SWARM ROBOTICS: Collective Decisions of Interacting Robots

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***Abstract*—Swarm robotics is an emerging field of robotics inspired by collective behaviour of social insects (swarms). While the usage of single robots is well established, the use of group of robots is an increasingly relevant topic of research. Based on local interaction of a single robot with environment and other few robots, the final aim is to design the emergent behaviour of a whole swarm of robots for specific tasks. Compared to a single robot, a swarm is more robust, flexible, efficient and scalable. Together with simulations, the availability of low cost micro robots allows the realization and study of swarm of robots in the laboratory, before the applications on the field. At the same time also the application of swarm design to drones and aquatic vehicles is gaining a momentum. Potential applications are -among the others- environmental monitoring, disaster rescue missions, precision agriculture.**

Keywords*–*Swarm Robotics, Bio-inspired Robotics, Collective Decision Making.

I. INTRODUCTION

In the last decade, Swarm Robotics is getting momentum, both on public media and in academics conferences and journals. Nevertheless, some confusion still emerge regarding the Swarm Robotics proper definition, which can be quite restrictive, or open to include many examples of multi-robots. Following the definition in [1], [2], "Swarm robotics is the study of how a large number of relatively simple physically embodied agents can be designed such that a desired collective behavior emerges from the local interactions among agents and between the agents and the environment". The most relevant keywords in this definition are in our opinion *simple* and *local*. The single robot has capabilities that are limited compared to what the task requires, while the swarm as a whole can achieve capabilities and intelligence much larger than the one of the individuals. This intelligence *emerges* (another fundamental keyword), in the sense that -in the same way of what is observed in many complex system- the behavior of the system is much more than the sum of actions of single units, but -using the interactions among the units- the system as a whole shows properties that are not observable at the individual scale.

This emerging coordinated action of single robots is achieved not through long range interactions (such as those achievable through wifi) but only using local interactions. From one side, these systems imitate natural swarms of bees, flocks of birds and schools of fishes, so these studies are valuable to pinpoint the key ingredients that allow collective behaviours in biological systems [3], [4]. On the other side, the absence of a network infrastructure is sometimes a specific requirement in remote environments such as underwater or outer space. Therefore, the understanding of how to get a collective intelligence in absence of an external infrastructure for sensing and control plays a crucial role in the design of exploration and other operations in such environments.

Many examples of swarm robotics can be found in literature and the potential benefits are clear: i) swarms are robust: in case of failure of single robots, the swarm can still pursuit and finalize its mission; ii) swarms are adaptable and flexible, in the sense that few single units easily recognize changes in the environment and the whole swarm rapidly adapt to that change; iii) swarms are scalable, because-being based on local interactions- there is no limit to the number of robots that can be added. In addition, a swarm can be cheaper than a single complex large robot, because of scale economies that can be generated and because of the low impact for the loss of only a single unit compared to losing a single complex robot.

Despite these evident benefits, real-world applications of swarm robotics are still few. As highlighted in [5], [6], the swarm of robots so far realized are either large systems of minimalistic robots with limited sensing and limited processing and exchange of data, or system of few advanced robots, that cannot be properly defined swarm due to their limited size. The most advanced examples of cyber-physical and robotic systems (like autonomous cars, quadruped robots, humanoid robots) usually do not interact with their similars in order to get a collective intelligence. Moreover, in industrial applications, some systems are defined as swarm even in absence of some of the above mentioned prerequisites: as an example in light shows (like in the Winter Olympics 2018), the drones are remotely operated, while in warehouses applications single robots are centrally organized and controlled. In this sense, these systems cannot be included in the most restrictive definition of "swarm". Finally, even if many points of contact are evident with IoT, like the interaction of many connected devices, the two communities of Swarm Robotics and IoT work mainly in parallel, without getting advantage of the use of interconnections among devices in a collective intelligence perspective. Nevertheless, some notable industrial applications already show the effectiveness of multi-robot systems designed with swarm intelligence. It is worth to mention, among the others, at least: GUARDIANS (Group of Unmanned Assistant Robots Deployed In Aggregative Navigation by Scent) developed for emergency and rescue purpose [7], SWILT (Swarm Intelligence Layer to Control Autonomous Agents) for scheduling purpose in large industrial plants [8], SAGA (Swarm Robotics for Agricoltural Applications) giving an application of a swarm of aerial drones for smart farming, particularly weed mapping [9], subCULTron (Submarine Cultures Perform Long-term Robotic Exploration of Unconventional Environmental Niches), consisting of an heterogeneous swarm of marine and underwater vehicles, used to continuously monitor the water quality in the Venice-lagoon and transmit data to humans[10].

From the above definition and examples, clearly the single robots have minimum requirements [4] : local communication capability (usually IR or radiofrequency on the ground or air, acoustic or electric underwater), sensing of neighbor agents and of the environment (accelerometer, gyroscope, ultrasonic and pressure sensors, infrared, depending on the specific application), easy on board processing of information, actuators and effectors (like legs, wheels, pins). A detailed taxonomy of swarm robotics has been provided in 2013 [2] and a different and more recent one was introduced in [11], defining few more tasks (see Table I for an extract).

TABLE I. Swarm robotics taxonomy[11]

Spatial organization	Aggregation
	Pattern formation
	Self-Assembly
	Object clustering and Assembly
Navigation	Collective Exploration
	Coordinated Motion
	Collective Transport
	Collective Localization
Decision Making	Consensus
	Task allocation
	Collective Fault Detection
	Collective Perception
	Synchronization
	Group Size Regulation
Others	Selh-healing
	Self-reproduction
	Human-Swarm Interaction

II. CONTRIBUTIONS

In this special track, three example of models of swarm intelligence for robotic applications are shown. The contribution "Collective decision making for environmental monitoring" [12] shows how the theoretical models of collective decision mechanism, specifically the best-of-n model, can be applied to environmental monitoring in dynamic environments, outlining an adapting strategy of the swarm of robots to changes in the environment.

"The effect of differential quality and differential zealotry in the best-of-n problem" [13] describes the interplay between differential option quality and differential quantity of robots with fixed opinion (similar to zealots in social systems), in a best-of-n problem with n = 2 options. A detailed study has been done on how the consensus equilibria change with respect to these two factors.

The paper "Area Inspection by Robot Swarms through Exploitation of Information Gain" [14] proposed a a decentralized and collaborative approach for area coverage and mapping, providing an application to weed monitoring in smart agricolture, but possibly extendable to similar problems of search and rescue. This method, based on Information Theory, improves the accuracy and reduces the exploration and mapping time.

III. CONCLUSION

Swarm Robotics is a new field getting a momentum in the last decade. While from a theoretical and scientific perspective is a well established field, its application to Industry is starting developing now, where we can find already some relevant applications. We hope that the increasing presence of Swarm Robotics special tracks in Autonomous and Robotics conferences will increase the occasions of joint interest and discussion from practitioners and academics working in more established Robotics fields to this new bio-inspired promising field.

REFERENCES

[1] M. Dorigo and E. Şahin, "Swarm robotics," *Autonomous Robots*, pp. 111–113, 2004.

[2] M. Brambilla, E. Ferrante, M. Birattari, and M. Dorigo, "Swarm robotics: a review from the swarm engineering perspective," *Swarm Intelligence*, vol. 7, no. 1, pp. 1–41, 2013.

[3] D. Floreano and C. Mattiussi, *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. The MIT Press, 2008.

[4] H. Hamann, *Swarm Robotics: A Formal Approach*, 1st ed. Springer Publishing Company, Incorporated, 2018.

[5] M. Schranz, G. A. Di Caro, T. Schmickl, W. Elmenreich, F. Arvin, A. Şekercioğlu, and M. Sende, "Swarm intelligence and cyber-physical systems: Concepts, challenges and future trends," *Swarm and Evolutionary Computation*, vol. 60, p. 100762, 2021.

[6] M. Coppola, K. N. McGuire, C. De Wagter, and G. C. H. E. de Croon, "A survey on swarming with micro air vehicles: Fundamental challenges and constraints," *Frontiers in Robotics and AI*, vol. 7, p. 18, 2020.

[7] J. Saez-Pons, L. Alboul, J. Penders, and L. Nomdedeu, "Multi-robot team formation control in the guardians project," *Ind. Robot*, vol. 37, pp. 372–383, 2010.

[8] E. Khatmi, W. Elmenreich, K. Wogatai, M. Schranz, M. Umlauft, W. Laure, and A. Wuttei, "Swarm intelligence layer to control autonomous agents (swilt)," in *STAF*, 2019.

[9] D. Albani, T. Manoni, A. Arik, D. Nardi, and V. Trianni, "Field coverage for weed mapping: Toward experiments with a uav swarm," in *Bio-inspired Information and Communication Technologies*, A. Compagnoni, W. Casey, Y. Cai, and B. Mishra, Eds. Cham: Springer International Publishing, 2019, pp. 132–146.

[10] R. Thenius, D. Moser, J. Varughese, S. Kernbach, I. Kuksin, O. Kernbach, E. Kuksina, N. Mišković, S. Bogdan, T. Petrović, A. Babić, F. Boyer, V. Lebastard, S. Bazeille, G. Ferrari, E. Donati, R. Pelliccia, D. Romano, G. J. V. Vuuren, C. Stefanini, M. Morgantin, A. Campo, and T. Schmickl, "Subcultron - cultural development as a tool in underwater robotics," 2016.

[11] M. Schranz, M. Umlauft, M. Sende, and W. Elmenreich, "Swarm robotic behaviors and current applications," *Frontiers in Robotics and AI*, vol. 7, p. 36, 2020. [Online]. Available: https://www.frontiersin.org/article/10.3389/frobt.2020.00036

[12] G. D. Masi and E. Ferrante, "Collective decision making for environmental monitoring," in *Special Track "SWARM ROBOTICS: Collective Decisions of Interacting Robots", ICAS2020*. IARIA XPS Press, 2020.

[13] J. Prasetyo, G. D. Masi, E. Tuci, and E. Ferrante, "The effect of differential quality and differential zealotry in the best of n problem," in *Special Track "SWARM ROBOTICS: Collective Decisions of Interacting Robots", ICAS2020*. IARIA XPS Press, 2020.

[14] C. Carbone, D. Albani, D. Nardi, D. Ognibene, and V. Trianni, "Area inspection by robot swarms through exploitation of information gain," in *Special Track "SWARM ROBOTICS: Collective Decisions of Interacting Robots", ICAS2020*. IARIA XPS Press, 2020.