Virtual Shells for Avoiding Collisions within Large Groups of Mobile Autonomous Agents

A. S. Morse
Yale University

Current interest in underwater, ground-based, and airborne mobile robots of all types leads naturally to the following question. Is it possible for a large densely populated group of mobile autonomous agents to be configured to perform useful tasks {possibly without a leader} in a school, swarm or flock-like manner without sustaining vehicle collisions? The aim of this talk is to outline some new, promising ideas which may lead to an affirmative answer to this question.

Perhaps the simplest idea one can think of for regulating spacing between vehicles in a swarm or school is to subject each vehicle pair to a virtual force of repulsion which grows without bound as the "spacing" between the two vehicles goes to zero. There are many ways to implement this idea, some using forces of positive values only for nearest neighbor pairs. A problem with this direct approach is that it is based on point models and one is still left with the problem of translating these virtual forces into appropriate actuator signals consistent with the dynamics of the vehicle being controlled. In this talk we outline a promising alternative approach, stemming from ideas studied some time ago in the context of automated urban transportation systems which in effect replaces the intuitive but problematic idea of a "point model" with that of a "moving virtual shell model."

By a *virtual shell* in real 3-dimensional space is meant a closed surface of appropriate shape. Similarly, in real 2-dimensional space, a virtual shell is a closed, simply connected curve. In either case, virtual shells are regarded as rigid bodies of mass which move through their ambient spaces in response to suitably defined force fields. Force fields are devised to cause groups {e.g. swarms, flocks, schools} of virtual shells to accomplish a particular task. As they move, virtual shells may gently hit each other and obstacles, {much as billiard balls do on a pool table} but all such collisions are elastic.

Collision avoidance is achieved by requiring each vehicle to remain within its own shell for all time. This is accomplished with a low level motion control system aboard each vehicle which causes the vehicle to track the motion and orientation of a suitably defined reference frame attached to its shell. This control system would be designed using a detailed vehicle model and standard control techniques. Shell motion is determined primarily by inter-shell collisions and "virtual inter-shell forces" while vehicle motion is dictated by the motion of the reference frame being tracked and by the properties of the vehicle control system doing the tracking . The virtual shell thus act as a bumper, much like the bumpers on familiar bumper cars found at amusement parks. In this talk we will discuss various factors influencing the selection of shell shape including vehicle dynamics as well as complexity issues such as the ease of deciding when geometric surfaces of particular shapes intersect.

Since each autonomous agent {i.e., vehicle} is required to track its own shell, each must know at least the position and orientation of its own shell. But since shells interact with nearest neighbors, each agent must also be aware of the position and orientation of the shells of its nearest neighbors. Since shells are virtual, this points to the need for communications between nearest neighbors.

The preceding informally characterizes the first two levels of one possible type of multi-level hierarchy devised with collision avoidance as the primary objective. At the next level up would be a collection of rules or forces, perhaps derived from potential functions, aimed at achieving such things as desired spacings between shells, relative shell orientation, relative shell speeds.

At the highest level one envisions mission statements composed of sequences of tasks, initiated by humans and communicated in software. An example of a mission {in this case a single task} is for a group of mobile ground-based robots to surround a specified object with equal spacing between agents. In this talk we will discuss this example in detail for the case when the autonomous agents are three-wheeled nonholonomic, kinematic carts whose forward and angular velocities can be directly controlled. We will present simulations and perhaps experimental results which demonstrate the utility of the virtual shell concept which we are proposing.