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Employing symbiotic robots to enhance pervasive systems

Florian Schlachter, Eugen Meister, Serge Kernbach, and Paul Levi

Combining swarm and reconfigurable robotics enables various forms of adaptation and can extend the range of pervasive-system applications.

We are increasingly surrounded by pervasive systems and applications allowing users to roam and benefit from different services, most of which are implemented in well-known environments. Devices are often distributed randomly or deployed according to preliminary considerations. Because the behaviour of users and the environment is not always known a priori (and can change frequently), pervasive systems occasionally have to adapt to new conditions. For some applications it is even desirable that devices can autonomously change their position, functionality or degree of connectivity, e.g., to guide and support people at airports or in museums. Mobile devices—such as autonomous robots—can adapt to the dynamic behaviour of passengers and visitors, and balance the available resources to the local demand to guarantee a reliable service. At night the same mobile devices can monitor facilities and adopt security functions. In an alternative scenario—such as after an earthquake where the functionality of the pre-existing infrastructure and power supply is limited—mobile devices can autonomously fan out to cover a wide area, e.g., to provide rescue teams with communication chanels or search for trapped people.

The SYMBRION and REPLICATOR projects[1,2] combine the benefits of swarm and reconfigurable robotics and also use paradigms from bio-inspired and evolutionary computation to develop a new generation of autonomous mobile-robot platforms. Each robot can behave independently, but when required they may aggregate into artificial organisms to achieve more advanced capabilities (see Figure 1). Such a symbiotic swarm of robots can therefore spread out and reach exposed, strategic vantage points. The robot swarm can exchange messages and resources—such as energy or computational power—over a common bus system. Consequently, a symbiotic organism can balance its workload and power consumption. In addition, the individual robots can be equipped with special tools and share information from remote or specific sensors. The symbiotic robots can therefore

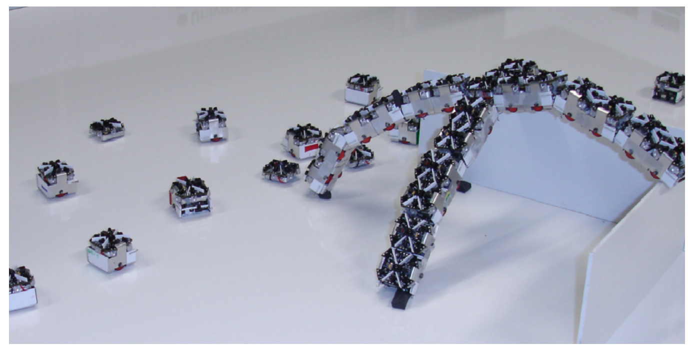

Figure 1. *Vision of SYMBRION: robots aggregate autonomously into an artificial organism to overcome physical obstacles.*

extend and equip pervasive systems with a new kind of capability: the adaptive system is physically assembled, and can autonomously sense and act in different environments. Most important, it can change its own spatial, functional and structural configurations on the basis of environmental feedback, without the need for human assistance.

In other (somewhat similar) past and ongoing projects the creation of autonomous multirobot organisms was never fully achieved. The aggregated structures in the Swarm-bots[3] and Swarmanoid[4] projects are limited to 2D configurations, and they do not have internal buses. The SuperBot[5] and Molecube[6] initiatives work on the basis of individual nonaggregated robots characterized by very limited mobility which cannot aggregate autonomously. Because of rapid technical progress in the past few years, new mechanical and electronic options have materialized. The development costs of embedded systems have become cheaper and allow for the design of small powerful robots. We can therefore improve upon the approaches used previously.

To achieve further mechanical development[7] we had to take into account several requirements. Because the individual robots must be able to change their position, we equipped each with an omnidirectional drive suitable for even rough terrain. These actuators have to be as efficient as possible to minimize power consumption for mobility. To overcome physical obstacles and gaps the robots can dock to each other. After

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having explored several potential designs we settled on a module type that allows us to construct several different configurations, similar to spider- or snakelike organisms. In addition, the docking mechanism must be highly robust to withstand the high kinematic forces acting upon it during operation and to enable exchanges of messages and power. At the same time powerful actuators are needed to lift other contributing modules and therefore act as a single organism.

To handle a variety of communication channels, actuators and sensors we need an elaborate electronic design. All electronic components must be integrated into the robot within existing space and weight constraints. The additional high computation power required by bio-inspired approaches (e.g., learning or evolution) encouraged us to use several microcontrollers and microprocessors in a single module. These consume different amounts of power and can provide a range of computational power and memory capacity. Depending on the situation and the assigned tasks, the robot can use these devices for optimal sensor processing, vital functions and image processing or evolutionary tasks online and onboard. Each module contains five different communication channels, including wireless, IR-based, sound-based, color light and interorganism communication over a high-speed data bus. In addition, all robots include a sophisticated power-management system which enables different voltages and, in particular, energy exchange over the common power bus.

To develop the control mechanism we follow two principal paradigms, i.e., engineering-based and bio-inspired. The former uses traditional approaches from cognitive science and robotics, while the latter is based on new concepts, including immune networks, genetic reproduction, the concept of death and sexual reproduction. In particular, the rich computation power allows us to apply new evolutionary concepts. The controllers can be evolved online and onboard without human supervision. Following both developmental strains, we hope to soon reveal a new combined paradigm of artificial-organism construction.

Adequate middleware takes care of all organism-wide functions, including communication, workload and power exchange. The resulting applications are modular and can adapt dynamically to new situations. Hence, we can combine a highly reconfigurable hardware platform with modular and flexible software applications. We can also investigate the interplay between hardware and software, which may lead to a new level of quality. This approach will thus push pervasive applications and adaptation further.

In general, the SYMBRION and REPLICATOR projects cover a broad spectrum of ongoing research efforts. Both projects share development of a common platform but differ in their approaches to constructing artificial organisms. SYMBRION explores the main principles of artificial evolution and embodied pervasive adaptation, while REPLICATOR strongly focuses on the cognitive capabilities of artificial organisms and their industrial applications. The forms of adaptation, the new possibilities of interaction within swarms and organisms and the expected embodiment resulting from the interplay between hardware and software in both projects enables enhancement of pervasive applications and adaptation. In the future we will extend the range of applications for symbiotic-robot platforms. Improved bio-inspired concepts and innovations in hardware and software development will be integrated to constantly push the limit of feasibility.

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Author Information

Florian Schlachter, Eugen Meister, Serge Kernbach, and Paul Levi
Institute of Parallel and Distributed Systems
University of Stuttgart
Stuttgart, Germany

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