SWARM Robotics: A Different Approach to Service Robotics

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Swarm Robotics: A Different Approach to Service Robotics

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ABSTRACT

Service robotics, as it has been intended so far, views the accomplishment of a service mission mainly as the result of the action of a single robot. Swarm robotics tackles the very same problem from a different stance, *i.e.*, as the result of a team effort of simple units. The project described here shows this particular approach. It defines first one simple unit (s-bot) capable of independently moving about on the ground and of dynamically establishing rigid or semi-rigid connections with other fellow units, and then it shows how a large group of them can, as a whole entity (swarm-bot), carry out a given task. Thanks to the ductility in assembling and forming its connections, a swarm-bot can readily cope with occasional failures of some components and promptly reshape the remaining swarm so as to replace the role of the failing units. Given such a plasticity, their possible applications is rather large ranging from harsh environment exploration to goods harvesting or goods transportation. At the moment, the project is at the stage of having defined a first simulating environment to be used both for the on-going hardware design and for the software control. The present paper describes this particular aspect of the project.

Keywords: distributed robotics, self-assembly robots, self-reconfigurable robots.

1 INTRODUCTION

Service robotics, as it is widely performed today, usually assumes a given service to be carried out by a single robot or, at most, by a small group of them working together. In any case, though, the concept of cooperation is intended more in the sense of a relay race, than in the sense of an actual team effort for achieving each single task. Each robot, in other words, is assumed to be able to cope with the basic problems of autonomy alone, i.e. locating itself, navigating within its environment, and in case also planning its own future actions.

A new and totally different way is the so-called *swarm robotics* that, as opposed to the more traditional approach, does not necessarily assume each robot as a stand alone independent unit. On the contrary, *swarm robotics* assumes that a given mission is the result of a joint action of a swarm of simple units. Such units, in theory, might even be unable to perform the bare locomotion without the aid of others of their kind. This approach finds its theoretical roots in recent studies on swarm intelligence [1], i.e., in studies of self-assembling and self-organising capabilities shown by animals such as social insects [2].

With this sort of approach, cooperation becomes of capital importance for the success of an overall mission. Indeed, since there is no predefined role, an artificial swarm (which we label swarm-bot) can be, as its counterpart in Nature, extremely robust: the function initially endorsed by a failing unit would simply be replaced by a reorganization of the whole group. Clearly, such a characteristic implies a swarm to show an overall behaviour which is both adaptive and emergent. Adaptive because it needs to change itself opportunely in order to cope with the surrounding world, and emergent because each unit (which we label s-bot) has no global cognition of an assigned mission: they simply respond to the external stimuli with specific local predefined behaviours. In this respect, exactly as simple behaviours interacting with each other would let a more complex one emerge, a group of s-bots acting on their own locality, would be able to perform an assigned task as the result of their team effort.

It is important to notice that physical reconfiguration, though, is not the only characteristic distinguishing a swarm-bot from a more traditional service robot. Self-assembly is the other important feature. Once a task is requested, in fact, a swarm-bot not only needs to evolve constantly its physical shape until the completion of the assignment is reached (final goal), but it also needs at the beginning physically to assemble its components (s-bots) from scratch. Moreover, once the goal is achieved, the bindings holding the swarm-bot structure together would simply be released and the whole group would disaggregate and eventually reform into a different shape when a new mission is reassigned.

The aim of this paper is twofold: first introducing our project and second discussing how to apply the key characteristics of our swarm-bot, *i.e.*, , team work, limited global knowledge, and emerging common goal, in order to achieve a service. The work is organized in the following sections: an introduction of the research context within which our research fits in (section 2), a brief introduction of our project (section 3), a more detailed description of our s-bots (section 4), a brief presentation of the 3D swarm-bot simulator developed (section 5), and a discussion of how a swarm-bot might be employed in order to carry out a specific service (section 6). Conclusions are drawn in section 7.

2 RELATED WORK

Considering the characteristics of a swarm-bot outlined above in the introduction, we could identify three research areas into which locating our concept: self-reconfiguration, self-assembly, and robot mobility.

In the first area, *i.e.*, that of physical self-reconfiguration, researchers have put great emphasis essentially on the task of dynamical reshaping of physical structures by means of simple units [3, 4, 5]. Because the research focus in this topic has mainly been the reconfiguration itself, the aforementioned simple units are not really entities independent from each other. As exemplified for instance in [6, 7, 8], these units could start their evolution to a goal structure only from a physically pre-assembled configuration. An implication, this, which implicitly pre-sets the number of structure components. A swarm-bot is, in this respect, more powerful, since it neither assumes to start its evolution toward a goal from an already pre-built configuration nor to have a pre-set limit of components.

As far as self-assembly is concerned, research in this area has basically just concentrated on the distributed algorithms needed for assuming certain loose formation ([9]), or maintaining a certain loose planar geometrical shape ([10, 11]). Swarm-bots share with such a line of research the idea of exploiting local sensing in order to achieve the overall control of the group. However, the bindings among the different units within a group are in general rather loose as compared with those encountered in a swarm-bot. S-bots might, in fact, establish physical connections with each other in order to reach a target configuration. Such a characteristic allows them to extend formation geometries in theory also into the third dimension.

Concerning robot mobility, there is a great deal of research being pursued stretching from mechanics to autonomous control. Our involment with mobility, and hence autonomy, stems from the fact that our s-bot units need to gather in order to assume a certain shape. This means that they need to be capable of moving about independently when they are not joined together into a structure. The solution chosen for our s-bots has in a sense a conceptual similarity with that implemented for the wheeled JPL mars rover ([12]). The difference, however, lies in the fact that our s-bots' locomotion subsystem is fixed to the main body, whereas that of the aforementioned rover has a variable geometry.

3 SWARM-BOT PROJECT

Having briefly introduced the context within which our research fits in, let us now present our project: the Swarm-Bot[1]. It is a three years pan-european reseach collaboration, currently in its first year, co-funded both by the Commission of the European Communities and by the Swiss National Science Foundation. Its main objective is to study a novel approach to the hardware design, implementation, and use of self-assembling, self-organising, and metamorphic robotic systems called swarm-bots. A large part of the research has so far consisted partly of feasibility studies and partly of physically implementing an initial design.

Since it is clear that hardware and control policies development go hand in hand, a 3D dynamic simulator has been under development since the beginning with the intent of using it both as a testing benchmark for the hardware design and as a tool for creating new group control algorothms. In this respect, although the project is currently still at its infancy, the particular phase we are in, here at IDSIA, is the completion of a first 3D simulator prototype which can already be used for hardware design testing and for developing distributed control policies with our s-bots. Notice that parallel phases of physical hardware construction and of definition of the controlling algorithms are also currently being carried out by the project partners at the Autonomous Systems Laboratory (LAS) of the EPFL in Lausanne and at the Institute of Interdisciplinary Research and Development in Artificial Intelligence (IRIDIA) of the Université Libre de Bruxelles, respectively. Concerning the other two partners, the Centre of Studies of Non-Linear Phenomena and of Complex Systems (CENOLI) of the Université Libre de Bruxelles and the Institute of Cognitive Science and Technology of the Italian National Reseach Council, they are involved since the beginning in bio-inspired research experiments and in evolutionary robot control development, respectively.

The project as a whole presents many challenges which

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[1] See *www.swarm-bots.org*

are both technical and scientific. On the technical level they are partly hardware and partly software. Hardware, because of the need of designing an opportune robot concept capable of

- moving independently on rough terrain as well as on smooth planes,
- navigating by sensing just its immediate surrounding environment,
- communicating with other fellow s-bots, and
- establishing rigid or semi-rigid contacts with other s-bots.

Whereas software, because of the need of devising group behaviours allowing the control of a large number of them as if they were one single entity able to aggregate into a team structure for the achievement of a task, and to disband its components as soon as its assignment is carried out.

On the scientific level the challenges lie basically in achieving the control and co-ordination of a swarm-bot both when it is in an aggregated configuration and when it is in a sort of loose scattered group.

At the end of the project the hope is to have developed new, self-organising rules achieving the desired objectives and at the same time allowing a swarm-bot system as a whole to be robust and resilient.

Given the generality of our concept, many applications requiring group work might be envisioned, such as cleaning of extended areas, transportation of large objects, patrolling of indoor and outdoor environments, harvesting of goods, planets' exploration, etc.. However, many more not currently foreseen might also be possible candicates. We will examine this in a later section.

4 S-BOT DESCRIPTION

As mentioned above, several phases of the project are being carried out in parallel. Since the physical s-bot is undergoing a continuaous development and refinement, we describe here just the parts so far agreed and approved.

As described in the introduction, a swarm-bot has to be thought of as a swarm or, better still, as a group of simple robots (s-bots) interacting with each other and with their surrounding environment for the achievement of a common goal. Given the characteristic of self-assembly, each s-bot is not only fully capable of moving about on the ground by itself, but it is also able to establish physical connection to other fellow s-bots either rigidly or semi-rigidly so as to form physical structures.

Viewed in details, an s-bot could be divided into four sub-systems: its locomotion, its main body, its top arm, and its gripper arm.

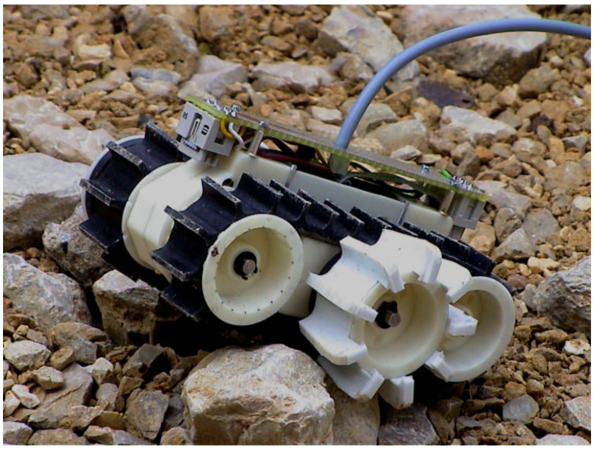

Figure 1: Real S-Bot Tracks Sub-System.

The first sub-system, *i.e.*, the one that realizes mobility (cf. Figure 1 for the real prototype and Figure 2 for its simulated model), is essentially made of a set of six teethed wheels, three on each side. The middle wheels are slightly larger than the others—a feature which helps to have more grip on the ground even in very rough outdoor terrains. The batteries, which provide energy both to the motors driving the wheels and to the circuitry for the sensors and communication devices, are encased between each side. An interesting feature of this part of the s-bot which is worth mentioning is the possibility to actuate the wheels on each side in opposite direction. This means that an s-bot, although in theory it is not a holonomic system, is anyway able to rotate on the spot, and hence achieve a sort of a two stages holonomy in the sense that an s-bot would first rotate its tracks to be parallel to the direction of motion and then move there[2].

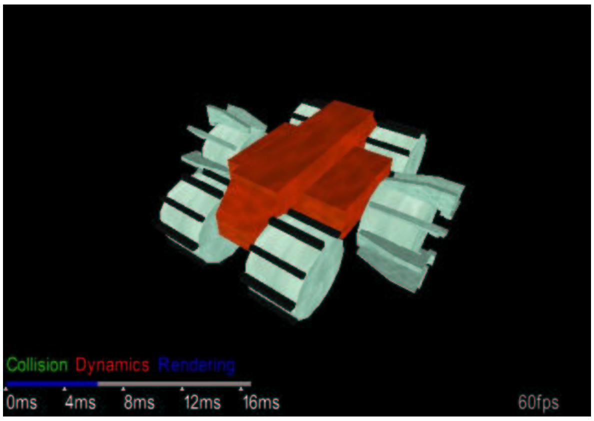

Figure 2: Simulated S-Bot Tracks Sub-System.

The second sub-system, *i.e.*, the main body (cf. Figure 3), is essentially a round flat cylindrical disc encasing the gears driving its own rotation about its central

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[2] A fully holonomic system would not need to orient itself to the direction of motion.

axis and those driving the front gripper and the top arm. A future development of the body will include extra gears driving motorized side arms.

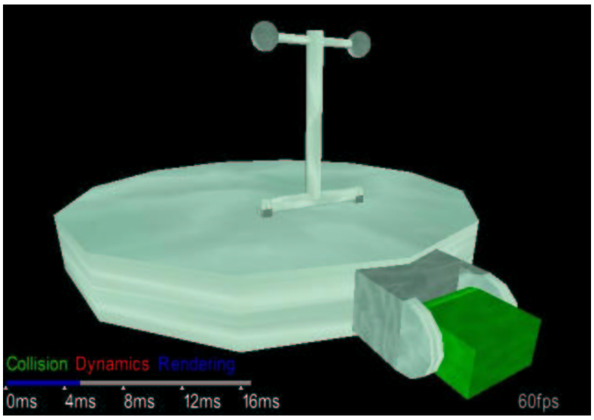

Figure 3: S-Bot Body, Upper and Gripper Arm Sub-Systems.

The third sub-system, *i.e.*, the top arm (cf. Figure 3), is meant to host a camera allowing an s-bot to get a longer range perception of its environment. Since such an arm is motorized, it becomes very useful in case an s-bot capsizes. In this respect, it has to be pointed out that, although such situations may be rare on flat environments, they are indeed very common on outdoor rough terrains which may have steep obstacles to be overcome, and s-bots are meant to survive in that kind of world.

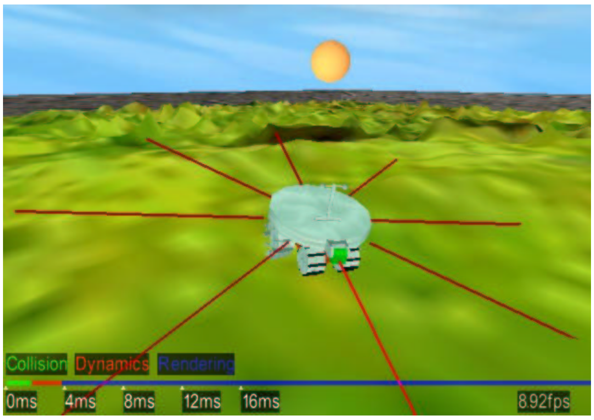

Figure 4: S-Bot Proximity Sensors.

The last sub-system, *i.e.*, the gripper arm (cf. Figure 3), is basically a raw hooking arm which for the time being is treated as a sort of idealized magnet allowing either a rigid or a semi-rigid connection. The rigidity is realized by making it stick to the contact point on the side surface of the collided fellow s-bot body, whereas the semi-rigidity is realized by allowing it to rotate about the side surface of the connected s-bot body. An already planned development is to refine this crude model with a more sophisticated jaw gripper, which will be able to grasp a fellow s-bot body and either firmly or loosely hold it.

Concerning sensors, several have so far been planned for an s-bot, and as matter of fact a first vision system to be mounted on top of the upper arm has already been put under development and a sound detector has also been lined up afterwards. Nevertheless, the only active sensing capability of an s-bot at the moment fully implemented and operative is just a proximity sensor. Such a sensor is physically made of emitters/receivers that have a maximum sensitivity span. They are evenly distributed around the side surface of each s-bot cylindrical upper body. Within our simulator such sensors have been modeled as an array of light beamers, each representing a direction (cf. Figure 4). In case of intersections caused by any sort of hindrance, the one returning anything different from the full sensor span indicates both direction and distance to the obstacle.

5 SWARM-BOT SIMULATOR DESCRIPTION

Having briefly outlined the different parts of one of our s-bots, let us now turn our attention to describe the simulator prototype which has so far been developed during the first phase of our project.

As mentioned earlier, our project required the definition and construction of a simulating tool specifically tailored to handle groups of robots. Such a tool was deemed necessary for two reasons: investigating the behaviour of optional hardware solutions, and designing and evaluating new distributed control algorithms with a given hardware.

Because of this twofold use, it is clear that this tool has to produce results the closest possible to reality. In this respect, it should be noticed that a kinematic simulator would not be able take into account situations involving forces, torques, inertia, and friction. This means that an hypothetical employment of such a kind of simulator might induce its user to draw flawing conclusions. Because of this, we decided to opt for a simulating engine[3] capable of handling kinematics as well as dynamics.

Our first prototype has several interesting features:

- possibility of selecting the type of environment, *i.e.*, rough terrain or smooth plane,
- modularization of the different parts of an s-bot[4] outlined in section 4,
- possibility of selecting which sensor to employ among those developed, and in case their granularity and sensitivity[5], and finally

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[3] Notice, that our swarm simulator is erected on top of Vortex^{TM}, a commercial general-purpose dynamic simulating engine by Critical Mass Lab, Inc.

[4] The tracks sub-system is assumed to be a compulsory item.

[5] This refers specifically to the proximity sensor which is currently the only one fully operative, but it may also refer in the future to the sound sensor.

- possibility of abstracting the control algorithms developed from the underlying hardware.

Although most of the s-bot motion dynamics have been implemented, there are still pending developments including future lateral arms, additional sensor modelling and coding of basic bahavioral patterns.

Group control policies are curently under investigation by all the research partners. Nevertheless, some simple individual behavior, such as wall-avoidance and light following, have been developed and included in the simulator as programming examples of our tool.

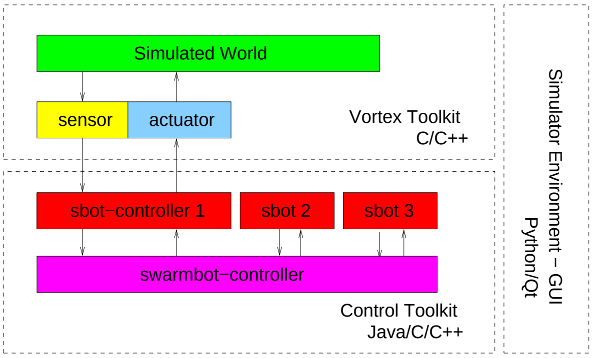

Figure 5: Design of simulation environment. The sensors/actuators are abstracted and separated from the environment to ease the porting of control software to the real hardware.

Figure 5 shows the design of our simulating environment. The simulation layer provides simulated reading for the sensors and evolves the simulated world according to the actuator outputs of the s-bot controllers. We use Python, an interactive scripting environment, for fast prototyping and for creating the GUI layer. The separation of the controllers and the sensors/actuators ensures that developed control algorithms can be used for both simulated and real world. This implies that we can upload the controller code directly on our s-bot hardware.

Using this simulating tool, we are currently investigating the construction and adaptation of shape formations with physical bindings starting from disbanded groups of s-bots with limited sensitivity and limited world knowledge. Figure 6 shows as an example the outcome of a square shape construction on a smooth world.

This kind of testing problem is interesting not so much from the classical control point of view, rather from the possibility of having the swarm, once a targeted shape is achieved, reach awareness of it (emerging awareness). Our focus, besides further refining and improve our simulator, is currently to develop further control policies for these kind of simple tasks while addressing issues such as task decomposition, group awareness, learning, and communication. We have also planned to employ our simulator as a tool to evaluate different robot control architectures, such as bahaviour-based control, GA-based optimization, and ant-based learning.

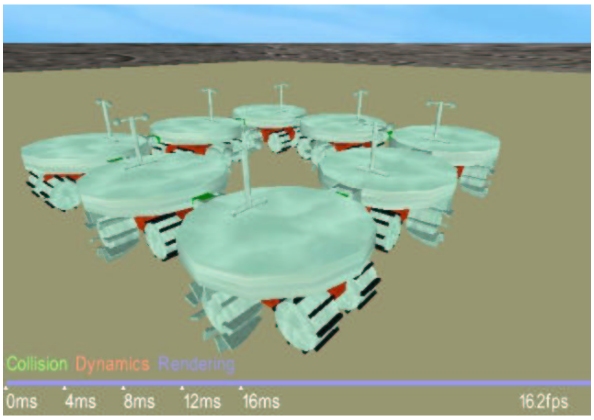

Figure 6: Square Formation.

6 A SWARM-BOT AS A SERVICE ROBOT

As mentioned earlier in this paper, a swarm-bot is not a robot intended in the classical way. Rather, it is an entity generated by an aggregation of independent units which join a group pursuing a common goal. Thanks to this characteristic, such an entity can erect both rigid and semi-rigid structures. In any case, once the goal has been achieved, the bindings holding it together cease to be enforced causing it to disaggregate into its atomic components (s-bots).

All these characteristics of ductility and robustness make a swarm-bot very suitable for tasks which require the collaboration of quite a large group of participants. Already mentioned applications such as food harvesting, cleaning of hazardous environment, or planet explorations, are just some possible use of this sort of robotic concept. However, if the idea of self-assembly and self-reconfiguration is fully extended also to the third dimension[6], then the range of possible services which they could provide would enormously grow. It should be noticed, anyhow, that already in our constrained world[7] our swarm-bots can carry out quite a few tasks such as transportation of objects too large to be handled by a single unit, or exploration of outdoor areas with obstacles too large or too steep to be overcome by a unit alone.

In general, swarm-bots are very suitable, and indeed preferable to classic mobile robots, for all those tasks requiring not only a high degree of team effort, but also a very low level of human intervention. In this respect, it should be pointed out that the relative simplicity of each s-bot and the plasticity with which a structure of s-

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[6] Currently our s-bots are just partially able to erect large 3D structures.

[7] This is essentially due to the limitedness of the 3D structures which our s-bots can currently erect.

bots is erected and evolved according to a common goal make a swarm-bot much more resistant to failure than classic service dedicated mobile robots. Having said this, though, should not induce to think that swarm-bots are always preferable. As a matter of fact, those tasks still requiring some level of individuality or not completely fulfilling the conditions mentioned above may still see classic monolithic mobile robots as the most suitable choice to carry them out. With this in mind, it seems that planets exploration or handling of dangerous materials in hazardous environment may be some of the first applications in which swarm-bots might be successfully employed.

7 CONCLUSIONS

Swarm-bots, because of their extreme plasticity, can find interesting applications anywhere it is required a high degree of physical adaptation and a low level of human intervention or monitoring. Tasks which fall in this category might be space exploration of harsh and humanly dangerous environments, assembly of space modules, handling of dangerous materials, mining, and even "harvesting" material or goods from a physically constrained location. Given such a multi-purpose nature, swarm-bots might also find further applications in the future which are currently even not foreseen.

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