Watching the Fish Swimming in 3D

University of BRISTOL

BRISTOL CENTRE FOR FUNCTIONAL NANOMATERIALS

Biological, Soft and Complex Matter Group

Yushi Yang[1,2], John Russo[3], C. Patrick. Royall[1,2,4]

[1]H.H. Wills Physics Laboratory, Tyndall Avenue, Bristol, BS8 1TL, UK.
[2]Centre for Nanoscience and Quantum Information, Tyndall Avenue, Bristol, BS8 1FD, UK.
[3]School of Mathematics, University of Bristol, Bristol BS8 1TW, UK.
[4]School of Chemistry, University of Bristol, Cantock's Close, BS8 1TS, UK.

Abstract

Active matter refers to a class of non-equilibrium systems where the energy is supplied to all individuals, who then make movements by dissipating the acquired energy [1]. A group of fish can be described as an active matter system, where the fish interaction gives rise to emerging collective behaviour. Up to now, a fundamental understanding of these interactions has been hindered by a the lack of experimental data. Here we aim at studying the collective behaviour of zebrafish, by a 3D reconstruction of their trajectories from stereoscopic images. Our trajectories demonstrate that a large group of zebrafish exhibits "collective behaviours without collective order", similar to what has been observed in midges.[2]

Introduction

When particles are capable of constantly moving themselves, by using environmental or internal energy, they form a class of non-equilibrium system called active matter.[1] Active matter includes objects across a large variety of length scales, from artificial particles to animals. The key feature of active matter systems is that they present stunning collective behaviours such as flocking, swarming and milling.[3, 5]

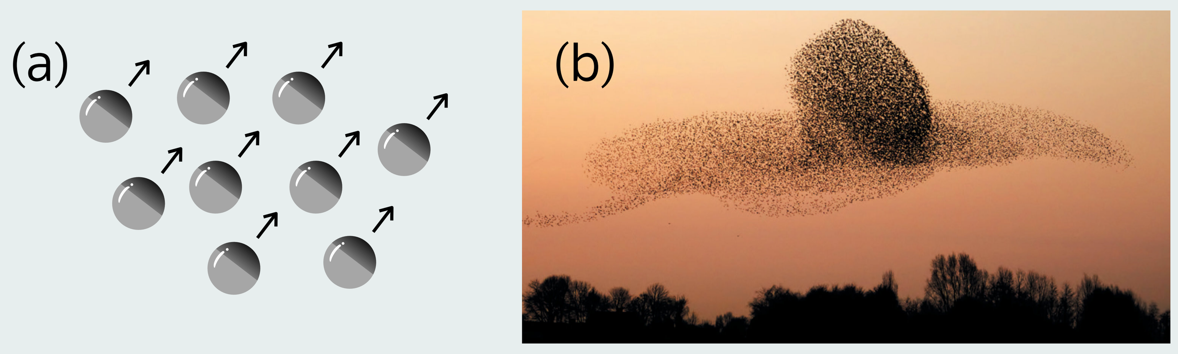

Figure 1. Two examples of active matter. (a) The schematic of flocking Janus particles under an a.c. electrical field pointing into the poster.[3] (b) The flocking birds. (The image was from [4]).

Inspired by the pioneering work of Cavagna et al. on the flocking birds [5], this study focuses on the collective behaviours of fish in 3D. Specifically, we are working on observing fish swimming, calculating their trajectories and analysing their movements.

Method

The observation setup is like what the whole poster presents: the fish were placed in a big hemispherical tank with three watching cameras.

The images in different cameras were analysed to find the 2D locations of different fish. Knowing the water-air interface, their 3D positions can be calculated by tracing individual refractive rays.[6] These 3D positions are then linked into trajectories using particle tracking package trackpy.

Figure 2 shows the example of 5 fish in the view of three cameras.

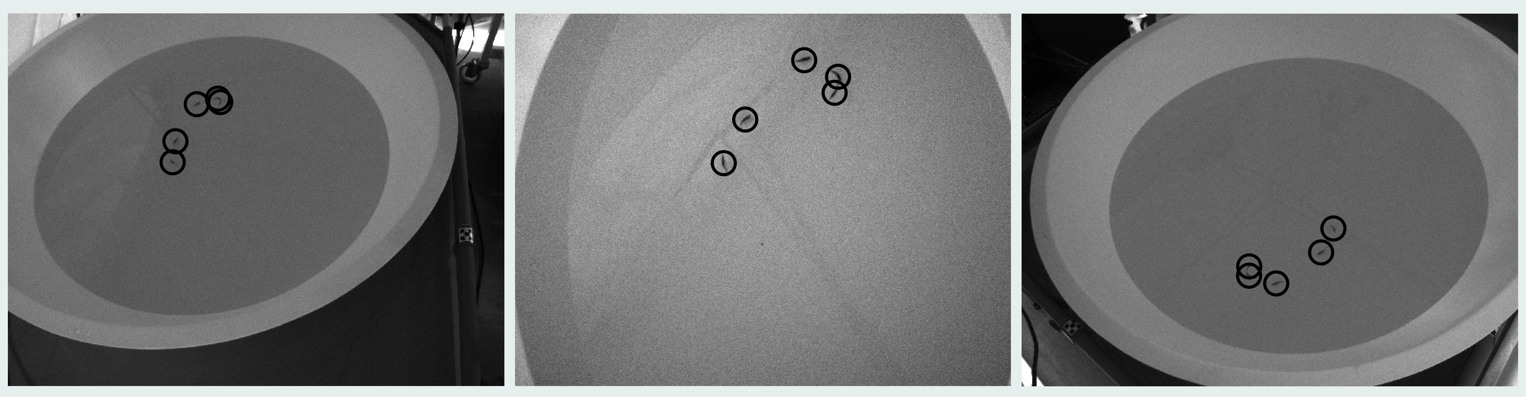

Figure 2. The images taken by different cameras. The circles illustrate the re-projected 3D locations of different fish.

Swarming Fish

The disordered swarming of 50 adult zebrafish was observed in 3D. Their movement is not ordered as all order parameters are low (< 0.5). The orientations of their velocities are correlated, and the correlation length (dashed vertical line in figure c) is about six body lengths.

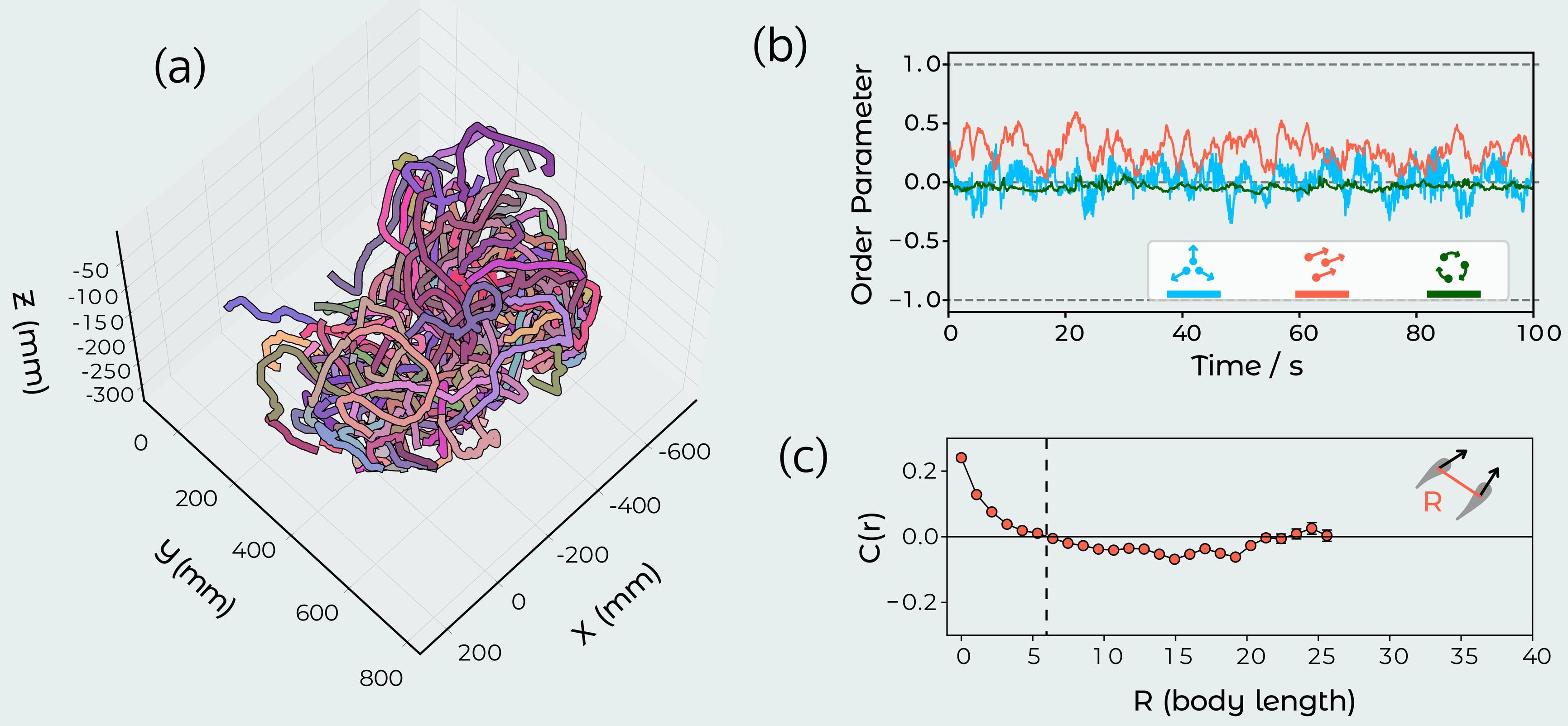

Figure 3. (a) The 3D trajectories of 50 swarming zebrafish. (b) The order parameter of the movement. (c) The orientational correlation as a function of fish-fish distance.

Schooling Fish

The juvenile zebrafish moved in a synchronised way: the polar order is high, their moving directions are aligned. The orientations of their velocities are also correlated, with the correlation length being about seven body lengths (dashed vertical line in figure c).

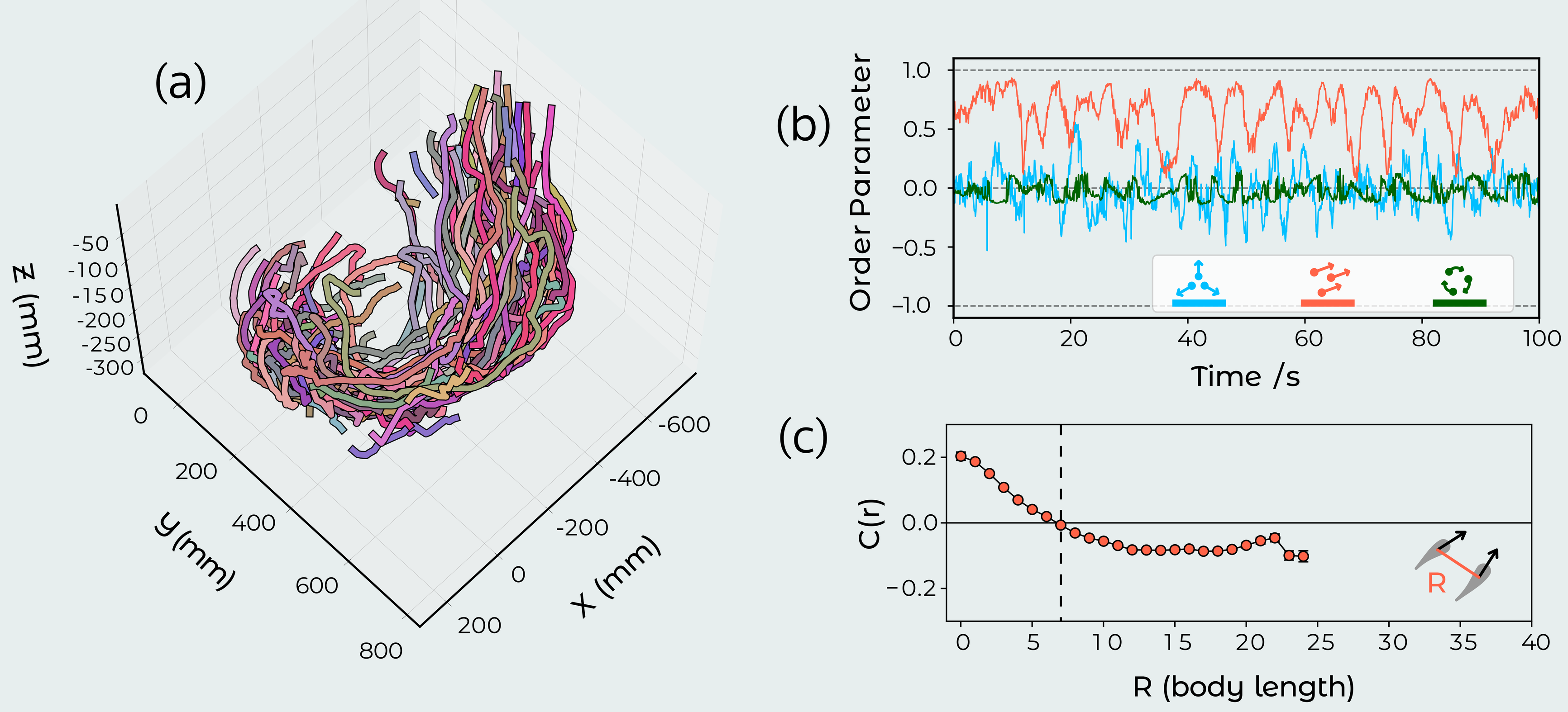

Figure 4. (a) The 3D trajectories of 50 juvenile zebrafish. (b) The order parameters of their movements. (c) The orientational correlation as a function of fish-fish distance.

Future work

Is their structure special? Are they in a critical state? Can we model their behaviours?

References

[1] Ramaswamy, S. J. Stat. Mech. 2017, 054002–17 (2017).
[2] Attanasi, A. et al. PLoS Comput Biol 10, e1003697–10 (2014).
[3] Yan, J. et al. Nat Mater 15, 1095–1099 (2016).
[4] Popkin, G. Nature 529, 16–18 (2016).
[5] Cavagna, A. & Giardina, I. Annu. Rev. Condens. Matter Phys. 5, 183–207 (2014).
[6] Gedge, J., et al. Canadian Conference on Computer and Robot Vision 146–152 (2011).

Acknowledgments

The authors thank the China Scholarship Council (CSC) for the financial support. Especially, Yushi thanks Dr. Erika Kague for the kind help with the fish.