SWARM-BOT: A Swarm of Autonomous Mobile Robots with Self-Assembling Capabilities

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We present a new robotic concept, called SWARM-BOT, based on a swarm of small and simple autonomous mobile robots called S-BOTs. S-BOTs have a particular assembling capability that allows them to connect physically to other S-BOTs and form a bigger robot entity, the SWARM-BOT. A SWARM-BOT is typically composed by 10 to 30 S-BOTs physically interconnected. S-BOTs can autonomously assemble into a SWARM-BOT but also disassemble again. This feature of the S-BOTs provides SWARM-BOT with self-assembling and self-reconfiguring capabilities. Such a concept, by taking advantage from the collective and distributed approaches, ensures robustness to failures even in hard environment conditions. The approach presented finds its theoretical roots in recent studies on swarm intelligence.

Introduction

Swarm intelligence [1], taking inspiration from social insects behavior [2], has shown to be very efficient for several tasks. Despite the increasing number of algorithms based on swarm intelligence, few research works aim at applying such a concept to real mobile robotics. In collective robotics, the research is pursued mainly at the control level. Researchers aim at achieving better robustness [10][6] or at improving performances in tasks such as searching [7], transporting [4], sorting [3] or structure building [2]. To the knowledge of the authors, nobody has so far tried to bring social behavior at a physical level, allowing robots, for instance, to self-assemble in the same way as insects do. The only research field where there is a hardware modularity and some attempts of distributed control is "self-reconfigurable robotics". The best performing systems in this case[1] are MTRAN [8] and PolyBot [5]. However, both systems have a centralized control and do not take advantage from the modularity at the control level. The only 3D self-reconfigurable robot with decentralized control is actually CONRO, a hardware with decentralized control done by Støy et al. [12] and by Salemi et al. [11]. Despite the interesting possibility of manually changing place of the modules, such a system is not able to readapt its configuration in a flexible and autonomous way.

As of today (Spring 2002), no research is done on the application of swarm intelligence at the physical level, resulting for this in a self-assembling system based on a swarm of robots. This is actually the aim of the SWARM-BOTS project presented in the next section.

The SWARM-BOT concept

The prime goal of this project is the study of a novel design approach to hardware implementation of self-organizing robotic systems called *swarm-bots*. A swarm-bot is a robotic entity composed of many (typically 10 to 30) smaller robots assembled together. These small robots are called *s-bots*. Each s-bot is a fully autonomous mobile robot equipped with assembling capacities. It can physically connect to other s-bots to form a swarm-bot. The swarm-bot can achieve tasks that are impossible to achieve for a single s-bot, like for instance passing gaps larger than the s-bot size. The hardware structure is combined with a distributed adaptive control architecture inspired upon ant colony behaviors. Such an approach finds its theoretical roots on recent studies in swarm intelligence, i.e., in studies of self-organizing and self-assembling capabilities shown by social animals.

Mechanical concept

The mechanical concept of one s-bot is shown in figure 1. As can be seen there, the mobility is ensured by a track system. Each track is controlled by a motor so that a robot can freely move in the environment and rotate on the spot. These tracks allow each s-bot to move even on moderately rough terrain, with more complex situations being addressed by swarm-bot configurations. The motor base with the tracks can rotate with respect to the main body by means of a motorized axis. A motorized pole on the top let the robot roll over if it capsizes. The same pole includes an omnidirectional camera used as sensor in standard conditions.

S-bots can connect to each other with two types of possible physical interconnections: rigid and semi-flexible.

Rigid connections between two s-bots are implemented by a gripper mounted on a horizontal active axis. This gripper has a very large acceptance area that can securely grasp at any angle and lift (if necessary) another s-bot. Similar connections are made by ants to build bridges or other rigid structures [9].

[1] For an overview of existing systems and characteristics see [8]

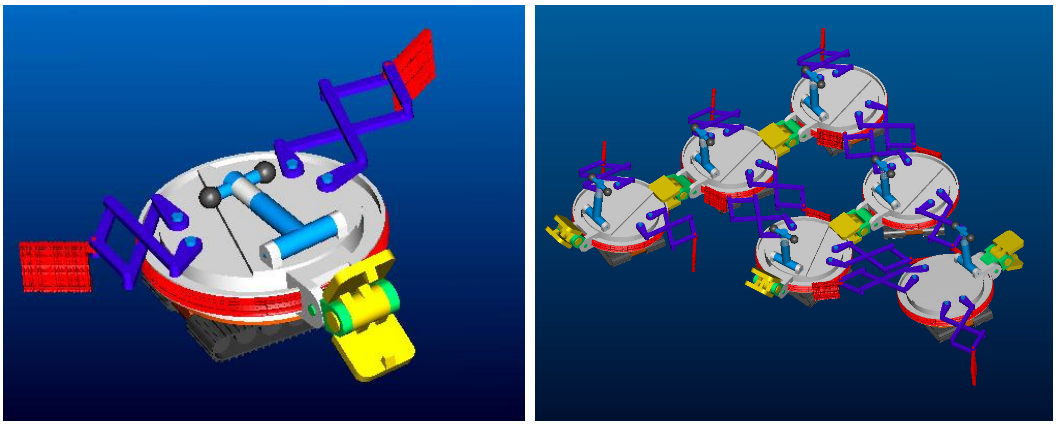

Figure 1: A graphic visualization of the first s-bot concept (left). The diameter of the main body is 110 mm. Several s-bots can self-assemble into a swarm-bot (right).

Semi-flexible connections are implemented by flexible arms actuated by two motors positioned at the point of attachment on the main body. The two degrees of freedom allow to extend and move laterally the arm. Each of these arms ends with a Velcro©[2] coated surface and can generate links with a complementary Velcro© on the body of the robot. Rigid and semi-flexible connections have complementary roles in a swarm-bot. The rigid connection is mainly used to form rigid chains that have to pass large gaps (cf. figure 2 left), whereas the semi-flexible one suits configurations where each robot can still have its

Figure 2: The rigid connection (left) can be used to form chains and pass very big obstacles and large gaps. The semi-flexible connection (right) is used to keep relative mobility between s-bots while they are in a swarm-bot configuration.

own mobility inside the structure (cf. figure 2 right).

[2]The "Velcro" trademark is the property of its owner.

A swarm-bot can of course also include mixed configurations with both rigid and semi-flexible connections, generating 2D structures such as checkerboards (cf. figure 1 right).

Simulation

Due to the huge effort needed to build physically the system, a simulator is going to be designed in order to start studying, testing, and evaluating the behavior of a swarm-bot. Given the complexity of a real s-bot, it has been thought of modelling one robot in a modular and hierarchical way. This means that an s-bot will be modeled in separate sub-parts which could be put together in order to reach the opportune level of realism required by the end user. Those details not needed will simply be unselected and hence not loaded. Such a solution allows to have a much leaner simulated world which could be evolved in a much more computationally efficient fashion by the underlying simulating engine (Vortex©[3]). This last is the core of our simulator and it is a fully dynamics simulating engine which is capable, among other things, of monitoring contacts and collisions among the various bodies loaded into the system.

Our software builds on top of Vortex© and it is specifically tailored to deal with a swarm of robots. Indeed, it is defined so as to allow end users to customize easily their model of each s-bot in a swarm and the experiment they need to run. In order to achieve this, a set of primitive statements is provided to an and-user for the control of the s-bots loaded into the system and for reading the sensor data gathered by each robot unit from the simulated environment. Notice that the software is thought to provide also an option for choosing either an outdoor environment (rough terrain) or an indoor one (smooth planes). As far as sensory system is concerned, it is thought of modelling several types (light sensor, IR, sound, simple vision). Each one, could be selected or unselected in the initial customization and, those selected, could also be toggled on or off on-line. The simulator will also provide a handler point, where user made control policy could be introduced in the system.

Discussion and conclusion

We presented the main aspects of the swarm-bot concept. This new self-assembling robotic concept extends swarm intelligence to a physical level. This allows physical collaboration between robots, for instance to navigate over difficult obstacles and gaps on all-terrain conditions. Moreover, the characteristics of the interconnections may help the robot to use their physical characteristics to simplify the behavioral algorithms. In the first instance, this concept is going to be simulated and an appropriate tool is currently under development. Such a tool will allow swarm-bot end users to tailor their swarms according to their research goal by opportunely tailoring the features of each s-bot they want to

[3]Trademark owned by Critical Mass Labs, Inc..

use. User made control policies can also be easily introduced in the system by means of handler point.

The next step of this project will consist, after having built the real prototypes, in testing the results obtained by simulation in realistic conditions.

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