COLLABORATIVE ROBOTICS

D. Ayyappaswamy, **Postgraduate**

T. Ravi Babu, **Professor**

P. Sridevi & N. Kalpana **Assistant Professor**

Department of Electronics and communication engineering

Miracle Educational Society Group of Institutions

Abstract:

This Paper provides an Overview of the Collaborative robots project, a robotics project sponsored by the future and emerging technologies program of the European commission. We describe the c-bot, a small autonomous project with self-assembling capabilities that we designed and built within the project. Then we illustrate the cooperative object transport scenario that we choose to use as a test- bed for our robots. Last we report on results of experiments in which a group of s-bots perform a variety of tasks within the scenario which may require self-assembling, physical cooperation and coordination.

1. INTRODUCTION

The main scientific objective of our research is the study of novel ways of designing and implementation self-organizing and self-assembling artifacts. We are particularly interested in approaches that find their theoretical roots in recent studies in collaborative intelligence (2).that is, in studies of the self-organizing and self-assembling capabilities shown by social insects and other animal societies.

Finally to implement autonomous reconfiguration and shape-changing activities when in collaborative-bot configuration. Also, a swarm-bot, once assembled, is not limited to a single configuration, but can change its shape while moving, according to its needs (as imposed by the user or by environmental constraints). From the control point of view, with the collaborative-bot we have pushed further the complexity of artifacts controlled solely by swarm intelligence techniques. To do so, we have exploited the integration of swarm intelligence with evolutionary computation.

Figure 1.The C-bot.

As already suggested, for example, by Martinoli [14]. We have used swarm intelligence principles to guide the definition of building blocks for the design and implementation of our self-organizing systems. We use evolutionary computation principles to guide the development of our c-bot controllers.

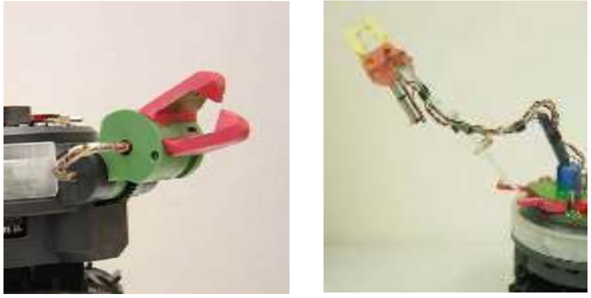
2. C-BOTS AND COLLABRORATIVE BOTS

S-bots are the basic elementary components of a swarm-bot. Each s-bot (see Fig. 1) is a fully autonomous mobile robot capable of performing simple tasks such as autonomous navigation, perception of the environment and grasping of objects. In addition to these features, one c-bot can communicate with other s-bots and physically connect to them, thus forming a swarm-bot (as shown in Fig. 2). A swarm-bot can perform tasks in which a single s-bot has major problems, such as exploration, navigation, and transportation of heavy objects on rough terrain.

The s-bot's innovative navigation system makes use of both tracks and wheels. Onemotor controls the wheel and track for a single side of the s-bot. The combination of the left and right side motors provides a differential drive system. This differential drive system allows efficient rotation on the spot due to the larger diameter of the wheels. It also gives the traction system a shape close to the cylindrical one of the main body (turret), thus avoiding the typical rectangular shape of simple tracks and improving the s-bot's mobility.

Figure 2. A Collaborative bot with a linear shape composed of four

The c-bot's traction system can rotate with respect to the main body by means of a motorized axis. Above the traction system, a rotating turret holds many sensory systems and two grippers for making connections with other robots. In particular, each c-bot is equipped with sensors necessary for navigation, such as infrared proximity sensors, light sensors, accelerometers and incremental encoders on each degree of freedom. Each robot is also equipped with sensors and communication devices to detect and communicate with other s-bots, such as an omnidirectional camera, colored LEDs around the robot's turret, and sound emitters and receivers. In addition to a large number of sensors for perceiving the environment, several sensors provide each s-bot with information about physical contacts, forces, and reactions at the interconnection joints with other s-bots. These include torque sensors on most joints as well as traction sensors to measure the pulling/pushing forces exerted on the s-bot's turret.



(a) (b)

Figure 3. (a) The c-bot rigid gripper. (b) The s-bot semi-flexible gripper.

Rigid bodies in 3 dimensions.1 Collaborativebot3d provides s-bot models with the functionalities available on the real s-bots. It can simulate different sensor devices such as IR proximity sensors, an omnidirectional camera, an inclinometer, sound, and light sensors. It provides robot simulation modules at four different levels of detail. The less detailed models are employed to speed up the process of designing neural controllers through evolutionary algorithms. The most detailed models have been employed to validate the evolved controllers before porting them onto real hardware. A full description of the s-bot's hardware as well as of the Swarm- bot3d simulation environment is available.

3. ANOVERVIEW OF THE EXPERIMENTAL RESULTS:

Over the course of the project we developed various controllers for the c-bots. These controllers were designed to enable the c-bots to perform tasks in the context of the experimental scenario described above. Inthis section we briefly summarize our methods and results.

To act successfully in the scenario, the s-bots must be equipped with controllers that allow them to successfully navigate in a totally or partially unknown environment in order to

Figure 4. A Collaborative bot composed of four c-bots in square formation passing over through

3.1 Coordinated motion

Coordinated motion is a basic ability required of a collaborative- bot. To allow the collaborative-bot to move, the constituent s-bots must coordinate their actions to choose a common direction of motion. This coordination is not self-evident, as each s-bot is controlled independently. The required coordination is achieved primarily through use of the s-bot's traction sensor, which is placed at the turret-chassis junction of an s- bot. The traction sensor returns the direction (i.e., the angle with respect to the chassis' orientation) and the intensity of the force of traction (henceforth called "traction") that the turret exerts on the chassis. Traction results from the movements of the c-bot's own chassis as well as the movements of other c-bots connected to it.

3.2 Self-Assembly

Probably the most characteristic capacity of the collaborative-bot system is that it can self-assemble; that is, move from a situation characterized by the activity of a number n > 1. Of c-bots to a situation in which these n c-bots physically connect to each other to form a collaborative-bot. To develop controllers capable ofletting c-bots self-assemble we used a perceptron-type neural network whose weights were evolved using an evolutionary algorithm (for more details see [7, 10]). These controllers were synthesized in simulation using up to 5 simulated s-bots and then ported to the real s-bots. In short, self-assembly works as follows. The start of the process is triggered by the presence of an s-bot which turns on its red lights. The s-bots which other or to an s-toy with red lights turned on (e.g., see Fig. 8).


(a) (b)

Figure 5. (a) Six c-bots at the start of a self-assembling experiment on flat terrain. (b) Two self-assembled collaborative-bot, each comprised of three c-bots, connected to the c-toy.

4. Cooperative Transport

Artificial neural networks were designed by artificial evolution to control the actions of a group of s-bots whose task was to pull and/or push a heavy object in an arbitrarily chosen direction. In this case, the s-bots could only interact through their physical embodiment to coordinate their actions during the approach and transport phase [9]. In a second study, we designed artificial neural networks to control a group of s-bots that had first to connect to the object and then transport it towards a target location. The best of the evolved controllers efficiently transported the object as required. Furthermore, these controllers proved robust with respect to variations in the size and shape of the object they had to transport [8].We also studied [10] the situation in which some s-bots were able to locate the transport target, while the others (called blind s-bots) were not. To enable a blind s-bot to contribute to the group's performance, it was equipped both with sensors to perceive whether or not it was moving and sensors to detect the traction forces acting between its turret and its chassis. For group sizes ranging from 2 to 16, it was shown, in simulation, that blind c-bots make an essential contribution to the group's performance.

The controllers for cooperative transport have been ported and validated on the real c-bots, using groups of up to 6 c-bots (e.g., see Fig. 9). In the experiments involving blind c-bots, it was verified that the blind c-bots do not be- have disruptively. On the contrary, it was shown that they can make an essential contribution to the performance of the group. The same controllers also proved successful at transporting the object over various types of rough terrain. Furthermore, the controllers also enabled the collaborative-bot to navigate over terrain with holes in it. (Some of these holes were sufficiently large that they defeated even a chain of two c-bots)

5. Ongoing Work:

5.1 Adaptive task location

Task allocation and division of labor are two important research areas in collective and swarm robotics. Previous studies have shown that an increasing group size does not necessarily implies an increase in the efficiency with which a collective task is performed [19]. However, inherent inefficiency of large robot groups can be avoided if such large groups are equipped with an adaptive task allocation mechanism which distributes the resources of the group based on the nature of the task and the diversity among the individuals of the group. In our research we are obviously interested in designing an adaptive task allocation mechanism which allocates a sufficient number of s-bots to each task, with- out reducing the efficiency of the entire group. In particular, we have been working on a mechanism which adaptively tunes the number of active robots in a foraging task: that is, searching for objects and retrieving them to a nest location. The robots, controlled by a behavior-based architecture, use a simple adaptive mechanism which adjusts the probability of each robot being a forager based on the current success rate of the individual in carrying out the task. As a resultOf this simple adaptive mechanism, a self-organized task allocation is observed at the global level.

6. Conclusion:

In this paper we have illustrated the most important features of a novel robot concept, called a collaborative-bot. A collaborative-bot is a self-organizing, self-assembling artifact composed of a variable number of autonomous units, called s-bots. As illustrated in Section 2, each s-bot is a fully autonomous robot capable of displacement, sensing and acting based on local information. Moreover, the self-assembling ability of the s-bots enables a group of them to execute tasks that are beyond the capabilities of the single s-bot.

Hardware versatility and robustness is ensured by the presence of many autonomous entities which can assembly into a single body and disassemble back into disparate elements as required. Because of this self-assembly/disassembly capability, supported by a great number of sensors and actuators, the collaborative-bot is more versatile than other robotic systems composed of small elementary units capable of reconfiguring themselves.

In the development of the c-bot controllers, extensive use was made of artificial neural networks shaped by evolutionary algorithms. The solutions found by evolution are simple and in many cases generalize to different environ- mental situations. This demonstrates that artificial evolution is able to produce a self-organized system that relies on simple and general rules, a system that is consequently robust to environmental changes and that scales well with increasing numbers of c-bots.

7. References:

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