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Fall 1986

# Quarterly Report

## Spoiled Food and Related Dilemmas

"Does your chewing gum lose its flavor on the bedpost overnight?" This line from an old-fashioned ditty indicates a modern problem, one that food, medical, and agricultural scientists may be much closer to solving with new advances in biotechnology.

The problem is food losing its flavor or freshness, and it extends to drugs losing their potency and agricultural pesticides waning in effectiveness shortly after application.

One solution, say many scientists, including Marcus Karel from MIT's Department of Nutrition and Food Sciences, is to control the release of flavor so that flavor does not escape prematurely during food processing. Likewise, timed delivery of a drug into the system or pesticides into the environment would allow these agents to perform when and as needed, perhaps over a period of time rather than in an initial spurt-and-die phase. Additionally, a drug could be targeted to the specific organ or cell needing treatment.

To build such controlled-release systems, Karel and colleague Robert Langer from MIT and the Children's Hospital Medical Center in Boston, are looking at biopolymers. These natural compounds—many come from the sea—have no harmful side-effects, are readily available in large quantities, and have a wide range of properties which make them flexible for varied uses.

Flea collars, time-release drug capsules, and the Shell No-Pest Strip introduced consumers to the idea of timed release. Like many others, the controlled-release factors in these products are based on artificial polymers, which have limited application because they are not as flexible as natural (bio-) polymers and are not always safe for human consumption. Biopolymers on the other hand have a long history of human use; civilizations have grown up on diets of seaweed, from which come the important biopolymers carrageenan and agar.

Polymers control the release of substances in three principal ways. The substance can be entrapped within the pores of the biopolymer, escaping gradually; the biopolymer forms a barrier around a reservoir of the substance, through which the substance diffuses gradually; or the polymer in which the substance is encapsulated slowly erodes, permitting measured release.

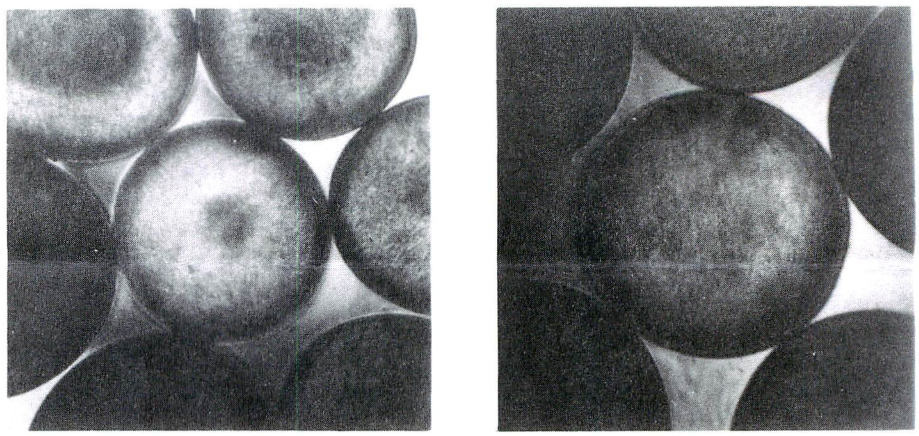

Figure 1. Microcapsules containing myoglobin-filled liposomes.
Left: before sonication. Right: after sonication

A good exercise in imagination is to contemplate the possibilities for using controlled-release systems. Take, for example, chewing gum. Your favorite flavor could be stored up and released fresh when chewed, renewed with each chew. Gum would not turn stale on the drugstore shelf nor peter out after a half-hour of enjoyment. Leaven could be released only at a certain stage during baking, when a temperature or pH change occurs. Preservatives, which are most effective on the surface, could be prevented from diffusing into the bulk of the food. How about encapsulating a Vitamin C or iron supplement to protect them from contact with other compounds to which they are sensitive?

Karel, who specializes in applications of controlled release to the food industry, is experimenting with marine biopolymers to stabilize food additives such as preservatives, sweeteners, flavors, colors, or nutrients. Since these tend to decompose over time or when exposed to heat, they cannot be processed if heat is involved.

Stabilization may be accomplished by encapsulating the additive to protect it from other compounds in the food which might react with it. Alternatively, a microenvironment can be created within the capsule which stabilizes the additive. For example, an electrically charged marine biopolymer such as carrageenan could maintain a low pH within the capsule.

Karel is also interested in speeding up the aging process in cheese. Cheese can take over a year to mature, necessitating expensive storage under controlled conditions. Aging happens as enzymes react with flavor precursors (proteins) in the cheese. However, the enzymes will "attack" any protein in the cheese, not just the flavor precursors. Much enzymatic energy is wasted. Karel suggests isolating enzymes and flavor precursors together in marine biopolymer capsules, where they can react and then diffuse through the biopolymer wall into the cheese. One scientist predicts that cheddar cheese, for example, could be ready for market in two or three months

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rather than the eight or nine months required now.

Medically, the advantage of controlled release is not only continuous drug delivery, but since waste is minimized by timing the delivery, the dose can often be drastically reduced. For instance, a contraceptive which continually releases estrogen can be inserted in the uterus or vagina. By releasing the estrogen locally rather than orally, the dose can be decreased up to 1,000 times. Antigens (for allergies), antibiotics, antidepressants, and insulin are other examples of drugs which are best administered continually to the system, rather than through a peak-and-valley delivery.

Langer, who specializes in the medical applications of controlled-release systems, is experimenting with pulsed drug delivery. He and associates Dr. Margaret Wheately and Professor Herman Eisen from MIT's Department of Biology, entrapped a protein, myoglobin, inside liposomes, which can be made sensitive to, for instance, detergent, sonic energy, temperature, or pH. The liposomes were then placed in a marine biopolymer microcapsule (Figure 1). This isolated the liposomes, which have side effects, from the body. Two factors could thus control the release of the protein: escape from the liposomes and diffusion through the polymer wall.

To achieve pulsed delivery the liposomes were treated with either sonic energy or detergent. The first pulse began immediately and delivered myoglobin for seven days; a second pulse started 18 days after the start of the experiment and lasted 30 days. Temperature-sensitive liposomes might be useful in response to fevers, and pH-sensitive liposomes could be triggered in different areas of the gastro-intestinal tract or at sites of inflammation.

In agriculture, although pesticides and fertilizers account for 60 percent of U.S. food production, these chemicals can cause serious contamination, and the standard application procedure—spraying—results in tremendous waste. What if pesticides could be encapsulated to protect them from environmental degradation, and released only on contact with soil or foliage?

"We are exploring what kinds of different control systems we can develop, rather than developing one specific system," Karel says. Once this question is established, he adds, he hopes to get industrial support for specific applications. ■

## Sewage Disposal: The Ocean Choice

Today in the U.S. 170 million people will send 23,000 tons of pollutants to 15,000 municipal sewage treatment facilities. By 2000, those numbers will grow with 248 million people sending 41,000 tons of pollutants to more than 21,000 treatment plants per day—at a cost of $110 billion. The waste problem began in the late 1800s when people left the countryside to congregate in cities near new job opportunities. Modern sanitary practice, or environmental engineering as we call it today, evolved between 1900 and 1930. Since that time, there has been little technological change beyond refinement of existing techniques.

What has changed substantially in the last 25 years is the increase in state and federal regulations. Funds accompanying environmental rules have been spent to increase the size and number of local treatment plants. Regulations spawned by new environmental concerns led to the development of biodegradable detergents and low phosphate household cleaners. As a result water quality in this country has improved. Typhoid and cholera are diseases of the past and polluted areas closed to swimmers and fishers have reopened in many areas. Still, the ever increasing volume and complex content of wastes raises concerns.

To help deal with these concerns Sea Grant asked 15 experts to recommend how to improve future waste management procedures, especially those governing ocean disposal. The papers, first presented at the Fifth Annual MIT Sea Grant Lecture and Seminar, have been published in a report, *Public Waste Management and the Ocean Choice.* The authors approach waste management from the assumption that if persistent toxics are removed at the waste source, then ocean, land, and air disposal are equally safe.

Thomas Jorling, professor of environmental science at Williams College, makes the most radical recommendation. Jorling notes that a global community of eight or more billion people who have ever increasing expectations cannot afford to throw anything away. Jorling emphasizes the need to "free our imaginations to do things differently" by recycling "all manner of things including batteries, paints, chemicals, metals and plastics." He is not alone in suggesting reuse of resources as a method for containing the enormous proliferation of waste materials.

Cecil Lue Hing, Research Director for the Chicago Metropolitan Sanitary District, in a review of treatment technologies and water quality standards, notes that there are some cities in the U.S. which do recycle the two main products resulting from current treatment practices—water and sludge. Until recently, sludge was used as landfill, but a shortage of sites and citizen concern about groundwater pollution have curbed this practice. Reprocessing the sludge into a soil conditioner has offered a profitable alternative. For some western communities, like Fountain Valley, California, water shortages can be met by recycling cleansed effluent for irrigation, recreation, and industrial purposes. Unfortunately, according to Hing, of the hundreds of millions of gallons of water used in this country only two percent goes through this recycling process.

It appears that substantial recycling of most materials in the U.S. is years away, while disposing of society's leftovers remains a real and critical problem. The oceans offer an inviting solution to heavily populated coastal communities. According to many scientists and engineers, including authors in this book, effective dispersal of sewage wastes is technically feasible. However, most of the authors like William Gaither, a member of a National Research Council task force on ocean disposal, believe that to minimize environmental harm "the importance of a carefully planned and diligently executed monitoring program cannot be overemphasized." According to Gaither and several other authors, public education and participation in the decision making process is critical to

*(please turn to back page)*

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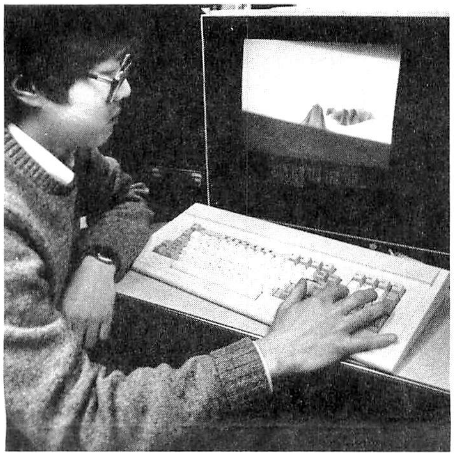
## *MIT Lab Profile*

# Where Outer Space Meets Deep Sea



Graduate student Ken Chin works in the Man-Machine Systems Lab on a simulation of the seafloor, part of a comprehensive simulation of an undersea vehicle. Photo by Donna Coveney

On a computer screen in MIT's Man-Machine Systems Laboratory (MMSL) an underwater vehicle crawls in and out of the maze-like underwater members of an offshore oil rig. It is a vehicle simulator, valuable for training operators of underwater robot vehicles, for mission planning, and pretesting operator-to-vehicle commands onsite.

More and more remotely-controlled vehicles will substitute for humans in the hostile environments of outer space and the deep ocean. Improving the control of these vehicles is why Thomas B. Sheridan founded the MMSL in 1959.

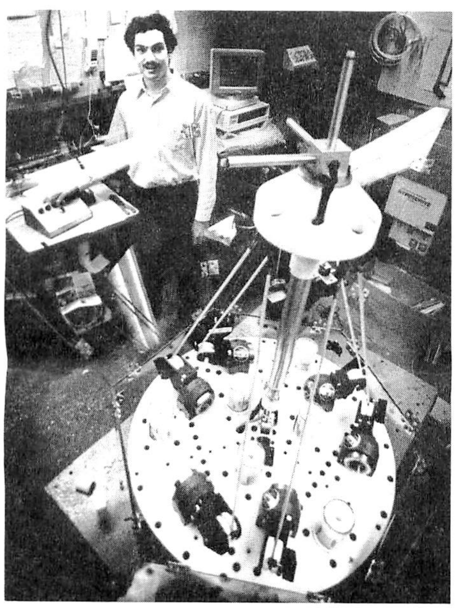
Supervisory control is human reasoning teamed with computer computation to control complex systems such as a remote robot vehicle. On his office blackboard Sheridan sketches a person operating a control-room computer, which signals another, remote computer aboard an aircraft or undersea vehicle. The remote computer directly controls some function of the vehicle, such as a manipulator.

Supervisory control solves the problem of humans working in the space and undersea environments by replacing them with robot vehicles, and it augments a person's ability to control the vehicles accurately and efficiently with the help of computers.

Most engineers would attribute the development of supervisory control to the MMSL. Here space engineer meets undersea engineer in the application of supervisory control to these two strikingly similar frontiers.

Strong parallels exist between control problems encountered in space and underwater, says Sheridan, yet there typically is not much communication between engineers working in both fields. In the Man-Machine Systems Lab, on the other hand, there is little distinction between the two areas of research. The underwater vehicle simulation, for example, could just as well, with adjustments, simulate a space vehicle.

On another computer screen in the small lab crammed with computers and robot-like apparatus, a manipulator grabs an object and attempts to fit it in a slot. Watching, an engineer operates the controls which move the manipulator. The engineer is working to solve the time delay between signals generated on earth to destinations in space. The delay, caused by the limited speed of light and the time for computers to relay information, may only be a second or two. But it is enough to cause instability in the control system.



PhD candidate Sam Landsberger demonstrates his new concept for a parallel-link manipulator, with motors clustered at the base. Photo by Donna Coveney

Time delay is one of many control problems that need to be solved before robot vehicles will become satisfactory remote workers. The solution being pursued in the MMSL is a computer model that anticipates the reaction of a space vehicle to a command from earth. The model immediately displays the anticipated reaction on a computer screen, allowing the controller to continue without waiting for the actual reaction to occur.

Half of the supervisory control equation is software, half is hardware. In the basement of MMSL, a young engineer with a joy stick demonstrates his radical new design for a parallel-link manipulator which concentrates the motors at the base rather than along the arm. The machine jerks back and forth with remarkable speed and force.

Manipulators are the working arm of the robot vehicle. They clean parts, tighten valves, or connect pieces on a space or undersea structure. Ultimately they want to do what a human arm and hand can do, only more. They must be extra strong, flexible, fast, and easy to operate. Sheridan thinks that the parallel-link design can achieve much better speed, stability, and mobility than conventional designs, less expensively (see *Quarterly Report,* Summer 1985).

Meanwhile, out in the real world of Boston Harbor, MMSL's own underwater vehicle, SEAGRANT I, dives, surfaces, dives again, preparing to field-test new hardware and software concepts such as the parallel-link manipulator and a novel touch sensor based on fiber optics. Donated by the founders of Perry Offshore, Inc. and supplemented by computers from AT&T and a low-light-level camera underwritten by Sargeant Industries, the vehicle entered the water for the first time in June 1985 and has since been undergoing improvements both in and out of the water.

Although space and undersea research constitute the bulk of Man-Machine Systems Lab work, another natural application of supervisory control is power plants and industrial processes. Testing a researcher's method for detecting potential system failures, for example, a computer in the MMSL is connected to the main computer at Boston Edison's Mystic I power plant, which supplies most of Boston's electricity. The lab's computer monitors signals from the power plant to anticipate whether something is malfunctioning.

Sheridan says the lab has only touched "the tip of the iceberg" in the field of supervisory control. "There is still a lot of mileage left in the idea of people and computers collaborating in industry, medicine, transportation, and education," he thinks. ■

sound waste management and monitoring is a cornerstone of public confidence in disposal system safety.

Philip Gschwend, associate professor of civil engineering at MIT, and Robert Eganhouse, assistant professor in the Environmental Science Program at the University of Massachusetts, are two scientists who have carried out research to improve monitoring techniques. Gschwend believes that he and others have made great progress in understanding how major natural processes govern the fate of waste chemicals. But still, he says, no one really can predict how these processes, such as volatilization, sorption, bioaccumulation, thermochemical transformation, photochemical reactions and biological degradation, cause or mediate change. He suggests quantifying the agents and ingredients governing individual coastal processes as an essential next step to develop improved models. The obstacles are considerable.

Eganhouse, whose interests lie in biogeochemistry, points out that municipal effluents are an exceedingly complex assortment of substances from many human activities and products. In fact only 10 to 15 percent of the organic constituents have been identified. The vast majority are either high molecular weight or are so complex that they are difficult to separate and analyze. The development of waste specific tracers and markers may be one way of evaluating what becomes of waste materials as they decompose in a seawater environment.

Environmental monitoring is expensive and hard to fund with government budget reductions. William Lahey, an expert in environmental law, proposes a fee system resembling that used by many European countries to scrutinize disposal practices and regulate air, land and water pollution. The disposer pays a fee based on volume, composition, and disposal location. The fee, used for scientific monitoring, keeps baseline information current and regulations relevant. In the long-run, the charge creates an economic incentive to improve waste processing and encourage recycling. Lahey suggests that communities use new mediation and negotiation techniques to resolve conflicts and achieve creative and more stable solutions for waste management. To order copies of *Public Waste* [illegible] *the Ocean Choice,* retur[illegible] ert in this *Quarterly Rep*[illegible]

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# Abstracts

## ☐ Public Waste Management and the Ocean Choice

Keith D. Stolzenbach
Judith T. Kildow
Elizabeth T. Harding, eds.
MITSG 85-36 280 pp. $15

Although extensive documentation indicates that the oceans can assimilate large volumes of sewage, sludge, and dredge spoils, there is also evidence that in a few cases environmental thresholds have been reached. Today, the public demands greater assurance that the oceans and coastal waters are not seriously degraded by future waste disposal.

This volume examines these issues and places ocean disposal within the context of other waste management options. Theory is blended with practice drawing upon scientists and public and private sector interests. Experience and planning in Philadelphia, Chicago, and New York illustrate the technical, economic and institutional aspects that communities face in disposing of their wastes.

The papers were presented at a symposium, "Ocean Disposal of Public Wastes: Technology and Policy for the future," in April 1985 at the MIT Sea Grant College Program Annual Sea Grant Lecture and Seminar Series.

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## ☐ Wide Bandwidth Positioning Systems for Space and Underwater Vehicles

Homayoon Kazerooni
Thomas B. Sheridan
MITSG 85-34 15pp $4

Remotely operated underwater vehicles sometimes must attach themselves to an underwater structure to employ manipulators and other tools for inspection, cleaning and repairing tasks. The interaction of classical control and the constraining attachment systems can result in high forces and possible destruction of equipment. To attack this problem, a general technique known as impedance control has been developed. In this report, the concept has been extended to include constraints as a special kind of external load. Thus, it is shown that the controller can be built to work safely with systems having constraints or attachment mechanisms which severely limit motion.

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## ☐ A Robust Design Method for Impedance Control of Constrained Dynamic Systems

Homayoon Kazerooni
MITSG 85-35TN 140pp $14

This report, which complements MITSG 85-34 (above), provides considerable detail on the extension of impedance control to include constraints as a special kind of external load. The research reported shows that a controller can be built to work safely with systems having constraints or attachment mechanisms which severely limit motion.

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## ☐ A New Design for Parallel Link Manipulators

Samuel E. Landsberger
Thomas B. Sheridan
MITSG 85-16J 3pp No charge

This paper describes a new manipulator arm configuration in which six degrees of freedom are obtained through one passive compressive spine and six active tension cables, all position controlled in parallel. The design has the advantage that all motors can be mounted at the base, the mass of the arm can be reduced greatly with greater rigidity and speed, and in contrast to conventional designs the inverse Jacobian required for control is easy to calculate. Reprinted from IEEE International Conference on Systems, Man & Cybernetics (1985), Tucson, AZ.

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## ☐ Directory of MIT Sea Grant Program Publications

Susan Stolz Goldie, ed.
Vol. 1, 1970–1977 MITSG 78-6
Vol. 2, 1978–1986 MITSG 86-11
No charge

Since 1970 the Program has issued a variety of publications on marine-related research and the use of ocean resources. The reports cover the range of Sea Grant research: coastal processes, coastal zone management, ocean mining, alternative energy sources, fisheries, marine biology and biotechnology, pollution, and ocean engineering, including offshore structures and underwater vehicles. Author, subject/title, and numerical indexes are included.

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## ☐ Tracing and Modeling Pollutant Transport in Boston Harbor

Richard F. Kossik
Philip S. Gschwend
E. Eric Adams
MITSG 86-16   227 pp   $5

The harmonic finite element circulation model TEA and the Eulerian-Lagrangian transport model ELA were modified and applied with high spatial resolution to Boston Harbor. The applicability of a number of volatile halogenated organic compounds as tracers in coastal waters was investigated, and complementary tracer experiments were carried out. The transport model was then calibrated to the tracer measurements in order to evaluate model behavior and investigate physical and chemical transport processes in the harbor.

Model simulations agree well with measurements, and calibrated parameters have physically realistic values. Comparisons with observations indicate that the models adequately represent the major processes acting in the system, and further validation efforts are justified.

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## ☐ Static and Fatigue Analysis of Multi-Leg Mooring System

Michael S. Triantafyllou
Antoine Bliek
Hynkyoung Shin
MITSG 86-21   75pp   $5

The report describes all theoretical developments for evaluating the fatigue life of multi-leg mooring systems. It is a continuation of previous, detailed research on the statics and dynamics of a mooring line. In the previous work, the authors concluded that the quasi-static approach to cable design becomes increasingly inapplicable in deeper waters, since the dynamic tension, although caused by small amplitude motions, is as important as the quasi-static tension caused by the large amplitude, slowly varying excursions of the vessel. This creates the distinct possibility of cable fatigue. One major decision was made at the beginning of the present study: drag nonlinearity was to be linearized stochastically and the cable dynamic code was to employ frequency domain techniques by iterating with respect to the nonlinear drag effect until convergence was achieved. This decision led to the development of very efficient computational methods to treat the very complex problem of long-term cable fatigue.

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## ☐ Citizen's Guide to Sources for Marine and Coastal Information in Massachusetts

Susan Stolz Goldie, ed.
MITSG 86-6   131pp   No charge

The 1986 edition lists more than 135 Massachusetts agencies, information centers, and organizations concerned with coastal affairs. Each entry includes office hours, address, and telephone numbers, as well as a brief description of the objectives, specialties and services of each organization. A subject index provides easy interest-group reference.

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