STUDY OF MACROSCOPIC MORPHOLOGICAL FEATURES OF SYMBIOTIC ROBOTIC ORGANISMS

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***Abstract*— This paper gives a brief overview of mechanical development within the "SYMBRION" and "REPLICATOR" projects towards swarming-capable and reconfigurable platforms. We demonstrate several different modules as well as topological modelling of possible macroscopic organisms built from these modules. The performed topological experiments allow comparing these solutions with well-known ones as well as drawing a few conclusions about possible functionality, morphologies, advantages and disadvantages of each of them.**

I. INTRODUCTION

European commission funded two new large-scale integrated projects "SYMBRION" and "REPLICATOR"[1] dealing with a new research initiative in the domains of swarm/reconfigurable robotics as well as micro-technologies and evolutionary computation [1]. The main idea of these projects originates from a biological observation of symbiotic organisms - individual elements, for instance cells, can dock to each other and build complex multi-cellular organisms [2]. Individual cells specialize in these organisms as well as share energy and other resources. When the need of aggregation is over (usually this is a reproductive functionality), these organisms can disaggregate and exist further as stand-alone cells.

Symbiotic organization as well as basic principles originating from swarm research and reconfigurable robotics provide many advantages for these robotic organisms. From the swarm's viewpoint, these organisms are very reliable due to a massive parallel computation, sensing, communication and actuation [3]. Destroyed and malfunctioning modules can be removed from organisms, provided a large number of these modules is available. From the viewpoint of reconfigurable robotics, the organisms ensure adaptive functionality and behavior of aggregated structures, their evolve-ability in open-end and unpredictable environments. Both projects share development of compatible platforms and corresponding software, however differ in application areas. SYMBRION is strongly focused on evolve-ability of organisms and is exploring artificial evolution in robotic population. REPLICATOR focuses on more application-related aspects, e.g. reconfigurability of sensors and actuation, with the main goal of creating mobile and adaptable sensor network for indoor environments.

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[1]see www.symbrion.eu, www.replicators.eu.

In this paper we briefly present a few current mechanical developments, which would satisfy goals of both projects. These solutions are developed by University of Karlsruhe, by Scuola Superiore Sant'Anna and by University of Stuttgart. Having different modules allows achieving heterogeneous swarms, where specialization of modules is established even in a mechanical design. Moreover, we performed real-size modelling of these developed solutions as well as of several well-known ones (e.g. "polyBot" [4], "superBot" [5]). These models are very simple polymer-molded elements, which reflect only main topological and DOF features of corresponding solutions. In this way, such a topological modelling represents very cost- and time-efficient way of morphological exploration of future organisms.

The rest of this paper is organized in the following way: In Section II we briefly represent developing platforms, in particular wheeled (II-B), 2 DOF wheeled (II-C), 1.5 DOF module (II-D) and crawling (II-E) ones. Section III gives an example of topological modelling and represents a few results of macroscopic locomotion and macroscopic functionality available on this stage, whereas Section III-C introduces arguments for and against homogeneous (heterogeneous) self-assembling swarms. Finally, in Section IV we conclude this work.

II. MECHANICAL ARCHITECTURE AND COMPONENTS

In this section we briefly demonstrate several mechanical designs on a low-details-level as well as introduce several general ideas of functionality required by/from these modules.

A. Functionality of mechanical modules

In modular robotics the overall functionalities of the assembled robotic organism are deeply related to the hardware structure and functions of its basic composing modules. Many basic functions have to be taken into account in order to achieve satisfactory mechanical performance of the robotic organism. The most important are:

- locomotion capability;
- docking mechanism;
- lifting/bending capability (related to the torque the integrated motor can supply).

The autonomous locomotion of modules should generally be a required issue, important to allow each module mainly to reach other modules (for docking and thus build up the final robot), a capability that only few modular robots have so far demonstrated in literature. The docking mechanism is the key for the assembly and self-reconfiguration of the robotic organism. It must allow a safe and stable mechanical connection between modules, stable electrical link between docked parts and, finally, it must allow an easy undocking of the modules, whenever required. Guarantying stable electrical contacts between docked modules is a critical requirements for docking systems: automatic coupling of electrical contacts is necessary for data exchange and power distribution between the modules assembled into an organism. The lifting capability enables one robotic module to lift (or finally actively pivot) one or more docked modules; this is a fundamental feature the final assembled organism needs to have in order to exploit coordinated movements, e.g. walking. In order to accomplish locomotion some different strategies can be followed, as described in the following.

B. Wheeled robotic modules

A novel feature in robotic modules is a wheeled approach for locomotion of single modules. Wheels can offer to the modules speed of movement and locomotion independence. This is a great advantage above all on flat surfaces, on which wheeled locomotion allows a great saving of energy. The increase in speed of single modules implies a higher capability of environment exploration and a faster gathering between modules for assembly. One of the modules developed following this strategy will include four wheels, two of which independently actuated by two motors, see Fig. 1. It will also include four docking ports, placed in the middle of each side of the structure, a rotational degree of freedom, actuated by a motor and placed in correspondence of a lateral docking port and a bending degree of freedom, enabled by a shaft-based structure actuated by a motor. While the bending structure provides a degree of freedom along the module axis, rotational DOF allows the rotation of attached modules on a perpendicular axis (that of wheels), enhancing the overall reconfiguration capability of the organism.

Concerning bending capability, the number of modules that is possible to lift up is an important parameter in the evaluation of mechanical performances and topological configuration of the organism. In particular, it is important in order to have the possibility to move from 2D to 3D-spatial configuration of the organism. Preliminary estimation about the lifting capability of a bending system for cm-sized robots follows. Considering a total mass of $150\ g$ (including robot

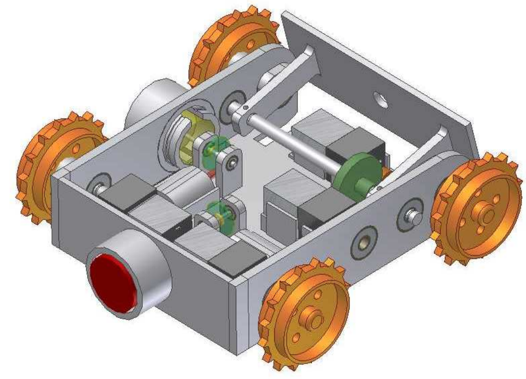

Fig. 1. CAD design of a wheeled module with bending capability and rotational degree of freedom; docking mechanisms (not shown in the picture) are placed on each sides.

chassis, mechanical and electronic components) and a center of mass for each robot in its geometrical center (robot length is preliminary fixed at about $60\ mm$), the torque needed to lift up **n** robots results from the equation:

$$\tau_n = n^2 \cdot W_f \cdot l_R/2, \tag{1}$$

where W_f is the weight for each module ($1.47\ N$) and l_R is the length of one robot. The torque needed to lift up one, two and three modules is, respectively: $\tau_1 = 44.1\ mN \cdot m$, $\tau_2 = 176.4\ mN \cdot m$ and $\tau_3 = 396.9\ mN \cdot m$. Using cm-sized commercial geared-micromotors (e.g. 12GN geared-motor from Sanyo) a torque of comparable magnitude can be produced with a typical rotation speed of about $20-30\ rpm$. This is enough to lift up two connected robotic modules, what most of the basic studied organism topologies typically requires.

The wheeled approach for locomotion presents advantages but also some problems. First of all a differential drive does not allow the docking of robots in the orientation of their wheel axis, reducing the reconfiguration capability of the organism (to solve this problem a non trivial motion could be used). The second problem concerns the weak capability of wheels in overcoming obstacles. While simple wheels can be extremely efficient on smooth surfaces, they could show limitations on sandy or pebbly surfaces, and even in facing small obstacles (like electrical cables, grass, etc.). A solution to this problem could be the use of a caterpillar-based robotic unit, able to provide locomotion even on challenging surfaces and environments.

C. Wheeled robotic module with 2 DOF actuation

The last of possible solutions represent wheeled module with 2 DOF actuation. This module (PuzzBot module, see Fig. 2) war developed with the objective of designing a small-size, multi-modular robot platform capable of swarming and docking to each other.

Single modules feature the capability to drive speedy on smooth surfaces, which provides the operation as a swarm robot platform. Moreover, single modules are able to

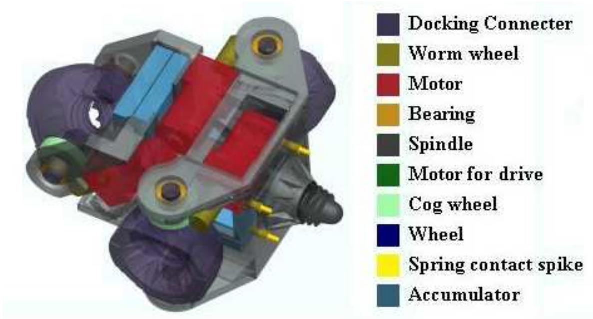

Fig. 2. CAD design a PuzzBot module with 2DOF.

Dimensions	Undocked:70.1 × 77.2 × 41				
	Docked: 70.1 × 62.7 × 41				
Mass	200 g				
Capacity of Docking Connectors	Motor ratio	1:56	1:100	1:150	1:298
	Torque	6.6	11.8	17.7	35.1
	Modules	2	3	4	7
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	Torque	6.6	11.8	17.7	35.1
	Modules	2	3	4	7
Max. deflection of connectors	Back Connector	±45°			
	Side Connector	±35°			
Cost	50-100 euros				
Assembling time	hours				
El. Capacity	1 Ah at 4.2 V				

TABLE I
CHARACTERISTICS OF A SINGLE PUZZBOT MODULE.

interconnect by means of a screw based docking mechanism and so establish stable mechanical connections between each other. Thereby the modules have the capability to aggregate from swarm to organism without human assistance as straightening or sticking together single devices. Installing hinges to the docking mechanism, allows assemblies of diversified organism structures and their locomotion.

Locomotion of single modules in undocked state is realized by installing a differential drive. Therefore, two miniature motors independently drive two wheels fixed on an axis. To get information of a module's position and angle, two LED optical sensors, as used in mouse devices, are fixed at the bottom of each module.

Each module, which is integrated in an organism, feature two DOF, respectively the capability to rotate docked robots around two different axes. The deflection of the hinges, thus the deflection of docked modules, is executed by gear motors and self locking worm gears with an additional ratios of 1:25. Different kind of gear motors, equal in form, are available with ratios from 1:56 up to 1:298. Therefore, specialization in strong(slower) or fast(weaker) modules is possible without changing the design of the modules. Because of the self locking property of the worm gears, no torque is impressed on the motor axes, while an organism do not move and the loss energy is reduced. The installation of miniature bearings minimize frictional resistance. Deflections of hinges are detected by joint angle potentiometers. Parameters of the PuzzBot module are shown in Table I.

As mentioned before, the interconnection between modules is based on a screw like docking mechanism. Thereby, each module features a conical thread spindle at its front and three docking connectors, each providing an applicable screw thread, at all the rest of its sides. In order to interconnect a module drives in direction of the docking connector, until the spindle interlock and screw into the thread of the docking connector. The spindle is driven by another gear motor. Some possible configuration are shown in Fig. 3. By means

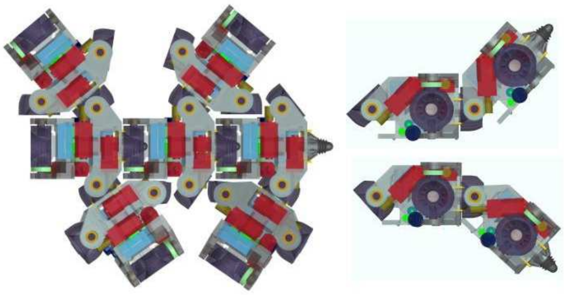


Fig. 3. Deflection of side docking connectors(±35°) and back docking connectors(±45°).

of optical and IR Transceivers, placed above each docking connector, the optimal approach can be calculated. When two devices interconnect four electrical contacts(for CAN and energy shifting) between them are established. Therefore four spring contact spikes are used. By the use of spring contact pikes certain variations in docking state can be tolerated. Four 4.2V, 250 mA Lithium-Polymer accumulators were installed. With the assumption that all motors are permanently stalling and the circuit board is working to capacity the energy would last for about 20 minutes.

D. 1.5 DOF robotic module

Another approach to realize a multifunctional robotic module is shown in Fig. 4. The idea behind this cubic shaped

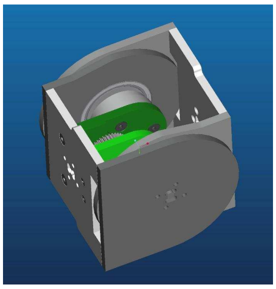


Fig. 4. Preliminary CAD design of a 1.5 DOF robot module.

robot (which shares similarities with "polyBot") is to use the high torque main motor not only for bending but also for turning. The robot will have four docking elements on each side and depending on which side another robot is docked, the relative movement to each other is based on turning or bending. Due to the mechanical restrictions bending and turning is only possible for angles between ±90 degree based on zero position shown in Fig. 4.

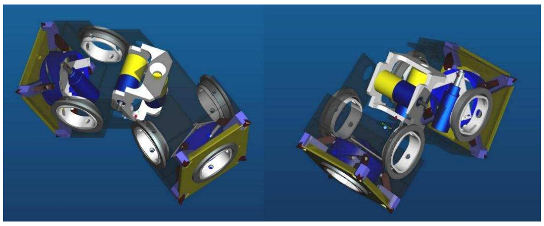


Fig. 5. Preliminary CAD design of a crawling robot module.

Compared to the other designs introduced in the sections before, this one assumes that more space is needed inside the robot (so the robot is much bigger) and that the total weight will be around 500 gram. Therefore more power is needed to lift the same amount of modules. Preliminary calculations showed, that the power consumption is several times higher than for the two robot models showed above. Due to the possibility to use one robot with only one DOF for two different kinds of movement, the structure of the robot is still simple but offers many different configurations to build an organism.

Each robot will be equipped with its own drive to achieve individual locomotion. In order to do that, the restrictions produced by the main motor laying on the middle axis have to be considered. The only space to mount the drive for movement is near the corners of the cube. Unfortunately, there is little space so only small wheels or small chains could be used. Currently, the space available for drive-motors is about $3cm^3$, wheels can not be bigger than 1.5cm in diameter. One advantage of this solutions is that internal movement is independent from the rest of the robot and can be exchanged easily. Also nothing sticks out of the robot, the outer shape is still a cube. What kind of movement will be best for this robot design is not decided yet. Ongoing development and tests will show which of the analyzed solutions is best suited in regard to energy consumption and maximum velocity of the single robot.

E. Crawling robotic modules

Another possible solution for the movement of each single robotic cell is to crawl. This solution is from a technical point of view more complex then wheels or chains but it is possible to overcome obstacles more easily. The basic idea of crawling is to use the high power motors needed to perform actions inside an organism for individual locomotion. So, no additional drive components like motors, gearboxes and wheels are needed. Also, you can save space inside the robot and there are no parts sticking out (like wheels do). Furthermore, the robotic cell is able to move free in 3-dimensional environment (see Fig. 5) which is not possible with a differential drive. On the other side, you have to consider that the main motors consume a lot of power while crawling. The mass of the robot has to be moved up and down and therefore more electrical power is needed. Also, include several high torque motors inside the robots casing is difficult and much more expensive then the components for the wheels.

In the end, crawling based movement could be interesting in areas where wheels will not work. Be it because of obstacles which are to big or due to harsh environments which will block the chain-drive after a while. Crawling is more robust in different locations, but also more complex in control and not so efficient for a plain surface.

III. STRUCTURES OF THE ORGANISM

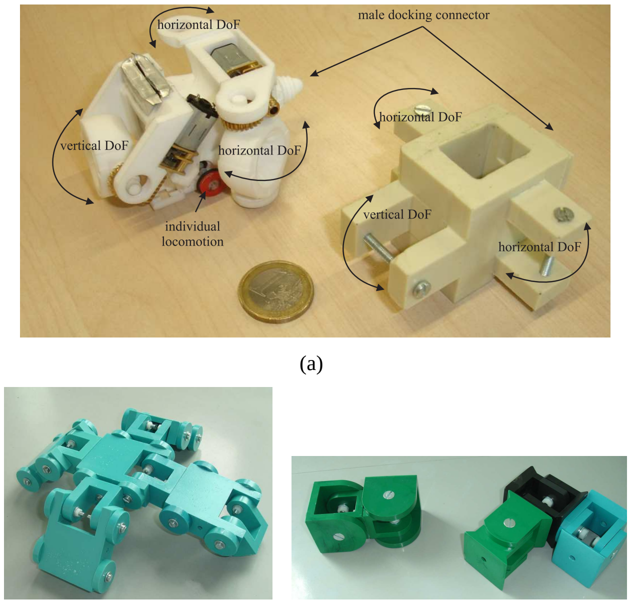
In this section we consider several issues related to structures of organisms:

- which macroscopic structures can be created from basic modules, which limitation are imposed on them as well as which building patterns are important;

- how many functionality of individual modules is used in macroscopic structures, in particular, relation between DOF of individual modules and functionality of organisms;

- swarm-behavior issues, for example, aggregation and disaggregation behavior.

To investigate topological aspects of aggregated organisms, we build simplified models of real modules. These modules reflect only real DOF, size, geometry and weight, see Fig. 6. Molding topological models in polymer repre-



(a)

(b) (c)

Fig. 6. *Topological models of different modules.* ***(a)*** *(left) First rapid-prototyping model with docking elements and individual locomotion, (right) topological model of the PUZZBOT;* ***(b)*** *Topological models of wheeled modules;* ***(c)*** *Topological models of different crawling modules with 1.5 DOF and 3 DOF.*

sents inexpensive and quick way of exploring morphological properties of different macroscopic structures. In following, we focus on two most important aspects: macroscopic locomotion and macroscopic functionality related to features of individual modules.

A. Macroscopic locomotion and imposed limitations

When an organism should survive in its environment, it should possess some obligatory functionality such as:

1) Macroscopic locomotion (organism should be capable of changing its own spatial position);

2) Actuation (perform activities set by designer);

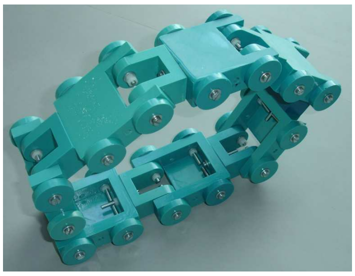
3) Sensing, computation, communication as well as supporting of its own homeostasis;

4) Energy harvesting.

Reconfigurability means that the organisms should be capable of dynamical changing the functionality, e.g. from wheeled to legged locomotion or from one specific actuation to another one.

In the following we concentrate on one aspect of the macroscopic functionality, namely on macroscopic locomotion. We differentiate between ”typical” locomotion such as legged and wheeled ones, and ”untypical locomotion” which is usually produced by evolutionary/optmization algorithms. ”Typical” locomotion is mostly a product of human experience and observations from nature and technics. This kind of locomotion is often represented by n-legs solutions, wheels in different positions of a body, snack-like locomotion as well as different combination of them (+ swimming for water-environments), see Fig. 7.

(a)



(b)

Fig. 7. *Examples of ”typical” macroscopic locomotion.* ***(a)*** *Legged scorpion-like organism;* ***(b)*** *Macro-wheeled locomotion of the organism.*

Examples of ”untypical” locomotion can be given by block-shift moving known from the ”HYDRA/ATON” [6] and ”molecube” [7] projects, moving cylinders from the ”superBot”[2] and others. We believe there are principal limitations imposed on typical locomotion strategies given by:

- the weight of the organism (passive parts which do not carry locomotion functionality and active parts with locomotion/actuation);

- to the torque of motors capable of carrying this weight;

- energy consumed by these motors to execute activities.

For example, the ”dog” structure, shown in Fig. 8, consists of 10 3DOF modules and 4 passive wheeled elements, estimated weight is about 8-10kg. Obviously, that this weight imposes some limit on the number of modules (we believe that organisms with e.g. 20-30 such modules will be not able to move in a legged way). Another problem is that there is a large number of modules in the ”dog” organism, which carry only a static load, e.g. modules in the backbone area. From about 40 motors in this organism only 15-20 motors

[2]see http://www.isi.edu/robots/superbot/movies/

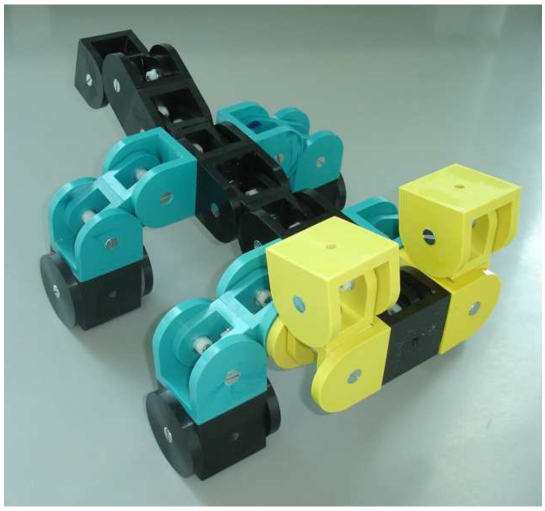


Fig. 8. *”Dog”-like organism consisting of 3DOF modules with legged and wheeled locomotion.*

will be used. Thus, weight and complexity of modules as well as their number in organisms represent an optimization problem, which can be treated in simulation. In general, we believe that there are several ways to deal with this problem:

1) to decrease the complexity of modules, e.g. to 1-1.5 DOF per module. In this way the weight of modules can be essentially decreased;

2) to specialize different modules in actuation and in locomotion. For example, some modules can have large wheels and can use them for the locomotion of the whole organisms. It is clear that there is no need to equip all modules with such wheels;

3) to produce passive modules without any actuation or locomotion at all. Instead, such passive modules can carry additional accumulator or powerful computational resources;

4) to produce separated tools without any essential computational resources.

In this way we intend to make a heterogeneous swarm of different autonomous modules with changeable tools. To exemplify all mentioned points, let us consider a relatively simple organism, called ”car”, see Fig. 9. This organism consists of one passive module (behind) with integrated large wheels (tools), two actuating module (middle) without individual locomotion and one actuating module (in the front) with integrated large wheels. The assembling start from modules which have individual locomotion. They look for other passive and actuating modules until the whole organisms or its part will be assembled. This strategy allows making more simple and more light modules, however it also transfer some problems from hardware into the software design.

In particular, we expect some swarming problems during aggregation and disaggregation phases. All robots should have a plan about the structures they are going to assemble. Moreover they should be capable of dealing with such situation where no required modules are found (or their finding os too expensive). Similar problems can appear during the

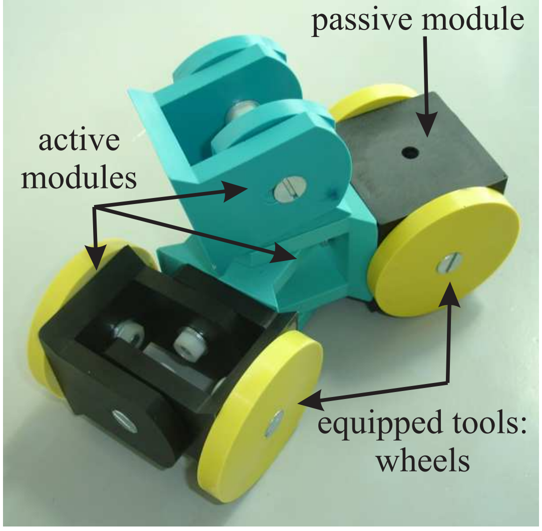


Fig. 9. *"Car"-like organism, consisting of heterogeneous modules.*

disaggregation phase, where a dedicated module should be removed from the organism.

B. Relation between individual modules and macroscopic functionality

Considering different "typical" and "non-typical" structures of topological models we are asking ourselves about a relation between functionality of modules and the emerged functionality of organisms. Preforming many experiments with topological models, we estimated that the number of DOF in individual modules does not essentially influence common capabilities of organisms. Having only 1-1.5 DOF modules (however a large number of such modules), would satisfy almost all requirements imposed on mechanical features of robotic organisms.

However, we remark that some specific configurations of an organism can essentially influence its macroscopic functionality. We give example by considering unsymmetrical scorpion, see Fig. 10. More generally, we say that

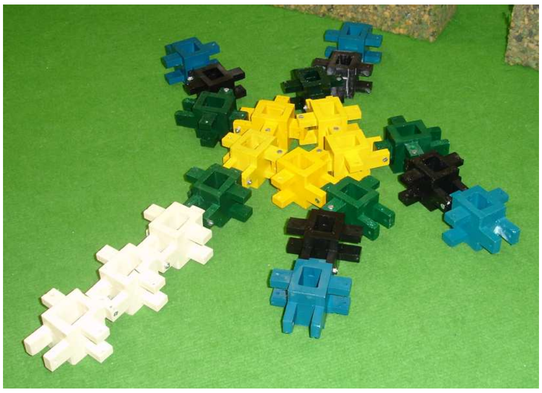


Fig. 10. *Unsymmetrical scorpion on a plane.*

unsymmetrical morphology of organisms has in many cases very amazing properties. It was already mentioned that it usually represents a result of evolutionary approaches, where the desired functionality is achieved in "unusual way" (from human point of view).

Unsymmetrical scorpion possesses very interesting property of mechanical amplification of torque from several motors. It is visible in the Fig. 11. Central modules of the

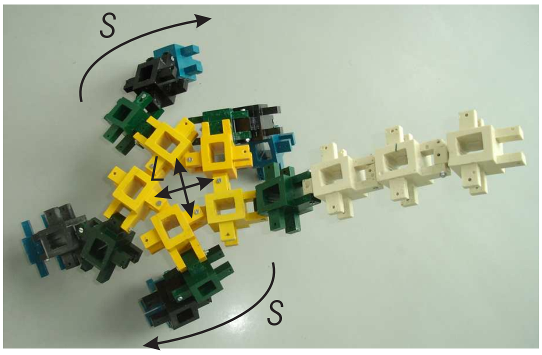


Fig. 11. *Top-down view on the unsymmetrical scorpion, central modules (yellow) built a ring. Deforming this ring, different movement of legs can be created.*

organism built a ring with four rigidly connected legs (0 DOF). Deforming the ring in different points by corresponding motors (L movement), different movements of pairs of legs can be created (S movement). Direction and strength of L movement is influenced by all motors of the ring - deforming the ring by different motors, diverse S movements can be produced.

Unsymmetrical scorpion gives an idea of how macroscopic topology can influence functionality of organisms. Based on this example, we can even draw several conclusions about the required features of corresponding modules. For example, we need a rigid connection between the ring and legs in horizontal DOF. However in general, this issue is currently open and needs more extensive experimental and simulative exploration.

C. Homogeneous and heterogeneous self-assembling swarms

As previously demonstrated, in its starting phases a project on modular robotics typically outputs several solutions in the design of the basic robotic module. Actually it is generally very difficult to envision the optimal compromise of features for having specific advantages at the level of the assembled organism. As a consequence each design tends to favor a particular aspect, namely, integrated degrees of freedom, locomotion capability, miniaturization, actuation power, etc.

From such a condition it is a natural consequence coming to the discussion about the possibility to:

1) Merge the best features of all the designs in a unique module accepting performance compromises of the swarm but making easier the control of the organism (*homogeneous* swarm). This is a way mostly followed by state-of-the art modular robotics.
2) Have different modules with specialized capabilities that can assembly by means of compatible docking

systems, and thus empowering the global swarm capabilities in detriment of a more complex control of the assembled organism (*heterogeneous* swarm).

3) Envision the development of a common robotic chassis with standardized interfaces to which it is possible to dock stand-alone "tool-modules". Tool-modules can be generally defined as devices that can simply dock with the robot, receive commands from the robot and send sensor data to the robot. These could be wheels, sensors, grippers, etc. The approach in this case can be even twofold:

    a) these tool-modules could be completely passive and manually assembled before starting the task according to the task itself, thus selecting a particular set of tools to equip robots with, or different set of tools for different set of robots, each specialized for a specific task. This would be a sort of pre-planned swarm for a specific known (but also unknown) task.
    b) the tool-modules could be part of the swarm as stand-alone modules placed in the environment: depending on the immediate and local needs each robotic module could decide to search and dock for specific tool-modules. In this case the swarm could specialize itself during a task, being more flexible and versatile. However, in this case not only the tool-modules would require some communication means (to communicate their presence to the robotic modules), but the searching process could be energy and time consuming and the robots would have to face a further self-assembling challenge before the self-assembly itself into a robotic organism.

A final decision about the approach to choose can be critical in terms of capability and performance of the robotic swarm and the final assembled organism(s). It should be mentioned, however, that much depends also on the particular application the robotic systems is intended to. For instance, an approach of the type 3a) would probably not match well the needs an exploration task in an unstructured environment would require: before becoming (better) operative, the robotic modules would have to search for "upgrades" (i.e. the tool-modules), a task that could be difficult in an unknown environment with obstacles and challenges for robots having limited capabilities. On the other hand the same approach 3a) could be very interesting from a scientific viewpoint for testing the capability of the swarm and assembled organism to configure itself in a basic test-environment also in terms of chosen tools-based functionalities and capabilities. Taking inspiration from the biological domain, it could be observed that natural swarms are often heterogeneous, not only for the different behavioral specialization of each swarm member, but also from a strict physical viewpoint (e.g., in a same colony there are insects with different physical capabilities). However, differently from natural insect swarms, the conceived robotic swarm should also be able to assembly and this goal can be more complicated with heterogeneous modules, regarding the assembly process itself, and, even more, for what concerns the software level (e.g., the self-learning and behavioral control of the assembled organism).

If the main application of the robotic system consists in a "real-exploration" of unknown and unstructured environments, the possibility to have robots that can be immediately operative and specialized, in diversified typologies, could be beneficial in terms of the swarm efficiency. In a similar case an approach like 1) could be not satisfactory due to the environment conditions (more advanced locomotion capability could be required for instance), while an approach like 3a), although it could guarantee the maximum swarm versatility and adaptability to the environment, could lead to stumbling blocks, due to the limited capabilities of the basic robotic modules. A possible basic approach in terms of heterogeneous swarms for applications in exploration scenarios could rely on 2 different robotic modules which are differently specialized, for example:

- An advanced-locomotion "scout" robots, equipped with far-range sensors and, above all, specialized in fast and precise locomotion in order to be immediately ready for quick environment inspection and also swift gathering of parts for the assembly. For this purpose, wheeled locomotion would be advantageous. On the other hand wheels integration generally lead to the design of car-like modules, as shown in the previous sections, inevitably loosing DOFs in order to avoid too high mechanical complexity on board the robot. Another different robotic module could consequently fill this gap supplying necessary DOFs on the organism level (see next point).
- Modules with higher DOF capability that would constitute the main backbone of the organism, while also integrating tools/sensors mainly useful to the assembled organism (e.g. grippers). These modules could be thought to be less mobile than scout robots (but not stationary, they could crawl, for instance) and they could perform a more detailed exploration of the immediate surroundings, while establishing communication networks to give positioning coordinates to the scouts for successive gathering and assembly.

IV. CONCLUSION

In this paper we represented to public review several preliminary designs in hoping to collect the feedback and to improve these designs. In this consideration we focused only on a mechanical elements and also meaningly leaved details of platforms because they do not contribute to a common understanding as well as due to early developmental stage of projects.

Very interesting results are obtained by real topological modelling (not in simulation!): we can estimate size and weight constraints imposed on aggregated organisms; we can draw conclusions backwards to modules' design; we can think about organisms-specific locomotion and macroscopic functionality. Several from many performed experiments are described in this paper, the rest can be found on the projects page. It seems that further optimization work is required in simulation.

The most important results on this stage are decisions about heterogenous modules and reducing a complexity of these modules. We are determining the notion of heterogenous self-assembling swarm and are working on different options: homogeneous basic platform with changeable tools, heterogeneous platform, heterogenous semi-autonomous tools and so on. We assume that this discussion can be also of interest for the robotic community.

It seems currently that 1-1.5 DOF would be enough to make most of all intended macroscopic structures. However we assume that a large number of them can be aggregated into the organism. The further development will show which modules are required and are feasible. Reducing complexity of modules has several advantages over more complex solutions (such as lover weight and costs, increased reliability), however they posses also some disadvantages. The most important are swarming-related issues during aggregation and disaggregation phases connected to finding/removing proper modules for intended organisms.

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