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Interactive Virtual Laboratory for Experience with a Smart Bridge Test

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Abstract

Virtual laboratory experiments can be cost effective, convenient instructional resources that have appeal to a wide range of learning styles. Expensive, time-consuming laboratory tests can be experienced repeatedly and remotely using interactive simulations and original video footage or animations. A virtual experiment can incorporate meaningful exercises, procedural options, and background hyperlinks to create a comprehensive "hands on" environment. Also, it may be used as preliminary training for the actual experiment.

An interactive LabVIEW-based laboratory for a load test simulation of an existing demonstration bridge was created. This smart truss bridge is instrumented with fiber optic strain sensors situated on the trusses. The user interface incorporates a synchronized image of the loaded bridge and a graph of the associated strains. A static display mode allows the choice of load placement and of data for single or multiple sensors. A continuous display mode shows the dynamic images of the bridge and strains on truss members. Options include the display of experimental data or of theoretical calculations. Hyperlinks give access to information on the sensors, the bridge construction, and the theoretical analysis. The program interface can also be used in the actual experiment to display data. The intended application is a laboratory for an interdisciplinary class on smart materials and sensors. The LabVIEW program can be easily modified for tests on other structures such as a full-scale bridge.

I.   Introduction

Virtual laboratory experiments are practical and effective educational tools. They may be used to allow students a more comprehensive, flexible experience and to prepare students for actual laboratory performance. The benefits include cost effectiveness and convenience. With a virtual simulation, a procedure can be repeated without cost of materials and labor, wear/damage on equipment, or loss of class time. Also, multiple equipment stations are not needed, lengthy experimental setups are avoided,[1] and one-time or remote field tests are facilitated. With a virtual laboratory, the student users control the pace, frequency, and time of the experiment. Also, distance learners can participate.[2]

Virtual laboratories have been found to be beneficial to students, improving their learning and helping them to understand the coursework. Research at the University of Arizona examined whether "modern simulation and communication technologies enhance delivery, learning and retention" and concluded that they were effective, especially for "difficult" topics.[3] Virtual laboratory experiences can reinforce concepts from lecture material, convey practical issues associated with actual experiments,[1,4] and illustrate applications absent from textbooks.[5] They appeal to different learning preferences through the interactivity of the simulations. Using the Kolb model of learning styles,[6] the student preferring concrete experience and reflective observation will benefit from the repeatability of the experiments. The student preferring concrete experience and active experimentation can adopt a trial-and-error approach to test potential theories and relationships. The student preferring abstract conceptualization and active experimentation can look for expected answers based on the conceptual premises. The student preferring abstract conceptualization and reflective observation can slow the pace of the experiment and explore all available information on the experiment.

This paper describes an interactive, LabVIEW-based resource for a load test simulation of an existing demonstration bridge. This bridge is a small, laboratory-sized truss structure that is instrumented with fiber-optic strain sensors. It is used to demonstrate structural and measurement concepts in an interdisciplinary engineering class on smart materials and sensors. The associated virtual laboratory is designed to display simultaneous images and strain data for complex experimental and theoretical load tests. Features include multiple options for data display and testing parameters as well as detailed supplemental information on the sensors, bridge, and analysis. Consequently, student users can tailor their learning experience per their interest and preferences. Applications of the interactive software are planned for other demonstration and field structures.

II.   The Smart Truss Bridge Project

The smart truss bridge is an instrumented, 2.44-m (8-ft.) structure developed for use in an interdisciplinary course funded by the National Science Foundation.[7,8] The course activities consist of multi-disciplinary topics, collaborative exercises, and hands-on applications.[9] The technical interest area is smart structures[10] which includes the intelligent monitoring of structures using permanent sensing systems and which requires engineering abilities crossing traditional boundaries. The truss bridge provides an introductory laboratory experience that integrates materials, structural analysis, and measurement. However, available time with the bridge is limited. Students with different majors, interests, and preferences can benefit from additional, flexible laboratory experience. A parallel virtual version of the laboratory addresses this need.

The bridge is shown in Figure 1. It consists of two aluminum trusses of four bays each. End supports, internal girders, and decking complete the design. The structure represents a scaled version of common steel highway and railroad bridges and provides an educationally-rich balance of simplicity and complexity.[11] It is easily assembled, can be reconfigured, and provides measurable strains for light loads. The pin-connected members are 1.9-cm (3/4-in.) aluminum equal angles. The 61-cm (2 ft.) deck pieces are independent for each bay and have a track to

guide a weighted cart. The estimated linear capacity of each truss alone exceeds 668 N (150 lbs.). Ideally, the members experience only axial tension or compression. This smart structure has permanent fiber-optic sensors on selected members to measure the axial strain.[7,12]
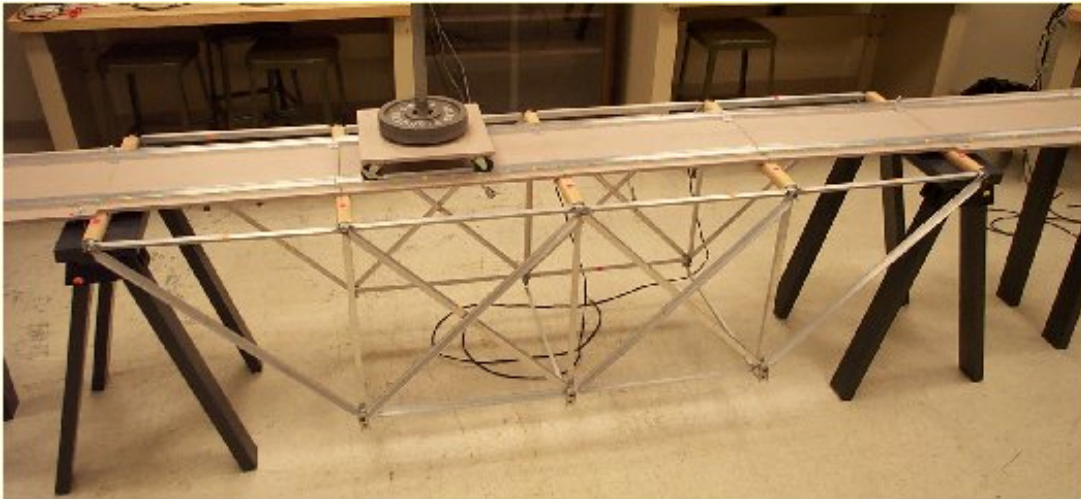

Figure 1: Smart Truss Bridge with Weighted Cart and Aluminum Members.

     The objectives of the laboratory exercises, both actual and virtual, are to show load-induced structural strain patterns and to related practical material, structural, and sensing concepts. The strain in selected members will vary with load magnitude and placement. A pin-and-roller-supported truss model is illustrated in Figure 2 with member designations. The V, H, and D prefixes denote vertical, horizontal, and diagonal orientations, respectively. Sensors provide experimental data for members V1, H2, D3, D4, and H5. To support the experiments, a theoretical analysis using RISA-2D (Rapid Interactive Structural Analysis) modeling software was available.[7,13] For example, the normalized strain pattern in member D3 as a function of load position is plotted in Figure 3. Note that the strain magnitude will be proportional to weight within the linear range. The overall tension and compression characteristics of the truss can be shown graphical as in Figure 4. Experimental data is similar.
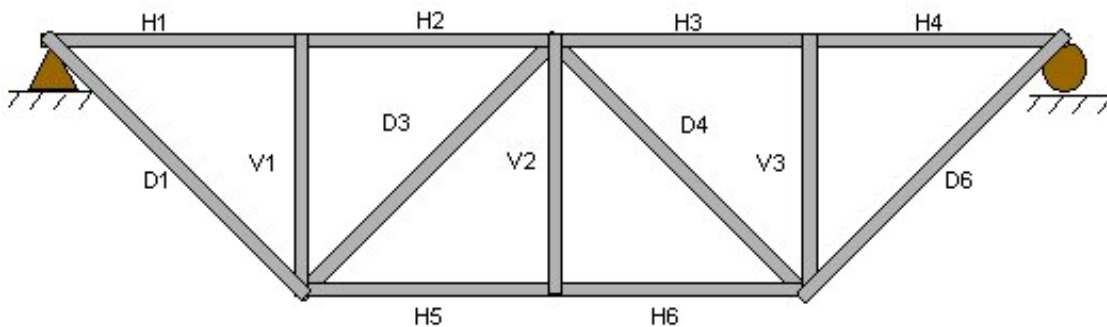

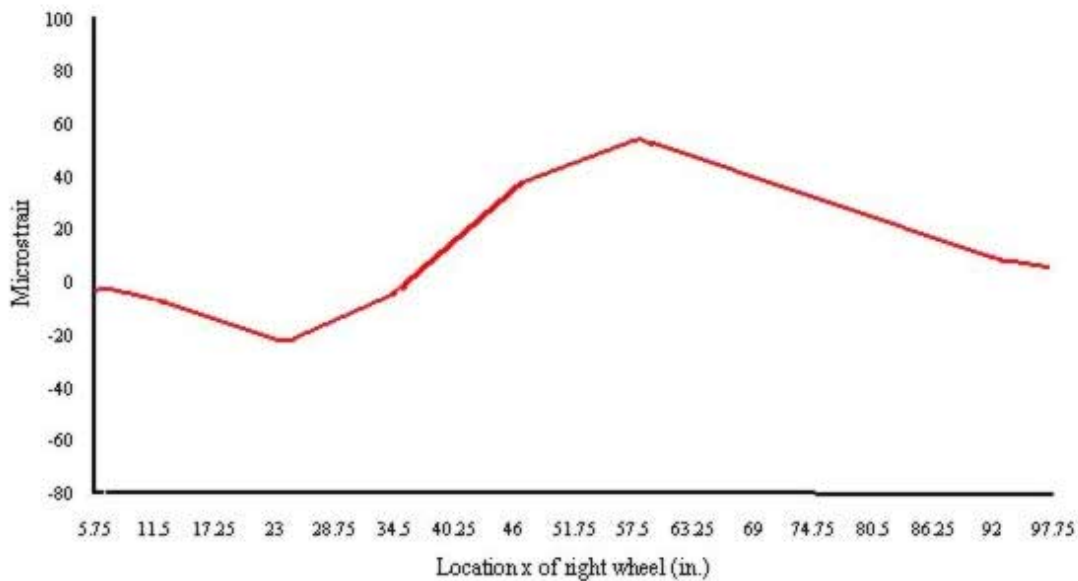Figure 2: Truss Model with Pin-Connected Members and Pin and Roller Supports.[7]

Figure 3: Compressive Strain for 668 N (150 lbs.) verses Load Position for Member D3.[7]
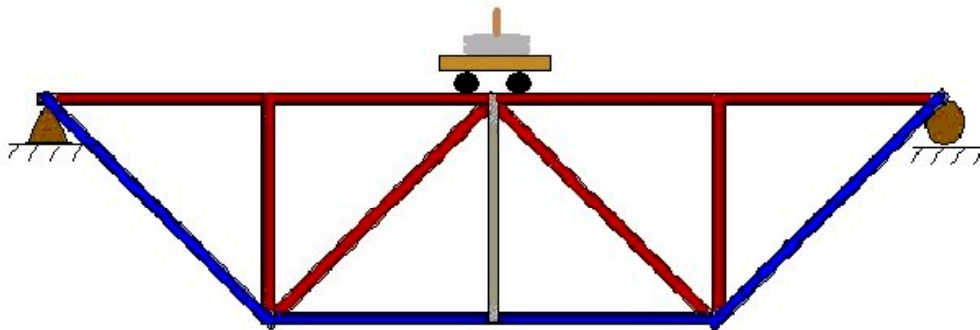

Figure 4: Truss Strain Characteristics for a Centered Load. Red members H1, H2, H3, H4, V1, V3, D3, and D4 are in compression and blue members H5, H6, D1, and D6 are in tension.

III.   Virtual Experiment Design

        The virtual LabVIEW-based experiment presents the experimental or theoretical performance of the smart truss bridge under load. The design was guided by three criteria:

- Simultaneous visual and numerical indicators should be displayed,
- Multiple data and display options should be available, and
- Supplemental information should be readily accessible.

Also, the programming should allow easy modification to incorporate other data and image files. The visual indicator displays a photograph of the bridge with the weight in position or a drawing of the bridge with qualitative graphical aspects such as color-coded characteristics of Figure 4. The numerical indicator plots the strain for a selected member or selected members. The interactivity options are summarized in Table 1. Any combination of the options may be

selected. Note that the visual indicator is coordinated with numerical data, i.e. the weight placement or color coding in the image matches the current display of strain. The simulation was created with LabVIEW which is a graphical programming language with numerous data acquisition, processing, and display features.[14]

Table 1: Features of Interactive Virtual Laboratory

	User Options	
Type	Experimental Test	Theoretical Analysis
Image	Photograph of Bridge	Graphic of Bridge
Measurement	Single Sensor	Multiple Sensors
Load	Stationary	Moving
Information Links	Bridge (Sensors, Design, etc.)	Test/Analysis Details

The user interface for the LabVIEW program is shown in Figure 5. The top screen displays the image output and the bottom shows the graphical output of the strain data. To the right of the graph are the user options. The first set of options is the four load choices. Below the weight options is the choice of data type. The user may choose to display experimental or theoretical data. The last set of options are the five truss members that can be displayed. The user may choose one member or any combination of the five. A small graphic depicting the truss with labeled members is displayed below the truss options to help remind the user what truss is being selected and displayed. The start, stop, clear, quit, and information options are located below the graphic and are Boolean parameters that are built into an array. This array is then sent to a *search function*, testing for a true variable indicating one of the buttons had been pressed. This information is then fed into a *case loop* which then finds the case corresponding to the true Boolean which tells the program which case to run.

A block diagram of the dataflow is shown in Figure 6. The LabVIEW programming in Figure 7 shows the "run" case of the program, which is the section where the data and image files are read and sent to the front panel.[14] The program used for this virtual experiment consists of three major parts – a *while loop*, a *case loop*, and the image and data files. A *while loop* was used to create a programmatic start button. When the run button in LabVIEW is pressed, the program will not run until the start button on the front panel is pressed, allowing the user to make data selections. Once the user has made the appropriate selections the start button can then be pressed and the data is sent to a *case loop*. In the *case loop*, the correct image and data files for the selected options are accessed. In this way, the program would be easily applied to another structure or expanded for more options by simply changing the file names. After the correct strain data folder and image folder are opened that information is then formatted for the corresponding graphical and imagery output. Once formatted the data is sent to the front panel to be displayed. Throughout the process the user has the option to stop the program and display stationary data. If the user stops the data by pressing the stop button on the front panel and then the start button is again pressed, the data is read from where it was before the stop button was pressed. The clear button sends a constant zero to the graph and an empty jpeg image to the image screen.
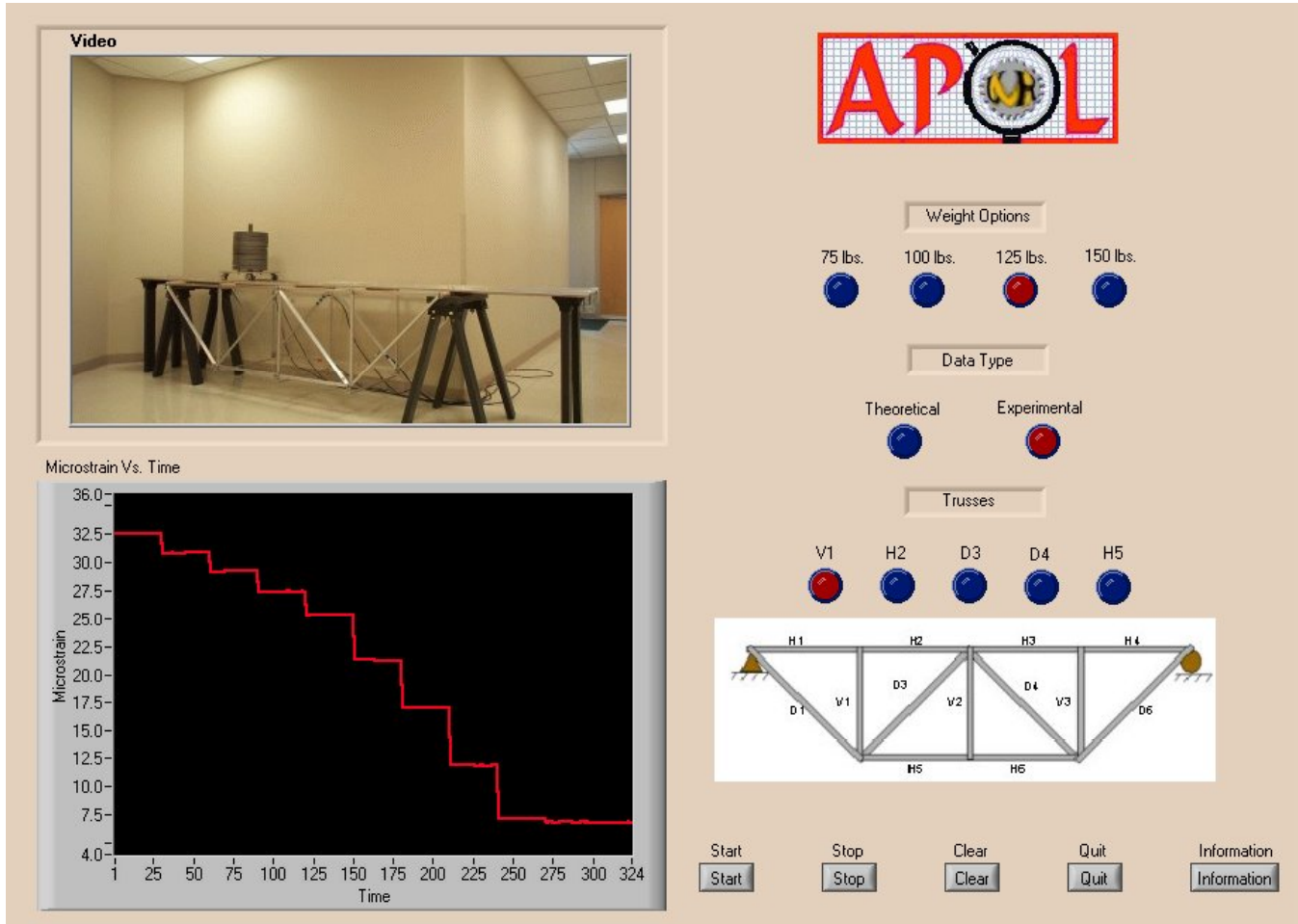
Figure 5: User Interface for Virtual Laboratory.

IV.   Usage and Application

The educational goals for the virtual laboratory are for students to integrate knowledge from several discipline areas and to understand the material, structural, and measurement relationships in a real bridge. The intended parent course is the smart materials and sensors course[8,9] and laboratory audience is interdisciplinary engineering students at the senior-elective undergraduate or introductory graduate level. Fundamental concepts from the interrelated topical areas are illustrated with instrumented truss bridge and a load test. The virtual laboratory may be used as an independent exercise or as a preliminary assignment before testing the actual smart truss bridge.
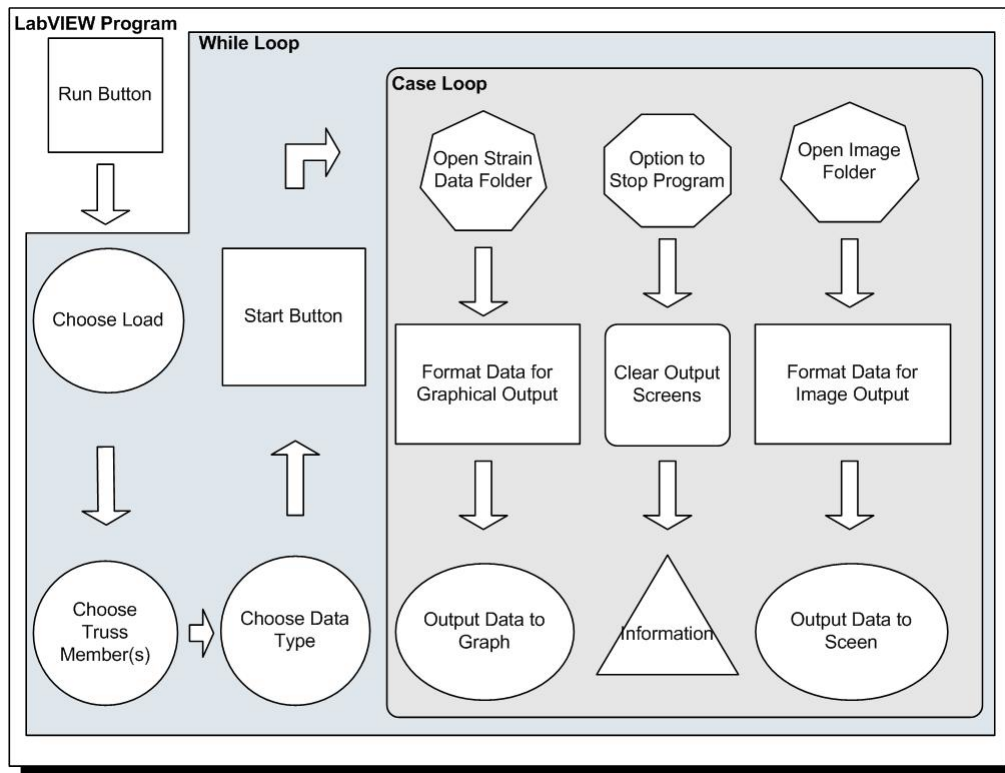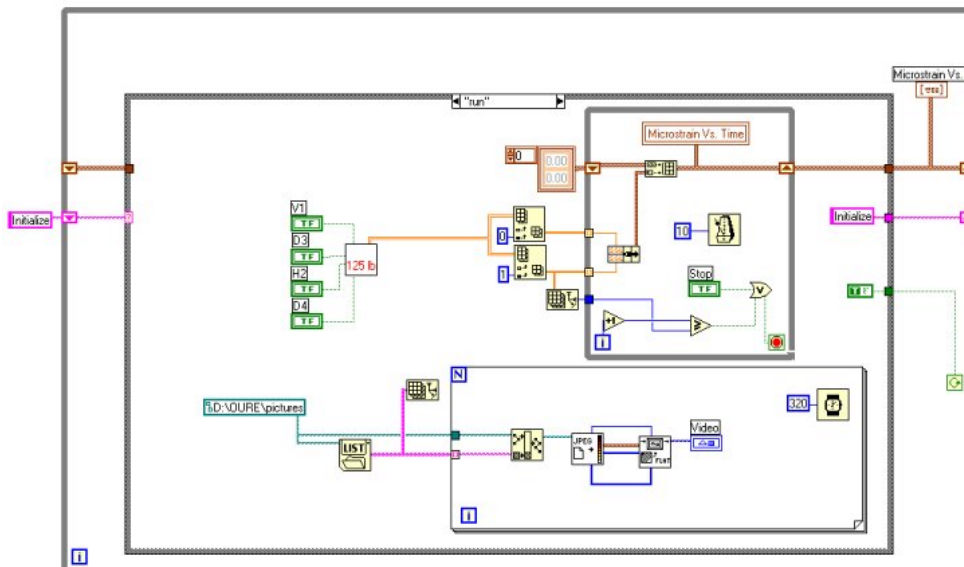
Figure 6: Block Diagram of Data Flow

Figure 7: LabVIEW Programming for "run" Case

The software design model is shown in Figure 8.[15,16] It should incorporate a balance of simplicity and complexity. Users have conflicting needs for consistent and usable content that is easy to understand and navigate and complex features that provide a flexible, user-center learning environment. Consistency and usability are provided by limiting the software module to just the smart truss bridge and by producing similar control buttons, images, and data displays for the experimental and theoretical tests. Other linked information is available, but does not clutter the main user interface. Complex multi-modality features include the simultaneous visual and data displays and the options for experimental and analytical results. Furthermore, significant interactivity and adaptability are provided by the other options for display and supplemental information. Planned companion software for other bridge tests will use a near-identical user interface to reinforce the overall effectiveness.

Assessment of the software is planned and has two stages.[15,17] The first stage is a formative investigation in which a small sampling of students are studied in a controlled environment. The effectiveness of design with regard to consistency, usability, multi-modality, interactivity, and adaptability will be evaluated. The second stage is summative and will be done in the associated course. It will include the Smart Truss Bridge virtual laboratory and companion virtual laboratories based on other archived field tests.
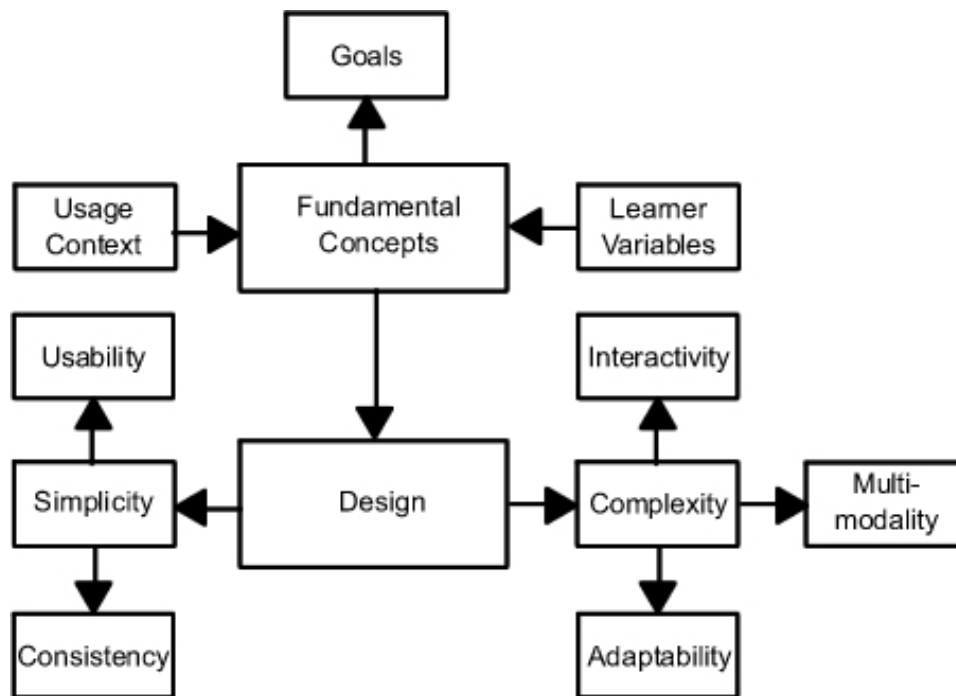

Figure 8: Design Philosophy for Multimedia Software.

V.   Conclusions and Future Work

The LabVIEW-based load-test simulation provides students with an interactive learning resource. It is a virtual laboratory experiment that presents both experimental and theoretical load tests on a laboratory-sized bridge. The smart truss bridge is an aluminum truss structure with fiber optic sensors to measure strain. It provides an introductory laboratory experience in the smart structures area that integrates materials, structural analysis, and measurement. The virtual experiment displays simultaneous images and strain data for complex load tests. Student users can select from a variety of image, display, and information options to create a rich "hands-on" environment. The LabVIEW environment is useful since it can be programmed with a variety of display options and interactivity, can be configured for Web-based access or as executable software, and can access stored image and data files or real-time information.[14]

Virtual laboratories can enhance learning as a supplement or a preparation for laboratory experience. The Smart Truss Bridge virtual simulation provides a comprehensive experience with an archived experiment and a theoretical analysis. The future plans for this project include the incorporation of more background information on the bridge and test, the setup of distance access through the Web site of the associated course, the evaluation and revision of features through student assessment, and the addition of other simulations. In particular, a field test of an instrumented bridge[18] will be setup in a companion simulation.

Acknowledgements

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