Current Topics in Classic Self-reconfigurable Robot Research

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***Abstract*— As opposed to common claims, self-reconfigurable robots have not yet been realized. Self-reconfigurable robots are supposed to be self-reconfigurable, physical, distributed and autonomous. Self-reconfigurable in the sense that they can change their own shape by rearranging constituent modules. Physical in the sense that they function in the real world. Distributed in the sense that control is distributed across the modules of the robot to ensure robust, fast, and parallel responses to changes in the environment. Autonomous in the sense of being able to adapt to changes in the environment. In this paper we try to identify classic research areas that are relevant for actually realizing self-configurable robots.**

I. Introduction

The purpose of this paper[1] is to identify research challenges that will bring the field of self-reconfigurable robots forward and potentially open the door to new potential applications. The goal we aim to achieve is to ensure that the community do not iterate on out-dated topics and instead focus its energy on productive research challenges. One step we have taken to nurture this development is the publication of books that make existing research more accessible and thus allow researchers to pick their path of research in an informed way [2], [1]. However, these books do not answer the questions of what are potential interesting research directions and maybe more importantly what are dead ends. In this paper we try to address these questions. The answer is of course subjective, but we hope that the views expressed here are representative of the views of the established self-reconfigurable robot research community in general. While we acknowledge there may be a potential in implementing self-reconfigurable robot using other technologies such as bio-chemo hybrids systems, we maintain a narrow focus on classic self-reconfigurable robots based on conventional mechatronics and computational architectures. The reason being that this is our expertise and where we can avoid speculation and contribute the most.

At the most general level robots do two tasks: locomotion and manipulation. These tasks are the ones we must also address in the self-reconfigurable robot community. Self-reconfigurable robots, of course, are based on an underlying assumption that a useful element is self-reconfiguration. While support for this is still work in progress, we accept this as an assumption for the purpose of this paper. We have thus divided the paper into these three fundamental capabilities of self-reconfigurable robots. We continue to briefly discuss the more general software challenges of self-reconfigurable robots and have even included a conclusion.

II. Definition

It is important to realize that our field has its primary historical roots in the field of distributed autonomous systems with influences from self-assembly, self-organization, distributed algorithms, robotics, and computer science. It is, therefore, fundamental to understand that self-reconfigurable robots are supposed to be distributed autonomous systems. While most modern self-reconfigurable robots are distributed none are autonomous, making it clear that we yet have to truly realize self-

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[1]The purpose is really to provoke a discussion at the IROS 2011 Workshop on Reconfigurable Modular Robotics: Challenges of Mechatronic and Bio-Chemo Hybrid Systems.

reconfigurable robots. Furthermore, a cornerstone of distributed autonomous systems is that they are scalable, which has not yet been demonstrated in a physical system beyond the inflated argument that just because snakes and walkers can be extended they are scalable. The definition we would like to propose is that self-reconfigurable robots are physical, distributed, autonomous, scalable, and, of course, self-reconfigurable.

III. Self-Reconfiguration

At its core self-reconfiguration is both a hardware and a software challenge. It is essentially meaningless to talk about each in isolation because the software is uniquely tied to the motion constraints and limitations of the hardware.

There are essentially no examples of self-reconfiguration algorithms able to control more than the particular self-reconfigurable robot for which they were designed. This is perfectly understandable since from a computational point of view the self-reconfiguration problem is believed to be NP-hard, if the problem is posed as how to optimally reconfigure between two general configurations A and B. This essentially means that there are no efficient, general algorithms to be discovered and thus useful algorithms always rely on simplifications, heuristics and on exploiting the specific features of the self-reconfigurable robot in question. A simplification that has become obsolete is the simplification of the motion constraints of modules. While having been useful in the past, e.g. the sliding cube model, the simplifications are less useful today because it is increasingly clear that it is not possible to build a self-reconfigurable robot with these motion characteristics and even using meta modules is not practical (meta modules become too large). We think that it is important for future work targeted at driving self-reconfigurable robots forward to only base algorithmic experiments on robots that have been physically validated. Unless, of course, the focus of the algorithmic work is to explore potential module designs, which, however, still need to be validated. Also, given the significant amount of work on planning, and the modern focus on distributed autonomous system, reconfiguration planning, whether online or offline, is not central to the field today. Rather, goal-driven distributed control algorithm for self-reconfiguration should be sought.

In terms of hardware, you would, judging from the papers published on the subject, imagine that three dimensional self-reconfiguration has been solved. However, the truth of the matter is that three-dimensional self-reconfiguration has only been **demonstrated**. We know for a fact that self-reconfiguration experiments with both M-TRAN and ATRON are painful and success is rarely the end result. As a consequence numerous, long running self-reconfiguration experiments using hardware have not been published. We could choose to ignore this problem and blame it on the prototypical nature of our hardware, but we would like to take a conservative position and accept that maybe our approach is fundamentally flawed. We would therefore maintain that the challenge of physical, three-dimensional self-reconfiguration remains unsolved. This means that validation of existing work should be considered a contribution and, at a higher level, explorative hardware development and contributions are crucial to the field.

This challenge can of course be addressed in many ways, but we think that maybe a concrete challenge can inspire old as well as new members of the community to revisit the important question of self-reconfiguration. The challenge we propose is vertical self-reconfiguration: build the highest tower possible given a number of physical modules. For now, we do not care whether the plan is made manually, offline or online, or whether the control is centralized or distributed. This challenge, while involving software, put an emphasis on the shortcomings of the current generation of mechatronics of self-reconfigurable robots. Another important effect of addressing this challenge is that this will be impressive for robotics as a whole and thus reach beyond the research community of self-reconfigurable robots.

IV. Locomotion

After self-reconfiguration, locomotion is the topic that has achieved most attention in the community. The main point of this work is to demonstrate versatility of the robot platform. It has also been used as a testbed for learning and control algorithms in general. However, for the sake of improving self-reconfigurable robots it is essentially useless to study locomotion in this manner. The reason is that locomotion is predominately a problem whose solution can be found in mechanics. Self-reconfigurable robots with their large amounts of redundant hardware and use of standardized actuators for all joints are largely unsuited for locomotion. It is therefore difficult to push the boundary of locomotion in robotics with these platforms. However, locomotion research can be beneficial if it is targeted towards radically increasing the autonomy of the robot. We will therefore propose that locomotion research is only pursued to the degree that it is possible to demonstrate superior autonomy of movement compared to conventional robots. A challenge is to traverse the deepest hole (or highest hill) possible with at least vertical sides (considering overhangs is even better). The hope is that a demonstration such as this will at least compare to the performance of snake robots, but hopefully exceed them due to the larger structural stability of self-reconfigurable robots.

V. Manipulation

Parallel arguments to those of locomotion apply to manipulation: manipulation is studied for the reasons of demonstrating versatility of a robot platform and for studying control and learning algorithms. However, again given the redundant hardware of self-reconfigurable robots, they are largely unsuited for studying manipulation in general. Only within the narrow domain of self-reconfigurable robots does this make sense. Fortunately, self-reconfigurable robots present two opportunities for studying manipulation: 1) three-dimensional, distributed manipulation and 2) collective actuation.

Three-dimensional distributed manipulation can be seen as an extension to the body of work on distributed manipulation, which is made possible by the three-dimensional nature of self-reconfigurable robots. The key difference is the third dimension and it is therefore natural to emphasize this with a challenge: transport an object as high as possible using a specific number of modules. This area, however, is open so other challenges are also relevant.

The challenge of collective actuation is to understand how many individual modules can combine their forces to create an external force that is significantly larger than that of the individual module. The challenge is: use physical self-reconfigurable robots to apply as high a force as possible to a point given a specific number of modules. Again this challenge is both a hardware and software challenge.

These challenges may lead to applications for self-reconfigurable robots and at the same time are also contributions to the wider field of robotics.

VI. Distributed Autonomous Systems

We have so far put emphasis on mechanics, but there is also a significant challenge in making a self-reconfigurable robot able to change its configuration, autonomously and in parallel, depending on changes in the environmental. In this case, the control should neither be playback, deterministic, nor centralized, but should be distributed and autonomous. The task can be as simple as possible, but the robot should keep working without human intervention.

VII. Research Platform for Software Engineering

Self-reconfigurable robots have also gained traction as a research platform for software engineering. In particular, the question of how distributed, mechanically coupled modules can be programmed and debugged has received significant attention. While this work is mainly a contribution in the area of software engineering, it is clear that increased programmability of these systems would allow for easier development and deployment of self-reconfigurable robots. This is certainly an important topic, but is at this point in time not the main obstacle for the application of self-reconfigurable robots. This may not be problematic to this line of research because the fundamental insights in software engineering may find its use in other application domains.

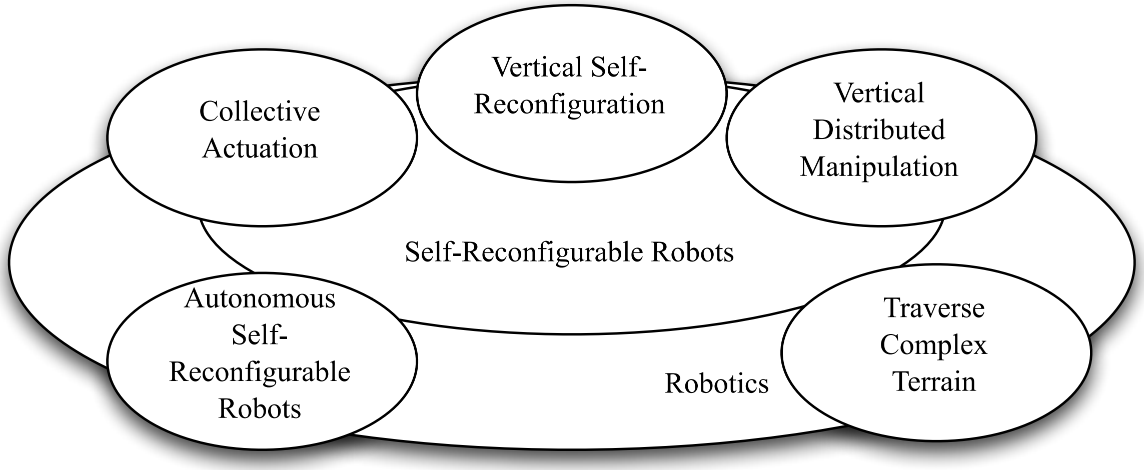

Fig. 1: The proposed areas of research will be a significant contribution to the field of self-reconfigurable robots and maybe more importantly to robotics in general.

VIII. Application

Applications of self-reconfigurable robots are still elusive. Essentially, we have three main ways to deal with this problem. The first is to say that we study self-reconfigurable robots as a basic research discipline in its own right. While this certainly has been a valid argument, it is becoming less strong given that these systems, depending on your view, have been studied to a sufficient level of detail. The second approach is as outlined above to push the field of self-reconfigurable robots forward in the hope that these new capabilities will allow self-reconfigurable robots to find an application niche in the real-world socio-economic environment, e.g. something as revolutionary as stomach inspection and surgery. The third path is to accept the state of the art and based on this look for applications. The first that springs to mind is education since self-reconfigurable robots and the simpler modular robots in general are suitable for physical experimentation on the part of the student. Other applications are probably out there, but they are likely to be found as a simplification of the more advanced concepts that we explore in research. If we for instance look at a none-load bearing architecture there is a potential in making two-and-half-dimensional self-reconfigurable structures that provide the building with dynamic facades for both functional and aesthetic purposes.

IX. Conclusion

The purpose of this paper is to point out future challenges of classic self-reconfigurable robotics which have the potential to lead to applications of self-reconfigurable robots as well as representing an advance for robotics in general. The proposed challenges, also illustrated in Figure 1, are:

- Build the highest structure possible
- Lift an object as high as possible
- Traverse the largest gap
- Apply as high a force as possible to a point
- Realize an autonomous self-reconfigurable robot

While there certainly are more challenges out there these represent the last challenges of what one could term classic self-reconfigurable robots. We feel that with these challenges addressed there is little in terms of science we can do to push self-reconfigurable robots forward. Instead, we have to focus on simplifications of self-reconfigurable robots for the purpose of pursuing specific application domains.

References

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