A New Approach to Construction Robot Programming

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ABSTRACT

The paper describes a virtual-reality-based approach to programming construction robots. This approach is needed because of the ever changing conditions and the nature of the construction work. As a result, construction robots need much more programming relative to their industrial counterparts, this being a labor intensive task using known methods. Unfortunately the massive programming investment is not compensated by mass production. The virtual-reality-based approach is demonstrated with the Multi Purpose Interior Finishing Robot for a masonry task, accompanied by a description of the virtual-reality-based programming model and approach.

1. INTRODUCTION

Robots are considered as flexible machines because they can easily be programmed to perform different tasks. Yet, often the complexity of the programming process limits more widespread use of robotic technology (Delson and West 1994). Researchers and practitioners alike are constantly looking for new methods of programming robots to save programming time and costs. This section reviews some advanced programming techniques.

Currently, most commercial robots are programmed in textual robot programming languages (RPLs) similar to Basic, Pascal or alike. Popular examples include VAL, RAIL and AML (Lees and Leifer 1993). These languages include positioning instructions, process parameters, and other instructions (Kamisetty and McDermott 1992). RPLs contain primitives to express manipulator motion in world coordinates as a location (x, y, z) and orientation (roll, pitch, yaw) (Heise 1993). Most languages also contain higher level control commands, like: *move*, *open/close gripper*, *wait*, *read*, *if/then/else/while* (conditional and loop commands), *and/or* (Boolean commands), etc.

A program in RPL can be written when the robot is in its designated work location (on-line programming). The advantage of doing so is that it is relatively easy, but during programming the robot, and the dependent equipment are idle, thus increasing programming costs significantly. Off-line programming is supposed to solve this problem but it is very difficult to carry it out without visual aids.

Off-line programming with simulators enables the programmer to write a program without recourse to the robot itself. It is done in a computer-graphic environment, enabling the programmer to preview, debug and verify the program before the robot is installed, or even bought. Thus simulators enable the development of typical tasks, examine different alternatives to perform them, test different control strategies, explore raw material supply alternatives, etc. Once a program is written, the programmer can visualize the robot's task being performed, check the planned paths' suitability for the performance of specific tasks, check that the robot does not collide with its environment, etc. When the programmer is satisfied with the program, it is translated into the robot's native language and downloaded to it.

One of the most important characteristics of graphic simulators is that they are able to measure cycle times, which is an important parameter influenced by the selected paths, by the control algorithms, by the material supply method, etc. Thus higher quality programs can be developed with the aid of graphic simulators, taking into account robot productivity as well. However, simulators still require the users to work with text-based languages and consequently only solve part of the problems associated with native robot programming languages (Lees and Leifer 1993).

"Programming by Example", or by human demonstration, is another method. The programmer demonstrates how the task is performed using a human/robot teaching device that measures the human's forces and positions (Delson and West 1994). The data gathered from the human is used to generate the robot's program. Another technique is "Automatic Robot Programming", where the goal is to get the robot to perform a task by telling it what needs to be done, rather than by explicitly programming it (Koza and Rice 1992).

Construction robots operate in an ever changing environment, producing one-of-a-kind, or at best small-batch products. Therefore the above mentioned programming methods and techniques are either unsuitable for construction robots or involve a lot of programming, which hinders their cost-effectiveness. The objective of this paper is to propose and examine a new approach to the planning of robot tasks and programming using virtual reality (VR) techniques.

As far as robotics is concerned, there are already several research projects investigating the use of VR as a tool for design and control of robots. For example, the VERDEX project (Stone 1992) evaluated the use of VR as an interaction tool between human operators and semi-autonomous robots to be deployed in hazardous environments, disaster areas and space.

Coiffet (1995) presents three main difficulties in current robotic applications and points out where "VR can deliver either an improvement or a new efficient approach". These difficulties are:

- the difference in behavior between what is forecast and what is really happening as a result of incorrectness in the matter of robot environment modeling,
- impossibility in understanding environments by mobile autonomous robots,
- the complexity of teleoperation, which requires sensory and mechanical adaptations, as well as decision support to the human operator.

To eliminate the first difficulty, the design of new robots can be assisted by VR, both in its geometric aspects (link dimensions, work envelope, etc.), as well as in its control aspects , such as visualizing sensor data, virtual navigation controller, etc. (Pimental and Texeira 1993, Coiffet 1995).

There are two main approaches, supplementing each other, to deal with the last two difficulties. One is to assist a remote robot operator using VR technology as a telepresence tool (Kim 1993, Stone 1992). This approach can also help in operators' training (Salisbury 1992). Another approach is to use VR as a tool for robot task planning, supporting off-line programming for both navigation simulation and task execution (Fraisse et all 1993, Burdea and Coiffet 1994, Strommel et al. 1993).

2. APPLICATIONS OF VIRTUAL REALITY TO CONSTRUCTION

Virtual Reality is an advanced computer graphics technology dealing with visualization (Machover and Tice 1994). As a computer graphics application it can be used for a wide variety of uses (Kalawsky 1993, Sherman and Judkins 1993, Vince 1995, Warwick et al. 1993). The use of object-oriented techniques for creating virtual environments was the key for a breakthrough in credibility and applicability of VR technology (Larijani 1994). Various definitions are suggested today, one which is both descriptive and short is by Pimentel and Teixeira (1993), who define VR as "the place where humans and computers make a contract" Similarly, Larijani (1994) defines VR as "the convergence of computer simulation and visualization that attempts to eliminate separation between a user and a machine". From their viewpoint, VR is an interface between humans and computers.

VR can be applied in building design and construction for a wide variety of uses as proposed in Bridgewater et al. (1994), Hendrickson and Rehak (1993), Retik and Hay (1994), Ribarsky et al. (1994), Stone (1993), Wakefield and O'Brien (1994), etc. During the design stages immersive virtual reality systems provide the only way to learn and experience a design to be constructed. Then, during the planning and scheduling of the virtual project, a construction manager is presented with an opportunity to test different construction methods applying value engineering techniques and checking buildability aspects of the construction process to select the best alternative.

Another important use of a VR system is their ability to provide training facilities for construction staff. The training which can be done with VR, due to its real time capabilities, is the most realistic situation that a person could encounter without actually taking part in the task itself.

Current research into the application of VR in construction robotics has mainly concentrated on the simulation of robot tasks, checking their feasibility and possible improvement. This paper suggests an approach to planning and off-line programming of robot tasks.

3. PROGRAMMING OF CONSTRUCTION ROBOTS

This Section explains the customary approach to programming construction robots using an example of the Multi Purpose Interior Finishing Robot (MPIR), whose working environment is a building skeleton, erected by industrialized methods, such as prefabricated (Warszawski and Navon 1991).

Presently, MPIR's operational concept is that it operates from stationary workstations, which means that it is stationary while it performs the actual task. Consequently, the programming assignment can be divided into two main categories: programming the movement between workstations, and programming the actual task at each workstation. The program of the movement between workstations includes the plan of the exact path between workstations, which assures collision free motion. Visualizing such a path is very difficult, or even impossible, for a human programmer to do off-line. Consequently there are two approaches to solve this problem: first, to write the program with the aid of a graphic simulator (as explained in the Introduction), whereby the building and MPIR are modeled and a program is written and tested before it is downloaded to MPIR. The second approach is to write an intelligent program which enables the robot to plan its own path and movements, and travel between the workstations in accordance to this plan and to the data received on-line from sensors.

The program of the actual task includes three elements, as described in the next sections.

3. 1. STABILIZATION AND CALIBRATION

When MPIR reaches a workstation it first has to deploy its stabilizers. This is done for three purposes: to level itself, to avoid skidding during operation, and to achieve greater stability during operation. In the calibration process MPIR surveys its immediate working environment relative to its position: the exact location of the building elements it will have to interact with, and the precise location of the raw materials. Naturally, the calibration is done on-line. It can be done by the programmer/operator leading the robot to key points (such as corners of walls, edges of columns, location of openings, etc.) and recording them. Alternatively, the calibration can be done automatically, by inserting reflectors in the actual location of the key points and letting the robot search for them, identify them and record their location.

3. 2. PRODUCTION PLANNING

The production plan details all the tasks that have to be done at a given workstation. It specifies the following (partial list):

⇒ The sequence of erecting the elements.
⇒ The order in which they will be taken from the raw-material stack.
⇒ The sequence and timing for sensor data to be measured.
⇒ The actions to be taken according to the value of these readings.
⇒ The conditions defining the termination of the job.
⇒ How to identify defective/faulty elements.
⇒ What should be done when defective/faulty elements are identified.

The production plan can be written off-line in a task oriented language. It can even be written in a parametric form, whereby the number of the elements to be erected, their collective location, and other parameters, would be programmed on-line. The collective location can be given by specifying the relative location of the first element together with a formulation of the pattern of their erection.

3. 3. ELEMENTARY MOTIONS

The elementary motions are specified in the robot's native programming language. It can be programmed parametrically, specifying the relative locations and orientations of the robot's end effector, or to move the parts (blocks, tiles, etc.) or the tool (e.g. spray gun).

4. A VR-BASED PROGRAMMING MODEL

The approach to the application of VR techniques to plan the robot's work on-site is an integral part of a comprehensive approach to automation of the construction process called Computer Integrated Construction (CIC). It is described in numerous publications, e.g. Yamazaki (1992), Retik & Warszawski (1994), and in Navon (1995 a and b). In CIC all the activities are carried out with the aid of computers, starting with design, through construction planning, to the actual on-site construction, including real time control, the latter being based on automated data acquisition. The construction on site is supported with various construction management software tools and is performed by robots.

The long term objective of this research is to develop a VR-based system for programming construction robots. An overview of the major components of this approach is given below.

Once the facility's detailed design is completed, it is entered into the system using the data exchange interface or regenerated using VRT's (Virtual Reality Toolkit of Superscape) editor and library. The current system prototype allows DXF files to be imported into the VR Toolkit. This transfer requires the user's involvement, especially for 3D designs, because of the different data modeling approaches (AutoCAD uses wire-frame modeling, while Superscape adopts constructive solid geometry modeling).

The next stage is the adjustment of the virtual environment or its regeneratin in 3D using 2D layout 'guidelines' and a 3D library of elements. If a 3D model of a building is successfully imported into the system, it will usually represent a 'design product' to be delivered to a client. In order to visualize and simulate the construction work implementing the imported design as a model, it needs to be adjusted, or modified (Retik 1995b). In the present case, the robot starts its job once the external envelope and the internal bearing walls are erected. After the model of the building is adjusted to the virtual environment, a robot and its operational interface are selected from the VR library to carry out the tasks. Presently, only one robot (V-MPIR) is available with an operational interface allowing its navigation and manipulation. In addition, virtual materials, palettes of blocks, etc. can be selected, from another library, and temporarily located within the building model.

At the next stage the user has to determine the robot's path by selecting workstations and locating material pallets (in case of discrete material supply). This is done by navigating the robot visually, using a joystick or a 3D mouse. The end effector is activated by using the interface buttons. The user is able to 'be' either outside the picture (remote control or navigation) or to locate him/herself on the robot ('drive-through'). In both cases, the planning is based on the user's experience and is carried out by using a trial-and-error strategy. The possible application of a case-based approach allowing adoption of previous solutions (in the form of existing programs) is under investigation.

Once the user is satisfied with the plan, the sequence of motions is recorded and played back to verify and refine the sequence and pallet locations. The simulation can be stopped at any point to allow the user to change a viewpoint or, in future development, to activate performance of a particular task interactively. After this, a program code is generated, based on the robot's movements, the geometry of the building and the location of the raw materials in the VRT built-in language - a program interface. The VRT code is then translated, by another program, to the robot's native language, and sent to the construction site to be transferred to the physical robot.

The proposed approach, once fully implemented, will facilitate planning of robot tasks, shorten robot teaching-time, and improve its performance, thus making construction robotics more cost-effective. The approach was demonstrated in a prototype system, the preliminary results of which are presented in the internet at ***http://www.strath.ac.uk/Departments/Civeng/vcsrg.html.***

5. SUMMARY

Existing robot programming techniques - native robot programming languages, off-line programming with the aid of graphic simulators, programming by example, etc. - are not suitable for programming construction robots. The reasons for this are the ever changing environment of construction (the construction robot changes its own environment during operation), and the fact that the construction product is a prototype, or one-of-a-kind. Consequently, in order to make construction robot programming more cost effective, this paper presented a different programming approach, using Virtual Reality (VR) techniques.

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