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ATREF: Application des Technologies Robotiques aux Équipements Forestiers

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Abstract

Canada is one of the world's leading forestry nations and luckily, there are still some Canadian world class forestry equipment manufacturers. This is all the more important since new technology in the resource industries is most easily introduced by equipment manufacturers, not end-users.

The four year, 2.2M$ ATREF project is one recent large-scale attempt in Canada to address this issue, by bringing together key players within the province of Québec: Denharco, one of Canada's leading forestry equipment manufacturers, Autolog, an independent company specialising in computerized control and embedded systems, the eastern division of the Forestry Engineering Research Institute of Canada (FERIC), two universities (Laval, McGill) and CRIM, a non-profit computer science research institute with a mission to promote technology transfer. ATREF began in January 1994 and in this article, we report on our early work.

1 Introduction

Forestry is Canada's most important industry in terms of net contribution to the economy, number of people employed, and socio-economic importance.

But competition is growing from timber-rich eastern Europe and from countries that benefit from longer growing seasons. In addition, stricter environmental regulation at home and abroad, and fierce marketing from foreign equipment manufacturers mean that Canadian forestry equipment manufacturers must develop innovative homegrown technologies in order to remain competitive.

Most modern Canadian forestry machines for wood harvesting are diesel-powered hydraulic construction equipment retrofitted with special end effector tools (also called 'attachments') and operator controls to manipulate trees and logs (felling, delimbing, and cutting to length) instead of earth.

But there is also an increasing need for machines with greater agility, lower ground pressure and higher tractive effort.

In part for this reason, new generation machines designed and built especially for forest harvesting are appearing, offering an integrated trio of end effector, manipulator arm and mobile base. Such machines have different kinematics and dynamics and pose different operator-system interface problems, since the operator doesn't rotate with the manipulator arm as in an excavator.

To increase the flexibility and effectiveness of these machines, electro-hydraulic actuation and computerized control is a most appropriate technology. However, designing such advanced actuation and control systems for forestry machines presents significant technical and scientific challenges including electro-hydraulic system non-linearities, large parameter variations, performance limitations of the industrial components used, operation in highly unstructured environments, and extremely harsh operating conditions.

Despite the suitability of telerobotic technologies for forest harvesting [1], Canadian research in this area only began in the late 1980s with the pioneering work by Peter Lawrence and his colleagues at the University of British Columbia [4].

One recent Canadian initiative in forestry robotics is 'ATREF' (Application des Technologies Robotiques aux Équipements Forestiers), a four-year 2.2M$ project which began in 1994 involving CRIM, McGill University, Université Laval, the Forest Engineering Research Institute of Canada (FERIC), and two leading Canadian companies in forestry equipment and automation: Denharco (Ste-Hyacinthe, Québec) and Autolog (Laval, Québec). The project is partly funded by the Québec government's SYNERGIE program, whose objectives stress the acceleration of technology transfer from Québec's research community to the private sector. In particular, the ATREF project intends to develop a set of readily marketable technologies by the end of the project. The industrial partners continue to work closely with their research partners to ensure, for example, that the proper balance is struck between innovation and technology transfer.

And in contrast to the traditional, excavator-based platforms, ATREF work is based on the FERIC forwarder, designed in 1986 as an experimental proof-of-concept prototype with a tiltable and wheeled mobile base.

In this paper, we report on work accomplished in the initial stages of the ATREF project with a special emphasis on the transformation of the FERIC forwarder into an experimental and validation testbed.

2 ATREF Overview

The ATREF project has three major development themes: computerized coordinated control of the end-effector, based on high performance industrial grade electro-hydraulics and advanced sensing techniques; design and engineering tools for simulating the kinematic and dynamic behavior of alternative mechanical configurations; a training simulator for operators.

At the core of the ATREF project is the mathematical modelling of the behavior of forestry machines. This effort, in progress at McGill University, uses the FERIC prime-mover as its target experimental system. The derived models will be simplified to create *approximate* models for (a) the on-board computerized control and (b) the graphical simulation to be developed as part of our operator training environment.

In what follows, we concentrate on the computerized control theme of the ATREF project by briefly describing the changes to both the structure and electro-hydraulic system of the FERIC prime-mover. The basic elements of our data acquisition system are then presented, designed to help us better understand the behavior of the control system elements to complement our theoretical analyses. Finally, we turn to the other two project themes and report on our early work.

3 Structural modifications to the FERIC prime-mover

In order to create a testbed more reflective of the forestry equipment market tendencies, it was decided to transform the side-loading FERIC forwarder into a wood harvesting prime mover. In particular, just the telemanipulator part of the FERIC prime-mover was structurally modified; the prime mover base was left unchanged.

The telemanipulator of the FERIC prime-mover has four articulations: rotation of the base or 'swing', boom, stick, and the orientation of the end effector. Changes were three-fold.

First, the physical arrangement of the structural components (diesel motor, pumps, etc.) on the mobile platform was altered, so as to move the telemanipulator base from the middle and side of the FERIC prime-mover to the front and centre. Secondly, the stick portion of the telemanipulator was lengthened, in order to obtain a work envelope more representative of commercial forest harvesting equipment. Finally, the end effector grapple designed for log loading was removed and replaced by a mock-up of a processing head, new harvesting technology designed to perform felling, delimbing, and cutting to length in sequence; a functional processing head will replace the mock-up later in the project.

The transformed FERIC prime-mover is presented in Figure 1.

4 Electro-hydraulic system modifications to the FERIC prime-mover

While the original electro-hydraulic system of the FERIC prime-mover reflected traditional industry practice, careful analysis suggested that the benefits of computerized coordinated control would be limited unless modifications were made to the actuation (and pump) system.

Traditional manipulation control in forestry and construction machines is based on open-loop joint control, i.e. the operator is controlling separately each joint of the arm, and mentally coordinates the motion of the arm's end-effector. Motion errors due to hardware limitations are partly compensated by the operator, depending on his skill and experience.

Clearly, operator workload may be reduced by assigning the coordination task to an on-board computer. Indeed, computerized control will be even more important for new generation machines for which active compensation of undesirable end-point oscillations will be possible, by adjusting the control setpoints of the telemanipulator and its tiltable base.

However, compensation for errors requires a responsive actuation and control system. To this end, it was decided to replace the original pilot-based proportional valve technology associated with the swing, boom, and stick, by a new type of electronic proportional valve technology developed for the machine tool industry and therefore largely unknown to the heavy equipment industry. In particular, the spools of these single-stage valves are controlled by high current coils, driven by advanced optimized electronic cards. As a result, these valves offer much better performance characteristics in terms of bandwidth and overall flexibility.

In addition, two other changes in the hydraulic actuation subsystem were required. Firstly, to improve responsiveness, the hydraulic pump system was reconfigured to work in a constant pressure mode, and secondly, finer filters were installed to address the stricter oil filtering requirements.

To size the new valves, a new procedure based on modelled dynamic behavior of the arm was employed. Traditional practice in sizing hydraulic components requires knowledge of constant 'loads' to be driven during a 'duty cycle'. However, in the case of a forestry arm, cylinder/motor loads are both static and dynamic, and time varying, with large variations. To address the sizing problem, typical and demanding end-effector tasks were selected. Using a preliminary model of the manipulation/actuation subsystem, pressure drop and flow requirements for all valves were computed. Then, valve sizing was achieved by matching computed requirements to manufacturer-supplied valve characteristics.

5 Data Acquisition System

We began by carefully distinguishing between the basic sensing required for computerized control and the 'extra' sensing required for the system modelling.

5.1 Basic sensing

Any closed-loop computerized control of the telemanipulator necessarily requires the measurement of the angular position of each articulation.

Given the hostile nature of the forestry environment (temperature extremes, vibration, dirt, etc.), we elected to choose resolvers. Indeed, our industrial partner Denharco has successfully used resolvers in the past and even developed their own packaging to make them more robust.

While the resolver represents the wisest technological choice in the short term, it does pose certain disadvantages. For one, a bundle of 6 wires are required for each resolver, along with specialised interface electronics. In addition, mounting resolvers at the pivot point of an articulation may lead to mechanical weakness. For this reason, we chose to install our resolvers on external linkages added to the telemanipulator, although such a mounting arrangement may give rise to a reduction in measurement precision.

With these thoughts in mind, we therefore decided to experiment with magnetostrictive sensing on the boom and stick as a possible technological alternative in the medium term. In this way, we will be able to compare the two sensing technologies so that our industrial partners may better evaluate their commercial advantages. Indeed, we believe that technology transfer is best addressed, in part, by experimenting with such *near*-term technological options.

As for the mobile base, its highly deformable wide tires and specialised wheel articulations together create a suspension which differs greatly from excavators. Here we measure the roll and pitch with inclinometers and the configuration of the wheel articulations using cable sensors, another proven sensing technology.

One last kind of sensing is required for computerized control: the measurement of operator input in terms of rate of change (instead of position). In typical forestry machines, the control of the four telemanipulator articulations (base rotation, stick, boom, end effector orientation) are assigned in pairs to two 2 degree-of-freedom (dof) joysticks. As an alternative, we are also working with a 4 dof *hand controller* in order to better evaluate, from an ergonomic point of view, the relative merits of two joysticks as opposed to a single hand controller, and how the control of the four telemanipulator articulations is best performed. Preliminary work in this direction has been reported by Lawrence [5].

5.2 Additional sensing

As previously mentioned, additional sensing is required in order better understand the behavior of the control system elements as part of the closed-loop computerized control, in order to complement our theoretical analyses.

After a careful analysis of the FERIC prime-mover, we elected to measure the following parameters: oil flow distribution and temperature, hydraulic system pressure, and valve spool positions.

5.3 Computing

Clearly, data acquisition and computerized control pose different kinds of computing requirements. In the first case, we are simply concerned with measuring, in real-time, variables associated with system behavior while the operator exercises the machine in a traditional, open-loop mode e.g. operator uses joystick to move the boom, while the data acquisition system records how the boom angle changes, how the oil demand changes, etc. All of the data processing is then performed off-line using a commercially available aid (Matlab/Simulink from the MathWorks).

In the second case, we will be calling into play, in real-time, extensive numerical calculations associated with the approximate models of system behavior.

As a result, we elected to design the computing for our data acquisition system in order to simplify the later 'migration' for computerized control. After much discussion with our industrial partners and especially Autolog, we chose STD-32 bus technology, a single Intel 486 CPU, and the real-time operating system QNX. The development of the data acquisition software under QNX was principally conducted by Université Laval.

Once again, the emphasis on technology transfer is evident. Autolog has worked extensively with STD and STD-32 bus technology and helped guide the selection of the necessary cards to carry out the electronic interfacing to the various sensors. As for QNX, this was proposed by Autolog as an alternative to their simpler proprietary real-time operating system and after carefully reviewing the commercially available Posix-compatible alternatives, QNX proved to be the wisest choice for our project.

In conjunction with STD-32, QNX provides a sound, industrial-strength foundation with the required flexibility. In particular, while our initial estimates suggest that that the single Intel 486 CPU used for data acquisition will also provide sufficient computing power for the future on-board computerized control and sophisticated operator-system interface, the support for distributed processing built into QNX will make possible a smooth transition to a multi-processor configuration if required.

6 Other project themes

6.1 Design and engineering tools

Clearly, the traditional kind of telemanipulator developed for construction industry excavators is less than ideal for working in the woods. For example, the serial kinematic structure, the relative size of the stick and boom, and their pivot point, are all optimised for moving earth, both above and below ground level. In addition, typical 'manipulations' are, of course, performed in uncluttered work environments.

As a result, forestry equipment manufacturers reposition the pivot point of the stick and boom as part of the work they perform when adapting an excavator for forestry work (in addition to replacing the end effector shovel with a specialised 'head' for manipulating trees).

In order to address this issue, a separate and additional activity has begun at Université Laval within the context of the ATREF project. Here the emphasis is on the interactive definition, in 3D, of kinematic structures, and the generation, in real-time, of its work envelope. Interestingly, the software tools now undergoing refinement also make it possible to work in the opposite direction, by interactively modifying the work envelope in order to refine the kinematic structure.

Some early results were previously reported in [6]. Work is now continuing on the investigation of parallel kinematic structures in order to obtain telemanipulators with improved operational characteristics such as improved dexterity and work envelopes better adapted for working in cluttered environments such as forests.

6.2 Operator training

The third and final theme of the ATREF project concerns the development of a computerized training environment. Since the emphasis is on *training* instead of *computer graphics*, the degree of realism with which we present a forest scene, for example, must be balanced by the available computing power so that the operator's gestures (joystick, hand controller) may be reflected, in real-time, as changes in the behavior of the machine. Early efforts also involved the development of a tool to help trainers interactively define forest scenes (kinds of trees, tree sizes, number, relative positions, etc.). Details associated with this early work will be reported elsewhere [2].

First contacts were made with a training centre in Mont Laurier, north of Montréal, in November 1994, one of just three such centres accredited by the Québec government to provide training to forestry operators. (The other two centres are near Québec City and Hull.) We will continue to seek out their help as potential end-users. And while our development platform is an Indigo-2 model Extreme from Silicon Graphics, we plan to port our efforts to PC-based platforms towards the end of the project.

As part of our visit to Mont Laurier, we were able to carefully observe a variety of novice operators with varying amounts of training (from a few weeks to a few months), and a preliminary ergonomic analysis of forestry machine operation will be reported in [3].

7 Conclusions

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