Bringing Control to Students and Teachers

The IEEE Control Systems Society's (CSS's) Technical Committee on Control Education strives to bring control system concepts and technologies to the awareness of high school and middle school students and teachers. Control is used in many common devices and systems, such as computer hard drives, VCRs, automobiles, and aircraft but is usually hidden from view. The goal of this committee is to promote an increased awareness among students and teachers of the importance and cross-disciplinary nature of control and systems technology.

To help meet these objectives, a workshop was held at the 42nd IEEE Conference on Decision and Control (CDC 2003) in Maui, Hawaii, on Tuesday, 9 December 2003. About 250 students from the Maui School District, which spans the islands of Maui, Lanai, and Molokai, attended this workshop, escorted by their teachers. In addition, teachers who had attended earlier workshops came from as far away as Florida to participate. Because of space limitations, several hundred additional students had to be turned away from this extraordinary field trip.

Bozenna Pasik-Duncan, chair of the Technical Committee on Control Education and CDC 2003's chair for Control Education Activities, organized the workshop with sponsorship from CDC 2003 and funding from the National Science Foundation (NSF) and the University of Kansas. Dr. Kishan Baheti, program director in NSF's Division of Electrical and Communications Systems, provided the NSF funding. The Technical Committee on Control Education has organized similar workshops at a number of earlier conferences. Workshops for high school teachers were held at the American Control Conferences in Chicago (2000) and Denver (2003). A workshop for high school students was held at the 41st IEEE Conference on Decision and Control in Las Vegas, Nevada, in December 2002.

Control system experts from our technical community were recruited to present at the workshop based on their willingness and ability to present control topics at an appropriate level for secondary school students. These experts sought to describe control and system technology ideas to the students and teachers and to expose them to control applications and research. Workshop presenters included Raffaello D'Andrea of Cornell University, Christos Cassandras of Boston University, Theodore Djaferis of the University of Massachusetts, Richard Murray of the California Institute of Technology, Mark Spong of the University of Illinois, and Katsuhisa Furuta of the Tokyo Denki University. In addition, Brian Rosen of Pixar Animation Studios, Kishan Baheti of the National Science Foundation, Shane Haas of AlphaSimplex Group, and Suzanne Lenhart of the University of Tennessee presented related dynamic system, nanoscale system, and probability topics.

The workshop began with welcomes from dignitaries from the NSF, the CSS, and CDC 2003. These included Vasundara Varadan, NSF division director for Electrical and Communications Systems; CSS President Cheryl

Students attending the NSF Workshop for Middle School and High School Students and Teachers held at the CDC 2003, Maui, Hawaii. Around 250 students from the Maui School District attended an all-day workshop on control systems.

(From left) 2003 IEEE CSS Vice President for Technical Activities Miroslav Krstic, 2003 IEEE CSS President Cheryl Schrader, IEEE CSS Technical Committee on Control Education and CDC 2003 Education Activities Chair Bozenna Pasik-Duncan, and NSF Program Director Kishan Baheti. Dignitaries from the IEEE Control Systems Society, the 2003 IEEE CDC, and the USA National Science Foundation welcomed the student participants.

Schrader; and CDC 2003 General Chair Frank Lewis. Technical Committee Chair Bozenna Pasik-Duncan opened the workshop.

During the day, the students and teachers learned about the power of feedback, the joys and perils of automation, soccer-playing robots, and an autonomous vehicle race. They also heard about how animation and lighting of characters is done for movies, the control of inverted pendula, embedded systems, careers in mechatronics, the new field of nanotechnology, and the importance of information in the financial markets. The students played a game, developed for the high school level, that demonstrates the nontransitivity of probabilistic phenomena.

The NSF offers support to those researchers who want to involve K–12 teachers in their funded research or to assist in the development of suitable materials for K–12 classrooms. Kishan shared information about the NSF Research Experiences for Teachers program with the audience, which supports the involvement of a teacher in funded research. The Technical Committee on Control Education also plans to assist in the development of appropriate materials so that students who are unable to attend a workshop such as this one can still be exposed to these topics. With the appropriate lesson materials—and the appropriate exposure themselves—teachers will be able to bring these topics into their regular classes.

The Power of Feedback

Ted Djaferis gave several examples illustrating the use of feedback, including walking, the outrigger canoe, body temperature regulation, and collision avoidance in automobiles.

When walking, we use our eyes to sense our position and observe our environment. We continuously monitor our position and compare it to our desired trajectory. We adjust our steps to move closer to our desired trajectory and avoid obstacles in our way. Taking our current sensed position and using this information to plan our future steps is referred to as a *feedback strategy*. Consider how difficult it is for blind people to walk because of the absence of feedback. A walking stick is used to partially replace feedback capabilities.

The temperature in the human body is regulated naturally. Whether we are in the sun or in an air-conditioned room, our body temperature stays close to our normal temperature. This normal temperature may vary from one person to another or from one time in our biological cycle to another, but it varies relatively little in response to changes in our external environment.

An example of feedback that is local to Hawaii is the outrigger canoe. The outrigger canoe made travel across the Pacific Ocean possible in ancient times. Ted previewed this example and announced that Danny Abramovitch would discuss this topic in a plenary talk the next day.

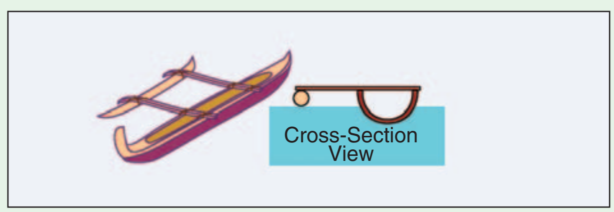
When we drive, we avoid collisions by driving at a safe

Outrigger
The Feedback Mechanism that Allowed the Polynesians to Colonize the Pacific

During a history session at CDC 2003, Danny Abramovitch presented a plenary paper showing that the outrigger on an outrigger canoe may in fact be the world's oldest feedback mechanism. The Polynesian migration to the Pacific dates back about 3,500 years ago

Modern outrigger canoe riding a wave, with the outrigger shown in the foreground. This ancient technology is still widely used.

and would have been impossible in dugout canoes without outriggers. Thus, the outrigger was one of the technologies that enabled the Polynesians to colonize the Pacific. At its most basic level, an outrigger consists of a float attached by means of one or more booms to the gunwales (top edge) of a boat. While modern outriggers can be made from a variety of sturdy, buoyant materials, the outrigger float has traditionally been a piece of light wood. Qualitatively, the



Drawings of a Hawaiian-style single outrigger canoe. On the left is a typical view of the canoe. On the right is a cross section showing how the outrigger improves the righting moment of the canoe. The single outrigger design is far easier to manufacture than a double-hull canoe, which requires matching tree trunks.

operation of the outrigger is rather simple. When the canoe rotates so as to raise the float from the water, its weight at the end of a boom provides torque to rotate the float back to the surface. When the rotation of the canoe acts to push the float into the water, buoyancy acts to restore the float to the surface of the water. Thus, the outrigger dramatically increases the roll stability of small canoes.

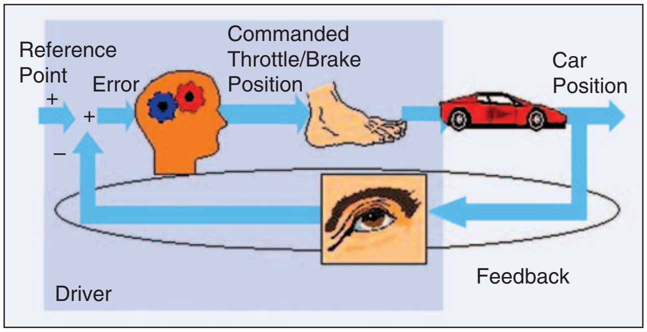


Figure 1. *Representation of how a driver uses feedback to follow other cars at a safe distance. Our eyes sense the distance between our car and the one ahead, our brain determines whether we must speed up or slow down to match the desired distance, and our foot actuates the car speed so that we drive at the desired distance.*

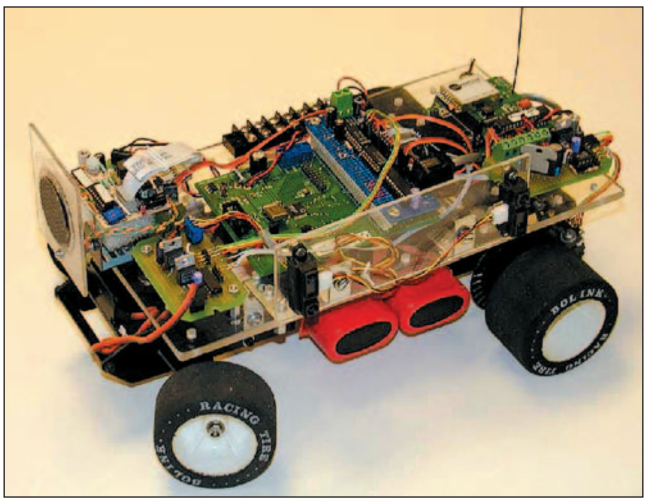


Figure 2. *Computer intelligent model car (CIMCAR) with servo motor and batteries. CIMCAR's speed is controlled by the current to the motor. Using a sonar sensor for its "eye" and a microprocessor for its "brain," the CIMCAR can be controlled so that it stops before hitting a wall, even if it is going up or down a ramp.*

distance from other cars. To achieve this goal, we must monitor the distance and modify our actions depending on what we sense. If we wish to drive 30 feet behind another vehicle, then we must look to see if we are closer or farther than that distance and adjust our position accordingly. A functional diagram of how this adjustment is accomplished by the typical driver is shown in Figure 1. Luxury cars such as Mercedes or Lexus models have systems that automate this process by employing a vehicle radar system that either warns the driver or applies partial braking.

Ted shared a photo and video of the computer intelligent model car (CIMCAR), a small model car operated by a servo motor, powered by batteries, with its speed controlled by the current to the motor; an example is shown in Figure 2. Without feedback, the car can be made to stop at the right place before a wall if it is on a level surface by turning the motor on and off at the appropriate precomputed times. However, if the car is then placed on a ramp sloping down and uses the same precomputed on-off times, it slams into the wall. If the distance between the car and the wall is measured (by a sonar sensor) and that information is used to determine how to control the motor (feedback), the car again can be made to stop at the desired distance away from the wall. Sensors, actuators, and microcontrollers are used to implement the control strategy. The algorithms are first tested using computer simulation before experiments are conducted on the CIMCAR.

Control engineers solve automatic control problems in service to humanity using science, mathematics, and engineering principles and practices, along with software and hardware. They apply their work to a diverse set of systems that may have electrical, mechanical, chemical, hydraulic, financial, or biological characteristics. Automatic control is a fascinating field of study. It is universal, multidisciplinary, helps one develop a systems viewpoint in the solution of problems, and allows one to work in theory, develop software, and build hardware.

The Joys and Perils of Automation

Christos Cassandras spoke about automating the control of both physical and man-made systems. He provided some basic definitions for the middle school and high school audience, the essence of which are:

- system: a group of objects working together toward a common purpose
- control: to exercise restraining or directing influence over; to regulate the system
- automation: an automatically controlled operation of a system to make the right decisions.

Christos showed block diagrams to illustrate the progression from an uncontrolled system [Figure 3(a)], to a controlled system [Figure 3(b)], to an automatically controlled system [Figure 3(c)]. For example, suppose a tank of water with fixed height K is being filled from a pipe at the top with the pipe's flow rate controlled by a valve, with maximum flow rate of ρ. At time t, the tank is filled to height $x(t)$, which must be kept less than K. The valve allows water to flow into the tank at rate $u(t)$, where $0 \leq u(t) \leq \rho$. If the tank is initially empty, how do we fill it completely without overflowing by controlling $u(t)$? This control objective is the "desired behavior" [Figure 4(a)].

One control solution is to select the flow rate $u(t) = \rho$ until $t = K/\rho$ and $u(t) = 0$ after $t = K/\rho$ [Figure 4(b)]. What could go wrong? This solution works only if K and ρ are known precisely. In addition, the solution requires an accurate clock in the controller. Furthermore, suppose there was a leak in the tank or someone added water to

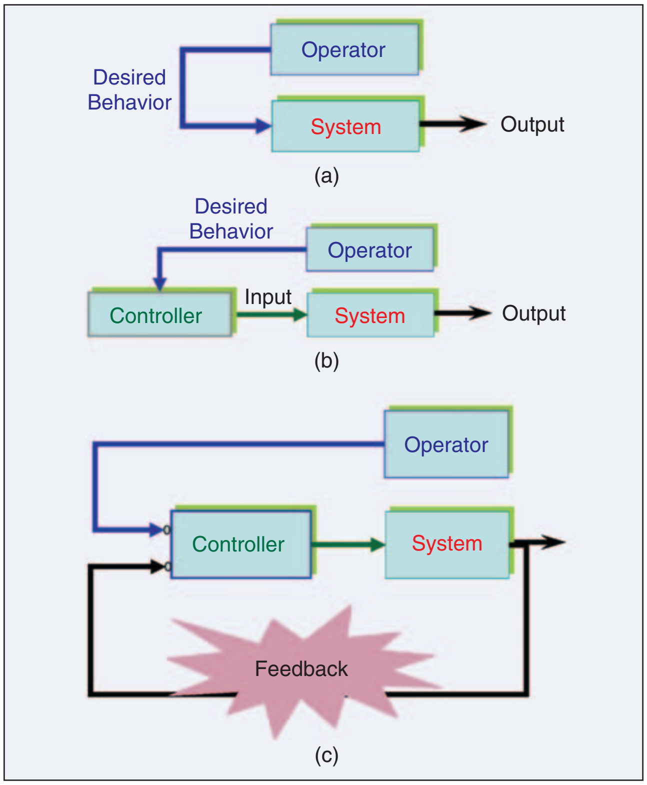


Figure 3. *Block diagram representation of the progression from (a) an uncontrolled system to (b) a controlled system to (c) an automatically controlled system. Notice that in the controlled system, the operator takes some control action to obtain the desired behavior. In the automatically controlled system, the control action is determined based on both the desired and actual behavior.*

the tank. This controller does not modify its operation if there are disturbances in the system, and the result in those cases would be an incorrect behavior.

Instead, we use feedback control to automatically control the tank until it is full. The controller forces the flow $u(t) = \rho$ while $x(t) < K$, but $u(t) = 0$ when $x(t) = K$ can be implemented by using a float connected to the valve. It is now becoming clear that we are modeling a flush toilet! The float blocks the input of water automatically when the tank becomes full [Figure 4(c)]. This mechanism, which is the basis for how toilets work, is so effective it has remained unchanged for generations!

Although automation has a cost—namely, the price of the float and related parts—it saves us from poor system performance when there is variability or disturbances. The resulting control $u(t)$ and the state $x(t)$ are the same as when the open-loop control is used, for the case when there are no disturbances on the system.

Our refined definition of automation is "putting together control and feedback." With this definition, some other examples of automation include the use of TCP/IP for Internet congestion control, autopilots in airplanes, and the control of train speed when approaching a station platform.

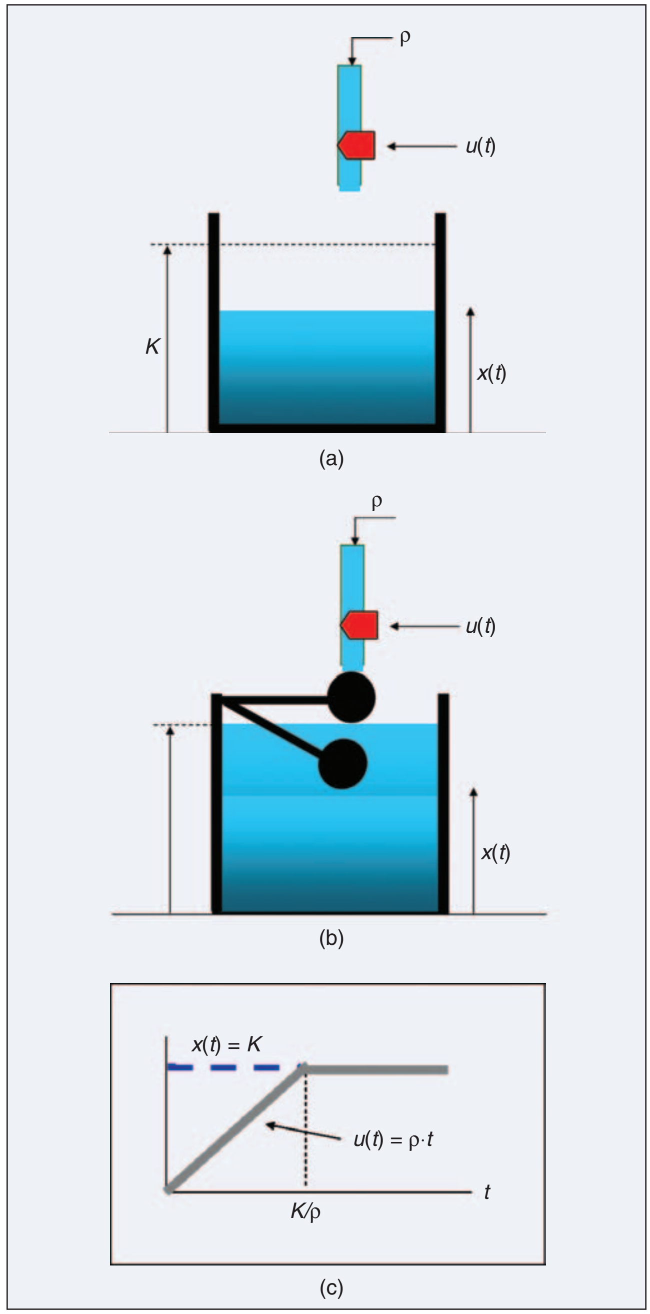


Figure 4. *Water tank system (a) without automatic controller, (b) desired behavior graph, and (c) with automatic controller. The water tank has a maximum height, and water enters through a pipe into the top of the tank. The position of a valve in the pipe can be adjusted to control the flow of the water into the tank. The graph shows how the height of the water in the tank varies as a function of time with the proposed controllers. The automatically controlled system uses a float to automatically cut off the water flow into the tank when the tank is full. This mechanism can be found in flush toilets.*

We can design controllers for physical systems or for human-made systems. Physical systems, for example, the

Comments from the Maui District School Superintendent

The following comments were received from Allen Ashitomi, Maui District School Superintendent:

Dr. Bozenna Pasik-Duncan, I am glad you received such an overwhelming response. I am really interested in science, and I believe we need to develop that component of our curriculum. I started in electrical engineering and then switched to education, but my heart is in the sciences. I am intrigued with the developments in genetics and astronomy. I'm still trying to understand string theory. Do you have a simple explanation? I again want to thank you for offering this opportunity to students in our school system.

toilet, must satisfy natural laws, such as the conservation of mass. The values of the state of a physical system are generally real numbers, and such systems are often time driven. In contrast, human-made systems can be created with any rules that the designer selects. This choice can result in a real mess! An example of a human-made system is an automatic teller machine (ATM) with a line of people waiting for service. In this system, the state, that is, the number of people waiting in the line, takes only integer values. Events, such as the arrival of a new person in the line or the push of a button, can change the state. Control protocols may take the form of the fair-play rule of first-come, first-served. Such control rules, although fair to people, may conflict with priorities for maintenance or medical help, as in a hospital.

When we look for control solutions for these man-made systems, we find that computers can be rather "dumb." Consider the example of a machine tool that operates on widgets. Suppose there is a buffer in front of a machine that can hold only a single part, and suppose the machine tool can only hold a single part. The machine will operate on the part and then either pass it on to an output area if the operation is successful or return it to the input buffer if it is defective. Unfortunately, if there is a waiting part in the input buffer, the machine tool will be stuck holding the defective part. Part 1 in the machine waits for the input buffer to be free, while part 2 in the buffer waits for machine to be free (Figure 5). This problem is called *deadlock*.

Here is a common *live-lock* example involving people. Suppose that two people are approaching each other in a hallway. Both people both decide to move out of the way by stepping toward the side of the hallway. Unfortunately, they both step toward the same side, still blocking one another. Next, they both move toward the other side, still blocking each other. Have you had that happen to you? The same problem arises in computer buses when two computers try to talk on the bus at the same time. The computers must try to talk again at random times or else there will be livelock.

Similar man-made systems, where appropriate analysis and scientific expertise are needed for design and problem solving, include communication networks, manufacturing systems, traffic systems, elevators, software systems, and video games. To illustrate such a system, Christos showed the students photos of a computer-controlled LEGO car factory that he uses in his courses. In real-world applications, computer simulations are used to analyze and validate solutions that are designed before they are implemented on a real system.

Robots Playing Soccer

Raffaello (Raff) D'Andrea described how university students under his supervision design and build small robots and the control and communication systems to support their operation. The robots play a scaled-down version of soccer, using balls about the size of golf balls (Figure 6). The game is played according to regular soccer rules; for example, holding is not allowed. The robots must play autonomously with no human involvement once the game begins. Student-designed robotic soccer teams compete in national and international tournaments, leading up to the RoboCup world championships.

The control structure here is more complex than those described above. Hierarchical control is used, separating local control tasks for robot operation from the centralized planning required for the robot team's play strategies. A vision system is implemented so that the information is available not only on your team's robots' locations but also on the location and behavior of the other team's robots and the ball. A communication system is needed to pass infor-

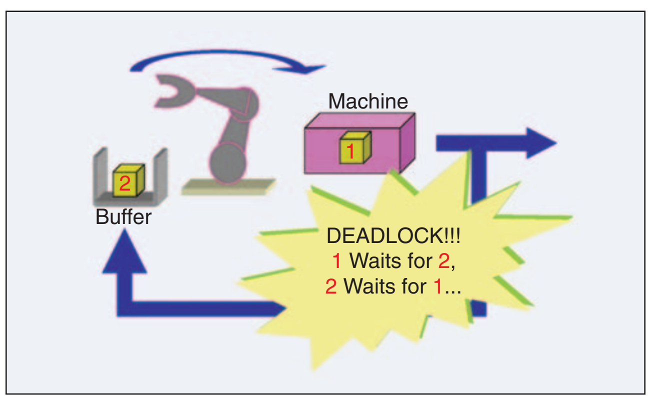


Figure 5. *Deadlock in a simple manufacturing system. A defective part must be returned to the input buffer of the machine tool for rework. If the input buffer can hold only one part and if there is already a part waiting, however, then there is a "deadlock" while each part waits for the other one to move.*

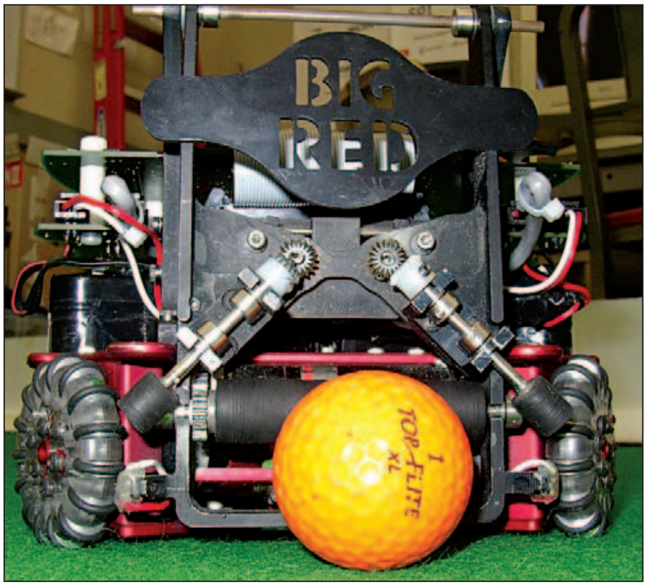


Figure 6. *One of the robots that won the championship in Padova, Italy, in 2003, with the golf-size soccer ball used in the RoboCup soccer competitions in front. This small-scale soccer game is played according to standard soccer rules by robots designed by teams of students. The robots must operate entirely autonomously during the competition, with no intervention or remote control by their human designers.*

Figure 7. *RoboCup competition with soccer game field. The robots work together in both defensive and offensive plays against the opposing team. Each robot has its own controller. A vision system is required to track the locations and actions of all robots and the ball on the playing field. A centralized controller uses this information to send play information to the individual robots so they can work together against the opposing team.*

mation between the vision system, the centralized controller, and the localized robot controllers. Physical design decisions include robot size, acceleration, speed, maneuverability, and inertial navigation. Low latency (meaning short time delay) is critical to the network design.

Other considerations include the following. For the local robot controller design, the robot-motor system dynamics has to be understood. Motion planning for a single robot includes path planning for obstacle avoidance, ensuring that the robot is where it is needed when it is needed there. High-level "plays" include both offensive and defensive strategies and transitions between them as appropriate. The time required for a play must be kept small in certain situations, otherwise the energy used has to be minimized. This objective determines the choice of control actions and trajectories selected. Algorithms are thoroughly tested using simulated games before they are implemented.

Raff showed video fragments of the international competitions in which the Cornell Autonomous Robotic Soccer Team participated (Figure 7). The Cornell team has won four championships in the last five years. For competition highlight videos, see www.mae.cornell.edu/raff.

Autonomous Vehicles: Racing from Los Angeles to Las Vegas

Richard Murray, from the California Institute of Technology, gave an exciting talk about autonomous vehicles. The autonomous vehicles in this case are four-wheel-drive vehicles that must race across the desert from Barstow to Las Vegas. The vehicles are not allowed to have a driver or any kind of remote control. The fastest truck that completes the route in ten hours or less will win the grand prize of US$1 million, a detail that caught the students' attention. The race was held on 13 March 2004.

Two hours before the race, participants are given a set of 1,000 GPS way points and a corridor 10 m wide to 10 km wide to stay within. The truck has no information about a feasible route within the corridor. The vehicle is not permitted to run into any other vehicles; Joshua trees, which are protected plants; fences; or other obstacles. The race is a 250-mi run with dirt roads, trails, rough roads, open desert, lake beds, overpasses to go under, water crossings, and dead ends.

For a professional desert racer with prior experience on a familiar course, the trip would take about four hours; on an unfamiliar route, however, it would take eight hours. It is clearly a serious challenge to have an autonomous vehicle navigate the course in less than ten hours.

Richard showed pictures of some of the vehicles that are being prepared for the race (see Figure 8). For the CalTech vehicle, the sensors consist of 12 cameras for vision, a GPS navigation system, inertial sensors (accelerometers and gyros), laser radar scanning (LADAR), and other devices. For actuation, the driver's seat has been entirely replaced with automated parts. A total of ten on-board computers are used for computation.

A video of a human-driven trial run with the truck hurdling through the desert showed the difficulty of keeping

Figure 8. *Interior of autonomous vehicle designed for competition in the DARPA Grand Challenge race. Actuators are installed in the driver's seat area to automate the mechanical actions that a human driver would make.*

to an ill-defined path. The students were fascinated by the difficulties of the task. For example, one poignant question that was asked was: "If the truck kills someone, are you liable for murder?" Richard assured the students that this event could not occur.

Better Movies Through Mathematics

Brian Rosen described how animated movies are made and the important role mathematics plays. His first point, illustrated with cartoon characters that were immediately recognized by the students (but not all of the CDC attendees!), was that art comes first; that is, you draw characters first. Next comes the mathematical representation of how to view or visualize the art. Much of the basic mathematics of visualization can be described at a level that can be understood by high school students.

The most basic problem is how to represent a line that is parameterized in terms of a start point (x_0, y_0) and an end point (x_1, y_1) with t as the line parameter with $0 \le t \le 1$. Brian gave several steps first, then finally gave the parametric form of the line $(X, Y) = (X(t), Y(t))$ in both coordinates:

$$X(t) = x_1 t + x_0(1 - t),$$
$$Y(t) = y_1 t + y_0(1 - t).$$

Representing various curves is in terms of third-degree polynomials with general coefficients $\{c_0, c_1, c_2, c_3\}$ so that

$$X(t) = c_1 t + c_0$$

is a straight line needing two points to describe it,

$$X(t) = c_2 t^2 + c_1 t + c_0$$

is a parabola needing three points to describe it, and

$$X(t) = c_3 t^3 + c_2 t^2 + c_1 t + c_0$$

is a cubic or third-degree polynomial needing four points to describe it. Beyond the straight line, knowing the start and end is not sufficient to determine the constants c_i for $i = 0, 1, 2, 3$, and some other information, such as a slope, is needed. However, using a little bit of high school calculus, we can also write the slope with respect to the parameter t for the cubic as

$$X'(t) = 3c_3 t^2 + 2c_2 t + c_1.$$

Now we use splines of curves to glue together pieces described by cubic polynomials since splines rely on both point and derivative information to give smooth transitions between spline pieces.

If we go to three dimensions, we need three cubic polynomials, one for each dimension, and then get surfaces of a figure of interest represented by meshes, which are sets of neighboring points on the surface of the figure. We move the underlying surface mesh to get motion and more realism in animated films and games.

The animation team consists of many people organized into departments. At Pixar, the number of team members could be as much as 100, depending on the film. The art department provides expressions for the characters. Flexible meshes are more detailed on the face to capture expressions. To do this, we need complex controllable meshes that can distort. Human reference subjects are used to mimic how the eyes move, say, from video tapes displaying eye movements. The goal is to capture details such as the movement of the skin and muscles when the eye moves.

It is also important in animation to capture the effect of light reflecting off of surfaces. For example, a sphere or ball that is just orange everywhere looks like a circle, unless we model how light interacts with the surface. For ideal surfaces, the reflection is specular; that is, the light is reflected directly to the viewer. This interaction for real surfaces when the object is not smooth and has imperfections leads to a dot product. Specifically, diffuse light reflection is proportional to the dot product $(\cdot)$ of the normal $\vec{N}$ to the sphere and the direction $\vec{L}$ of the source of light given by

$$\text{diffuse} = \vec{N} \cdot \vec{L}.$$

However, the eye of the viewer also receives directly reflected light such that

$$\text{brightness} = \text{specular} + \text{diffuse}.$$

Specular color has a shaping effect that is iridescent and modifies specular light. In reflection, color comes from the environment and color shape reflection. Another technique is procedural displacement using sine waves and random noise to provide greater realism.

To obtain realistic lighting effects, there are teams of people who adjust computer light sources. An advantage of the computer-generated lighting is the ability do things that are not possible in real life; that is, if the scene were being filmed. For example, light shines only on part of the scene in animation but not in real life. Negative lighting is also possible, as well as different colors appearing on different objects in a scene.

Production of an animated movie can take three years: one year for concept development and two years for production. The efforts of roughly 200 people can be required during production.

One student asked how long it takes to learn the necessary math. Brian replied that he learned computer graphics in his sophomore year of college. Three years later he had a job in animation, and he continued to learn on the job.

This talk was a resounding success, with cheers from the students. Later, in the panel discussion, Brian answered more questions and gave extended explanations of the role of mathematics during animation production, including the important role that algebra, trigonometry, geometry, and other areas play in scientific visualization and animation. There were many specific questions on the making of certain animated films and the possibility of sequels to existing films. The subject of computer games also arose, and it was clear that computer games can serve as a motivation for exploring mathematics and computer science. This talk made a convincing argument for the necessity of learning mathematics well enough to be able to apply it to science and engineering as well as diverse applications.

Finally, some of these questions led to more general questions in the later session about careers and college, such as the cost of college, the relative benefits of public versus private colleges, what college is like, and how one chooses a major in college.

Past Speakers and Topics

This series of workshops has benefited from a group of exceptional speakers and researchers in control systems and mathematics. Past talks have included:

- "Using Mathematics for Epileptic Seizure Warning," Ivan Osorio, M.D., director, Comprehensive Epilepsy Center, University of Kansas Medical Center, and Mark Frei, Ph.D., operating manager and technical director, Flint Hills Scientific, L.L.C.
- "Music, the Brain, and Complex Adaptive Systems: Using Musical Metaphors and Models to Study Brain Functions," Bryan Haaheim, University of Kansas, and Deron McGee, University of Kansas
- "Brownian Motion: Past and Present," Tyrone E. Duncan, University of Kansas
- "How the Internet and Wireless Networks are Controlled: What's Happening behind the Scene," P.R. Kumar, University of Illinois at Urbana-Champaign
- "Control of Jet Engines," Richard M. Murray, California Institute of Technology
- "Powerful Ideas in the World of the Child," Alan Kay, Disney Fellow and vice president of research and development, The Walt Disney Company
- "Making Calculus Fun: How to Entertain at Parties," Colin Adams, Williams College
- "Systems, Control, and Mathematics," Stephen Boyd, Stanford University
- "How Feedback Changed the World," Dennis Bernstein, University of Michigan. This talk resulted in the articles "Feedback Control: An Invisible Thread in the History of Technology," *IEEE Control Systems Magazine*, vol. 22, pp. 53–68, April 2002, and "Introducing Signals, Systems, and Control in K-12," *IEEE Control Systems Magazine*, vol. 23, pp. 10–12, April 2003.

Understanding and Controlling the Pendulum

Using videos and equations, Katsuhisa Furuta showed the students how pendulums could be controlled to stand upright. In fact, many of the principles of control can be understood by studying the pendulum.

Long ago, Galileo Galilei investigated the periodic swinging motion of a hanging pendulum. Today, a technological challenge is to build a device to keep the pendulum inverted, much like holding an umbrella upward with only a very small grip on the handle. The problem is to exert appropriate control to counterbalance the downward pull of gravity. Video examples were shown of a single pendulum balanced by means of a robot arm using a vision system.

Comments About the Workshop

Numerous rewarding comments were received from participants after the workshop, including: "What a wonderful day. My students were all greatly impressed with the level of knowledge presented, the achievements of the young students, and the many ways that math could be applied. Of course, the soccer team was the favorite, but among my students it seems that most of the presentations were a favorite with a smaller group of students. Education is a very hard sell so the kind of exposure you offered our students was most welcome. Thank you again for the invitation."

"It was wonderful. The students had wonderful things to say about the speakers we heard. Thank you for taking the time to arrange this very worthwhile event for us."

"The trip to the Workshop had a lot of information that at first seemed to not appeal to a middle or high school student. After a short time, with the excellent treatment from the hosts, it promised to be a beneficial experience. I enjoyed, and found interesting, all of the presentations, although some were beyond the middle or even high school level. When presenters were lecturing students at the high school level, we could immediately see the wonders of what they were talking about to us. We saw everything from futuristic cars to ingenious displays of mechatronics. We could instantly see the application to our education and what there is in the future. Of course, being interested in math and science, we could even imagine ideas of fascinating creations beyond what was presented."

"The workshop was the most memorable and successful event. It was truly a collaborative effort of so many people."

"I do not know how to find the words for how wonderful my trip was—I learned SO much and am forever grateful. As I write this, I am also working on a number of lesson plans based on the information I learned. You did an amazing job with the full-day workshop. I know how much work those are and have organized them myself. On the whole, I felt that the students took away a lot of newly found enthusiasm for engineering. Now, that enthusiasm has to be cultivated by their teachers. I am working on condensing my notes into an outline form and will e-mail it to you once I am done. Feel free to share it with the other teachers if you'd like to. I would love to help you put on your next one so please, keep me in mind! I could certainly put together some pre- and postactivities and assessments and would enjoy doing it."

An inverted single pendulum is now a standard demonstration at conferences and in classroom laboratories. However, a composite of two pendulums seems much more difficult, but by using very fast vibrations the inverted double pendulum can be stabilized. Multiple single pendulums mounted on the same platform can be stabilized by fast vibrations of the platform.

The single pendulum, hanging or inverted, satisfies

$$J\theta'' = -mgl\sin(\theta),$$

where m is the pendulum mass, l is the pendulum length, g is the acceleration of gravity, $J = ml^2$, θ is the angle measured from the downward vertical axis, and θ'' is the second time derivative or angular acceleration. For the inverted pendulum, we let $\theta = \pi - \psi$, so $\psi = 0$ corresponds to the marginally stable inverted pendulum pointing upward. Hence, using a little bit of trigonometry, for the inverted pendulum it is easier to use

$$J\psi'' = mgl\ \sin(\psi).$$

To have the pendulum swing upward, we can use control to artificially apply gravity in the reverse direction. To accomplish this reversal, we consider the equation

$$J\psi'' = -mg\,l\,\sin(\psi),$$

where reversed gravity is modeled by the minus sign on the right-hand side of the equation. How can we accomplish this artificial gravity reversal? Although we cannot change the gravitational force of the Earth, we can apply an external force to the pendulum that emulates reverse gravity.

Adding a control term to the pendulum leads to

$$J\psi'' = mgl\ \sin(\psi)\ -\ uml\ \cos(\psi),$$

where u is the control variable. The control (meaning the equation for u in terms of ψ) that makes the right-hand-side of the equation take the form of the pendulum with gravity upward rather than downward is

$$u = u(t) = 2g\ \sin(\psi)/\cos(\psi).$$

Using this controller, we have added a force that makes the pendulum behave as if gravity were reversed.

More videos showed the double-link pendulum being stabilized after the double pendulum is swung up. Even more extraordinary, the triple pendulum was shown to be stabilized [Figure 9(a)]. Finally, Katsuhisa showed "cooperative control," the handoff of an inverted pendulum between one robot and another [Figure 9(b)]. The coordination of the robots is the hard part.

Katsuhisa also told the students about the important and dangerous job of clearing land mines in war-ravaged parts of the world and how that job is becoming automated. This application resonated with the students because a nearby Hawaiian island that had been used for U.S. military target practice has recently been cleared of unexploded ordinance. There are 10 million buried mines in Afghanistan alone, and many more in Cambodia, Vietnam, and Laos. The hand clearing of mines needs to be replaced by machines for safety, and Japanese engineers are helping.

Future Careers in Embedded Systems, Mechatronics, and Control

Mark Spong spoke about embedded systems and mechatronics, the hybrid combination of mechanics and electronics, and problems that exist in the field.

Cell phones have computers in them, so they are called embedded systems. Embedded systems link together different devices emerging from the IT revolution. Mechatronics involves the blending of mechanical systems with electronics such as sensors, actuators, computers, software, and intelligence. Examples of mechatronics include automotive systems; adaptive cruise control; and the conversion of gas engines to hybrid, fuel cell, drive-by-wire, and camless engines.

In a traditional car, the car turns when the steering wheel is turned. There are various mechanical linkages in this arrangement. The steering wheel is a danger to the driver in an accident. If the steering column and mechanical connections are replaced by sensors, actuators, and embedded microprocessors, then not only is the steering column eliminated, but also a left-hand drive car can easily be converted to a right-hand drive car.

In a traditional engine, a mechanical cam pushes the rods as it turns to open and close the valves. The cam has a shape that dictates the timing of the valve operation. If motors are used to open and close valves instead, then complete control of timing is possible. Some of the pistons can be stopped at traffic lights, when the extra thrust is not needed.

Robots are the ultimate mechatronic systems by enabling unmanned vehicles, telemedicine, and automated manufacturing. Mark played a video showing a robot, developed by his students, that played air hockey against a human opponent. At the end of the video, the robot lost control after an unusual maneuver, prompting a series of questions.

How to Turn a Single Dollar into Billions

Shane Haas gave a talk on how the timing of investments could be used to maximize return on investments (if anyone had perfect information!). A surprising number of the students were knowledgeable about finance, and a few owned stock and so had a personal interest in his talk. He described an investment approach where an investor moved his or her entire investment, at regular intervals, to the best instrument for the next period of time. These could alternate between a savings account with a low fixed rate of return and a volatile investment such as a stock fund. The portfolio instant rate of return is

$$P(t) = \text{maximum}\,[B(t), S(t)]\,,$$

where $B(t)$ is the riskless fixed rate of return and $S(t)$ is the risky stock fund rate of return.

Shane used monthly closing data for the period from 1926–2003, updating the portfolio each month according to the formula, for U.S. Treasury bills as low-risk investment and the Standard and Poor's 500 stock index as the high-risk investment (simulating a large stock mutual fund). Starting with one dollar in 1926, the final amount was an amazing US$14.3 billion! If one invested their money in S&P 500 stock index, the US$1 would have yielded US$2,171 over that time. In a savings account with a low fixed interest rate, the return would have been US$17.

This perfect market-timing investment strategy—that is, switching between the better of S&P 500 or Treasury bill returns—is equivalent to buying treasury bills and a call option on the S&P 500. Remarkably, the Black-Scholes formula can price this option to determine the value of this investment strategy. This analogy motivated a question from our student financial experts about investment or transaction fees, and Shane said that according to the Black-Scholes formula, the fees justified for someone with perfect monthly prediction would be 24% of the investment on an annual basis. Of course, this assumes perfect market timing! If perfectly switched between those two on a daily basis, then it would be far more than US$14 billion with perfect timing.

He also suggested a better alternative market timing portfolio

$$P(t) = \text{maximum}[\text{Intel}(t), \text{Microsoft}(t)],$$

where the Intel(t) and Microsoft(t) are the daily returns. With daily perfect market timing, US$1 invested on 5 January

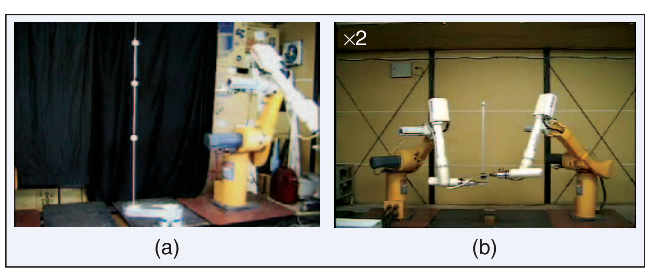


Figure 9. *(a) Stabilization of a triple inverted pendulum and (b) a single inverted pendulum being passed between two robots. These mechanisms were stabilized using a vision system to sense the pendulum angles.*

NSF Research and K-12 Education: A Winning Partnership

NSF Program Director Kishan Baheti gave an overview of NSF's mission to support fundamental research and education in science and engineering. Dr. Baheti highlighted NSF's role in the emerging field of nanotechnology that will lead to unprecedented understanding and control of the fundamental building blocks of all physical things. This field is likely to change the way we design and manufacture computers, vaccines, automobiles, and many other products. To encourage innovation, Dr. Baheti described NSF's Research Experience for Teachers (RET) Program, which supports a primary or secondary teacher's direct experience in a research laboratory or similar research environment. The program connects a teacher with a researcher who can supplement an existing NSF grant or initiate a new one to obtain teacher support. Researchers are encouraged to involve teachers in funded research. The NSF program encourages transfer of new knowledge to precollege classrooms and provides support for both teacher enhancement and the development of educational materials for the K–12 classroom.

1990 would become US$2.6 trillion on 5 December 2003. Shane encouraged students to download historical data from finance.yahoo.com and try other stocks.

Of course, we do not recommend that students try timing the market with their own money. No one has perfect timing, and the minimum investment in a hedge fund ranges from US$1 million to US$25 million. Pension funds, wealthy individuals, and endowment funds typically invest in hedge funds.

Mathematical Games

Suzanne Lenhart of the University of Tennessee and past president of the Association for Women in Mathematics ended the program with mathematical games. The students played Hex, which is a positional-strategy, two-player game, and then conducted some probabilistic experiments with number spinners relating to the well-known "rock-paper-scissors" game. By playing these games, the students learned about the property of transitivity. For an example of nontransitivity, if spinner P beats spinner R with probability 5/9 and spinner R beats spinner S with probability 5/9, it is not true that spinner P would beat spinner S.

Acknowledgments

The members of the CSS Technical Committee on Control Education wish to thank Dr. Kishan Baheti of NSF for supporting this workshop. The authors are also supported by NSF Grants DMS-0207081 and ECS-9988435.

We are grateful to the CSS and the University of Kansas for support and sponsorship of this CDC workshop. Frank Lewis, general chair of CDC 2003, provided unwavering support, and other conference organizers helped to accommodate the demands on space and other requests. Linda Bushnell and Miroslav Kristic of CSS provided valuable support for the workshop. The speakers provided extraordinary presentations, and they assisted in the preparation of this article. Without Bozenna Pasik-Duncan this workshop would not have come into being, since she initiated the concept, obtained CSS technical support, applied for and obtained NSF and other funding, and recruited presenters and students. Members of the Technical Committee on Control Education, four University of Kansas undergraduate students, and one University of Kansas graduate student contributed countless hours to the development of the materials for the workshop, interactions with the student and teacher attendees, and videotape development. The University of Kansas supplied logistic and financial support. Finally, the students, teachers, and the extremely helpful Maui School District Superintendent Allen Ashitomi made this workshop the success that it was.

—Molly H. Shor
Oregon State University

—Floyd B. Hanson
University of Illinois

ISIC'03 Conference Report

The 18th IEEE International Symposium on Intelligent Control (ISIC'03) was held 5–8 October 2003 at the Westin Galleria in Houston, Texas. The theme of the conference was "Intelligent Control for Complex Systems." Papers were solicited in all areas of theory and applications of intelligent control, including control architectures, learning control, path planning systems, machine learning, neural networks, fuzzy logic, genetic algorithms and evolutionary computing, hybrid dynamical systems, supervisory control, knowledge-based sensor fusion, intelligent mechatronics, distributed and embedded systems, and applications in the aerospace, process, and power industries.

The conference was a great success, with 183 attendees. Technically, 264 papers—including 235 regular papers and 29 invited papers, authored by 592 researchers—were submitted from 32 countries and regions. There were 178 talks structured into three days, with four parallel sessions. Plenary speeches were delivered by Frank Lewis ("A Hamilton-Jacobi Setup for Constrained Neural Network Control"), Ricardo Sanz ("Scalable Distributed Intelligence"), and Tong Heng Lee ("Intelligent Control of Mechatronic Systems"). A panel session (Intelligent Control Imitating Biology: Promises, Challenges, and Lessons) was moderated by Panos Antsaklis, with panelists Jim Albus, George Pappas, Ricardo Sanz, Tong Heng Lee, and Kevin Moore. All presentations were well received by the attendees with enthusiastic discussions throughout the conferences. For those readers who wish to know more about the conference, please visit the conference Web page at http://vlab.ee.nus.edu.sg/~isic2003/, where presentation materials are archived from each of the plenary and panel speakers.

Four preconference workshops were presented on computational intelligence, embedded systems, fuzzy logic identification, control, and decision-making. Six invited sessions were organized covering complex systems and nonlinear control, fuzzy control and intelligent robotics, and adaptive critic control and autonomous systems and navigation.

Apart from the technical sessions, a number of social events were enjoyed. The welcoming and closing receptions featured live local music, whereas the conference banquet presented a dynamic mixture of cultural entertainment in the reception hall on the 24th floor, which offered a breathtaking view of Houston. The conference venue was held inside the Houston Galleria, offering premier shopping and a fun atmosphere for conference attendees.

— Gary G. Yen
General Chair

Seventh European Control Conference (ECC03)

The European Control Conferences (ECC) are held every two years, under the auspices of the European Union Control Association (EUCA). Th 2003 conference, held 1–4 September in Cambridge, U.K., was the seventh in the series. Previous conferences were held in Grenoble, France, 1991; Groningen, The Netherlands, 1993; Rome, Italy, 1995; Brussels, Belgium, 1997; Karlsruhe, Germany, 1999; and Porto, Portugal, 2001. The next ECC will be held in Seville, Spain in December 2005, jointly with the IEEE's Control and Decision Conference.

The conference was held at the Faculty of Law on the campus of Cambridge University with the exception of the opening plenary talks, which were held at the Corn Exchange in the City Centre. Accommodations were available at several hotels, bed and breakfasts, and local colleges.

Scientific Program

The scientific program for the ECC03 included 606 regular papers (537 oral and 69 poster presentations), three plenary talks, six semiplenary talks (with two held concurrently), three minicourses, and two roundtable sessions. In addition, two tutorial workshops were organized in association with the conference. There were also minitutorials comprising half-day tutorials integrated into the conference program. All of these events were presented in up to 15 parallel sessions.

Following previous ECC practice, one day was designated as Industry Day. Papers from authors based in industry, and other application papers, were concentrated in sessions on this day. Industrial delegates can often attend a conference for only one day, and our goal was to maximize the value to them of attendance on that day.

The role of systems and control in a modern knowledge economy was highlighted by a number of contributions, particularly those concerned with some emerging applications of the field. For example, the plenary talks on congestion control of the Internet by Frank Kelly of the University of Cambridge and on hybrid systems by Manfred Morari of ETH Zurich, and semiplenary talks on bioinformatics by Bart de Moor of Katholieke Universiteit Leuven, cell biology by Pablo Iglesias of Johns Hopkins University, and quantum control by Gerard Milburn of the University of Queensland all emphasized the pivotal role of systems and control as a provider of analytical tools and enabling technologies in these application areas.

One of the roundtable sessions, organized by Peter Wellstead, emphasized the role of systems and control in innovation, illustrating how people trained in this area are crucial facilitators of innovation processes in modern industry and commerce and how the discipline provides an integration technology in such processes. Another roundtable session, organized by P. Frank, was devoted to exploring funding mechanisms in the European Union's Sixth Framework in relation to systems and control. Other notable contributions to the conference, which clearly showed the expansion of the field into relatively new areas, included three sessions devoted to communications networks as well as two sessions devoted to automated drug delivery. All of these sessions had strong participation by industrial and medical authors and speakers, indicating that these sessions were reporting more than purely academic research.

Other plenary and semiplenary contributions, such as those by Richard Murray of CalTech and Gary Balas of the University of Minnesota, surveyed the application of systems and control in more traditional areas such as atmospheric flight, spacecraft control, robotics, materials processing, and manufacturing. A new aspect of these applications is an increasing emphasis on autonomous operation and survivability. The remaining semiplenary and minitutorial contributions covered nonlinear predictive control (Frank Allgöwer of the University of Stuttgart), stabilization of nonlinear systems (Anders Rantzer of the Lund Institute of Technology), hybrid complementarity systems (Bernard Brogliato of INRIA and Maurice Heemels of Eindhoven University), linear matrix inequalities (Pablo Parrilo of ETH Zurich and Sanjay Lall of Stanford University), and the behavioral approach to systems theory (Harry Trentelman and Jan Willems, both of the University of Groningen).

There were two tutorial workshops. A workshop on advanced computational tools for computer-aided design of control systems was presented by Peter Benner of TU Chemnitz and Paul van Dooren of Université Catholique de Louvain, and a workshop on stochastic hybrid systems with particular application to air-traffic control was offered by John Lygeros.

Papers based on the plenary, semiplenary, and minicourse presentations were published in a special issue of the *European Journal of Control* (vol. 9, no. 2–3, 2003), entitled "Fundamental Issues of Control." Other papers and posters were made available to delegates on CD-ROM.

The Organizing Committee consisted of General Co-Chairs Jan Maciejowski and Keith Glover, IPC Chair Ian Postlethwaite, and Treasurer Peter Fleming. The Secretariat was provided by the U.K.'s Institution of Electrical Engineers.

Conference Delegates

The total number of delegates was 693, which included 169 student registrations. We were pleased to welcome Cheryl Schrader, president of the IEEE Control Systems Society; Vladimir Kucera, president of IFAC; and Jorge Martins de Carvalho, president of EUCA, among the delegates.

Delegates came from 50 countries. The largest number, not surprisingly, came from the United Kingdom (117). There were notable delegations from outside Europe, in particular, Japan (37), the United States (27), Australia (20), and Mexico (16). Unfortunately, some countries from Eastern Europe and the former Soviet Union were underrepresented, with only six delegates from Russia, for example, presumably because of the difficult economic conditions in those countries.

Student registration fee reductions were partly sponsored by the European Commission, and the social reception on the first evening was sponsored by the Cambridge, U.K., office of The MathWorks.

— Jan M. Maciejowski
President, European Union Control Association

After Graduation: Women in Control Taking a Leadership Role

A workshop was held at the 42nd IEEE Conference on Decision and Control (CDC) in Maui, Hawaii, on Wednesday, 10 December 2003, on the progress of women in the control field. Bozenna Pasik-Duncan organized the workshop, in part to honor Cheryl Schrader, who served as the IEEE Control Systems Society's (CSS's) president for 2003 and who was recently appointed dean of the College of Engineering at Boise State University. The workshop was cosponsored by the USA National Science Foundation (USA NSF), the IEEE CSS, the IEEE CDC 2003, the IEEE CSS Women in Control Standing Committee, and the IEEE CSS Technical Committee on Control Education. Seventy-five women and several men from academia and industry attended, including students and professionals from universities and government agencies. The workshop focused on progress made in past years as well as problems that remain for women in this technical field.

The workshop opened with welcoming remarks by Bozenna Pasik-Duncan (chair, 2003 CDC Control Education Activities), Frank Lewis (2003 CDC general chair), Anna Maria Perdon (chair, CSS Standing Committee on Women in Control), Cheryl Schrader, and Kishan Baheti (program director, Electrical and Communications Systems Division, USA NSF). Vasundara Varadan, division director for Electrical and Communications Systems at the NSF, was the keynote speaker on "Women in Engineering—Are We There Yet?"

Two panel discussions were held on "Women in Control as Leaders—Challenges, Opportunities, and Rewards." The participants on the first panel were John Baillieul (chair, Department of Aerospace and Mechanical Engineering, Boston University), Chris Byrnes (dean, School of Engineering and Applied Science, Washington University, St. Louis), Peter Crouch (dean, Ira A. Fulton School of Engineering, Arizona State University), Pramod Khargonekar (dean, Engineering School, University of Florida), Belinda

King (chair, Department of Mechanical Engineering, Oregon State University), and Cheryl Schrader. The second panel was comprised of Anuradha Annaswamy (MIT), Lucy Pao (University of Colorado at Boulder), Anna Maria Perdon (Universita di Ancona), Jing Sun (University of Michigan), and Dawn Tilbury (University of Michigan). Suzanne Lenhart (University of Tennessee, past president of the Association for Women in Mathematics) spoke on the Association for Women in Mathematics (AWM) and the Society for Mathematical Biology activities that support women.

Panel participants and speakers addressed topics relating to women faculty and leadership. The participants discussed the need for more women engineering faculty and leaders, mentoring of women faculty, improving the academic climate for women, advice on balancing career and family, diverse pathways through which women enter academia and leadership positions, and advice for new faculty. Several issues affecting women were discussed, including recent legal rulings that affect admissions policies supporting student diversity, as well as concerns about the challenges faced by daughters in pursuing technical careers. Finally, advice was offered on how to develop programs to support women graduate students and new faculty in mathematics and engineering.

The Need for Women Faculty and Women Leaders

The fact that women are a small minority among the faculties of many colleges of engineering is viewed as a serious problem by the deans who spoke on the first panel. During the workshop, various reasons were given for increasing the number of women faculty in engineering colleges, including the need to provide role models for female students. It was noted that it is not uncommon for an engineering college to lose 40% of its students in the first year, with disproportionate losses among the women students. In a focus group of women students, the most common reason for leaving was the lack of women professors. It is widely recognized that women faculty can offer perspectives on issues that are largely specific to women, such as the tension between family and academic careers.

Additional discussion was held on the effects of subtle discrimination toward women faculty. It was noted that by identifying the sources of discrimination and educating people about inequities, the climate can be improved for the benefit of everyone. In this regard, the NSF sponsors grants for institutional change with the goal of improving the atmosphere at academic institutions.

Another discussion focused on the fact that, although women are awarded tenure at the same rate as men when they are considered for tenure, a smaller fraction of women starting out in the tenure-track process ultimately apply for tenure. A woman faculty member described the challenges of her first few years as a faculty member, such as choosing relevant research problems and recruiting good students. Although these struggles exist for both genders during the tenure track period, it was noted that the tenured faculty position is not designed for women who are in their birthing and child-raising years. Surveys of women engineering faculty have reported that the primary negative career impact was the challenge of balancing work and family.

The deans who spoke stressed that the women who work in academia are generally excellent. Yet, women are underrepresented in the engineering workplace (30–40%), and even more so in tenure track and tenured positions in engineering (7%). A relatively low percentage of women with Ph.D.s are in the workforce, compared to men.

A Pipeline, or Diverse Pathways, into Academia?

For several years, concern has been expressed that girls and women drop out of the "pipeline" for academic careers in engineering and mathematics when choosing majors in college, graduate programs, and careers. On the other hand, many of the senior women in engineering came through different pathways; for example, through science. Similarly, women are finding their way into leadership positions through nontraditional paths such as through leadership roles in professional societies and government agencies. An NSF survey found that 30% of the women engineering faculty earning high salaries had earned their highest degree in the physical sciences rather than engineering. These data suggest that a pathways paradigm may be more relevant than a pipelines paradigm for

Past CSS president and dean of the School of Engineering at Boise State University Cheryl Schrader (right) and Bozenna Pasik-Duncan attend the Women in Control Workshop held at the Conference on Decision and Control in Maui, Hawaii, in December 2003. Prof. Pasik-Duncan is the recipient of the prestigious Louise Hay Award of the Association for Women in Mathematics for her "broad and inspiring vision of mathematics as a discipline and as a profession."

Bozenna Pasik-Duncan Receives Louise Hay Award for Contributions to Mathematics Education

Prof. Bozenna Pasik-Duncan has been awarded the Louise Hay Award of the Association for Women in Mathematics (AWM) for innovative approaches to technical education at all levels and for her support of professional advancement for women. The award was presented during the annual Joint Mathematics Meetings held 7–10 January 2004 in Phoenix, Arizona. These meetings constitute the largest annual gathering of mathematicians in the United States and provide a significant platform for the most important professional awards in mathematics and related disciplines. In recognition of this award, Prof. Pasik-Duncan will deliver the 2004 AWM-MAA Louise Hay Lecture, entitled "Mathematics Education of Tomorrow" at MATHFEST, to be held 12–14 August 2004 in Providence, Rhode Island. The Louise Hay Award recognizes Bozenna for "her broad and inspiring vision of mathematics as a discipline and as a profession, and for her remarkable skill and commitment in carrying out the role of professional mathematician in a wide variety of communities and settings."

Bozenna is active in the IEEE Control Systems Society (CSS) as the current chair of the Technical Committee on Control Education. (See http://www.ieeecss.org/TAB/Technical/ education.) In this capacity, she has organized several workshops for high school students and their teachers at major international conferences, including the two most recent conferences on Decision and Control (Maui in 2003 and Las Vegas in 2002). Dr. Pasik-Duncan's past activities in the CSS include service as associate editor of *IEEE Transactions on Automatic Control* from 1990 to 1997, member of the CSS Board of Governors from 1991 to 1992 and 1997 to 2002, chair of the standing committees on Assistance of Engineers at Risk and Women in Control, and associate editor at large of *IEEE Transactions on Automatic Control*. Additionally, she was chair of the Standing Committee on International Affairs, chair of the Task Force on Globalization, and CSS vice president for Member Activities from 1998 to 1999.

Dr. Pasik-Duncan is a Fellow of the IEEE and in 2000 was awarded the Third Millennium Medal in recognition of her achievements and contributions to the control systems field. She received the IEEE Control Systems Society Distinguished Member Award for significant technical contributions and outstanding long-term service to the CSS.

understanding the routes that girls and women follow in technical careers.

Several participants noted that in the CSS women have become authors, associate editors, conference organizers, session chairs, award winners, program chairs, and plenary speakers at conferences. For example, more women are becoming IEEE Senior Members and Fellows. These changes have occurred thanks to the support of CSS's leadership and the efforts of women in the Society. The presence of women on committees of the IEEE CSS has helped to raise the awareness of the Society to women's needs and their accomplishments.

Increasing Enrollments of Women in Engineering

Why is it important to increase the number of women and other underrepresented minorities in engineering, science, and math education? Some of the speakers reported statistics concerning the low percentage of U.S. citizens and permanent residents studying engineering as well as the predicted drop over the next 20 years in the number of non-U.S. students who come to the United States to study engineering and remain after graduation. This information motivates the need to recruit, develop, and retain women, Hispanics, and African Americans and the need to restructure engineering education to appeal to students in these groups. Restructuring of engineering education may attract not just more underrepresented students but more U.S. students in general.

What About Our Children?

While some speakers reported that their daughters and sons were selecting engineering and mathematics careers, other speakers noted that their daughters often became discouraged about pursuing a technical field, sometimes as early as in the fourth through sixth grades. Although 70% of fourth graders report that they like math, that number drops to less than 50% by 12th grade. Of those who report that they like math, fewer girls than boys report that they are good at math, which may reflect lack of confidence in their math abilities by that grade. Teachers frequently observe that, by fourth grade, girls typically become interested in subjects other than science and become less apt to speak up in class, whereas boys start participating more in the classroom.

At the middle school level, science is often taught using a hands-on approach, and boys are typically more comfortable with technical equipment in those years. One remedy that was discussed is the development of all-girl schools. Currently, more female high school students are taking chemistry and biology rather than physics.

Overall, the participants expressed the view that engineering needs a presence in K–12 education to improve the public perspective on engineering as a profession that empowers women. The IEEE CSS Technical Committee on Education, under the leadership of Bozenna Pasik-Duncan, has held workshops for high school and middle school students; see page 20 for a description of the workshop held in Maui.

Programs to Support Women

The IEEE CSS's Standing Committee for Women in Control has sought to support female students and new faculty members by creating a community for them, promoting their participation in CSS activities, and recognizing their accomplishments. To create a community, CSS sponsors regular "Women in Control" luncheons at major CSS conferences and supports a Web page for "Women in Control." A "Women in Control" newsletter is published a few times a year, and an e-mail alias is available for the dissemination of information. Women are encouraged to participate in CSS activities, editorial positions, conference organizations, program committees, and standing committees. Women have been appointed and elected to the CSS Board of Governors and to the CSS Executive Committee. The accomplishments of women in the control systems community have been recognized through elevation to IEEE Senior Member and Fellow, CSS Distinguished Service Awards, appointments on journal and conference editorial boards, and the selection of women in the field to serve as plenary speakers at CSS conferences.

Little has been done to create a formal mentoring program for young women. More has been done in other fields, and Suzanne Lenhart spoke about programs supported by the AWM and the Society for Mathematical Biology.

The AWM, a nonprofit organization founded in 1971, seeks to encourage women and girls in the mathematical sciences. The association supports workshops for graduate students and post-doctoral fellows, travel and mentor grants, high school workshops, a mentor network (www.awm-math.org), and a regular newsletter. AWM has 4,000 members and numerous student chapters.

AWM workshops are held twice a year, at the AMS/MAA annual meeting and at the SIAM annual meeting. These workshops showcase the work of young women mathematicians and provide career advice. Participants are matched with mentors for the duration of the conference. The mentors provide career advice and constructive feedback on presentations.

In addition, a panel discussion or career minisymposium is held on a particular topic. Topics covered in past workshops include balancing career and family, visiting and post-doc research opportunities at institutes, proposal writing advice, preparing papers for publication, industrial and academic career advice, receiving tenure, and becoming a manager in a technical field. The topic for the SIAM 2004 meeting in Portland, Oregon, is on preparing for leadership positions.

Acknowledgments

We thank all the participants who traveled to the conference to join in the conversation, Frank Lewis and other CDC 2003 organizers for their excellent organization and support that helped make the workshop possible, and Linda Bushnell for her generous assistance in preparing for this workshop. Warm thanks go to Dr. Vasundara Varadan of USA NSF for making a special trip to speak at this workshop and to Dr. Suzanne Lenhart for helping build bridges between IEEE CSS, AWM, and SIAM.

This workshop was an attempt to understand and appreciate the challenges facing the female members of our Society. We invite ideas and participation from all CSS members.

—Molly H. Shor
Oregon State University

It's not every day that a control innovation appears on a postage stamp... If you look very carefully you can spot the most visible of all control innovations. Often mistakenly attributed to the Scottish engineer James Watt, the rotating speed governor was developed for windmills and adapted in 1788 by the millwright John Rennie, who was hired by Watt to install steam engines at a corn mill in London. The dynamics of governors were subsequently studied by the renowned scientists Airy, Foucault, Lord Kelvin, Siemens, Maxwell, and Gibbs.