Virtual Nonlinear Optics:
Real-time Simulations of Laser Experiment

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Abstract

The description of the pilot version of LaserLab CBT in the field of nonlinear optics and laser spectroscopy, based on the real-time simulation of laser experiments, is presented. The core of the system contains simulations of experimental setups for modeling phenomena of the interaction of laser radiation with the matter. Interactive computer models were developed with Asymetrix ToolBook[1] and used a collection of virtual devices and units: laser sources, passive and active optical elements, optical and electrical signal registration devices and converters, etc. The real-time simulation engine of LaserLab incorporating the dynamic mathematical models of the nonlinear optical phenomena and the devices used in the experimental setup, controlled the data flows between units. The units processing the data in accordance with their specific algorithms and properties, realized the visual feedback to the user, reacting to user's manipulations with controls. The virtual experiment development environment provided a special tools for creating new devices, contained reference materials about their operation. The development of the multi-user and multi-language courses management subsystem, with the strong educational content in the field of nonlinear optics and with ability of user's managing and testing and the report generating, was su pposed.

[1] Asymetrix, OpenScript, and ToolBook are regi s-tered trademarks of Asymetrix Learning Systems, Inc.

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1. Introduction

The trends in the up to date learning and especially computer-based training technologies demonstrate a rising role of the interactive computer courseware. The most effective CBT (Computer Based Training) are simulating the object using computer technologies and are creating a learning environment authentic to the target object. Trey are treating the student as an active participant of the training process.

The presented virtual laboratory or *LaserLab* project is a CBT program for the computer modeling of physics phenomenon in the field of nonlinear-optics and laser spectroscopy. The program was developed with Asymetrix (now Click2Learn.com) ToolBook[2] (TB) with original DLL and ActiveX components and operates under Windows 9x/NT.

The current version of LaserLab comprises several sample simulations: - second harmonic generation, - stimulated Raman scattering, parametric generation, and some other. Developed in minimal configuration and continuously growing library of virtual experimental devices, laser sources and optical components makes possible the construction of virtual set-ups of almost any complexity.

2. LaserLab Architecture

LaserLab CBT program has three basic levels of operation (beginning from the topmost):

Courses Manager

The *Courses Manager* provides user with the standard set of services of the traditional CBT courseware, including learners registration, progress tracking, evaluation and testing with report printing features. Through this module user has an access to the conventional learning materials, e.g. task specific manuals either in TB native or PDF format, various audio, video or animation resources and other reference files, that help learner in understanding the nonlinear-optical phenomena and the routes of its experimental investigation.

[2] http://www.asymetrix.com

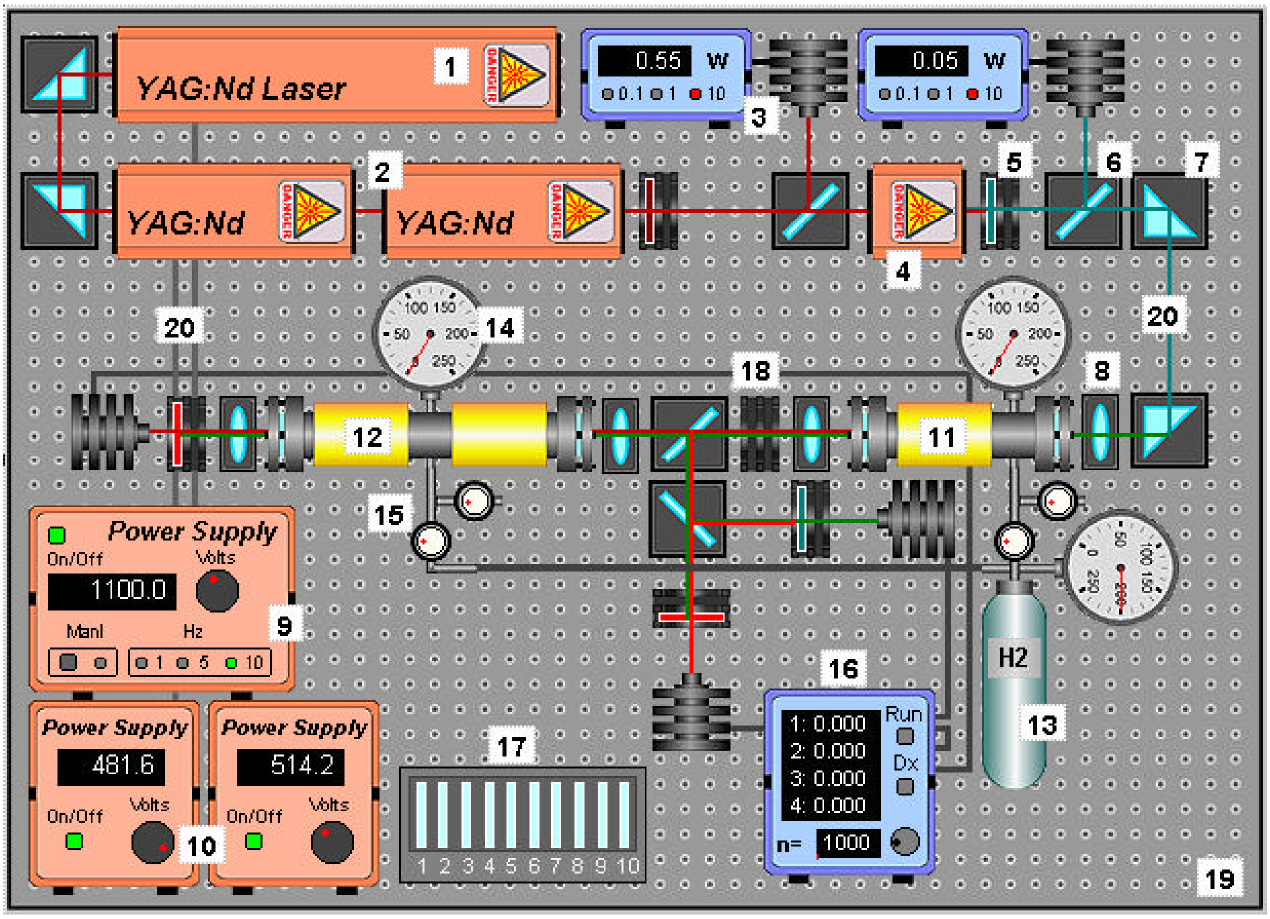

Figure 1 Sample simulation - Stimulated Raman Scattering (SRS) generation in hydr ogen
Shown elements: laser sources YAG:Nd^{3+} laser (1) with amplifiers (2) and pulsed laser power supplies (9,10), frequency doubler (4). Passive optical elements: glass filters (5), beam splitters (6), prisms (7), lenses (8). Registration devices: standard laser radiation power meter (3) and four channel strobed energy meter (16) with the measuring heads. Gas supply subsystem: high pressure optical gas containers (11,12), container with hydrogen (13), gas manometers and feeding valves (14,15). Sup-

We are supposing to develop CBT with a open architecture and ability to link training/simulating modules via the unified interface. By now this part of the project appears to be the less studied and will be completed after developing of the laboratory simulations and learning content.

Virtual Set-Up

The *Virtual Set-Up* or the simulation of the laser set-up is the core of the system. The user through the *Courses Manager* has an access to various sets of CBT simulations in the different areas of nonlinear optics and laser spectroscopy.

The typical view of the *Virtual Set-Up* is presented on the Figure 1- a screen shot of Stimulated Raman Scattering generation experiment. Real-time simulation with rich interface and feedback implies an active participation of the student in the virtual experiment and in the same manner as it could be done using the real devices. The virtual set-up panel provides a friendly interface with the real-time simulation engine of the system.

Real-time Simulation Engine

The real-time simulation engine of LaserLab incorporates program code written in native TB OpenScript language and for time critical procedures uses custom DLLs or even original ActiveX components. Almost 95% of the code relate to the virtual devices, arranged in a kind of a library with the shared scripts. Only 5% of the OpenScript programs are task specific, accounting for the mathematical model of the phenomenon under investigation. Timer triggered simulation code of the LaserLab was processing the information about the current device controls position, their current states and properties, computing experimental object and devices states, usually solving a set of differential equations and displaying results in appropriate format using the displays of digital or analog d evices.

3. Virtual Set-Up

From the developmental point of view the Virtual Set-Up (VS) is a regular TB page with the optical table image at the background (19, Fig.1) and numerous TB objects or groups of objects at foreground, all of them forming a schematic view of laser sources, registration devices, power supplies, etc. sometimes very close to their real appearance. Some of these units represent a bitmap, e.g. lenses (8) or other passive optical elements on Fig. 1, some have rather complex structure and functio nality.

Experimental devices similar to ones, shown on the Figure 1, are presumably a groups of TB objects with a background images. They have a control panel with alpha numeric or analog displays, buttons, switches, etc. through which their operation can be controlled by the user. They also contain special scripts for simulating the operation of the real device.

For the reusability of the code and easiness of future modification of devices simultaneously in all LaserLab simulations the devices were designed from unified control elements and with shared OpenScript codes and graphical resources.

Virtual Device

All of the Virtual Devices (VD) had the unified interface for exchanging data between themselves and simulation engine. VD was controlled also by the Courses Manager by standard TB messages, for example "Reset" command.

Various properties of VD were used for reading or writing information and served as a ports in the data flows. Below are presented a key elements of the VD interface:

- General purpose system messages (Reset, printReport, etc.);
- timer notification messages for the devices operating in the real-time;
- read/write properties, which were accessible "online" and were containing valuable information, that defines the current state of the simulation model: laser pulse energy, angle of the specimen rotation, temperature, etc. These so called dynamical parameters were used then as a variables in mathematical equations, describing both the device and physical phenom enon;
- read only VD properties were serving as a static parameters in the same equations and were accessible only through a special device editor module. A good example of such parameters are a capacitance value of the laser power supply or reflectance (transmittance) constants of beam splitters (6, Fig. 1) – user couldn't change them, but they defined the energy output of the laser;
- *internal* device parameters, e.g. display readouts or accumulating registers of power meters, were not accessible outside the VD, however were used in its script

User Interface

The User Interface (UI) proposed an intensive usage of the mouse and especially its left button. Right button was reserved by the help subsystem and device editor module. A friendly UI of LaserLab was based on the standard TB control objects – buttons, graphic elements, text fields. In the case of the analog input we used a jog shuttle (rotating control) or sliders.

Though all of the VD were digital internally, sometimes instead of digital feedback and appropriate alpha-numeric displays we used their analog modification with analog scales, as it was done with the gas manometer in the stimulated Raman scattering experiment on Fig.1 or with the chart recorder for the experimental data recording (fig. 3).

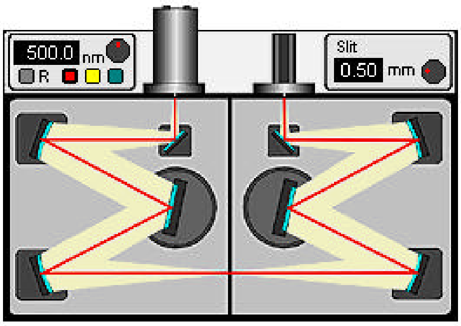

Figure 2 Double monochromator with a photomultiplier tube

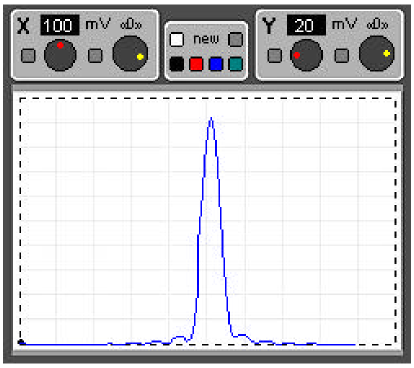

Figure 3 XY Chart Recorder

The other important feature of UI was a drag-and-drop option for changing specimens or attenuating laser beam with the help of a filter set (17, Fig. 1) and filter holder (18). Corresponding filter absorbance constants served as a parameters of the model.

4. Devices Library

The development of LaserLab was started from designing of the basic set experimental equipment and components for the generation and registration of optical and electrical signals. Some of devices from this list are presented on figures 2 and 3. As a result of permanent VD development Devices Library already contains dozens of them with much more to come in the nearest future.

A special equipment was designed for making electrochemical or cryogenic experiments or experiment in the ultra high vacuum. With the laser light/electrical signals switches and specimen manipulation units (Fig. 4) the student had an opportunity to make multiple experiments without modifying a virtual set-up.

Devices Profiles

Once the VD were created, the process of "assembling" of the virtual set-up became a technical issue and did not take much time. For the quick creation of the custom device from a device template we introduced an external profile files with all valuable device information and co nstants.

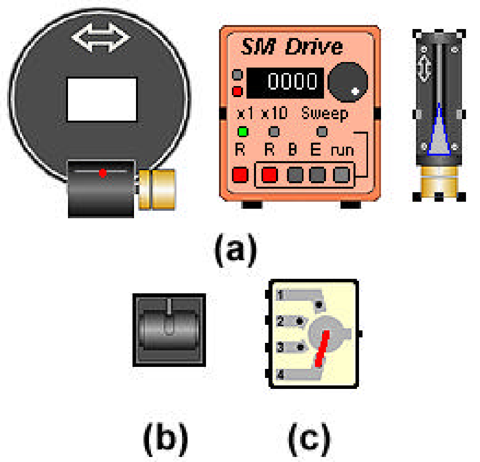

Figure 4 Sample Virtual Devices:
(a) Stepped motor controlled optical rotation table and optical wedge with the motor controller unit,
(b) beam polarizer /analyzer,
(c) four position electrical signal switch.

5. Virtual Instructor

The third virtual component of LaserLab, that we were planning to add in the future, is a Virtual Instructor (VI) module. Being an alternative source of the control commands for the specially designed virtual set-up, VI (Fig. 5) will simulate user's action, accompanying them with step by step instructions [1] and will su pport following modes of operation:

- Let me try – the normal operation of the set-up, which allows student to try on his own to accomplish the task objectives;
- Show me – VI gains full control over the virtual set-up, learner is observing its manipulations with the animated hand like cursor. Computer operating the devices in the same manner as user does accompanies its actions with audio/visual comments.
- Test me – testing and evaluations. VI recording learners action, compares them with the task objectives.
- Guide me – in this mode similar to "test me", VI monitoring the learners actions guides him through a series of instructions.

6. Web deployment

One of the targets of LaserLab project was the creation of version, that could be delivered to the users over the Internet. Running original TB files in the Web can be accomplished with the help of free Neuron plug-in for Internet browsers. Assuming certain limitations of the module size and its functionality, for the Internet deployment we are planning to use a separate modules with simplified UI, each including a single laser experiment.

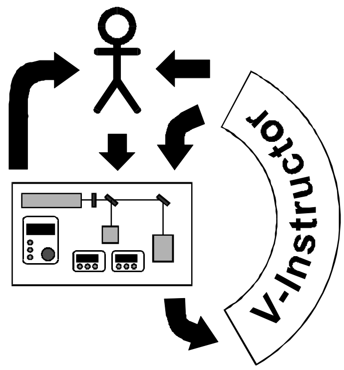

Figure 5 Virtual Instructor module interaction with the learner and the virtual set-up

4. Conclusion

During the development of LaserLab CBT pilot version the following preliminary results were achieved: (1) the CBT architecture was outlined, (2) a library of virtual devices was collected, (3) several real-time simulations of laser experiment were developed. Finally, the successful implementation of the idea of the virtual experimental set-up in the nonlinear optics makes possible its extending to the other areas of physics or even to the other technical sciences.

References

1. Esikov D.A., Sullivan J.L.. «Instructional design for computer-based simulations» *European Simulation Symposium (Erlangen, Germany), 1999.*