Review of the Dissertation Thesis

Intrinsic behavioural parameters of autonomous objects based on motion

Author: Kirill Lonhus

The dissertation is devoted to various aspects related to observing and data collection, tracking, image processing and analyzing complex behavior. The dissertation consists of two parts. In the first part, the author introduce the main issues and give a very detailed overview about the current state of the art. The second part consists of five papers which give or at least suggest many solutions to problems mentioned above.

In the first paper, the authors studied a collective behavior of a school of aquarium fish. To ensure the least interference the authors used only a camera to record fish behavior. After a suitable image processing they were able to track various fish. Analyzing individual path they could identify roles of single fish in the school. The roles were nicely displayed and further analyzed by graph theory.

In the second paper, the authors suggested a clever solution to the problem of overlapping objects. The problem cannot be avoided and is closely related to the first paper. Moreover, the problem is highly nontrivial in cases where the observed objects lack some symmetries.

The third paper is related to estimation of diffusion and viscous coefficients in cells. The main idea is again based on clever tracking of objects inside the cells and the decomposition of their motion between drift and Brownian motion. The diffusion and viscous coefficients are then recovered using physical relations.

The last two papers are related to quality of video recording followed by image processing. The main aim is to get as many as possible features of the object without distortion.

I must say that I really enjoyed reading the thesis and I am highly impressed with physical, mathematical and coding background of the author and his creativity when solving the various problems mentioned above. The only thing I don't like is the form of the thesis which is less reader-friendly than it could be. My questions are thus related to more clear explanation of several relations.

1. In Paper 1., p. 5, I would expect square roots in the denominator in (2). Why can we work without them?

2. In Paper 1., p. 9, I do not understand why fish # 6 is not oppressed as well. Can you explain me the meaning of the second figure in Figure 4D?

3. In paper 2, pp. 6-7, I would like to see more detailed explanation of relations (3)-(7). Using a simple example or figures could be very helpful.

4. In paper 3, I am not sure that the relation (1) on page 1107 is correctly written because the left-hand side seems to be n dependent. Could you explain the relation?

In my opinion the dissertation thesis fulfills the criteria for the doctoral program and I thus recommend it for the defense.

Olomouc, January 24, 2022

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REVIEW OF PHD THESIS BY KIRILL LONHUS

Dear Colleagues,
allow me to provide you with a review of the PhD thesis,

Intrinsic behavioural parameters of autonomous objects based on motion
by,
Kirill Lonhus,MSc

1. The importance of the topic of this work

Analysis of a collective behaviour is applied in many fields and is not limited to the concept used in this thesis -- behaviour of aquarium fish. The framework presented by the author can be used for analysis in any multi-agent system and therefore this work has far outreach and is of great importance. It allows for the development of a new knowledge on complex system description, behaviour and control. The method itself is proven to be able to monitor behavioural changes due to some externally induced stress. In the case of fish, this was intended to monitor a water quality based on the monitoring the fish collective behaviour. Apart from the analysis of the multi-agent system, extreme effort was dedicated to the accurate image acquisition and processing, together with multiple object tracking, allowing the data collection and further analysis. The most important result is the fact that presented work enabled exploration of laws of collective behaviour by developing the whole original framework of precise data collection, processing and novel analysis.

2. Methods of approach

The motion of a Tiger Barb fish was used in order to characterize the collective behaviour. The author developed original in-house multiple-object tracking software (together with improved image registration, segmentation and processing techniques) that was applied in observations of a fish school. Based on these observations the analysis of a collective behaviour was characterized by means of a follow-up causality network invented by the author. The 'information' flow is then used to attribute three different roles (their probabilities) to observed agents. Stress-induced alteration of the roles are then elegantly observed as a change in Gaussian components that model the particular PDF associated by the role.

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3. Whether the work fulfilled its aim

This work fulfilled its stated goals. It is an essential step in the right direction. I believe that there will be even more achievements in this regard in the future research as declared within the thesis.

4. Results and the scientific contribution

Based on an enclosed publications, both the results and scientific contribution of this work are outstanding. The thesis proves the author's ability to master and further develop a new and difficult problems of interdisciplinary character. Methods and approach to the problem are novel, there are a lot of new information and aspects at different levels that will help with further research in this field. Moreover the work undertaken by the author lead to production of the industrial device for monitoring of water quality, based on fish behaviour. Author managed to publish his results in several impacted journals and those articles are already cited by other researchers that further emphasize the quality of his own work.

5. Questions to be asked during the defense

- What is the most challenging task during the image acquisition and processing considering the CPU/memory demands and is there any way how to speed it up, e.g. by parallelization (OpenMP,MPI,CUDA,OpenCL)?

- When the same individuals are repeatedly challenged by the ethanol, is there a possibility that, by some point, they become addicted to it? How this could possibly alter the results?

- Did you observed any spontaneous change in the roles without any external force.

6. Minor notes

On the page 18. there are two identical paragraphs of the text.

7. Conclusion

In view of the above mentioned, I fully recommends this thesis for proceeding to a successful PhD defense. The problems tackled and solved, the extent of the work done and presented in this work, goes far beyond the average PhD thesis and in my opinion could be refined to, at least, two another equally excellent ones.

Sincerely,

R. Straka, MSc, PhD

Evaluation report on the PhD thesis of MSc. Kirill Lonhus: "Intrinsic behavioural parameters of autonomous objects based on motion"

I have evaluated the PhD-thesis of MSc. Kirill Lonhus entitled "Intrinsic behavioural parameters of autonomous objects based on motion", and this report summarises my reflections on the work and the way it is presented in the candidate's thesis.

As the title implies, the main focus of the thesis is to develop knowledge and methods for motion analyses for identifying behavioural parameters for autonomous objects. The final outcome of the work is a directed graph tool that can be used to automatically analyse machine vision data by converting time series datasets describing the positions of features in the images into leader-follower networks. The tool is completely model free, in the sense that they are not specifically aimed at a specific type of entity such as animal species or cell type. This renders the tool generic, meaning it can be used to detect collective behaviours in any type of leader-follower based system, ranging from animal groups, through social human interactions to intra-cellular features. While it is possible that custom made model-based approaches can utilise existing knowledge on the system in question to gain more insight into the system dynamics, the generality of the model-free approach presented here is very attractive as it allows for rapid deployment to many different systems. Moreover, extensive use and validation of this method based on different types of systems could also enable the future derivation of some sort of general or fundamental "law" for collective behaviours in biology, something that appears to be part of the motivation for choosing this track.

On his way towards the final goals, the candidate has gone through a learning process, where he has achieved knowledge and skills within areas such as optics and spectroscopy, image processing and calibration, statistics and optimisation, and artificial intelligence/neural networks. These are all elements he synthesises in the final solution. The systems analysed in his work vary between microscopy of intracellular properties and fish in aquaria. Although these application areas are not necessarily closely linked scientifically, the candidate has focused on solving challenges that are generic across these fields, acquiring the knowledge and skills needed to solve his final task. This also underlines the generic focus of the work done in this thesis, which is in line with his main aims.

The thesis is built up with a logical structure, where the candidate uses chapters 1-2 to present the theoretical foundation for his work and the final version of the graph tool he has developed, while chapter 3 presents the five papers included in the thesis. Although I missed a clearer link between chapters 1-2 and the papers while reading these for the first time, this link became very clear once I read the papers afterwards.

Chapter 1 contains a comprehensive review of the different theoretical and practical elements required to obtain and analyse image data, which serves both as a useful background for the papers in the thesis and as a bridge between these in linking their respective topics. In the second chapter, the candidate presents the method that emerged from the work in the end, and thus expands the work beyond that reported in the papers. At the end of chapter 2, the candidate presents some very interesting preliminary results where his method was applied in an experiment to investigate stress effects in aquarium fish, and states that these data have not been thoroughly analysed yet. I very much hope that these analyses can be done in the future and presented in a scientific publication. This would be a very suitable way to conclude the research track the candidate has been on the last years. All papers presented in chapter 3 are either already published in international peer-reviewed

journals or will be published soon. The candidate is the first author of four of these papers, clearly implying his key role in both the work itself and how it is presented. I find that the three chapters together provide a good insight into the work the candidate has done.

I find the thesis to be of a good technical standard, with a logical structure that presents the results and outcomes in an intuitive and comprehensive manner. The English language is good, and I had no problems understanding the presented material, particularly in the synopsis part (i.e., chapters 1 and 2).

I have some queries and discussion points on the thesis I would like to raise to the candidate both here and during the defence:

1. Throughout the thesis you focus on model-free approaches. Can you think of any advantages to using more model-based approaches instead?
2. In section 1.3 you say that the reduction in pixels due to the Bayer approach is unsuitable for commercial purposes. Does not this also render the method unsuitable for scientific purposes, as the requirements for detail are then often higher in scientific than in commercial applications (as you state on object detection in section 1.4, page 7)?
3. In the introduction of paper 1 you argue the case that collective behaviours featuring heterogeneous individuals is best achieved using model-free approaches. However, I would argue that this is also possible by including individual variations in more classical model-based approaches. What are your thoughts on this?
4. Do you think it is feasible to apply the method you have developed to commercial fish farming situations, such as tank- or cage-based production? If so, what do you think would be the main challenges you would first have to counter?
5. What do you think would be the outcomes of applying the method proposed in paper 1 and the synopsis to a "leader-less", i.e., self-organised, group of animals? Would you see a more "flat" distribution of roles, more noisy output or would you perhaps identify "hidden" leaders?
6. When applying the method presented in paper 2, fish that are more distant from the camera would appear smaller, and hence have shorter lines than those closer to the camera. This would limit the application range of the method. Do you have any thoughts on how this could be compensated to allow its use over a wider range of distances from the camera?

My conclusion on this work is that Kirill Lonhus has achieved the goals set for his project, and that his effort has resulted in contributions in the form of both new methods and increased knowledge for how optical methods combined with data-driven approaches can be used to automatically quantify collective processes. His thesis and the papers therein, prove his abilities in conducting scientific experiments and presenting their outcomes in scientific publication channels. Based on these reflections, I fully recommend the dissertation for defence.

Trondheim, Norway, January 24, 2022,

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