

Integrated Laboratory Instruction in Robotics

V.V. Illarionov, A.G. Leskov¹, S.M. Leskova, A.V. Shumov, A.M. Zimin
Bauman Moscow State Technical University, Moscow, Russian Federation

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The Remote Access Laboratory for Robotics is designed on the basis of the Hybrid Simulating Testbed (HST) for the International Space Station manipulators. The HST was designed at Bauman University and has successfully operated there for the past few years. The HST serves as a backbone for building simulators to test the principles and algorithms of robotic system remote control, and is also used for training the personnel to support robotic operations in space. At present the HST includes the latest industrial robot of the Kawasaki Company. At the first stage, the interactive training subsystem provides the try-out of the virtual robot control modes via the Internet. The exchange of information is arranged in such a way that laboratory work can be carried out in a remote computer classroom. The next step of training in the interactive mode is the remote control of a real robot.

INTRODUCTION

Bauman University, the oldest technological university of the RF, places great emphasis on the use of modern information and telecommunication technologies, and methods of remote control of sophisticated engineering systems [1]. Working in the frames of the Russian national project 'Education', BMSTU has recently developed the Internet Laboratory 'Robotics' based on the unique Hybrid Simulating Testbed (HST), also designed at the University. Using network access technologies, the Laboratory makes it possible to carry out integrated remote laboratory training both on virtual (computer) models, and real robotic equipment.

A number of reports made at INEER conferences were devoted to the use of information and communication technologies in teaching the fundamentals and specialized issues of robotics. [2][3][4]. As distinct from the common concept of using simple laboratory robots in student training, Bauman University has adopted a concept whereby senior year students are trained on modern sophisticated, and often unique robotic equipment designed for different purpose intellectual systems.

Unlike most papers of similar profile, which are basically devoted to practical training in robotics, we consider theoretical issues as well. Namely, general issues of kinematics, dynamics and control of robot manipulators. The main purpose of the Laboratory is training students majoring in manipulation robotics. Besides, it can be used for training robotic operators and preparing robotic operations, as well as for trying out robotic system components.

THE MATHEMATICAL MODELS AND ROBOTIC EQUIPMENT

The heart of the Laboratory is the Hybrid Simulating Testbed comprising a number of PCs linked into a network, industrial robots, man-machine interface tools, TV systems, sensing tools, and multi-media systems with sound and image transmission via the Internet. The HST is a semi-real complex which allows simulation of practically a full range of robot manipulator operations both virtually (by means of computer models) and physically.

The HST software includes: a real-time system for simulation of robot manipulator kinematics, dynamics and control processes; simulation system for manipulator control algorithms, system for generation and simulation of operation programs (missions, autosequences), registration system for control processes, system for estimation of operator performance, simulation software for safety system operation, man-machine interface control panel simulator.

Robot manipulator simulation procedure includes two stages. At the first stage, on the basis of the data entered by a user, the HST software automatically generates a robot computer model in the form of a system of differential and algebraic equations. At the second stage, this system is solved with numerical methods.

Mathematical models are generated by the simulation core of HST (the Model-server). The actuation mechanism can be formed as a mechanism with open kinematic chain, with unlimited number of links jointed with each other by 5-class kinematic pairs, the links considered to be elastic bodies. The drive models

¹ E-mail: agleskov@rambler.ru

are also generated automatically. Then the models of actuation mechanisms and drives are combined and completed with models of control mechanisms. The resulting models are presented in the normal Cauchy form and then integrated with numerical methods.

The Motion Control Algorithms Software forms the planned trajectories in the form of a sequence of points in the Cartesian or generalized coordinate space of the actuation mechanisms. The three main motion control laws are realized – point-to-point control, speed control and force vector control.

The Mission Simulating Software generates and realizes robot operation scenarios for a certain manipulation (e.g., moving an empty gripper or a gripper with load to a given point in space, etc.). One mission contains a group of motion control commands.

The Safety System Software prevents collisions of robot links with environment objects or other links of actuation mechanisms.

The Man-machine Control Panel Simulator enters motion control commands and gives information on robot state, commands, and motion parameters.

The robot model generation procedures and the procedures of obtaining solutions for generated models are optimized for time reduction. Along with calculating absolute coordinates of actuation mechanisms, the software performs calculation of relative Cartesian coordinates of the objects mounted on the robot base (e.g., survey TV cameras) and the implements attached to actuation mechanisms.

The registration system makes it possible to select, of all the model variables, the ones that are supposed to be sent to HST physical devices or to be received from them, or to be memorized (registered). The system allows calculation of some estimates of the registered variables (mean values, functions, etc.) as well as their storage in numeric or graphic form.

The HST software has an advanced interface that serves to enter into a model the parameters of actuation mechanisms and drives, to select motion control algorithms, to program and simulate missions, to establish relationships between virtual and physical variables, to select variables for registration.

A separate interface is provided for entering the coordinates of external objects and attached implements.

The basic operation mode of the simulation core is real-time simulation, but work in other time-scales is also possible.

The HST includes a modern industrial robot of Kawasaki company (Fig.2). This robot offers a wide dynamic range of mechanical movements.



Fig. 1. Internet Laboratory equipment

Advanced interfaces, a flexible scheme of distributed calculations enable the HST to be used as a multi-functional simulation core for applied simulation systems of different types and purposes.

ORGANIZATION OF REMOTE ACCESS TO MATHEMATICAL MODELS AND EQUIPMENT INTERNET LABORATORY

A comprehensive approach to training (conducting both virtual practical training and practical training with real unique equipment) helps to realize the gradual principle of training “from simple to difficult”. The virtual part of the Internet Laboratory makes it possible to increase the number of users by attracting those who are only interested in mathematical simulation of robot behavior and do not need the remote control of real equipment.

The virtual part of the Internet Laboratory comprises the Web-server and Model-server (Fig.1). The remote control interface is a Windows application which can be downloaded by a user from the Laboratory site after agreeing with the Internet Laboratory administration on the conditions of the remote experiment.

¹ E-mail: agleskov@rambler.ru

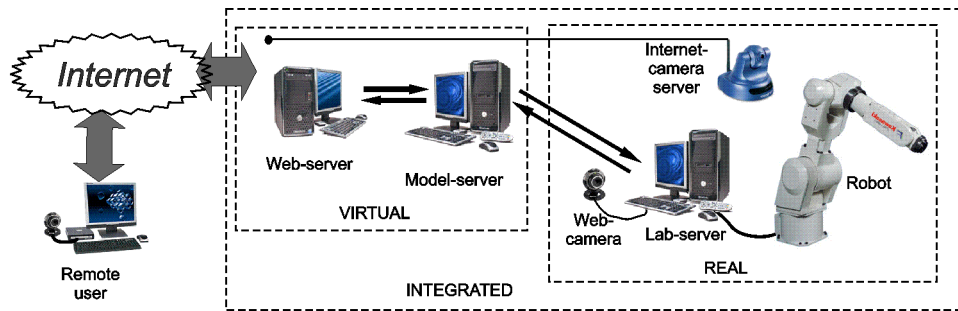


Fig. 2. Flowchart of the Internet Laboratory "Robotics"

At the agreed time a remote user is connected via the Internet to the Laboratory Web-server where he is granted authorization. Then the server sends to the Model-server the sequence of control commands in accordance with the mission generated by the user.

Working with a virtual robot, the Model-server implements the commands set by the user for the robot simulation model, and feeds back the virtual robot state parameters with the frequency of about three times a second. These data received by the Web-server are then transmitted to the user interface via the Internet. The Web-server also determines the Model-server status, and after testing a current command either sends the next command of a mission, or finishes the remote control session.

Working with a real robot, the state parameters of the robot mathematical model are continuously transmitted from the Model-server to the Lab-server controlling the robot. The main task of the Lab-server is moving the Kawasaki robot in accordance with the coordinates and speeds of robot links received from the model, on condition of their feasibility. As we have to deal with highly sophisticated robotic equipment, the main requirement to the remote control system is protection from the scenarios that could damage electronic or mechanical robot systems. Therefore, provision is made for a multi-level system to check the feasibility of control commands at each stage of robot operation. Since the operation system of the control unit has the widest possibilities of robot control, one of the main functions of the Lab-server is automatic cancellation of the remote user commands that could lead to breakage of expensive equipment.

The user remote control interface also provides connection to the Internet Camera Server which displays a video of the robot. A user can move the camera horizontally and vertically, zoom in and out to look at different parts of the robot.

During the remote control session a user can communicate with the robot operator by means of a freeware program Skype installed on the remote user computer. Multi-media components installed on the Lab-server maintain a direct duplex audio and video communication with the robot operator who monitors the user mission implementation.

Method of a remote experiment in control of a virtual robot or real robotic equipment via the global network includes the following main stages:

- familiarization of a remote user with the purpose and peculiarities of the given object, and with the list of subsystems allowing remote adjustment of operation modes;
- detailed study of the subsystems whose operation modes can be changed via the Internet;
- familiarization with the possible operation modes of the subsystems and recommendations on their realization;
- familiarization with the control interfaces of the subsystems, and practicing in using them for changing the settings.
- user testing to assess his knowledge of material;
- sending an application for a remote experiment, e.g. by e-mail, and payment for services if required;
- allocating passwords for entering the control mode, and a time span for the experiment;
- entering the control mode;
- selecting a control scenario from those available on the control server;
- generating a scenario and modes of remote experiment;
- checking the feasibility of the selected modes within the allocated time span;
- sending the scenario to the object server using the appropriate protocols;
- physical connection of the object control server with the control computer at the object location;

¹ E-mail: agleskov@rambler.ru

- transmitting the scenarios and control modes to the control computer;
- launching the scenario and running the remote experiment;
- presenting the results of the experiment on the control server.

THE INTERNET LABORATORY WEBSITE AND CONDUCTING REMOTE PRACTICAL TRAINING

You can enter the Internet Laboratory Website through the 24-hour BMSTU Remote Laboratories Website (<http://lud.bmstu.ru>). The latter also contains the demo-version, whose main pages are given in Russian and in English. A full English version of the site is due in the near future, which will allow conducting experiments from other countries.

Geographically, the Web-server is located at the Dmitrov Branch of BMSTU in the Robotics Laboratory containing the Kawasaki robot which was acquired in the frames of the Education Project. The methodical part of the Internet Laboratory was developed for this robot, with consideration for its further updating and fitting with end effectors for contact operations.

The Server and its Website, as well as the software for robotic equipment remote control have been designed with the use of the 'client-server' technology.

In accordance with the PHP technology, all website pages have a common design and color scheme. The left-hand part of a page contains a three-level menu with instructions. The upper part of a page is invariable, containing the names of the site and the developer, while the central part varies and contains the contents of a corresponding section.

The site gives information on the HST structure, principle of operation, purpose, and each of its units components. There are photos of the main components, their characteristics and functional schemes. All this information helps to get the idea of the equipment, its possibilities, operation peculiarities, possibilities for adaptation to other execution devices, etc. Coordinate systems for control, motion control commands for free space and near basic points, contact operations – are also presented. A separate section is devoted to robot control organization by means of the advanced user interface.

The site provides for user registration so that the latter could get access to different site sections.

As applied to space robot manipulators, the HST allows a user to study kinematics, dynamics and control of robot in zero-gravity conditions, both virtually (on computer models) and physically (on real equipment). That is why, the Internet Laboratory can also be used for training operators for space robot manipulators.

The designed laboratory practical works include three cycles: fundamentals of designing execution systems and robot motion control systems; theoretical fundamentals of robotic system control organization; and practical training in robot operation control. The laboratory practical works are designed for education purposes, and therefore contain methodical sections devoted both to general issues of design and control of different purpose robot manipulators, and to specific applications.

The first cycle involves only the software for mathematical simulation of robotic systems, where not only models are available for change, but also their parameters. This allows students to introduce their own robot parameters, and for these, to calculate the Jacobian matrix elements, inertial coefficients, the external forces and moments with respect to drives axes, the forces and moments acting on robot links and developed by drives during robot motion according to a given law; to build load charts and frequency characteristics of drives; to study the stability of the robot control system, including that with consideration of dynamic interaction of drives; to solve the direct and inverse kinematics problems and make other calculations that are common for robot manipulator design.

The second cycle also involves simulation software, but not only for robot motion but also for missions. Students study robot motion in different control modes, with different man-machine interface tools, in different coordinate systems, etc. The safety system operation is considered. The developed software makes it possible to program autosequences by means of a special-purpose high-level programming language. These autosequences are then sent to and implemented by the real equipment of the HST.

The third cycle allows a user to solve a practical manipulation task by himself, e.g., to move a load from one point of space to another; to orient the gripper in a given point; to place a load. The student chooses a means of information presentation (virtual display, TV camera views), control mode (virtual or real hand controllers), command coordinate system (internal, external). All control processes are registered and available for processing and estimation.

Work in the second and third cycle is performed either without or with the use of the industrial robot (in the latter case the force sensor and technical vision are involved). The robot is switched on only after the

¹ E-mail: agleskov@rambler.ru

student has acquired necessary skills in robot control on virtual models, and only when the safety system is activated.

USER INTERFACE FOR REMOTE CONTROL

The Remote control interface is used both for operating a virtual robot, and the real Kawasaki robot, in the latter case by using the connection scheme described above. The corresponding Windows application generates a multi-window friendly interface (Fig.3). In its upper part there are login and password fields, color indication of connection to the Internet Laboratory Web-server, and the robot status field.

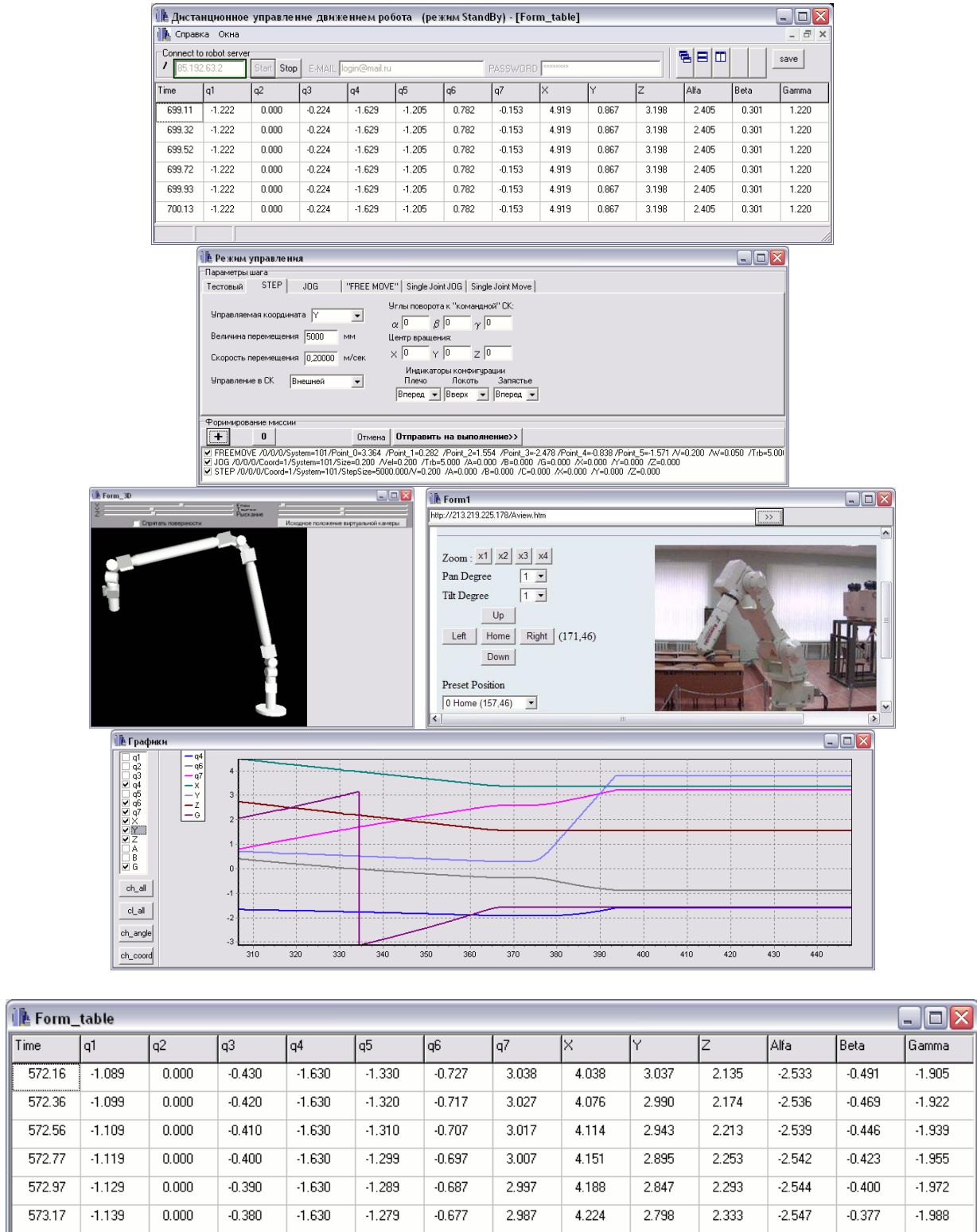


Fig. 3. User interface for remote control of robotic equipment

¹ E-mail: agleskov@rambler.ru

A separate window is used for generating a robot mission from the following basic control commands, for which a user should set necessary parameters:

- moving to the point with the Cartesian coordinates set by a user;
- moving along one of the Cartesian coordinate axes of the gripper for the distance set by a user;
- moving the gripper along one of the six Cartesian coordinate axes with the speed set by a user;
- movement with the set speed in one of the joints;
- moving one of the joints to the position set by a user;
- test mode (sending stepped control impulses to each DOF drive in turn).

After the generated mission is sent to the Web-server, the program starts collecting data on the robot state. These data are presented in the form of a chart, graphs and 3D robot model in the corresponding windows.

When a user operates the real robotic equipment, he can see a dynamic video image of Kawasaki robot in the window for receiving information from the TV camera server. This allows the user to compare the movements of the 3D model and real robot.

The advanced user interface and flexible calculation scheme make it possible to simulate and imitate by means of the available equipment the operation of a wide range of robot manipulators in the normal and abnormal modes. This makes the Internet Laboratory useful for different levels of specialist training both in design and operation of robotic systems.

CONCLUSION

The Internet Laboratory designed at Bauman University allows students to carry out both distributed mathematical simulation, and remote control of different purpose sophisticated robotic systems. A comprehensive approach to training (conducting both virtual practical training and practical training with real unique equipment) helps to realize the gradual principle of training “from simple to difficult”. The virtual part of the Internet Laboratory makes it possible to increase the number of users by attracting those who are only interested in mathematical simulation of robot behavior and do not need the remote control of real equipment.

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¹ E-mail: agleskov@rambler.ru