Proceedings of DETC'03
ASME2003 Design Engineering Technical Conferences
and Computer and Information in Engineering Conference
Chicago, Illinois, September 2-6, 2003

DETC2003/CIE-48258

THE SMART CAR PROJECT: DEVELOPMENT AND IMPLEMENTATION OF A MODULAR SCALED TEST-BED

Seung kook Jun
Mechanical and Aerospace Engineering
State University of New York at Buffalo
seungjun@acsu.buffalo.edu
WWW: http://mechatronics.eng.buffalo.edu/

Venkat N. Krovi
Mechanical and Aerospace Engineering
State University of New York at Buffalo
vkrovi@eng.buffalo.edu
WWW: http://www.eng.buffalo.edu/~vkrovi

ABSTRACT

In this paper, we investigate the development, implementation and testing of an inexpensive scaled-prototype "Smart Car" test bed. The test bed consists of retrofitting a commercially available Radio-Control (RC) truck with a PC/104 based computer, various embedded sensor- and actuator-subsystems together with multiple modes of communication.

The overall goal of our work is the creation of an inexpensive test-bed capable of operating in real time equipped with a real-time mediated control system to enhance the overall system autonomy and robustness. This test bed enables us to study several concepts including: (i) Mediation of human user control of complex robot systems; (ii) Multi-user shared teleoperation; and (iii) Robustness of the control in the presence of varying grades of communication that are relevant to a number of current and future generations of military/civilian systems

KEYWORDS

Embedded control, mediated operation, Multi-user shared teleoperation, Mobile platform, Wireless internet, XPC, Real time Workshop.

INTRODUCTION

In recent years, many research groups across the world have focused on the issues pertaining to the development and implementation of Intelligent Vehicle Highway Systems (IVHS) of the future. Central to this concept is the development of a "Smart Car" that can act as a (semi-) autonomous intelligent agents capable of: (i) extracting information from the users (drivers/passengers) and the surroundings (vehicle/ highways) via sensors; (ii) exchanging information with central servers and nearby vehicles via the internet and (iii) ultimately altering their behavioral patterns to enhance safety [1][2].

These computer-enhanced operations can range from relatively simple and unobstrusive information augmentation of the driver (night vision or GPS enhanced route-mapping) to failure compensation at various levels (adaptive lane changing, adaptive cruise control systems, adaptive braking). For example, an intelligent sub-system of such a vehicle could estimate a car drivers' intended actions from how the steering wheel is controlled and how the accelerator pedal is pressed, comparing patterns of the control input with pre-stored action models of drivers.

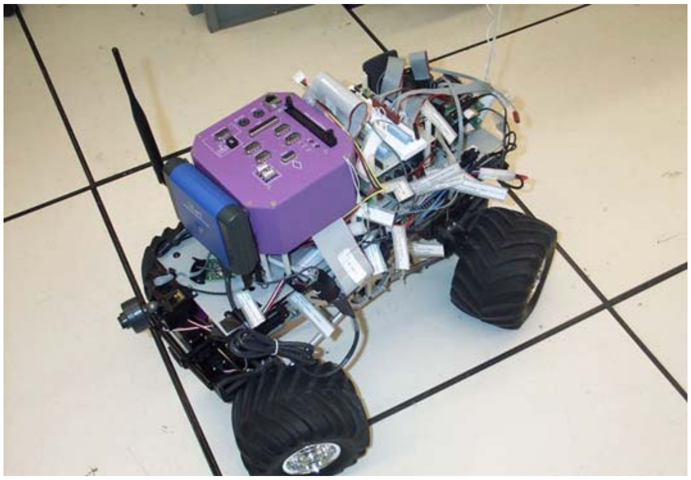

Figure 1: The modular scaled "Smart Car" testbed

Our long term focus is on the development of various intelligent subsystems for a “Smart Car Control System” that continuously gathers a range of inputs from the user, the vehicle and the environment and uses this to mediate the natural driver inputs. While considerable research efforts have been reported, most of these have been carried out either completely in simulation on virtual models or on full-scale models. Each of these has its limitations – the virtual models depend on the fidelity of the simulation while the full-scale models tend to be very expensive to create and operate.

In this paper, we report the development, implementation and testing of an inexpensive scaled-prototype “Smart Car” test bed (shown in Figure 1) to examine many of the issues and test various proposed control schemes experimentally. The test bed consists of retrofitting a commercially available scaled Radio-Control (RC) vehicle with a PC/104 based computer, various embedded sensor- and actuator-subsystems together with multiple modes of communication (Radio Frequency (RF) and IEEE 802.11b wireless Ethernet). Some of the concepts we wish to examine include: (i) mediation of human user control of complex robot systems; (ii) multi-user shared teleoperation; and (iii) robustness of the control in the presence of varying grades of communication.

BACKGROUND

At the highest-level view, the overall system shown in Figure 1 consists of a human operator directing the movement of this remote vehicle via a communication channel. Currently, in many of teleoperated systems, the human-in-the-loop operation typically operates at low bandwidths and is intended primarily for giving high-level instructions to the remote system. A real time control system is often included to permit the remote system to respond to external disturbance and stimuli with minimal delay and to ensure stability (auto pilot, cruise control). While such a partitioning of functionalities (and human-in-the-loop control) can enhance robustness to unexpected disturbances, varying communication bandwidths can introduce variable time delays that can interfere with the effectiveness of the teleoperation. A considerable amount of literature in teleoperation emphasizes the usefulness of “mediated teleoperation” where a virtual environments and predictive display serves as a mediated human-computer interface between the varying time scales of interaction between the human user and the complex machinery [3]-[6]. Our test bed is intended to permit examination of many of these issues.

Hardware-in-the-loop testing

Many of the studies have been carried out either completely in simulation on virtual models or on full-scale hardware prototype frameworks. Simulation-based-design studies, is rapidly gaining importance as the engineering practice of choice to aid rapid product development and shorten the design cycle. However, the usefulness of such a virtual prototyping exercise is limited only by the fidelity of the model and the accuracy of the results. Some of the factors affecting this accuracy include: (a) the modeling skills of the designer; (b) the selection of suitable effects to model; (c) the coupling between various physics phenomena; and most often (d) the availability of computational power. For example, oftentimes, there are many effects such as friction, contact etc. that are very simplistically modeled (for computational efficiency or for the lack of more accurate models) and can only be accurately determined by physical testing. However, there are many effects that need to be physically tested and hence a scaled physical model can provide an inexpensive framework to test (provided scaling effects can be taken into account)

Rapid Control Prototyping

One of the goals in this paper is to also investigate the process of rapid development and implementation of control algorithms and parameter-selection for the overall system. This paradigm shift for rapid development, refinement and implementation of real-time control system design, emphasizes: (a) Development of the control scheme in a user-friendly, graphical, high-level block diagrammatic language (that preserves design intent but permits hierarchical abstraction and encapsulation [7]; (b) Rapid conversion of the refined control system into a form suitable for real-time execution on an embedded controller for Hardware-in-the-Loop Testing [8]. In this project, new commercially available automatic code-generation tools are used to progress from controller design, to simulation, and finally to implementation on embedded hardware. In recent years a number of other authors have also reported successful implementation of this paradigm in other contexts [9].

SYSTEM OVERVIEW

Figure 2 presents an overview of the hardware infrastructure used to implement the SmartCar tested capable of being operated by multiple operators. Each of elements will be discussed in greater detail in subsequent sections.

Hardware overview

Description	Specification
Prometheus PC/104 CPU Module	ZFx86 100 MHz CPU
Flash disk	32MB

module	
Diamond-MM (PC/104)	12-bit A/D, D/A and Digital I/O
PCM-NE2000 (PC/104)	Ethernet controller board, 10Mbps, NE2000
Jupiter-MM	50 Watt PC/104 DC/DC Power Module (PC/104)
Panel I/O board(PC/104)	4 Serial ports, Parallel port, 2 USB ports, Ethernet, Input power
BasicStamp2	
74HC595	8-bit serial-in/serial or parallel out shift register with output latches
74HC165	8-bit parallel-load shift register
Tamiya TXT-1 (Mechanical Platform)	4 wheels driving and 4 wheels steering
Futaba 6YG 6-Channel FM	
Futaba R127DF FM 75MHz receiver	
Linksys BEFW11S4	Wireless Access Point Router with 4-Port Switch
Linksys WET11	Wireless Ethernet Bridge

Table 1: Overview of the commercial off-the-shelf hardware components used in the setup.

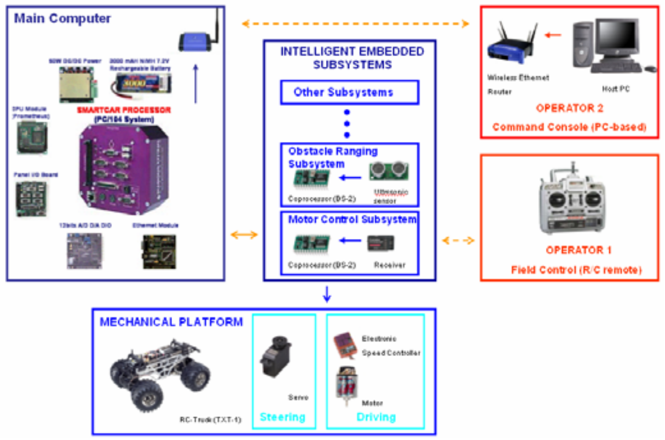

Figure 2: System overview showing the various hardware components and subsystems.

Mechanical Platform:

We chose a 1/10 scale remote control monster truck, the Tamiya TXT-1, as our platform and the handheld transmitter is a six channel Futaba Skyport 6 with dual joysticks. The mechanical platform, TXT-1, is rugged enough for the outdoor and enough to maneuver in tight areas with ability to be easily modified to mount the PC/104 system, embedded subsystems, sensors, actuators and miscellaneous items.

Main processor:

The smart car uses PC/104 system as the primary processor, consisting of a CPU module, and Digital I/O, ethernet, power and I/O interface modules. The selection of a PC/104 form-factor makes the overall system very compact while the selection of an x86 architecture processor enables us to use standardized and commercial off-the-shelf PC-based accessories and software. The main processor communicates with other embedded subsystems through latched digital I/O. An Radio Frequency (RF) based serial communication system and a wireless internet (802.11b) connection enables us to connect the PC/104 system with host PC.

Embedded Actuator/Sensor Subsystems:

In our testbed, the sensing and control load on the main processor is distributed onto multiple intelligent embedded subsystems. While, this offers many benefits including reducing the computation loads on main processor and extending its capabilities, it comes at the price of increased need for communication protocols, greater overhead of coordination and ultimately increased complexity.

The embedded subsystems, shown in Figure 3, consist of: (i) an IR sensor system; (ii) a motor control system; and (iii) receiver subsystem. Three IR sensors detect obstacles and an embedded controller (BS2) continually monitors these sensors and either updates the main processor upon request or in emergencies. The motor control system, an electronic speed controller (ESC) together with an embedded controller, independently drives the actuators based on a downloaded desired high level position/velocity command from the main processor. The receiver subsystem, consisting of the RF receiver interfaced to the embedded controller, receives, decodes and send user-input information as latched digital data to the main processor.

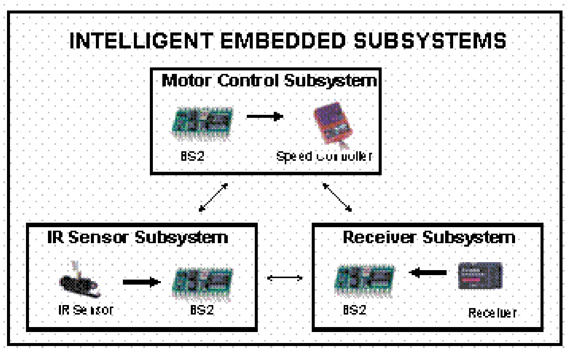

Figure 3: Currently implemented Intelligent Embedded Subsystems

Software Overview

Our approach emphasizes: (a) Development of the models and algorithms in a graphical, high-level block diagrammatic language, Simulink that preserves design intent but permits hierarchical abstraction and encapsulation; and (b) Rapid conversion of the refined algorithms into a real-time executable, using xPC Target for operation on the distributed PC/104 type embedded computers on the SmartCar for hardware-in-the-loop testing with the sensors and actuators. The programs on the dedicated microcontrollers can be updated using wired or wireless RS-232 serial connection.

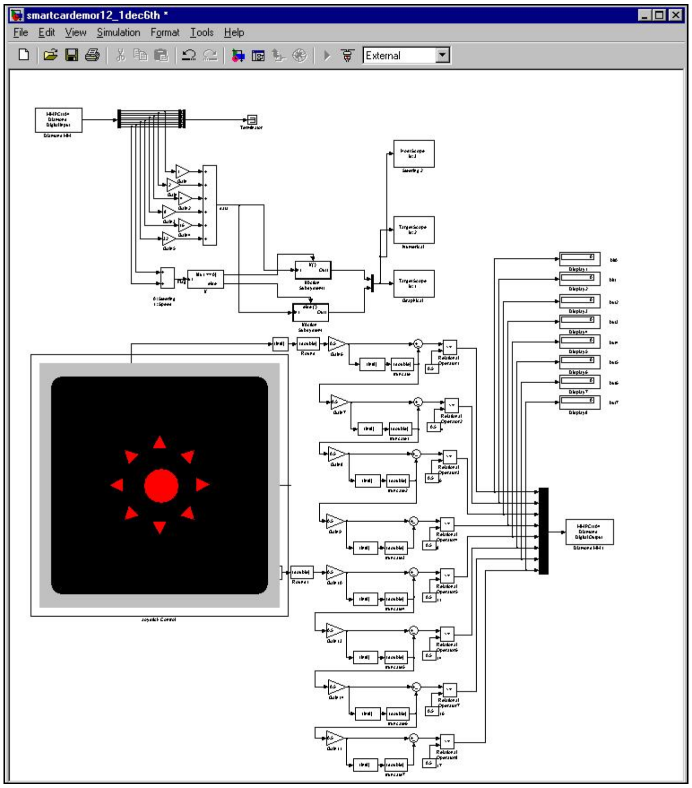

Figure 4: A Simulink block diagram with the virtual joystick.

The ease of development of hardware-in-the-loop simulations play a significant role in speeding up the process of development and testing of not only the control algorithms but also of future generations of the overall electromechanical systems and subsystems.

System Operation

In a user-determined hierarchical decomposition of tasks between main processor (PC/104) and embedded sub-processors, both main processor and the processor of subsystem can work independently. The decision to adopt this hierarchical decomposition was made primarily to reduce the burden of main processor by offloading some of the time-intensive but computationally simple tasks to the embedded subsystems (e.g. the task of keeping the servos alive or reading the inputs from the IR sensors). The multiple processors in this system operate independently but share data and synchronization information via latched digital I/O.

A number of behaviors/virtual fixtures were implemented and in the current form, they interact by a simple superposition scheme. For example, a local closed loop maintains the forward speed based on a reference input. A second controller implements a stopping behavior (with speed-sensitive threshold distances) to stop the vehicle when it comes close to an obstacle. A third behavioral controller compares the obstacle distances from the two walls to ensure a passage following behavior. This function can be used to take burden from operator. When operator controls multiple robots at a time, it is very useful in giving partial autonomy to the robots.

ALTERNATIVE CONFIGURATIONS

Figure 5 shows the traditional configuration of a remote-controlled RC platform where the wirelessly transmitted Pulse Width Coded Modulated (PWCM) signal is decoded by the receivers and passed on to the electronic speed controller which derives the various motors.

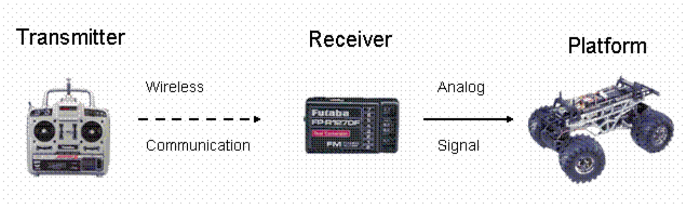

Figure 5: Standard configuration for operation of a commercial-off-the-shelf RC system

With the configuration shown in Figure 5, the operator has direct control over the mobile platform which means that the success of a task depends completely on the operator's skill. We examined various ways in which this standard configuration could be enhanced as discussed further in the three case studies below.

Case Study 1: Mediation of human user control

Figure 6 demonstrates the first stage of mediation of the human user control. The receiver subsystem (discussed in the previous section) is now responsible for receiving and decoding the Pulse Width Coded Modulated (PWCM) data stream and making this information is available as latched digital data to the motor control subsystem. This latched digital data exchange between the two subsystems takes the place of the direct analog connection between the receiver and platform seen in Figure 6.

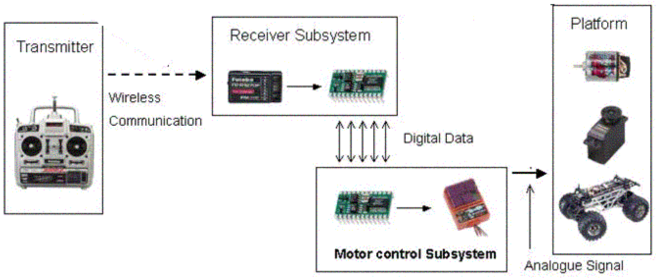

Figure 6: Digital transformation of the input signal between the transmitter and destination.

The availability of the information content in digital form is the biggest advantage offered by this framework which more than offsets the complexity introduced into overall system by this approach. In particular, in this digital form it is very easy to transform and manipulate the digital data between A/D and D/A interfaces. At the most basic level, the input signal can be output directly to the actuators without any alteration (there by emulating the original system shown in Figure 5)

However, a wide variety of linear/nonlinear, continuous/discrete transformations can also be applied on the input data, there by creating a wide variety of functional input-output (I/O) relationships. Furthermore, these I/O relationships need not be static – they may be dynamically altered based on sensory input or by human intervention. For example, by enhancing the overall configuration to include a sensor subsystem as shown in Figure 7, if it is possible to mediate the user-input based upon sensor data. Specifically, two variants have been implemented. In the first variant, the drive input to the motor is scaled based on distance measurements obtained from the IR ranging subsystem while in the second variant a speed-sensitive user-input /motor output and scaling based on the wheel-encoder measurements was implemented.

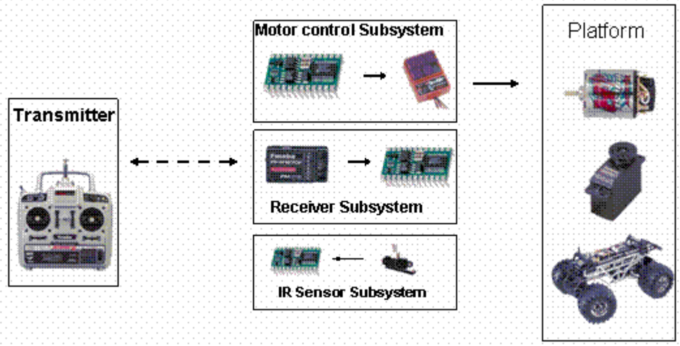

Figure 7: A sensor-subsystem allows a sensor-mediated input-output functional mapping

Therefore, such configurations can tremendously assist the operator by sensing the environment, avoiding obstacles and preventing dangerous/harmful user-commands from being encountered by the system.

Case Study 2: Multi-User Mediated Operation

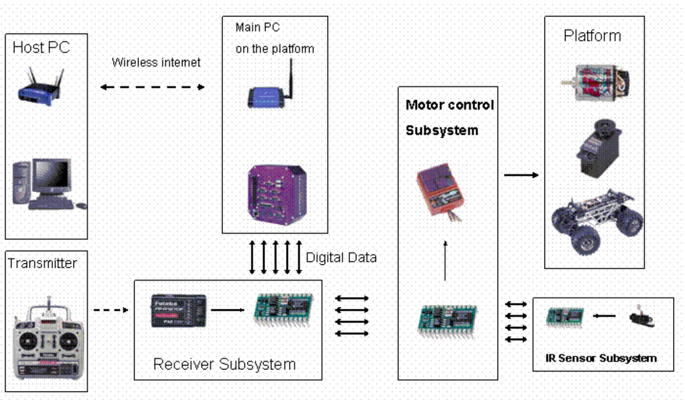

Figure 8: Two alternative pathways for shared control of the common mobile platform.

Two alternate path ways for shared control of the testbed platform are shown in Figure 8. The first operator can control the overall system using the handheld remote control unit with the inclusion of mediation. As discussed in the previous case study, this mediation can occur at two stages – in the receiver subsystem or in the motor control subsystem. The second pathway is currently implemented using the PC/104 system mounted on the mobile platform and connected to the internet via wireless internet (802.11b). The second operator sitting at the console of a host computer can now control this overall system by manipulating a virtual joystick.

This configuration therefore allows multi-operator control of the testbed and currently we use a discrete switch between operators. In either case, the operators regulate the speed and direction of the vehicle from a distance and their control inputs are prone to the various time delays and errors introduced by the transmission medium. The vehicle's onboard real-time control system therefore plays a critical role in ensuring overall system stability. Currently while we use a discrete switch between operators, we are investigating the use of varying levels of shared control in this system.

Case Study 3: Varying grades of communication.

As shown in the Figure 9, the framework can be easily altered to permit to the connection of the host PC system to the embedded PC/104 system using a variety of communication channels. This enables us to very easily study the effects of varying rates of communication redundancy in communication and incorporation of mechanism for graceful degradation of the operation in the absence of communication.

In this scenario, the mediation of the user's input can now occurs at three stages – at the host computer level, at the main PC/104 level or at the embedded motor control subsystem level. There by permitting this ability to distribute the implementation of the mediation and in particular to create redundant levels of mediation is very useful from the view point of enhancing robustness and permitting graceful degradation especially in the presence of communication breakdown, signal disturbance or other error especially for mission-critical or safety-critical applications.

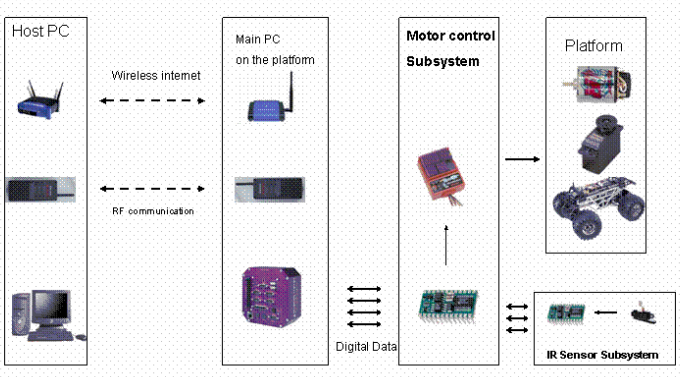

Figure 9: Redundant communication pathways for shared control of the common mobile platform.

DISCUSSION

The proposed system will allow us to test a variety of issues that are relevant to a number of current and future generations of military as well as civilian systems, including distributed command and control algorithms, multi network communications, human computer interface and high confidence software for distributed computation.

In general, this framework is also very well suited for control of multiple semi-autonomous mobile agents in the field by a single operator giving relatively high-level commands, taking advantage of the partial autonomy of the individual controllers.

In the intelligent vehicle system domain, mediation can be used to modify the driver's responses in X-by-wire (brake-by-wire, accelerate-by-wire and steer-by-wire) systems. For example, these different inputs can be modified to avoid obstacles that are detected by the on- board suite of sensors.

This test bed can also serve as a useful testing ground initially for studying HCI issues in individual drive-by-wire systems or for examining issues related to "Ground Traffic Control" in an Intelligent Vehicle Highway System.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support for the first author by the New York State Center for Engineering Design and Industrial Innovation (NYSCEDII).

REFERENCES

[1] N. Bourbakis and M. Findler, "Smart Car as Autonomous Intelligent Agents," 13th IEEE International Conference on Tools with Artificial Intelligence, Dallas, Texas USA, Nov. 7-9 2001.

[2] S. Tsugawa, T. Saito and A.Hosaka, "Super Smart Vehicle System: AVCS related systems for the future," IEEE Symposium. IV-92, pp. 132–138, Detroit, MI, June 1992.

[3] R. Paul, J. Funda, and T. Lindsay. "Teleprogramming Toward delay-invariant remote manipulation." Presence,vol. 1, No. 1, 1992.

[4] Craig Sayers. "Remote Control Robotics." New York: Springer Verlag, 1998.

[5] T. Sheridan. "Telerobotics, Automation, and Human Supervisory Control." Cambridge: MIT Press, 1992.

[6] J. Vertut and P. Coiffet. "Robot Technology." vol. 3: Teleoperations and Robotics. Prentice-Hall, 1986

[7] Mathworks Inc. "Simulink User Manual" Natick, MA. 2001.

[8] Mathworks Inc. "xPCTarget User Manual," xPCTarget, Natick, MA. 2001

[9] K. Rahnamai and S. Northrup, "Fan and Plate Apparatus for Illustrating Stability Concepts Using Xpc Rapid-prototyping Environment," ASME Design Engineering Technical Conferences and Computers in Engineering Conference, Montreal, Canada, Sep.29 - October 2, 2002.