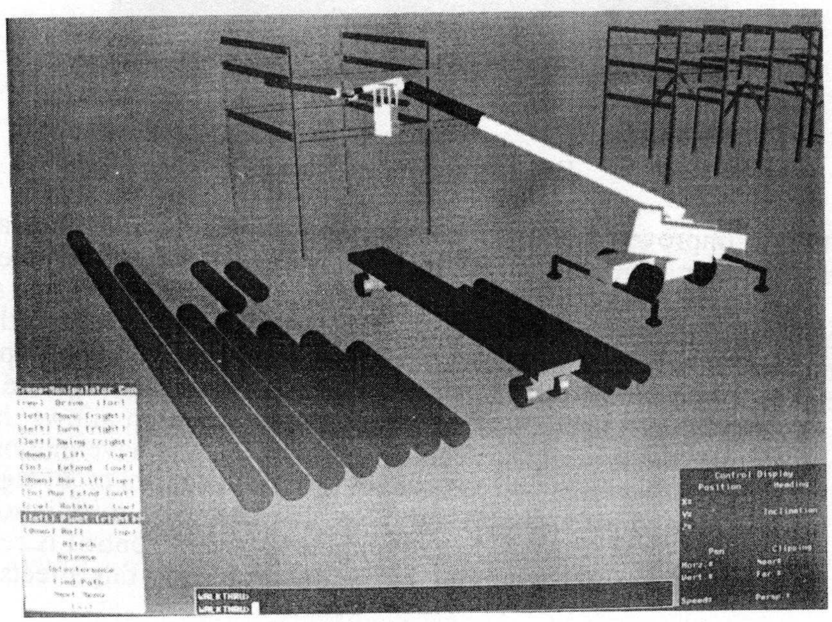

Figure 5
Computer Graphics Model

Another important feature of WALKTHRU is its interfacing capabilities. WALKTHRU gives the user the ability to communicate to the model interactively through external software. This was crucial for us to be able to interface the ergostick control system to the model. The actual connection between the ergostick system and WALKTHRU is illustrated in Figure 3. The ergostick control program processes the operators inputs and converts the axis control information to serial data which is communicated to the Silicon Graphics workstation. A control program on the SG reads and decodes this information and generates commands that WALKTHRU can understand. The commands update the model on the screen and the process repeats. The result is a real-time moving image which simulates the pipe manipulator in operation.

CONCLUSIONS

Initial field testing indicates that the ergostick system does indeed provide smooth, intuitive control of the manipulator. Present work consists of investigating real-environment imperfections not encountered in the simulated computer graphics environment. These include dynamics of the manipulator boom and dead bands in the actuating valve characteristics. Important studies in the future will include on-line calibration of control parameters for consistent and accurate response (especially for the kinematic functions) and closed loop automatic control for fully automatic positioning. Another topic of interest is in using the graphics simulator as a training tool for operators. Operators can develop their skills in the safe and cost effective computer graphics environment rather than on the actual machine.

The ideas and approaches presented in this study have and will produce vast improvements in the operation of the Pipe Manipulator. For more information concerning this work consult the references listed below. We feel the study provides a fruitful platform for development of ideas and practical approaches applicable to other large scale construction manipulators.

AKNOWLEDGEMENTS

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