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ANNUAL RESEARCH REVIEW

A Look into the Future...

THE FUTURE OF Robotics and Control Systems

HOTTEST TOPICS: **Robotics and Control research is undergoing a renaissance spurred by new applications. One topic involves autonomous robots to replace humans in risky environments. Professors Linda Bushnell and Alex Mamishev are developing autonomous robotic systems, and Professor Mohamed El-Sharkawi is part of a group investigating autonomous swarms of robots for undersea applications (see page 9). Swarm robots with emerging behavior are of particular interest. Another hot research topic is the control and programming of self-assembling systems. Professors Eric Klavins, Karl Böhringer and Babak Parviz are exploring this topic, along with many faculty in the UW Nanotechnology Center. The underlying question is: What makes simple matter become complex?**

In the recent past, robotic surgery is beginning to be economically viable. This technology can provide better, less invasive surgical interventions for diseases. Remote surgery can provide better access to advanced medical care and specialists for people in remote locations. The application of telerobotics to surgery is driving major innovations in mechanization, control, and user interfaces. Haptic interfaces are being developed which will let people routinely touch and manipulate objects that exist only in the computer. This adds new realism and tactility (a "hands-on" quality) to training, entertainment, and appreciation of art such as sculpture. It will also enable new advances in computer-aided design. Professors Blake Hannaford and Jacob Rosen are developing new techniques and devices for haptic interfaces and telerobotic surgery. Professor Howard Chizeck is exploring the effects of randomly varying communication delays on these systems.

Professors Deirdre Meldrum, Mark Holl and others are involved in the applications of automation for genomics and proteomics (see page 23). In work building on the same technology base, Professor Chizeck is applying methods of systems and controls engineering to the analysis and design of cellular processes. This work concerns genetic circuits for intracellular sensors of metabolites in single living cells.

IN THE NEXT DECADE: **Significant improvements in the efficiency of DC motors, new magnetic materials, superconductors and similar advances will make miniaturized robots and haptic devices possible. A broad and useful class of programmable self-assembling structures or devices at the molecular scale will be developed. High fidelity multi-finger haptic devices will become available (currently these are mostly limited to one finger touching). Low cost and widely available haptic devices with open software tools will become available in portable and hand-held devices for better user interfaces in cell phones, gaming systems and entertainment devices. The need for light-weight and powerful actuators is a major obstacle.**

LONG RANGE FORECAST: **In the next 50-100 years, ubiquitous autonomous and networked robots will become reality. We will be able to program and build reliable, robust and high performance molecular machines, which will have profound implications to the treatment and cure of disease. We may achieve the (ethically and religiously challenging) ability to reprogram ourselves.**

ROBOTICS IN MEDICINE

PROFESSOR BLAKE HANNAFORD

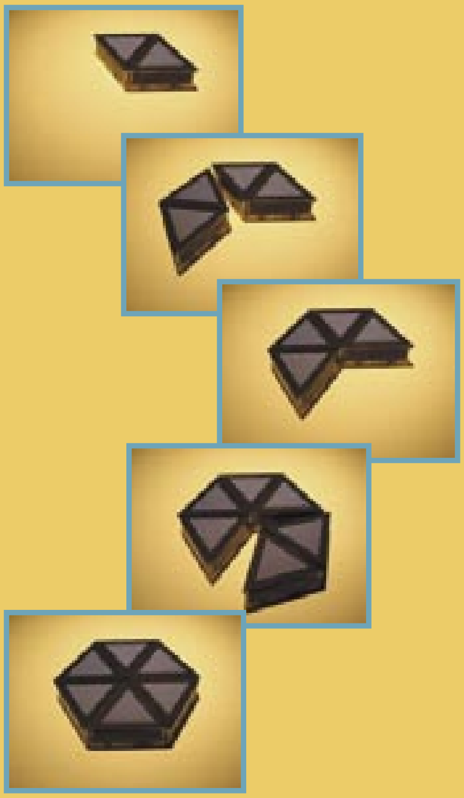
Today, one company (Intuitive Surgical Inc.) is marketing an FDA-approved robotic surgical tool. Always in the surgeon's complete control, two tiny (10mm) mechanical hands manipulate inside the patient through tiny incisions. So far, the "Da-Vinci" robot is mostly a new technique looking for a compelling application, but two procedures are starting to show promise in terms of achieving better results than manual surgical techniques. These are the radical prostate-ectomy (in which the prostate gland is removed from an incision in the lower abdomen), and certain pediatric procedures. In both of these applications, the tiny mechanized hands give surgeons extra dexterity inside tiny body cavities.

THE OPERATING ROOM OF THE FUTURE. THE ONLY HUMAN PRESENT IS THE PATIENT.

During the next five years, look for robotic surgical technology to establish footholds. Improved operations will set a new standard of medical care in terms of outcome, patient recovery time, and safety. Remote surgery will let a surgeon be thousands of miles away from the patient, operating via a high-speed network connection. Image compression technology will send HD quality video to the surgeon and tools will respond to hand motions. Applications include care of combat casualties on the battlefield, and delivery of state-of-the art healthcare to underserved populations in rural and remote areas.

In the next decade, surgical robots will be extensively integrated with medical imaging. The surgeon will have combinations of a video image of the patient precisely overlapped with MRI, ultrasound, and x-ray images. Cancer cells will be visible directly in the operative field and thus it will be easier to extract them while sparing healthy tissue, vital nerves and organs. All operating room functions will become part of the system so the patient will be the only person in the OR. Operating room cleanliness will consequently improve to the level of semiconductor clean-rooms. Advanced sensors, integrated into the tools, will give the surgeon haptic cues about the composition and pathology of tissues being touched. Patient-specific rehearsal systems will allow the surgeon to practice an unconventional procedure on a patient with unusual anatomy.

In the next few decades, although many forms of treatment will be dramatically improved, the need for surgery will persist in treating trauma, cancer, and resistant infections. After two decades of clinical experience, understanding of the basic sciences underlying surgery (like biomechanics, histology of tissue damage, wound healing and human factors) will advance to the extent that autonomous software will begin to take over the simple steps of surgery such as suturing, preparing, and closing the patient. The robot will become a smart assistant by monitoring the surgeon's performance and raising alerts when it detects signs of tremor, suggesting steps when detecting hesitation, and keeping detailed records of every manipulative step in the procedure. Within a century, surgery will have new roles in addition to its evolving role in trauma repair. Installation of artificial organs will create new challenges for life support. The shrinking of surgical tools might stop as molecular approaches are able to repair capillaries, neurons, and other distributed micro-structures. Low cost and highly networked robotic clinicians could be deployed in villages with populations as low as 100 - distributing high tech healthcare to billions of people. Finally, surgical systems with a great degree of autonomy may allow small groups of humans to be launched in space flights lasting decades aimed at colonization of other planets. **EEK**2005



SELF-ASSEMBLING ROBOTIC PARTS

Professor Eric Klavins has developed a testbed for self-assembling programmable parts (pictured above). Each part is capable of binding to other parts, communicating with the parts to which it is bound, and detaching from other parts. The parts rely on the environment for mobility; they float on an air-table and are mixed by overhead fans. Thus, all interactions between parts begin with chance collisions. A sequence of events resulting in self-assembly into a hexagon is shown.

The resulting dynamics are nondeterministic and concurrent. Many interactions may occur simultaneously and the order in which interactions occur is not determined. Therefore, each part is provided with a rule book (i.e. a graph grammar) that prescribes the outcome of each possible interaction. In this example, each part has a microcontroller that can store both a rule book and an internal state value. Each rule in the book is of the form L => R. If the internal states and local topology of a pair of interacting parts matches L, then the parts rewrite their states and local topology with R. It can be shown that a rule book can be designed so that the parts assemble into any desired structure. Rules that produce limit cycles (i.e. processes such as sequences of global shape changes) can be generated as well.