Multiple, Cooperating, Simple Agents for the Area Coverage Problem

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INTRODUCTION

Many seemingly complex behaviors observed in animals are actually simple reactive behaviors to sensory stimulus. It is believed by many researchers that all motion in animals is activated by combinations of these low-level behaviors. Moreover, community activities, such as gathering in groups or cooperative searching for food has also been successfully demonstrated as using simple primitive behaviors. Many robotic tasks can be accomplished using the same types of simple reactive primitives.

However, the environment to which animals have adapted does not always map easily to "structural" types of robot tasks. For example, in robot floor vacuuming, the goal is to insure that the living room is completely swept while avoiding obstacles, pets, etc. While animals have adapted by evolution to robustly catch prey and avoid predators, they rarely exhibit behaviors that insure complete coverage of a local area. (In fact, extracting all the prey from a local area may not be in the best evolutionary interests of the animal since it would be eliminating the replenishing capability of a nearby food source.)

In this paper, we discuss our preliminary ideas about primitive behaviors that can be appended to animal-based behaviors, that may be used for floor vacuuming and other area coverage problems. The approach is to have a single sweeping robot that moves across the room from end to end. Two simple robots act as mobile beacons to find and demarcate the ends of a sweep path . We add a simple behavior to the beacons that cause then to move only a short distance to mark the end of the next path. The sweeping robot uses simple animal like tracking behaviors. We show our initial experiments in multiagent floor vacuuming and compare these results with other types of solutions.

FLOOR VACUUMING

In robot floor vacuuming, the goal is to insure that the room is completely swept while avoiding obstacles, pets, etc. In our work we focus on insuring that the area of the room is completely vacuumed in all areas that the robot can reach without moving furniture.

As additional constraints, we want to insure that the system is simple to operate. Therefore, there should be no "set up" procedures for the operator to undertake before the robot can adequately vacuum (i.e. I do not want to be personally responsible for setting up the robots for all my neighbors). This implies that the robot cannot be trained on a world model.

We also want to insure that the robot is as inexpensive as possible so that it is a viable consumer product (so I can afford to buy one myself.)

A secondary concern for our work is the speed of operation. If all the above constraints are met, then the better system will require less time to perform its floor vacuuming, (i.e. I can run the floor vacuuming robot while I'm at work or running errands.)

APPROACH

We propose to use a multiple robot solution to solve this problem which almost entirely controlled by object tracking. Object tracking is prevalent animal behavior (e.g. predators are adapted to find and home in on prey animals.)

The floor vacuuming experiment is an extension of our current Phaeton project in which we are investigating the control of mobile robot control using deictic primitives. We are investigating general purpose navigation and do not assume that the robot has any geometric environment and object information available. Each deictic primitive requires tracking of targets. For an inexpensive floor vacuuming system, we propose to use additional robots to serve as targets for a vacuuming robot. Our goal to show that deictic primitives can be used to solve area coverage problems without generating geometric world models.

To evaluate the results of our system, we have built a simulation to perform experiments in robot floor vacuuming. We have implemented three different types of floor vacuuming algorithms so that comparisons can be made.

Basic Robot Hardware

Because we want our robots to be inexpensive and low power, we assume that we have limited robot hardware, on board computation, and sensors. Our robot platforms are assumed to be omnidirectional and are therefore easily maneuvered around furniture and objects.

Active sensors, such as ultrasonic sensors, often are often unreliable in the home environment due to multipath and interreflections. Therefore, our robot is equipped with soft bumper sensors which can measure close distances. These bumpers cover the entire surface of the robot. We have developed an initial prototype of this bumper. This soft bumper is made of a soft foam material will not damage any furniture and could even collide with a small pet without damage (although as far as pets are concerned, even the author's rabbit is intelligent enough to get out of the way of a vacuum cleaner. Natural selection is recommended.)

We also want to include some type of beaconing system so in a multi-robot solution, each robot can determine the relative positions and orientations of the other robots. Infrared detectors and simple vision systems can be considered for this sensor.

EXPERIMENTS

We conducted several simulation experiments on a typical living room shown in Figure 1, that approximates the living room of the author. The dark gray areas represent furniture or other objects in the room. An arrangement of a sofa, end table, two chairs and a coffee table are at the base of the room. A corner cabinet and books shelves occupy the corners. The light gray are represents carpet that needs to be swept. This scenario is close in proportion to a typical living room.

Sweeping Pattern

Our first attempt at robotic floor vacuuming is a back and forth sweeping pattern. The size of the robot was chosen to be in proportion to the standard sized upright vacuum. This is the simplest of systems since the robot only requires bumper sensors. Initially, the robot is placed in the room facing a wall. The robot moves forward until it encounters an object. It then steps slightly to the right and moves backward across the room. This pattern is continued until the robot it cannot move to the right after both a forward and backward motion. At this point, the robot will turn 90 degrees to the left and continue.

Figure 2 shows a simulated result of this type of floor vacuuming motion in our example living room. The light gray regions show the floor area that was missed and the white area shows the part of the carpet which has been swept. Notice that in this example, because the robot was larger in size, it was unable to vacuum between the sofa and coffee table.

However this robot system also misses areas of the carpet that are accessible near the book shelves.

Random Movements

In this experiment, we included 10 smaller robots that have a simple random motion pattern. The robots can be set anywhere in the room and at any orientation. The robots move forward until they touch an object. At that point they change their orientation in a random fashion and begin a new forward motion.

As can be seen in Figure 3, the random motion robots do pretty well at vacuuming the carpet, however, there are areas that are missed. By using a random patter, we cannot guarantee that the robots will cover the entire surface area of the carpet.

Beacon Tracking

This system requires three robots cooperate to vacuuming the floor. The idea of the system is to have a vacuuming robot move back and forth across the floor similar to that of the sweeping system described earlier. To insure that the entire region is covered, two beacon robots are used in the system to mark the endpoints of the current sweep. Each of the robots have a very simple control algorithm.

The robot beacons remain still until the vacuuming robot touches them. Then they take one step along perimeter of the room working its way around furniture positioned against the walls. The beacons are placed against a wall, back to back, and track the perimeter of the room until they meet a the opposite side.

The vacuuming robot uses our tracking algorithm to navigate to a beacon robot. Once reaching one of the beacons, it will begin tracking the second beacon robot.

The results of our cooperative solution to floor vacuuming is shown in Figure 4. Notice that all accessible areas of the room were cleaned. Another feature of this algorithm is that a termination condition exists for the robots, unlike the sweeping and random algorithms presented earlier.

DISCUSSION AND CONCLUSIONS

Our initial experiments have shown that even simple robots can perform floor vacuuming at some level of competency. If total area coverage is not essential, then any of the presented systems are adequate, and therefore, either of the two initial approaches, simple back-and-forth sweeping and multiple random motion robots can be employed.

The multiple random robots have the advantage in that over time, most likely, all areas of the room will be swept. An issue with this approach is deployment and power. The distribution of power cords to randomly moving robots is currently impossible without altering the environment. (Even if power cords were hung from the ceiling, the robots would soon have the cords tangled and would be unable to navigate the area of the room.) Therefore all the robots must be battery powered. This can get to be expensive to purchase batteries (even if they are rechargeable).

The sweeping robot could probably be made to vacuum the entire room if an initial location were to be carefully selected (although this location is not obvious given inaccurate motions of the robot.) This system, if it only performs one pass could use an extracting power connection. Therefore this system would be adequate if only the major portions of the room need to be swept.

Our multiple, cooperating robots was the only system that was able to clean the entire room. This approach is promising for vacuuming and we plan to investigate this approach with more experimentation.

The largest challenge is to develop the sensors and algorithms for team robot localization. In the future, we will explore options for this function.

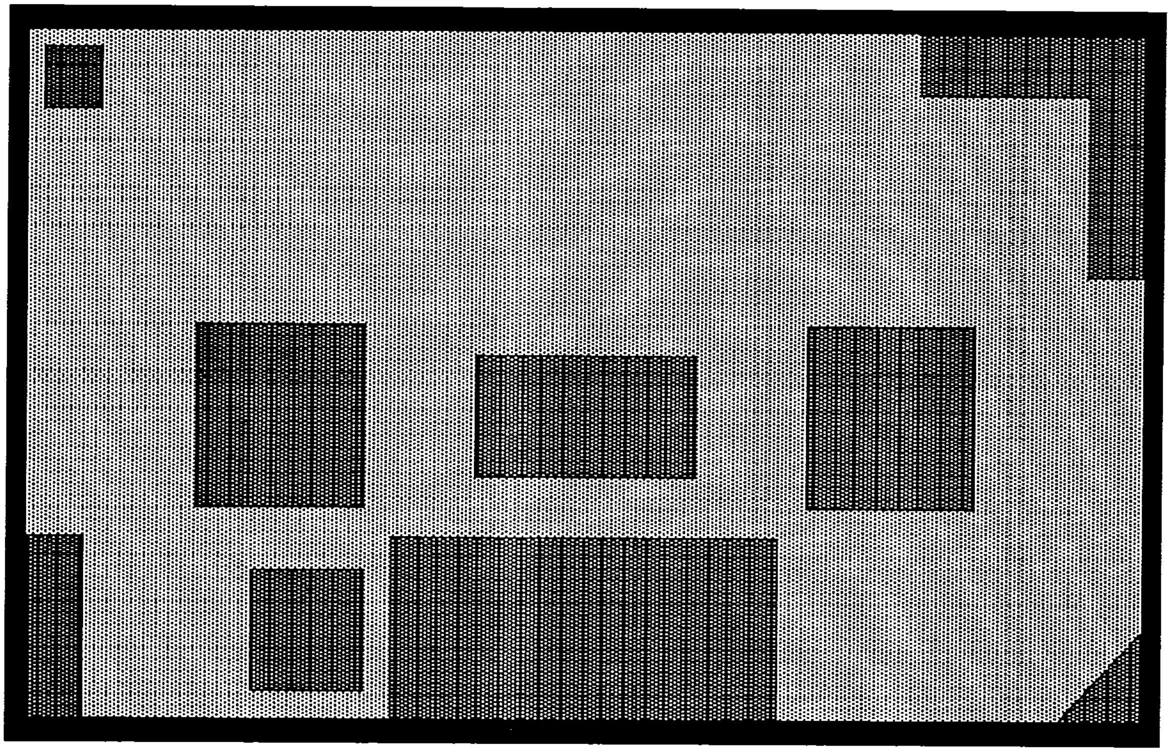

Figure 1: The layout of a living room that was used for our experiments.

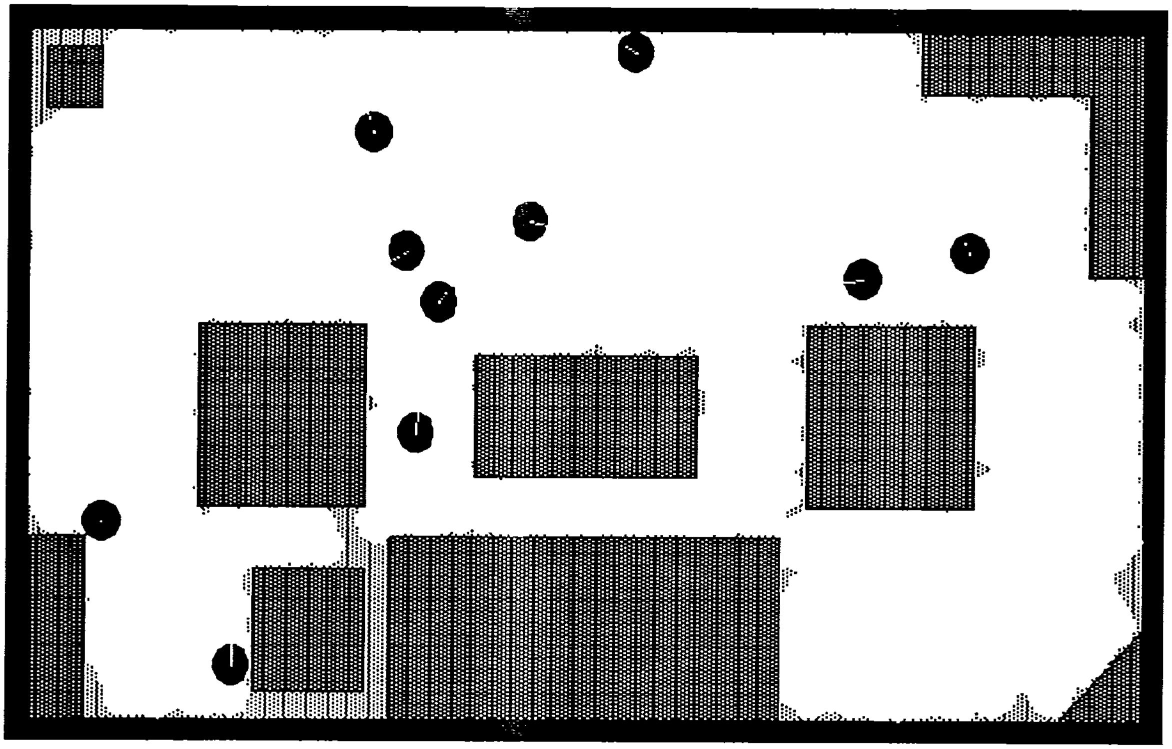

Figure 2: Results of using multiple robots which steer at random directions when they come in contact with obstacles. Notice that there small bits and pieces of the room that are not vacuumed.

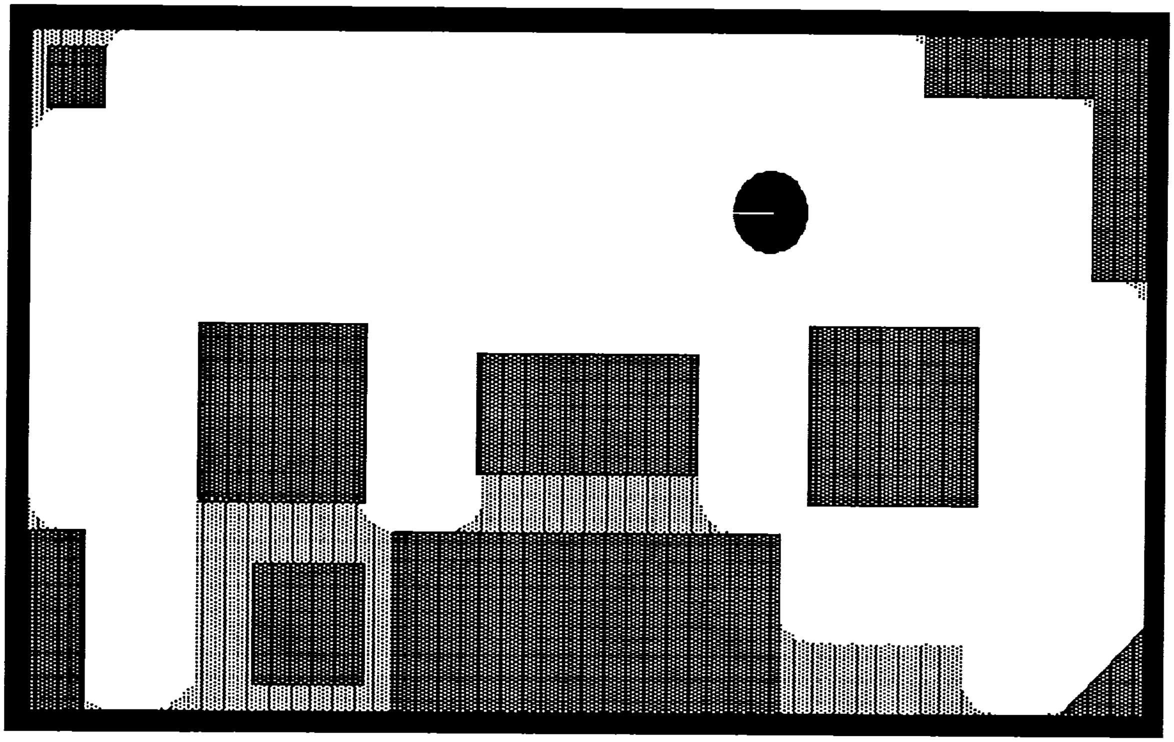

Figure 3: The result of a robot implementing a forward and backward sweeping pattern. Notice that there are sections of the room that are not vacuumed which are accessible to the robot. These different results were obtained by placing the robot at different starting locations.

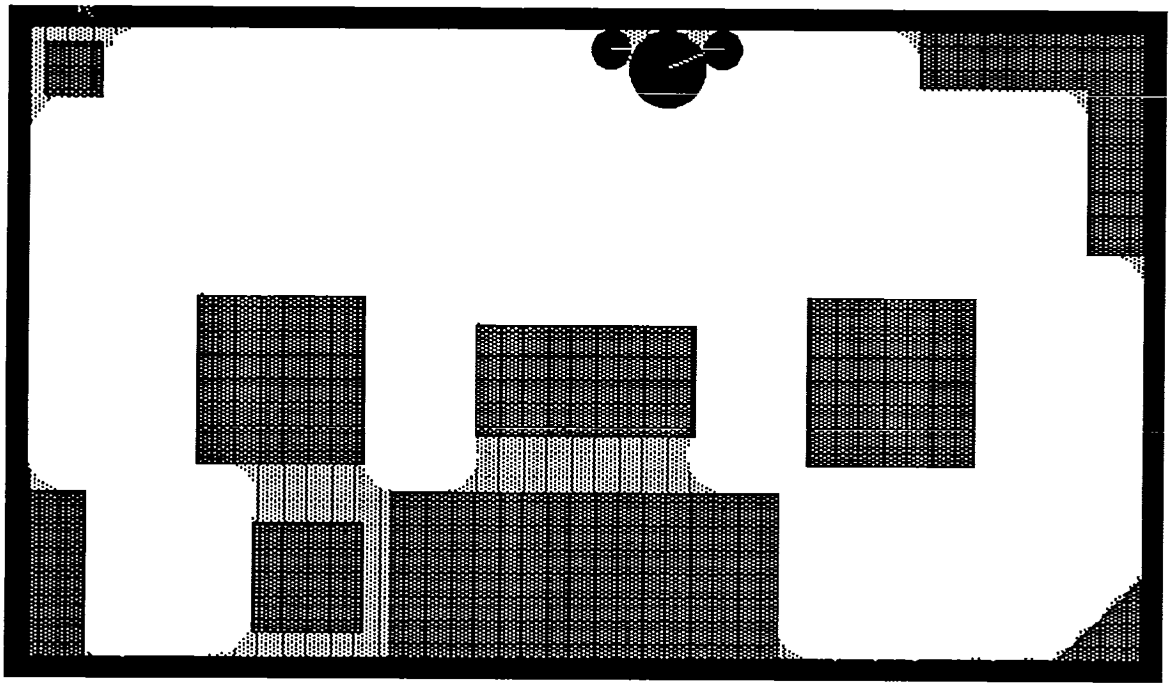

Figure 4: Results of a cooperative multiple robot solution. The two smaller robots serve as beacons and move in opposite directions along the outside of the room. The larger vacuuming robot moves from beacon to beacon. As can be seen in this case, the robot system was successful at covering the entire accessible area of the room.