Vision-based Measurement Methods for Schools of Fish and Analysis of their Behaviors (Summary)

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We presented measurement methods for schools of fish with image processing technology and used them to analyze the behaviors of a large school of sardines, in the thesis.

The collective behaviors of animal groups such as crowds of people, flocks of birds and schools of fish are attractive not only from the viewpoint of animal behavior but also from the perspectives of statistical physics, behavioral economics, and engineering. However, the behavior of schools of fish, in particular large and dense schools have not been sufficiently empirically analyzed and understood, compared to the behaviors of other insects and animals such as ants, bees, and birds. It is mainly because there are difficulties in measuring the behaviors of such fish schools. Nevertheless, to investigate the mechanisms and functions of schooling behavior is important not only for natural science but also for engineering because such knowledge related to schooling behavior must be useful for developing systems to observe the health and growth of schooling fishes in aquariums and fish farms, and improving their survival rate.

Based on this research background, we set out to develop measurement methods for a large and dense school of fish in this thesis. We also have recorded such schools of fish in an aquarium to conduct our research. For such schools, we can sometimes track the members manually even though there are occlusions. On the other hand, we often cannot track members of the schools, even using manual methods, due to frequent occlusions. It is hard to develop a measurement method that deals effectively with these different situations. Therefore, we have divided the schools into two types: relatively sparse and relatively dense. And we have proposed measurement methods which are suitable for each type of density.

The second goal of this thesis is to find and analyze characteristic features of schools of fish. We focus on sardine and anchovy schools, usually observed rotating in solid torus. With the proposed measurement methods, we first measure fundamental features of the school, such as body length distribution. With these measures we are able to determine the speed structure of the rotating school and analyze the time development of the structure.

The thesis consists of 8 Chapters.

In Chapter 1, we presented the background and motivations of this thesis. The goals of this thesis are also stated.

In Chapter 2, we briefly reviewed research into collective behaviors, especially for behaviors of fish schools. Measurement methods for collective behaviors were also summarized. We pointed out that automatic measurement methods had not been sufficiently developed, particularly for schools of fish.

In Chapter 3, we explained the way videos of schools of fish were recorded in Kujukushima Umikirara Aquarium. The filmed videos are used to conduct experiments for the proposed methods in this thesis and analyze the behavior of schools of fishes in Section 7. We also stated that the water tank and the school of sardines in the tank have a lot of advantages, mainly because the water tank is open air and has a large school of sardines throughout the year.

In Chapter 4, we proposed a measurement method for tail beat frequency and an estimation method of coast phase for isolated fish in a school of fish. In our experiments, we recorded a large school of sardines and applied our method to a scene taken from the video. The average difference of the tail beat frequencies using our method and using manually estimated data was 0.126 (Hz). For estimation of the coast phase, the precision and recall of the classification result were 0.945 and 0.879. These results indicate that our method is practically useful. We expect that our method is useful for observation of individual behaviors in school of fish.

In Chapter 5, we proposed an appearance-based tracking method for multiple fish in a relatively sparse school. For the test scenes in which two or three fish overlap with each other, our tracking method exhibited practical performance (80% for Type B and 100% for Type C), although the FP-LK method failed in all the scenes. The trajectories tracked by our method were also accurate, because the average differences between the trajectories of our method and the ground-truth in the three scene types were less than 4% of the BL of the school. However, our algorithm is still slow due to combinations of parameters. We need to accelerate our algorithm in order to track thousands of fish.

In Chapter 6, we proposed a speed distribution measurement method for collective motions of highly dense homogeneous groups with optical flow. The main idea was that we could measure a speed distribution by extracting flows that are relevant to fish behaviors with a number of proposed constraints. To measure speed distributions, we partition a group into regions and estimate mean speeds in each region by extracting only flows that are relevant to collective motions and averaging them over a period of time. We applied our method to rotating schools of sardines and measured their RCs. To compute RCs automatically, we also proposed a center estimation method from the school flows with least-squares method. Experimental results show that our method is accurate for simulation scenes of rotating schools and that it works well for real scenes as well. Our method facilitates the automatic estimation of RCs over a longer period of time with practical accuracy, even when individual tracking is difficult. We applied our method to a longer video of a school of sardines and confirmed that time series of RCs can be estimated automatically. In addition, in order to detect noticeable events in a long time video, we proposed two features derived from flows and we detected such events. We also applied our method to a school of anchovies. This measurement method will be useful for the observation of schools of fish and determination of proper mathematical models and their parameters. However, there are some problems for further analysis of schooling behaviors. For example, we still cannot analyze information transfers such as agitations in fish schools, because the spatial and temporal resolutions of our method are low.

In Chapter 7, with the method proposed in Chapter 6, we investigated the time development of the rotation curve for the solid torus shape of fish schools. We found the speed structure in rotating schools of fish through analysis of the long time series data. The existence the averaged tori is also demonstrated in this chapter. The speed structure we discovered where, outer fish always swim faster in a rotating school, is a new discovery of fish behavior and it is impossible to analyze the time evolution of the speed distributions for large school of fish without the proposed automatic measurement method.

In Chapter 8, we summarized this thesis and discussed the directions of future work.

To summarize the thesis, the proposed methods enable us to analyze some aspects of fish schooling behavior such as body length distribution, speed distribution, and time series of speed distribution. It is hard or almost impossible to manually measure the behaviors of thousands of fish for hours. Therefore, we believe that our method opens up the possibility for a new research field into behaviors of large and dense fish schools.