NOVEL ROBOTIC EXOSKELETONS FOR SPACE EXPLORATION AND COLONIZATION

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ABSTRACT

In this paper, we describe a novel robotic concept targeted towards future space colonization missions. We propose to use Robotic Exoskeletons to introduce dynamic function changing to our swarms of compliant robots and to control our overall system using advanced Deep Learning techniques aimed at emulating the adaptation capabilities of social insects' colonies.

1 INTRODUCTION

Space colonization is a long-term goal of international space programs, and ambitious mission concepts involving full-fledged space cities have started to take shape in recent years. However, such challenging goals require a change of paradigm in space robotics to create more flexible and versatile platforms and control infrastructure able to ensure and support human presence on extraterrestrial celestial bodies. In this paper, we present innovative and disruptive robotics' concepts to tackle the challenge of space exploration, with the long-term goal of creating permanent human colonies in extraterrestrial environments. We introduce the notion of robotic exoskeletons and modular robots, then show how they can be combined with advanced Artificial Intelligence and Deep Learning techniques to create a versatile and efficient robotics framework for space exploration and colonization.

2 BACKGROUND

Self-Reconfigurable Modular Robots (SRMRs) are robots able to adapt to the task at hand autonomously and have been proposed to provide more versatility to robotic systems [1]. These systems can tackle complex tasks by having the assembly of SRMRs change its shape to adapt and overcome unexpected difficulties. SRMRs are particularly well suited for missions with versatile objectives in largely unknown environments. The fact of being more versatile presents a considerable advantage when considering space missions in which payload is extremely limited. However, these platforms have traded specialization for versatility, resulting in lower performance than that of a dedicated system.

3 ROBOTIC EXOSKELETONS

We propose to tackle the challenges of the upcoming space missions using a novel concept based on SRMRs and Robotic Exoskeletons (REs) [2]. REs can be thought of as external suits that the robots can equip to boost their capabilities along a given performance axis. For example, a rolling robot design to move on solid terrain could equip a specialized exoskeleton, which gives it better traction on sand. Using REs offers excellent flexibility in terms of mission planning since the capabilities of the robots can be changed on the fly depending on the task to be performed and on the stage of the mission. The resulting system is not only more robust against unexpected failures due to the decoupling between specialized actions (via REs) and core functionalities (SRMR basic units), but it is also upgradable, which is a property that has never been implemented in such space systems. By sending new REs on the mission site, the systems can gain new or improved functionalities, and the overall cost of exploitation of the sys-

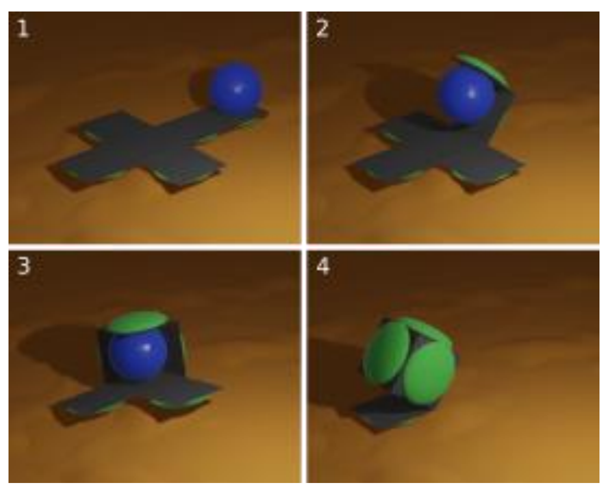

Figure 1: A conceptual depiction of a Base Unit (blue sphere) equipping an exoskeleton (grey and green planar structure).

tem will be reduced.

In order to cope with payload limitation and heavily constrained on-site production capabilities, we will take inspiration from the art of origami to design our REs. We propose to create planar REs that the base robotic units can autonomously equip via a rolling motion on the RE, which will trigger a sequential folding of the RE around the unit (Figure 1).

Another limitation of individual SRMRs is the issue of the scale of the basic unit. Some tasks, such as long-range exploration missions, may require considering large units while others, such as the exploration of small crevices, need small and flexible robots. We propose to tackle the scaling challenge by introducing Multi-Units REs (MUREs). We are designing small Base Units (BUs) that have the ability to use MUREs to connect with each other and to amplify some of their capabilities. For example, several Base Units could equip a large MURE capable of not only transporting the BUs themselves, but also carrying several REs as cargo, and travel long distances using motion amplification. When they arrive at their destination, they separate again, use the REs to carry out their mission and go back to the base station.

4 BASE UNIT

The design of the Base Units is challenging since they will be the core element of the system. Considering past results [3] showing the benefit of using compliant structures for locomotion and impact absorption, we decided to create compliant Base Units able to exhibit fast locomotion on rough terrains and to withstand considerable impacts. These Base Units are equivalent to compliant modular units with active connection capabilities to equip the REs and interact with the environment. Determining the set of functions that the Base Units should have is a problem on its own that needs in-depth investigation. The balance between BUs and REs for function allocation is similarly crucial.

The field of compliant robotics has rapidly expanded in recent years. Compliant platforms offer significant advantages over their rigid counterparts in terms of robustness against perturbations and impact resistance, mimicking living organisms in many aspects. They are exceptionally well suited for applications in which the environment is mostly unknown and when interacting with humans or fragile objects is required. However, they also introduce challenges mainly at the level of their control architecture since compliance is hard to model and to account for in classical control schemes. Several control schemes have been developed to introduce compliance into the field of modular robotics [4,5,6] with promising results for locomotion performance and impact absorption. However, compliant mechanisms and platforms have been seldom used in the space domain due to the inherent control difficulties and the choice of material that need to resist the harsh environment of space. The design of our BU is inspired by the Minerva II (JAXA) [7] and MBlocks (MIT) [8] robots. The materials available for compliant robots and the current mechanisms are complex to design and produce, which makes them unsuited for on-site production in space. The proposed approach requires simplified yet efficient structures able to withstand the constraint of space environments in terms of material choice but also from a structural point of view.

5 CONTROL FRAMEWORK

The autonomy of our robotic framework will be one of the critical elements to developing large scale infrastructures through ever-changing conditions and objectives. In order to empower our system with such a level of autonomy, we extend our recent work [9], and we explore the use of advanced Artificial Intelligence and Deep Learning techniques [12] for the control of individual units, robot sub-teams, and at the level of the entire swarm. The framework that we are proposing relies on a multi-level dynamic task and function allocation that has not been investigated yet. One of our objectives will be to emulate the impressive behaviors observed in social insects' colonies.

6 CONCLUSION

This paper summarizes the main elements of a new framework for future space exploration and colonization missions based on the novel concept of Robotic Exoskeletons and controlled using advanced Artificial Intelligence techniques.

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References

[1] Yim, Mark, Wei-Min Shen, Behnam Salemi, Daniela Rus, Mark Moll, Hod Lipson, Eric Klavins, and Gregory S. Chirikjian. "Modular self-reconfigurable robot systems [grand challenges of robotics]." *IEEE Robotics & Automation Magazine* 14, no. 1 (2007): 43-52.

[2] Miyashita, Shuhei, Steven Guitron, Shuguang Li, and Daniela Rus. "Robotic metamorphosis by origa-

mi exoskeletons." *Science Robotics* 2, no. 10 (2017): eaao4369.

[3] Bonardi, S., Romanishin, J., Rus, D., & Kubota, T. (2019, May). Central Pattern Generators Control of Momentum Driven Compliant Structures. In *2019 International Conference on Robotics and Automation (ICRA)* (pp. 3585-3591). IEEE.

[4] Vespignani, M., Melo, K., Bonardi, S., & Ijspeert, A. J. (2015). Role of compliance on the locomotion of a reconfigurable modular snake robot. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 2238-2245). IEEE.

[5] Vespignani, M., Melo, K., Bonardi, S., & Ijspeert, A. J. Snake robot locomotion with compliant elements.

[6] Bonardi, S., Vespignani, M., Moeckel, R., Van den Kieboom, J., Pouya, S., Sproewitz, A., & Ijspeert, A. (2014). Automatic generation of reduced CPG control networks for locomotion of arbitrary modular robot structures. In *Proceedings of Robotics: Science and Systems* (No. CONF).

[7] Kubota, T., & Yoshimitsu, T. (2013, June). Intelligent rover with hopping mechanism for asteroid exploration. In *2013 6th International Conference on Recent Advances in Space Technologies (RAST)* (pp. 979-984). IEEE.

[8] Romanishin, J. W., Gilpin, K., Claici, S., & Rus, D. (2015, May). 3D M-Blocks: Self-reconfiguring robots capable of locomotion via pivoting in three dimensions. In *2015 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 1925-1932). IEEE.

[9] Sakamoto, T., Bonardi, S., & Kubota, T. (2020). A Routing Framework for Heterogeneous Multi-Robot Teams in Exploration Tasks. *IEEE Robotics and Automation Letters*, *5*(4), 6662-6669.

[10] Baker, Bowen, Ingmar Kanitscheider, Todor Markov, Yi Wu, Glenn Powell, Bob McGrew, and Igor Mordatch. "Emergent tool use from multi-agent autocurricula." *arXiv preprint arXiv:1909.07528* (2019).