15th Triennial World Congress, Barcelona, Spain

COMPLEX BEHAVIORS OF TELEOPERATED ROBOTIS

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Abstract: There has been much interest lately in the area of Internet-based control and robotics education. This is needed because the real plants and robots are very expensive to buy. This paper presents a series of experiments in autonomous collective robotics that are taken by students in control engineering and cognitive science. They allow the student to test different control algorithms from a remote location. Moreover, it is now possible to control a team of two robots connected to the same remote computer. Different complex, global behaviors are generated from simple individual behaviors. *Copyright © 2002 IFAC*

Keywords: remote control, telerobotics, education, agents.

1. INTRODUCTION

At a time when control engineering departments worldwide are making larger investments in hardware and software, and are increasingly turning to distance education technology to reach a broader customer base, it is critical to maximize the effectiveness of technology for learning.

Educational technology is at a crossroads in terms of making a true impact in control engineering and robotics education. The main challenge is how to use the advantages of digital communication technologies, and multimedia systems, and how to integrate them with the traditional education.

The aim of this paper is to present a laboratory for automatic control education. Its main idea is to use telepresence as an efficient vehicle for flexible learning. This paper aims to present a new way to implement collective intelligence and presents some experiments with simple human-like behaviors that are implemented on real autonomous robots. The global behavior thus resulted is very complex. The main contribution of this paper is that the robots can be remotely controlled via Internet and serve educational purposes.

The paper is organized as follows. Section 2 gives an overview of a distributed laboratory which uses telepresence as a vehicle for flexible and efficient learning and section 3 describes robotics experiments that implement simple human-like behaviors and serve as introduction to autonomous robotics. Section 4 presents a set of three collective telerobotics experiments based on Java and LabView systems, while section 5 gives some conclusions and directions for further research.

2. TELEPRESENCE IN EDUCATION AND RESEARCH

2.1 *DLAB - a distributed laboratory for control education*

Telepresence means a virtual presence at a remote location that is served by information and communication technologies. The idea is that technology has the potential to improve the increasingly ineffectual model of one-to-many classroom instruction and institutional education. By using a wide range of technologies that can be classified as audio, data, video and virtual environments, a human user can get a sense of being present at that remote location. When multiple users are virtually present at the same remote location one can speak of collective telepresence.

Of course, the Internet is an ideal candidate for telepresence systems and there are already some remote control laboratories in use. In (Vilalta, *et al*., 2001) it is presented a general framework for implementing and deploying remote experimentation solutions. Java and LabView implementations are considered and compared. The application taken into account is the teleoperation of an inverted pendulum which seems to be a favourite application for teleoperation via Internet (Sanchez, *et al*., 2001). However, even industrial pilot plants are being considered as candidates for remote control (Dominguez, *et al*., 2001).

DLAB is a distributed laboratory for remote experimentation and control. DLAB is operational since November 2000 (www.dlab.pub.ro). It hosts a total of six PC-stations and a server, interconnected via a fiber-optic link with the main node of the Romanian Academic *RoEduNet* WAN. DLAB is the first of its kind in Romania and its aim is to be part of a ring of remote experimentation and control teaching laboratories.

The idea behind DLAB is the versatile use of the equipment together with on-line testing of control algorithms written by the students. This led to two different approaches, depending on the effective users: the students that actually use the laboratory during classes or the remote (in sense of other campuses) users that access the experiments via Internet. Of course, DLAB is real in both cases, but in the second case one can speak of a virtual laboratory (from the users' point of view).

Both solutions require multi-user, client-server architectures of the applications and allow complete data management. However, major differences appear when considering the speed, the limitation in bandwidth and, more critical, the multiple computing platforms.

2.2 *DLAB applications*

One set of applications implies remote-accessed instruments, mainly digital multimeters and oscilloscopes for measuring and monitoring purposes, and function generators for test-signal generation.

Two different types of DAQ cards are presently being used, namely the high- performance National Instruments AT-MIO-16, and the Keithley PCI-MIO-16E-4. Students can practically experiment with all typical I/O functions like analogue input (A/D conversion), buffered data acquisition (high-speed A/D conversion), analogue output (D/A conversion), signal generator, digital I/O, counter/timer operations, etc. (Albu, *et al*., 2001a).

They can also practically experiment with a fuzzy-logic micro-controller. For this purpose, an industry-standard, stand-alone FLC, type Kloeckner-Moeller *fuzzy*PLC, Model PS 4-401-MM2, is being used. One of the DLAB devices is a plug-in device, with a simple schematics using relays, which enable the remote students to put in a shut-down mode all devices (such as measurement instruments, fuzzy-PLC systems etc.) connected to the computers network via a digital interface (Albu, *et al*., 2001a).

Most of the applications are developed under LabVIEW™ using a client-server approach and it is intended to add communication and safety control modules realised under Java. LabVIEW™ is used for programming both DAQ card types. LabVIEW™ features interactive graphics, a state-of-the-art user interface, a powerful graphical programming language, and is supported by extensive libraries.

One software module that can be used into the remote-experiments has the shape of a chat window; it allows a fast communication between users, one of them being the class instructor (Albu, *et al*., 2001a). Figure 1 shows the control panel of a function generator that controls a data acquisition board.

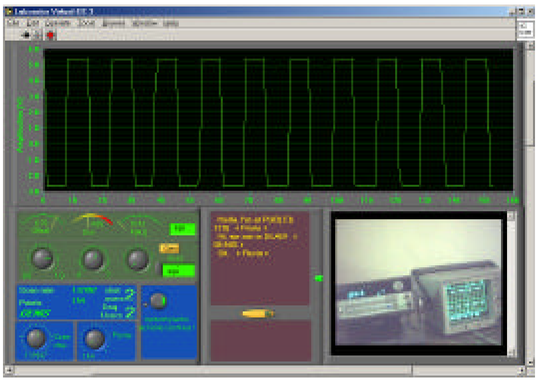

Fig. 1. Panel-window of a multi-user application on Internet

The DAQ digital-to-analogue converters are set to output the waveform corresponding to the settings on this panel. Each application consists into a server virtual instrument (VI) that is continuously running and a client application that can be downloaded from the web page.

The server VI provides the protocol communication via TCP/IP and multi-port access of DAQ board for control applications.

It has to run continuously on the computer that hosts the DAQ-board. This VI shows also the number and main properties of the users that announced their intention to control the application, when login in the specific client application.

3. AUTONOMOUS ROBOTICS EDUCATION. FIRST STEPS

Valentino Braitenberg describes a series of thought experiments in which "vehicles" with simple internal structure behave in unexpectedly complex ways (Braitenberg, 1984). For an introduction to autonomous robotics, DLAB classes are taking into account these vehicles. They are very simple to understand and allow a gentle introduction to the problems related to the control of autonomous robots. DLAB has three Khepera autonomous robots and one Koala robot in use (www.k-team.com).

In his book, Braitenberg describes 14 different thought experiments. Each experiment is a vehicle with known properties. Braitenberg begins with his simplest vehicle, one in which a single sensor is attached to a single motor.

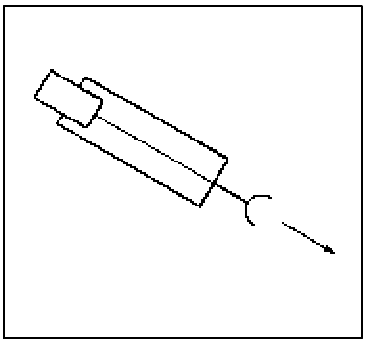

Fig. 2. Basic Braitenberg vehicle (one sensor, one motor)

The sensor controls the motor's activation: the propulsion of the motor is directly proportional to the signal being detected by the sensor; so, the stronger the sensed signal, the faster the motor goes (fig. 2). He then adds multiple motors and multiple sensors, crossing their wires and making some of them inhibitory. Together with simple control mechanisms, this produces vehicles which are still extremely simple, but show fear, aggression, love, affection, and other complex cognitive abilities.

Many people have done work related to Braitenberg vehicles using Java, Lisp and other languages. The authors of this paper have simulated Braitenberg vehicles using ®Matlab and a set of Matlab primitives named k-Matlab developed by Yves Piguet (Copyright (c) 1998/99, K-Team SA).

The following behaviors that are inspired by the Braitenberg vehicles were implemented:

1. aggresive robot: the robot detects obstacles, either static or moving, and moves straightforward to them;
2. loving robot: it “likes” a light source or an obstacle staying close to it;
3. coward robot: it “dislikes” light sources or obstacles and runs away from them;
4. explorer robot: it “likes” the nearby source (or obstacle), but keeps an eye open for other, perhaps stronger sources.

All the behaviors were tested in simulation using the KIKS environment (www.kiks.net) and on a real Khepera robot (Buiu and Pop, 2001).

The simulation of simple Braitenberg vehicles is the first experiment aimed to our students in robotics, and cognitive science as well. It is very simple and attractive giving them a first view of the autonomous robotics field. They understood that even very simple control mechanisms can give rise to complex behaviors that can have analogies with the human behavior and that is quite complicated to guess the control mechanism given the behavior of the vehicle.

The second step was to design a program by which the user can simulate 2 robots. The user can specify a pre-defined behavior for each robot. For example, the first robot could be aggresive, while the second could be coward (in Braitenberg’s terms). So, one can simulate the well known prey-predator problem (or the cat-mouse problem). As at that time DLAB had only one physical robot this second experiment was only simulated but it gave interesting observations and led us to the idea of collective tele robotics.

4. COLLECTIVE TELE-ROBOTICS

Collective intelligence is a property that can be easily found in natural systems. In artificial systems, collective intelligence is a feature which can be shown by collections of autonomous agents (such as autonomous robots) which communicate directly or indirectly (by sharing some common environment) with each other and which collectively solve problems. Bio-inspired collective robotics takes inspirations from natural collective intelligence demonstrated by social insects. It favors decentralized solutions, i.e. solutions where coordination is not taken over by a special unit using private information sources, or concentrating most of the information gathered by the individual robots (Martinoli, *et al*., 1999).

From an educational point of view, collective robotics is very interesting and our many years teaching experience has shown that the students are very sensible to the analogies with the real world. They have an acute need to see that control and robotics field is not an artificial one, but has deep connections with the real world. From this point of view, collective robotics with its natural inspiration sources is very attracting to both teachers and students.

Romanian students in control and robotics have an additional problem. From financial reasons, real-world plants and experiments are very difficult to buy. This is especially true for robots which are quite expensive. This is why the authors of this paper have taken into account the idea of giving the students the possiblity to access a wide range of control experiments from remote locations by using an Internet connection that is easily available in most of the laboratories and even in the students' campus. The students are quite proficient in using the Internet and are very open to understanding basic notions (such as client-server architectures) that are needed in order to remotely access control experiments.

The tele-access to remote experiments and learning environments is drastically reducing the infrastructure requirements of experimental equipment for practical work in training engineers. So, the learning process becomes more flexible and tailored to individual needs. Finally, it is possible to bring items of equipment at different distant locations into the teaching process without having to move them.

The third experiment reported in this paper address the problem of collective robotics from a telepresence point of view which is the main contribution of this research work and of this paper.

First of all, the user has the option to remotely test simple robot commands (turn left, back, forward etc.) (fig. 3). Secondly, the remote user has the option to select from four possible robot behaviors:

1. explorer;
2. agressive;
3. coward;
4. lover.

and to remotely test each behavior (fig. 4). A video window is always displayed on the screen, giving the user an idea of how looks that particular behavior.

The Braitenberg-like control algorithms, which simply relate the motors of the robot to the sensors, are written in Java. This experiment is used by students in robotics and by students in cognitive science, as well.

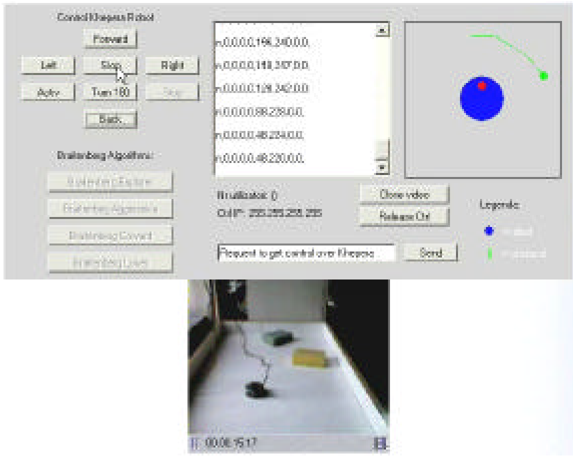

Fig. 3. Simple robot telecommands

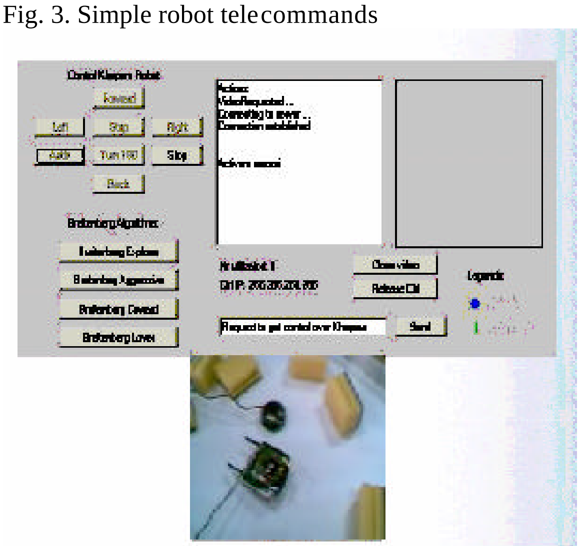

Fig. 4. Braitenberg control algorithms

Two experimental set-ups are possible. In the first one, the teacher takes the control and demonstrates basic robot movements and simple control mechanisms. After that, each student will take the control and will remotely test the system, all the other students having the possibility just to view in a video window that behavior, having no possibility to control the robot. In the second set-up, a group of two students (there are 2 physical robots used) may test a particular behavior for each robot. Each robot is connected to a different computer, but both robots operate in the same environment. So, there is a team of 2 robots with different individual behaviors and the team has a global, complex behavior. Each user is able to perceive the global behavior in its browser's video window.

There's also a supervisor of the whole experiment, that is the teacher that has a global video image of the experiment also and the opportunity to interact with each student by using a chat window.

The fourth experiment moves forward and its main difference from the previous one is that the two robots are connected to the same computer on both serial ports. So, there's only one server and the application is developed in LabVIEW™. LabVIEW™ based applications are very powerful and easier to develop in a graphical oriented environment. A free LabVIEW™ player is available on the net for various platforms and allows the programs to be run on the user's computer.

Fig. 5. A LabVIEW™ client for remotely control two robots

By using this client (fig. 5), one has the possibility to remotely control two robots that are connected to the same computer. One may notice two similar parts, each one being dedicated to a different robot. The user can give different speeds to the motors and also has a graphical, radar-like, representation of the surround obstacles. One can test for each robot a simple obstacle avoidance rule-based algorithm and 4 Braitenberg-like control algorithms (the same as above) having a continuous visual feedback. The system works fine and it is the first remote collective robotics experiment. Now, the student is able to take the experiment in collective robotics whenever and wherever he wants.

The server VI is shown in fig. 6 and one can see how the speeds are displayed, together with sensor information for each robot. The user needs not to know any information about the server. All what he sees is the behavior of the robots and the effect of his commands on the global behavior.

The fifth experiment is dedicated to the same application, i.e. there are two Khepera robots connected to the same computer via the serial ports. Now the client application (fig. 7) gives the user the possibility to control just one robot.

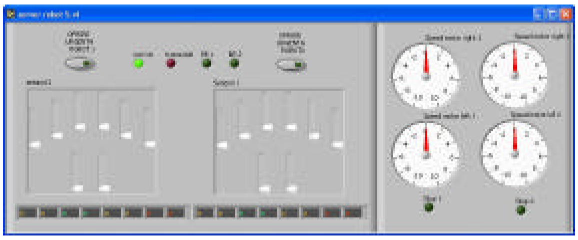

Fig. 6. The server VI

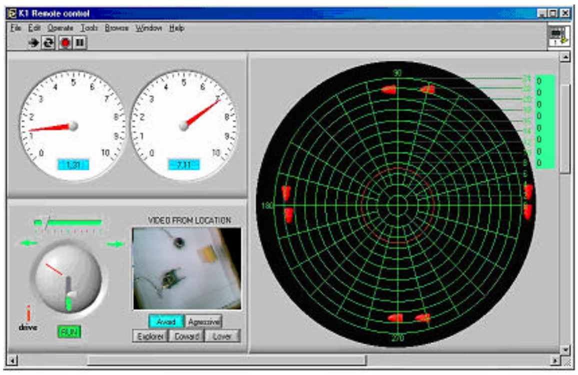

Fig. 7. An one-robot client

Of course, the experiment has to be taken by two students at a time and each student controls a different robot. Each student can see the global behavior that is a result of his and his colleague's actions.

This kind of application is to be used for educational purposes, but can be used for other purposes as well. For example, both users can be given a task to be solved, for example to control the respective robot in order to follow a line marked on the table. This application also opens the way to remote football games. So, it is not needed to organize robot soccer competitions where each one brings his own robot(s). Now the potential competitors have a soccer set-up remotely available, while different teams can connect via Internet and play the game. Of course, the teacher has still the option to supervise the application, i.e. the actions of the students and the movements of the robot. The teacher has the possibility to interact with the student by using a chat window and to stop the experiment when necessary.

All the five experiments described above can have an increased pedagogical impact by using software agents. The first experiments of this kind are described in (Albu, *et al.*, 2001b).

The experiments, as they are conceived and implemented, are used by students in cognitive science as well. They can see that very simple individual behaviors can generate very complex global behaviors. The experiments generate a lot of questions that are interesting from a cognitive science point of view. For example, what about the team? Is it only a collection of individual intelligences or does it have a collective intelligence?

5. CONCLUSIONS AND FURTHER WORK

Difficult economical conditions give rise to new and attractive educational solutions. For students in automatic control and robotics, the tele-access to remote experiments and learning environments will drastically reduce the infrastructure requirements of experimental equipment for practical work in training engineers. The learning process will become more flexible and tailored to individual needs.

Finally, it is possible to bring items of equipment at different distant locations into the teaching process without having to move them.

The main contribution of this paper is that it proposes a series of experiments in autonomous robotics that introduce the student to some of the related problems in an intuitive way. The experiments can be run from distant locations without moving the robots all the time, engaging the students in an easy, intuitive, yet challenging activity.

The paper has also a scientific dimension as it proposes a new possibility to run collective robotics experiments. This opportunity is offered by telepresence by which remote users can control individual autonomous robots working in the same physical area. Telepresence is offering interesting opportunities for further research in collective robotics.

While simple Braitenberg-like control mechanisms can offer the student some basic notions of autonomous robotics, intelligent control methodologies (fuzzy logic, neural networks) combined with some learning mechanisms such as genetic algorithms will give the student the possibility to develop applications for more critical tasks and to remotely test them. This integration of intelligent control techniques is a question of further research.

Security problems related to this kind of remote experiments and access to autonomous robots represent a delicate problem which needs further research. Until now, the remote access to the robots has to be pre-scheduled with the instructor and a more simple and reliable mechanism has to be implemented.

ACKNOWLEDGEMENTS

We acknowledge the financial support of Swiss National Science Foundation (Grant 7RUPJ062223, within the SCOPES framework). CNCSIS financial support (Runda IV, Cod 120) is also acknowledged. We also want to thank Mihaela Albu, Marius Rosca, Marius Magirescu and Stefan Voicu.

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