POINTER: Portable Intelligent Trainer for External Robotics

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ABSTRACT

Intelligent Tutoring Systems (ITSs) play an increasing role in training and education of people with different levels of skill and knowledge. As compared to conventional Computer Based Training (CBT) an ITS provides more tailored instruction by trying to mimic the teaching behaviour of a human instructor as much as possible and is therefore much more flexible.

This paper starts with an introduction to ITSs, followed by the description of an ITS for training of an (astronaut) operator in monitoring and controlling robotic arm procedures. The robotic arm will be used for exchange of equipment between a space station and a space plane involving critical and accurate movements of the robotic arm.

The ITS for this application, called Pointer, is developed by TNO Physics and Electronics Laboratory and is based upon an existing ITS that includes procedural training. Pointer has been developed on a workstation whereas the target platform was a portable computer. Therefore, a lot of attention had to be paid to scaling effects and keeping up with user friendliness of the much smaller user interface. Although the learning domain was the control of a robotic arm, it is clear that use of Intelligent Training Technologies on a portable computer has many other applications (payload operations, operation control rooms, etc.). Training can occur at any time and place in an attractive and cost effective way.

INTRODUCTION

Intelligent Tutoring Systems (ITSs) emerged with the advent of Artificial Intelligence research. Conventional Computer Based Training (CBT) methods were of limited flexibility and had a number of disadvantages: every step in the learning process had to be pre-programmed, domain knowledge was hidden in learning material and initiative was mainly taken by the computer. This often resulted in boring learning material presentation.

An ITS tries to mimic a human instructor as much as possible by combining Artificial Intelligence techniques with Computer Based Training. These techniques enable reasoning on domain knowledge which is the basis for adaption to student behaviour and answering student questions about the learning domain.

In general, ITSs are built according to an architecture that contains five modules: domain expert module, tutorial module, interface module, student model module and control module.

In the late 80s TNO Physics and Electronics Laboratory gained experience with Intelligent Tutoring Systems by developing an ITS for a message handling domain. The good results of this ITS, that includes procedural training, encouraged us to continue research and development in the field of intelligent training technology. Based upon the existing ITS framework for message handling TNO Physics and Electronics Laboratory has now developed an ITS, called Pointer, for the European Space Agency (ESA). The Pointer-project has the objective to investigate the feasibility of an intelligent system for training complex robotics operational procedures.

The uniqueness of Pointer lies in the fact that an existing operational application for operating a robotics arm is combined with (the functionality of) an existing ITS. This feasibility study has made the requirements for robotic training systems explicit.

AN ITS FOR SPACE ROBOTICS

Learning domain: robotic arm

The domain to be addressed for the ITS is the operation and control of an External Robotic Arm (ERA). This manipulator arm is used to provide ESA with a robotic in-orbit space plane servicing capability. It is used for the exchange of supplies or equipment boxes generally called Orbit Replaceable Units (ORUs) between e.g. a space plane resource module and a space station.

The robotic arm, which is still under development, has 7 joints and 6 degrees of freedom. Its length is 9.09 meters and it can manipulate objects from several kilos up to 20 tons with a high accuracy. It is to be operated in a 0-G space environment, either from the inside of the space station (MIR) or in EVA (Extra-Vehicular Activity). Monitoring of arm operations takes place via three cameras that are connected to the arm.

Robotics tasks

ERA is a priori meant to be used for several mission types or even space operation scenarios. In this section we describe the type of robotic tasks foreseen for the MIR2 space station. However, it is evident that the design of ERA has quite a generic value.
The typical tasks foreseen for MIR2 are:

- assembly of truss elements;
- mounting of station bulky elements;
- re-docking of station modules;
- installation/removal of orbit replaceable units (ORUs);
- inspection.

In the MIR scenario, certain tasks such as ORU or payload transfer require the presence of an astronaut in EVA to perform proximity operations such as final placement of objects attached to the robot.

Also in this scenario, ERA's base is installed on a trolley which can move along a truss structure. Strictly speaking, operations of the trolley are not considered part of the ERA operations, although an astronaut would have to learn to operate it.

Operation and control of the robotic arm

To supervise, or perform, the tasks, the operator has two interaction devices depending on his location:

- inside the vehicle, he will use a portable unit, called ERA Portable Brain (EPB);
- outside, in EVA, the astronaut will use a simpler device, called the EVA panel, which is based on the direct view the astronaut has on the operations.

The EPB, in its current implementation, is a portable high-performance workstation which includes:

- a synoptic area for displaying status information and arm movements in a graphical manner;
- commands, acknowledge and stop switches;
- choice of mode, control gains, procedures and graphical views;
- 2 video screens, external to the workstation but attached to it, to display the camera views as seen from the robot.

The EVA panel is a much more simpler device allowing automatic and manual modes with only a numerical display and selection switches.

The tasks of the operator will be:

- in automatic mode, to supervise and acknowledge transitions; eventually hold or stop the robot arm (emergency) while it is following pre-defined procedures;
- in manual mode, to control degrees of freedom, one at a time, but also according to a pre-defined procedure.

The complexity, criticality and required accuracy of the tasks to perform, make high demands upon robotic arm operators. Therefore, training facilities that guarantee the education of personnel that is well-qualified to perform the job, are of essential importance.

Training issues

Based upon the tasks mentioned in the former paragraph, the high level objective of the training is learning to control and monitor a robotic operation through a portable monitoring workstation.

To achieve this objective, both the interactions with the system and the procedures to operate the ERA must be trained. Each procedure is split up in a number of segments. At the end of each segment the operator must perform status checks and use acknowledge functions in order to continue in automatic mode. Errors in the automatic progress must be recognized and if necessary the operator must stop the progress and take corrective actions. These corrective actions often require the ERA to be piloted. Piloting the ERA is a complex activity where the operator must constantly be aware of physical limits (e.g. accuracy and speed), time limits and power consumption limits of the ERA.

In summary, the operator should learn:

- a great variety of foreseen tasks;
- to recognize and deal effectively with non-nominal situations as well;
- to perform an enforced procedure concept;
- all elementary functions, which are the building blocks of all operations;
- operational rules concerning safety procedures, EVA/ERA cooperation, communications with the ground;
- the physical limitations of the arm with respect to kinetic and dynamic behaviour, accuracy, speed, etc.

Constraints. The operator is supported by a number of displays. However, the portable computer poses a number of constraints on the Man Machine Interface:

- because displays can be called up one at a time, the operator should only request these displays and information pages when he really needs them and with a given purpose in mind.
- scarce MMI resources in the EPB impose a certain slowness in the operations;
- since not all MMI information is available at hand, the interaction with the workstation is also part of the operator procedure. Thus training will cover these aspects also.

Motivation for a Portable ITS

The need for an intelligent and portable training system originates in:

- a requirement for self-training and refresher training. In the long duration mission foreseen for MIR2, robotic tasks will have to be relearned by astronauts on their own. Thus the ITS will need to take over parts of the instructor role. In particular, procedural training is addressed here and the need for a student model which allows monitoring of the trainee performance was identified early.
- a requirement for a portable unit because the EPB itself is a portable unit. Thus the attached training system would have to be also portable.

Pointer: the ITS-solution

Because one aspect of the existing ITS was aimed at procedural training and because it has a domain independent framework, this ITS was chosen as the starting point for the robotics application. The same architecture was used, however extended with a simulation and an EPB-application interface.

The tutoring system is composed of three main parts:

1. a simulator of the ERA
2. the EPB application itself connected to the simulator
3. a tutoring environment which includes the EPB application

Two ITS modules, domain expert module and interface module, are described:

Domain Expert module. The expert module consists of a formalized domain knowledge base and an interpretation mechanism to reason about this knowledge. Reasoning occurs when a student asks for support while learning to perform a procedure. The student can ask what the next action is he should perform (forward), ask for a hint what to do next (hint), let the system predict what will happen if he performs a certain action (what if ...), ask to evaluate his behaviour (evaluate) or request why certain actions were wrong (explain). This expert functionality allows the student to take initiative in the learning process himself and

makes the learning process much more flexible.
In the domain expert module, clear separation of domain knowledge and interpretation mechanism has been taken into account. This enables reusability of the interpretation mechanism and easy maintenance of domain knowledge. This is an important benefit as compared to conventional computer based training because updates of the domain only have to be imported in the knowledge base instead of in all hardly traceable places of the courseware that are affected by such an update.

Interface module. The delivery system is a portable workstation with a small screen. It therefore imposes some constraints upon the implementation of the user interface. So, the user interface has to be very efficient.

The solution that was chosen to deal with the small size of the user interface is based on the principle of sliding windows. We created a virtual screen that is exactly twice as large as the display of the portable computer. The left side of the virtual screen holds windows of Pointer, the right side holds windows of ERA Portable Brain. By sliding the pointing device from left to right, the student can switch from learning environment to the application he is learning about. This solution ensures that it is always clear to a student which windows belong to Pointer and which to the EPB.

The Pointer side of the virtual screen contains a button area, an area for lectures, questions, tasks and feedback and an area for pictures and animations. The user interface is user-friendly, intuitive and consequent.

Learning procedures. Procedures are learned in small parts, called topics. The student level determines the size of these parts. For every topic, a short lecture with text, pictures, animations and examples precedes questions that are asked to check if the student is ready to perform a task. While performing a task, the student is supported by expert functionality to deal with uncertainties about how to go on or to satisfy his curiousity. After mastering all parts of a procedure segment, a task is generated to perform this segment. Pointer adapts the learning process to the student level. The student can take initiative, is aware of his progress and feels confident.

Development and delivery environment

The system was developed on a commercially available workstation and is delivered on a portable workstation. Programming language is C, MOTIF is the look and feel and DataViews and X-Designer were used to create the user interfaces.

Further areas of research and development

In this study we have proven the applicability of intelligent tutoring techniques towards procedural training, also taking into account the specific means of interaction of the operator with the robot arm. Further work will concentrate on contingency training, system level training, integration with virtual reality and ground operator training.

CONCLUSION

This paper has focussed on Pointer, an Intelligent Tutoring System for training complex operational procedures. Based upon the positive experiences with a former developed ITS, this teaching technology offered promising results that have been caught up with a new (portable) application for a robotics trainer for space applications. The new ITS is an important resource for establishment of requirements for intelligent robotic training systems.

Although the chosen domain was the robotic arm ERA, it is clear that the use of Intelligent Training Systems on a portable computer has many other applications (e.g. payload operations and operation control rooms), everywhere there is a particular need for refresher training and self training. By using an Intelligent Training System on a portable computer training can occur at any time and place, finally in an attractive and cost effective way.

SESSION SA

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