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ENG AM/MN 740

TERM PROJECTS IN INTELLIGENT MECHATRONICS

Some of these projects have been done before; some have never been done. They are offered only as ideas to guide your thinking as you come up with your own project proposal.

I. Lab Oriented Projects:

1. Design, Integration, and Testing of Novel Intelligent Systems. Ongoing research in the Boston University Intelligent Mechatronics Laboratory and many of the research projects described in this list require the design of novel hardware components, as well as the integration of software and hardware into novel systems. Currently, there is interest in controlled formation motions of mobile robots and the use of networks of distributed sensors. Several mobile robot platforms are now being evaluated—including the Palm Pilot controlled device shown in the figure below. Important features of these small mobile robots include low-power wireless communications capabilities (*Bluetooth*™, IEEE 802.11, etc.) and PDA-based user interfaces (as well as possible future interfaces with devices like smart phones). It is of continuing interest to provide enhanced functionality to these devices including:

- enhanced sensing capability,
- enhanced communication capability, and
- improvements to the programming environment and user interface.

We are also interested in sensor networks where devices communicate using low power wireless links. (See e.g. http://www.xbow.com/Products/productsdetails.aspx?sid=69.)

2. Control of Underactuated Mechanisms—The Case of Robots Bearing Dynamic Loads. A broad and interesting class of problems in robot control involves situations in which not every degree-of-freedom has an actuator. Such problems arise in many contexts—one of the most intersting being the case in which a robot is called upon to handle a large mass of dynamically active material, such as fluid sloshing in a container. The focus of this project is on the development of control strategies for rapidly but stably moving dynamic loads between prescribed locations.

3. Theory and Experiments in Sensor Fusion. Advanced robotic control systems will involve a variety of sensing devices whose concurrent operation will provide real-time data streams which must be carefully processed for use in feedback control implementations. The various sensors will operate asynchronously, will typically differ with respect to characteristic time constants, and may involve the synthesis of data streams from spatially distributed arrays of devices. A term project in this area might involve the following components: (i) Investigate important control theoretic issues in the use of multiple sensor technologies (especially emphasizing distributed sensors such as those described in Item 1 above and also the synergistic integration of information provided by qualitatively different sensing modalities—e.g. force and proximity sensing). (ii) Design a control system using hardware available in the B.U. Robotics Laboratory featuring inputs from multiple sensors. (iii) Design a set of experiments to illuminate important issues in sensor fusion.

II. Math Oriented Projects:

4. The Nonlinear Dynamics and Control of Rotating Mechanical Systems. Classical celestial mechanics has been concerned with complex dynamic interactions between gravitational and inertial forces due to revolution in multiple body planetary systems. Other very rich classes of interesting dynamics may be found in studying the vortex interactions around various solid and elastic structures and in the dynamics of complex man-made systems. Identify and study some particular class of systems (e.g. rotating kinematic chains or vortex motions around an aircraft body).

5. Computational Issues. For the planar 3–bar linkage considered in class, we have seen that there are two solutions to the inverse kinematics problem. How many solutions are there for the PUMA? How many solutions are there for a six axis robot with **no** zeros in the Denavit-Hartenberg table? How does geometry seem to affect this number, and why does Bezout's theorem give such misleading predictions? How much does the geometry and the presence of nonzero Denavit–Hartenberg parameters increase the run-time computational burden?

6. Group Theory and Robotics. At the beginning of the term, we'll see how the coordinate transformations of robotics were represented in terms of elements of $SE(3,\mathbb{R})$. $SE(3,\mathbb{R})$ is an example of a *Lie group*; this is a group on which there are defined notions of dimension and differentiation. Each of the three types of one degree-of-freedom mechanical joints (revolute, prismatic, and screw) corresponds to a type of one dimensional subgroup of $SE(3,\mathbb{R})$. Explore the structure of open and closed kinematic chains in terms of the structure of the various subgroups of $SE(3,\mathbb{R})$.

7. Design and Control of Kinematically Redundant Robot Manipulators. There are many advantages in developing robot arms with more than six degrees of freedom. (The human arm, for instance has seven degrees of freedom.) There are also interesting design and control issues. You may find it of interest to write a research/survey term paper on this technology.

8. Nonholonomic Path Planning. Certain mechanical systems move under the influence of velocity constraints which cannot be derived from pure position constraints. (Think of the motion of an ice-skate, which can only move in a direction aligned with the blade of the skate.) Such constraints are called *nonholonomic.* Study and write a paper on motion planning for robotic devices (wheeled robots, multifingered hands grasping smooth objects, etc.) whose motions are governed by nonholonomic constraints. Special cases of current research interest involve motion planning for robots carrying dynamic loads (See Topic 2 above.) and motion planning for groups (formations) of mobile robots. Identify and study interesting issues in the motion control of formations where the global and relative distance information available to each component agent is intermittent.

III. New Paradigms for Robotics:

9. Next Generation Robot Actuators. "The robot is willing, but the actuators are weak!" is a lament heard frequently among robot designers. Based on what you know about E & M, determine the fundamental strength limitations (as functions of size and weight) of the various standard DC motor technologies. Look into alternative forms of actuation (electro-static, etc.). Determine how the performance characteristics of various types of actuators scale with size; what are the most promising technologies for actuating micro-robots. Write a paper on your findings.

10. Biological Motor Control. The capability of movement has evolved along many different lines in the animal kingdom. For vertebrates and higher invertebrates, the control of movement involves coordination of complex actions at various levels in a hierarchy having muscles at the bottom and the neuro-cortex at the top. A complete understanding of motor control in such organisms is a goal that must be relegated to the distant future. For primitive animals such as one-celled organisms and simple invertebrates, however, it may be possible to develop a detailed theoretical understanding of the neuromuscular dynamics of animal motions. Indeed, a scientific literature on biological motor control in a number of simple creatures now exists. An interesting term project could be done on the theory of motion for an appropriately selected animal.

11. The Behavior of Braitenberg's Vehicles. The simple "vehicles" described in *Vehicles* by Valentino Braitenberg (MIT Press, 1984) move according to simple kinematic laws, but their motions may be quite complex. Write a set of computer programs to graphically simulate the behavior of some of these vehicles.

12. The Sociology of Autonomous Entities, I. When autonomous entities (mobile robots, Braite-nberg-type vehicles, etc.) have the capacity to sense and react to each other, certain patterns of collective emergent behavior may be observed. At the most basic behavioral level, if some autonomous mobile robots with proximity sensors are required to move within a confined space, they may be expected to avoid each other as well as any obstacles placed in their paths of motion. They may in addition tend to produce apparently organized patterns of motion. Understanding when and how this might occur is a worthwhile goal of an AM/MN740 project.

In the book *Self-Organization in Biological Systems* (538pp by S. Camazine, J.-L. Deneubourg, N.R. Franks, J. Sneyd, G. Theraulz, and E. Bonabeau, Princeton University Press, 2001), a number of simple behavioral models are proposed for interactions of groups of biological organisms. The synchronous firing of fireflies, schooling of fish, flocking of birds, swarming of ants, etc. An MN740 project could consist of a detailed technical book report together with implementations of simulation models proposed in the book.

IV. Advanced Technologies for Robot Users:

13. Robot Graphic Animation Project. Many questions regarding the motion of a robot arm may be most easily answered by real-time graphical simulations. The importance of simulation tools has been widely recognized for a long time, but a great deal needs to be done in order for the potential of this technology to be realized. A possible AM/MN740 term project is the design of simulation software for some interesting class of robotic devices. (By interesting, I mean there should be more than just a single serial manipulator like the MERLIN, PUMA etc.) One could choose to study, for instance, manipulators in congested environments, mobile robots, multi-fingered robot hands, groups of interacting mobile robots or entities *a la* paragraph 12 above, etc. Think about the nature of the data which will be input to your program. A primitive motion simulator would have joint trajectories prespecified. More sophisticated programs would include motion planning algorithms.

A JAVA based web simulation would be of great interest this year, but a caveat to those choosing this as their term project is that the software they develop should work with virtually all current browsers.

14. Virtual Environments for Teleoperator Simulation. To a large extent, modern robotic technology is descended from the teleoperators that were built to manipulate hazardous materials in the early days of atomic energy R&D. Considerable ingenuity was (and remains) required to let the operator "feel" the dynamical effects of grasping and moving an object. The next challenge in teleoperator technology will be to design systems for manipulation of very small (micron) scale or very large (10m - 1000m) scale objects. Research is required to understand operator interfaces and human factors issues in this type of teleoperation. At one extreme (the realm of the very large), human operators will need to develop a feel for moving objects of very large inertia. At the small extreme, on the other hand, inertia is a completely inconsequential aspect of manipulation, while friction in various manifestations becomes terribly significant.

V. *Mechano-informatics* - The Interplay of Physics, Communication and Information Theory:

An almost completely unexplored research topic is the role of information and communication in the control of complex systems. Here are some specific suggested topics.

15. Problems in Communications and Information Processing in the Design and Implementation of Feedback Control. Study the effect of *latency* and other aspects of communications overhead in *Bluetooth*^{TM} and other wireless communications technologies. Take a benchmark undergraduate control-laboratory project such as stabilizing an inverted pendulum. For what parameter ranges (parameters being mass, inertia, and so forth) can we close feedback loops through *Bluetooth*^{TM} channels? How do data requirements depend in general on control system parameters?

16. Feedback Control Designs Using Bandwidth-limited Communications Channels. Device arrays of MEMS actuators such as micro-pistons and micro-valves are quickly moving beyond the "proof-of-concept" stage in which relatively small arrays, with between four and twenty actuators on a single chip, have been tested with each device in the array having direct communication by means of "wires" for both control and sensing. We have recently fabricated arrays with between 50 and 100 devices on a single chip, and these designs seem to have achieved more or less the maximum possible device density in which direct addressing of each actuator is feasible. In the next generation of device arrays, which will feature as many as 10,000 actuators on a single chip, it will be necessary to close feedback control loops using communication channels shared by multiple device elements. Work is only just now beginning on the switching and encoding strategies that will be needed to produce stable closed-loop dynamics across a broad spectrum of applications. We are finding that many of the bandwidth assignment issues that are predominant in managing the traffic in modern communications networks are also present in some form in networked actuator arrays. This project is to develop the elements of control and communications theory needed to assign channels and effectively encode and transmit actuator and sensor data over the links in a device network. Issues of multiplexing, addressing, and resource allocation will need to be addressed.

17. Communications Issues in Multiagent Systems. Previous MN/AM740 class projects have shown that multiagent systems (See Topic 12 above!) do exhibit self-organizing behavior when the agents have the sensory capacity to detect proximity to each other. Another project along these lines would be to study the effect of inter-agent information exchanges on group behavior. In keeping with Braitenberg's simple constructive approach to synthetic psychology, explore the changes in group behavior that occur if agents are capable of exchanging a limited amount of information (say one bit) every few (say five) clock cycles in your simulation.

18. Controlling Communications-enabled Swarms of Mobile Robots. *Bluetooth*^{TM} technology provides great flexibility in short range, low power communications. This 2.4GHz digital spread-spectrum wireless system has been design to provide "wireless connectivity made easy." While the technology supports communications at up to 100 meters, it is also envisioned to have a maximum range of 1-5 meters for very low power applications. A very interesting project would be to study the (supervisory) control of a swarm of robots which must provide high level feedback and communications using very low power transmitters and receivers (such as *Bluetooth*^{TM}). Some of the same issues arising in Topic 16 will be present here, but there will be additional latency issues associated with need to continually reconfigure piconets.

19. The Geometry of Motion Produced by Digital (Quantized) Actuation. Consider robotic systems in which each actuator's output can take on only a finite (and possibly small) number of values. Is there a nice theory of motion for such systems? How can they be used effectively in the *continuous* world? For mobile robots, as a case in point, what do "shortest paths" look like for a mechanism which can only be steered along curved paths with a small discrete number of turning radii?

20. Vison-Based Search and Surveillance Missions. There is now a fairly mature body of literature concerned with the problem of placing guards in an art gallery such that every point in the gallery is visible to at least one guard. (See, e.g. [1].) Under the assumption that the space in the gallery, its contents, and visual obstructions are rectangular polygons, upper bounds on the number of required stationary guards are given in terms of the total number of vertices of these polygons. This problem can be shown to be equivalent to finding a minimal covering of the gallery space by a set of star shaped polygonal regions.

Figure: In the polygonal idealization of the art gallery problem, guards must must be able to observe all of of a not necessarily simply connected space bounded by the sides of polygons. In this figure, we consider only rectangular polygons.

This project calls for research on a class of related problems which we refer to collectively as the mobile museum guard problem. The simplest of these problems is to find the shortest path a mobile guard can follow to inspect or observe the entire space.

REFERENCE:

1. J. O'Rourke. *Art Gallery Theorems and Algorithms*, Oxford University Press, 1987.

Project proposals (one page) due 1/28/04.