

Swarm Robotics: A Formal Approach

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Preface

My major motivation to think about swarm robotics is the question of how probabilistic local actions of small robots sum up to rational global patterns shown by the swarm. For the engineer, it has potential to let a dream come true because complex problems may be solved by designing simple collaborating components. For the scientist, it has potential to help explain grand questions about consciousness, human societies, and the emergence of complexity.

Swarm robotics is a maturing field that deserves a book being dedicated to it completely. Until now there were many interesting books also treating swarm robotics besides other subjects, but there is no fully dedicated book yet. As a resource, especially for young researchers and students, a book seems important. I am trying to fill this gap. This book tells the story of designing maximally scalable and robust robot systems, which turns out to be challenging with today's methodology. Therefore, join me on our journey to find better and novel approaches to designing decentralized robot systems.

Like many other books, this one has a quite long history of origins. In 2013, I started to teach a quite special master's course for computer scientists called "swarm robotics" at the University of Paderborn, Germany. When I was creating the course, it was particularly hurtful not to have a book that teaches swarm robotics in a complete piece. Of course, there are books that contain material relevant to swarm robotics, such as the books on swarm intelligence by Bonabeau et al. [48] and Kennedy and Eberhart [210] and the great book on bioinspired AI by Floreano and Mattiussi [122]. However, they do not define a complete curriculum. So I had to go through what any teacher has to do when creating a course from scratch: define a canon of the most relevant subjects that each student needs to know and create all the teaching material. Probably back then I already had in mind that writing a book may help the field and be a reasonable option. This was certainly confirmed when students were desperately asking for accompanying reading material and I had to keep telling them: "Yes, that would be great but nobody has yet written that book on swarm robotics." So I started the long writing process slowly back in 2013 and students kept asking me for that book over the next years. In the years between

2013 and 2016, I taught that course four times and was able to improve the material. During the main writing period in 2017, I had moved on to another professorship in Lübeck, Germany; meanwhile, I was happy that I often could just write down what was already in my head from teaching the course. However, for a more complete picture of swarm robotics, it was necessary to add much more material going clearly beyond the content of a course. One can tell from the references in this book that I tried hard not to leave out relevant papers. It is still possible, however, or rather quite likely, that I have overlooked something or somebody maybe very relevant to swarm robotics. In that case, please accept my apologies and please let me know about it.

I hope that this book will help at least a few lecturers out there, in the case that they teach either a course fully dedicated to swarm robotics or a course that partially contains material on swarm robotics. You should not go through the same pains that I had when preparing a course out of nothing. Hopefully, also students find it useful, easy to follow, and maybe even a bit entertaining. Young researchers, who want to study the field and to do research on swarm robotics, will hopefully also find some useful information in here as a starting point. At least the problem of overlooking an important paper may be less likely. Finally, I also hope for enthusiastic swarm robotics hobbyists, who dare to look into such a rather scientific book with all that hard-to-follow terminology. Again, I have tried hard to make this text accessible pretty much to everybody or at least to those who know a bit about computer science or (computational) biology.

This book, of course, is only possible because there were many people who either helped me directly with this book or indirectly by discussing swarm robotics with me over the last decade or by letting me know about relevant new or old papers. I want to thank Marco Dorigo, Thomas Schmickl, Payam Zahadat, Gabriele Valentini, Yara Khaluf, Karl Crailsheim, Ronald Thenius, Ralf Mayet, Jürgen Stradner, Sebastian von Mammen, Michael Allwright, Mostafa Wahby, Mohammad Divband Soorati, Tanja Kaiser, Eliseo Ferrante, Nicolas Bredeche, Sanaz Mostaghimi, Jon Timmis, and Kasper Støy. In addition, I want to thank my students attending the swarm robotics course in Paderborn between 2013 and 2016 for asking so many interesting questions, for sharing their solutions to problems of swarm robotics, for motivating me with their enthusiasm, and for challenging me with skeptical questions.

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