1 Introduction

Abstract: Problems in modeling and control of crowds of pedestrians are firstly presented. Short comments on previous research and the organization of this book are also presented in this chapter.

1.1 Motivation

Humans are the most socially complex animals on this planet. It is not surprising that research related to crowds of pedestrian has received a lot of attention in recent years. A lot of work has been conducted for particles, vehicles, robots, animals, and even human beings from the perspectives of behavior, psychology, cognitive, and network theory (see [8, 9, 11, 23, 20]). Among the previous work, problems related to crowds of pedestrians are the most challenging due to difficulties in modeling of human beings, as there are no universal tools to characterize the complex temporal and spatial features of crowds.

On the other side, more and more tragedies due to people's stampede have been reported in recent years. The most tragic stampede occurred in Mecca in 1990, where 1426 pilgrims were trampled to death or suffocated. In evacuation, people got injured or lost their lives due to panic motion or running in every direction without aim. The catastrophic events have demonstrated the need to reanalyze and reexamine current evacuation policies and procedures for crowds of pedestrians. Thus, policy makers urgently need better crowd management or evacuation strategies.

The problems confronted in research of crowds of pedestrians can be listed as follows:

(1) How to characterize or obtain a satisfactory social-dynamic model for crowds of pedestrians that is much closer to reality compared to the previous model.
(2) How to enforce and stabilize the desired pattern formation of crowds of pedestrians and how to avoid some rare or dangerous formation pattern in evacuation of crowds.

1.2 Current status of research

1.2.1 Modeling of crowds

According to the differences in scales, the models for crowds of pedestrians can be categorized by microscopic model,macroscopic model and mesoscopic model (see [10, 3, 14, 2, 7]).

https://doi.org/10.1515/9783110473988-001

(1) The Newton principle is a powerful tool to describe the motion of particles at microscopic scale but the heavy burden of computation will not make it a better choice with the increase of the number of particles.
(2) Conservation of mass and momentum is the basic principle employed in obtaining the macroscopic model. Although the computation burden has been reduced greatly, the individual character of each pedestrian has been ignored when using this kind of method and the heterogeneity of different pedestrians can't be easily characterized at the macro-scale.
(3) For a mesoscopic model, not only the computation burden has been reduced, but also the heterogeneity of different pedestrians can be guaranteed. However, qualitative and quantitative results are not easy to obtain for integral-differential equations obtained at this scale.

Besides the problem of multiple scales in modeling crowds of pedestrians, there are a lot of other effects that influence the pattern of motion of crowds, such as imitating behavior of neighbors, following external signals, psychological unity, emotional intensity, and level of violence, as shown in [5]. The present status is that there is no common agreement on which model is the best one in describing this kind of complex social dynamics. A new methodology and theory are required for better approximating and characterizing this complex social-dynamic system.

1.2.2 Control of crowds

Compared to the modeling of crowds mentioned above, control of crowds is much more challenging as shown in recent work; see [14, 4, 10, 12, 6, 24].

- A lot of evacuation procedures or policies have been designed using computer simulations. Considering the adaptability and robustness to the environment, the method of simulation is not a good choice as the obtained modeling results or evacuation policies are not effective anymore in different buildings or different scenarios.
- In some of the previous research based on the mathematical model, pedestrians have been treated as particles and some of the characteristics of human beings have been neglected in control of the crowds, such as short-range and long-range interactions, effects of memory, and statistical characters at the temporal or spatial scale.
- In large crowds of pedestrians, self-organization or cooperative movement have been observed a long time ago. But there is little research on how to realize the desired formation patterns and prevent dangerous patterns so that a stampeding tragedy can be avoided.

As there is no perfect model for all kinds of scenarios, there are no universal controllers that can solve all evacuation problems. Based on models that are much closer to reality, many efforts have been made as regards control of crowds for the purpose of better management and efficient evacuation of crowds.

1.2.3 Comments

Some manuscripts have been published in recent years concerning the modeling and control problems of crowds of pedestrians, such as [22, 13, 25, 19, 1, 18, 21, 26, 17, 16]. But the authors found that some important characteristics of the crowds have been neglected in previous research and their effects should be reconsidered and reexamined in both the modeling and the control stages for crowds of pedestrians.

(1) *Integer order versus fractional order at temporal scale.*
The movements of each pedestrian are the results of a complex interaction between physical and psychological issues. Inter-event time has been proved to play an important role in analyzing the movement of crowds, as shown in [27]. Contrary to the fact that the distribution of inter-event time satisfies a power law distribution in most cases, an exponential law distribution has been assumed in most of the previous research within the framework of calculus of integer order. The calculus of fractional order has been introduced at the temporal scale as a remedy for this gap in this book.

(2) *Integer order versus fractional order in spatial scale.*
Another important thing should be pointed out: the spatial scale is assumed to be uniform and the dimensions of space are restricted to one dimension, two dimensions, and three dimensions in the previous research. But these assumptions are only reasonable if the crowds of pedestrians can fill space like particles of gases or fluids, while this is not the case as is clear from observations. Theoretically, only a normal diffusive process has been considered in the previous research and few results have been reported for sub-diffusive or super-diffusive processes for modeling of crowds.

(3) *Short-range interactions versus long-range interactions*
Short-range interactions have been extensively considered in the schooling of fish and flocking of birds and in the control of multi-agent systems, while long-range interactions dominating a system's phase transition only has received attention recently. Based on the results obtained in [15], long-range interactions at the micro-scale have been proved to be closely connected to the dynamic model of fractional order at the macro-scale. Not only short-range interactions but also long-range interactions can easily be manipulated using the framework of the calculus of fractional order.

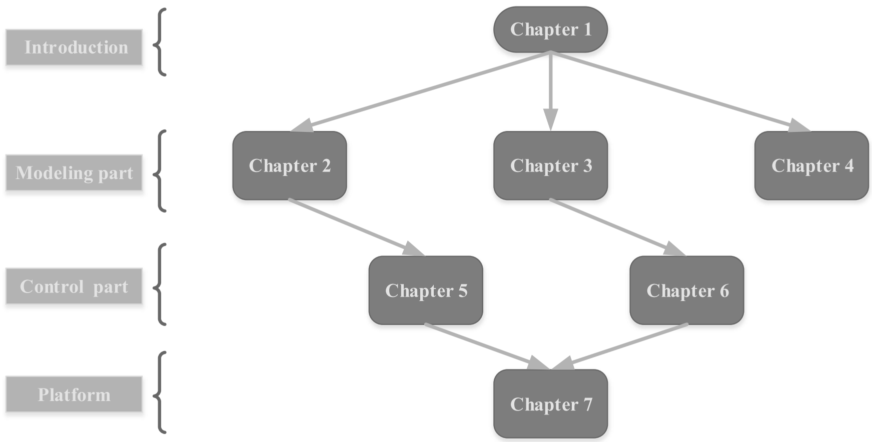

Figure 1.1: Organization of this book.

1.3 Organization of this book

In the first part of this book, a dynamic model of fractional order for crowds of pedestrians is studied at the micro-scale, macro-scale, and meso-scale. Ordinary differential equations (ODEs) of fractional order, partial differential equations (PDEs) of fractional order and coupled ODE-PDEs of fractional order have been obtained for modeling of crowds where the characteristics of temporal, spatial, and long-range interactions mentioned above have been embedded. Based on the obtained models, control or evacuation of crowds is considered in the second part of this book. An intelligent evacuation system based on FO-Diff-MAS2D is also introduced to illustrate or show the effectiveness of the theoretical results. The organization of this book is shown in Figure 1.1.

References

[1] N. Bellomo. *Modeling Complex Living Systems: A Kinetic Theory and Stochastic Game Approach*. Birkhäuser, Boston, 2008.

[2] N. Bellomo and C. Dogbe. On the modeling of traffic and crowds a survey of models, speculations, and perspectives. *SIAM Review*, 53(3):409–463, 2011.

[3] N. Bellomo, B. Piccoli, and A. Tosin. Modeling crowd dynamics from a complex system viewpoint. *Mathematical Models and Methods in Applied Sciences*, 22:1–29, 2012.

[4] N. Bellomo, C. Bianca, and V. Coscia. On the modeling of crowd dynamics: an overview and research perspectives. *SēMA Journal*, 54(1):25–46, 2013.

[5] A. E. Berlonghi. Understanding and planning for different spectator crowds. *Safety Science*, 18(4):239–247, 1995.

[6] P. Bogdan and R. Marculescu. A fractional calculus approach to modeling fractal dynamic games. In *Proceedings of the IEEE Conference on Decision and Control and European Control Conference*, pages 255–260, 2011.

[7] D. Christian. On the modelling of crowd dynamics by generalized kinetic models. *Journal of Mathematical Analysis and Applications*, 387(2):512–532, 2012.
[8] I. D. Couzin. Collective cognition in animal groups. *Trends in Cognitive Sciences*, 13(1):36–43, 2008.
[9] I. D. Couzin, J. Krause, N. R. Franks, and S. A. Levin. Effective leadership and decision-making in animal groups on the move. *Nature*, 433:513–516, 2005.
[10] E. Cristiani, B. Piccoli, and A. Tosin. Multiscale modeling of granular flows with application to crowd dynamics. *Multiscale Modelling and Simulation*, 9(1):155–182, 2011.
[11] A. Czirok. Collective motion of self-propelled particles kinetic phase transition in one dimension. *Physical Review Letters*, 82(1):209–212, 1999.
[12] C. Dogbe. Applicable thermostatted models to crowd dynamics: Comment on “thermostatted kinetic equations as models for complex systems in physics and life sciences” by Carlo Bianca. *Physics of Life Reviews*, 9(4):410–412, 2012.
[13] H. Haken. *Information and Self-Organization A Macroscopic Approach to Complex Systems*. Springer, Berlin, Heidelberg, 2006.
[14] D. Helbing, L. Buzna, A. Johansson, and T. Werner. Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions. *Transportation Science*, 39(1):1–24, 2005.
[15] R. Ishiwata and Y. Sugiyama. Relationships between power-law long-range interactions and fractional mechanics. *Physica A*, 391(23):5827–5838, 2012.
[16] B. Jaume. *Fundamentals of Traffic Simulation*. Springer Science and Business Media, Berlin, 2010.
[17] P. Kachroo. *Pedestrian Dynamics: Mathematical Theory and Evacuation Control*. CRC Press, Taylor & Francis Group, London, 2009.
[18] P. Kachroo, S. J. Al-nasur, S. A. Wadoo, and A. Shende. *Pedestrian Dynamics Feedback Control of Crowd Evacuation*. Springer-Verlag, Berlin, Heidelberg, 2008.
[19] W. W. F. Klingsch, C. Rogsch, A. Schadschneider, and M. Schreckenberg. *Pedestrian and Evacuation Dynamics*. Springer-Verlag, Berlin, Heidelberg, 2010.
[20] M. Moussaid, D. Helbing, and G. Theraulaz. How simple rules determine pedestrian behavior and crowd disasters. *Proceedings of the National Academy of Sciences of the United States of America*, 108(17):6884–6888, 2011.
[21] N. Pelechano, J. M Allbeck, and N. I. Badler. *Virtual Crowds Methods, Simulation, and Control*. Morgan & Claypool, Williston, 2008.
[22] A. Quarteroni and A. Veneziani. Analysis of a geometrical multiscale model based on the coupling of ODE and PDE for blood flow simulations. *Multiscale Modeling and Simulation*, 1:173–195, 2003.
[23] K. Spieser and D. E. Davison. A cooperative multi-agent approach for stabilizing the psychological dynamics of a two-dimensional crowd. In *Proceedings of the American Control Conference*, pages 5737–5742, 2009.
[24] D. Stuart, K. Christensen, A. Chen, K.-C. Cao, C. Zeng, and Y. Q. Chen. A framework for modeling and managing mass pedestrian evacuations involving individuals with disabilities: Networked segways as mobile sensors & actuators. In *Proceedings of the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, DETC2013-12652, 2013.
[25] D. Thalmann and S. Raupp Musse. *Crowd Simulation*. Springer, Berlin, 2007.
[26] H. Timmermans. *Pedestrian Behavior: Models, Data Collection and Applications*. Emerald Group Publishing Limited, Bingley, 2009.
[27] B. J. West, M. Turalska, and P. Grigolini. *Networks of Echoes Imitation, Innovation and Invisible Leaders, volume Computatio*. Springer International Publishing, Switzerland, 2014.