A NEW TAXONOMY AND GRAPHICAL REPRESENTATION FOR VISUAL FISH ANALYSIS WITH A CASE STUDY

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Abstract

The wide variety of problems in fish ethology ranges from small larva motion analysis to open water tracking of big adult fish. In order to cover this variety of problems, and to develop a new systematic way to tackle them, it is necessary to perform an adequate classification attending to their properties. In this paper, we define a new taxonomy for visual fish analysis, and propose an easy-to-read representation based on star charts. Each problem is described by a chart, allowing to compare among them. Also, we present a case study of visual fish location in tanks in day and night conditions. The problem is solved by using adaptive background models and a median based locator. It has been applied to real zebrafish and gilt-head sea bream (GSB) experiments, achieving a high accuracy and robustness.

1. Introduction

Working as a computer vision expert in a multidisciplinary research team with biologists can be an exciting challenge, since every new experiment seems to require the application of very different techniques. In our experience in fish ethology research, we have dealt with problems of 2D and 3D fish location, multiple and single animal tracking, analysis of larva and adult fish, day and night lighting conditions, restricted and free motion, etc. In order to classify all this wide variety of cases, we propose a new graphical notation to describe fish processing problems. The proposed representation is based on star charts, and is intended to increase the reuse of code and techniques for future new problems.

As an application of this methodology, we present a robust solution to a case study: zebrafish and GSB location in fish tanks. Our aim is to show that it is possible to create a highly accurate location method for both problems by combining two techniques: the improved adaptive background model proposed by Kaewtrakulpong and Bowden in [4]; and a simple and robust locator based on the median operator. Our solution includes a method to remove the noise that arises from camera vibrations, shadows, reflections, etc.

2. Related work

Different researches into the fields of biology and ethology have lead to the development of several object location and tracking methods based on a wide variety of techniques. For example, Evans in [2] uses a mixture gaussian model to define each fish, and then with an EM algorithm performs an estimation of the hidden parameters of the model. In [5] Perner et al developed a system to track pigs into a stable by using a non-adaptive background model and a spatial-moments tracker.

Other authors have solved similar problems extracting color or shape features. We can outline the works of Di-Gesú et al in [3] and Brooks et al in [1]. In [3] it is described how to count starfish by using shape descriptors and a Bayesian classifier. On the other hand, in [1] color features and monochromatic near-infrared light are used together, in conjunction with a background subtraction method, in order to track rodents into different light conditions.

3. Fish processing problems taxonomy

From our experience in fish ethology research, our main concern was that new visual analysis software had to be developed very frequently, in order to adapt to the changing conditions of the experiments.

We decided to create a new methodology in order to describe the main properties of each particular problem. This notation was designed with the following purposes: (i) to describe in a complete and easy-to-read way all problems in fish processing; (ii) to allow a fast identification of similarities and differences among problems; and (iii) to simplify the adaptation and reuse of techniques and source code to solve new problems.

3.1. A star chart notation

In general, star charts are used to represent points in an n-dimensional space, with $n > 2$. Each axis is a dimension of the space, and refers to a property –either numeric or symbolic– that can be placed in a scale. A point in the n-dimensional space is given by a polygon with n vertices, each one in a different axis. In our case, the scale measures relative complexity –e.g., the problem is easier when fish move slowly–. We have identified seven main properties in visual fish ethology problems, as shown in the star chart at figure 1.

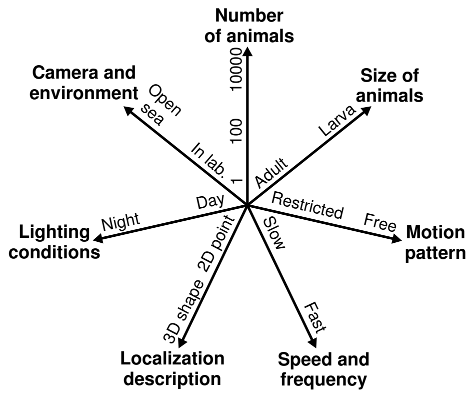

Figure 1. Proposed star chart for representing visual fish processing problems.

3.2. Axis of the notation

As stated before, each axis is sorted by the relative complexity of the cases it may contain. Some sample star charts are shown in figure 2.

- **Lighting conditions**. Fish behavior dramatically changes from day to night lighting conditions. In the latter, infrared lights and cameras have to be used. Reflections and refraction of the light –when fish tanks are used– can pose serious difficulties.

- **Camera and environment**. Some experiments use small and transparent fish tanks, so the cameras are situated outside; background and light can be controlled. In bigger tanks and open sea, cameras have to be situated inside the water.

- **Number of animals**. Some experiments may involve several fish, while others may require to analyze thousands of small animals.

- **Size of the animals**. We refer to the apparent size of fish in the images. Small larva can only be treated as dots; medium size animals, as zebrafish, can be seen as blobs; while working with bigger fish, we could distinguish the tail, head, etc.

- **Motion pattern**. Some fish present a complex behavior: rapid, unpredictable movements and complex interaction. In the experiments, motion can be restricted by delimiters inside the tank, thus avoiding occlusion among different fish.

- **Speed and frequency**. Typically, visual fish analysis has to be performed in experiments that last many hours, or even days; video processing is usually done at low fps (frames per second).

- **Localization description**. In many cases, biologists only need to know wether fish move or not; a simple 2D point localization is enough. In other cases, such as studying interaction of multiple fish, a complete 3D localization could be required.

4. Case study and proposed solution

In this case study, we deal with the location of zebrafish and gilt-head sea bream (GSB) into a controlled context. Fish tanks have delimiters that restrict fish to cross with each other, so avoiding occlusion. Some samples are shown in figure 2. We use zebrafish because it is a model species for basic research in biomedical sciences; meanwhile, GSB is a fish model with great commercial interest for Mediterranean aquaculture.

The localization process must be accurate and robust in both day and night conditions. In the case of night videos, image quality is poor due to low lighting conditions (infrared light is quickly absorbed by water). Another important factor is related with the vibration of the camera, originated by the cooling system of the experiment, seriously affecting the recorded video.

The similarities of the problems of locating zebrafish and GSB are properly shown in the star charts of figure 2. From the first and third charts, we can deduce that it is possible to develop a common solution for both. So, henceforth, we will treat both problems as the same one.

4.1. Proposed approach

Our solution to the problem combines and adaptive background model and a simple localization technique.

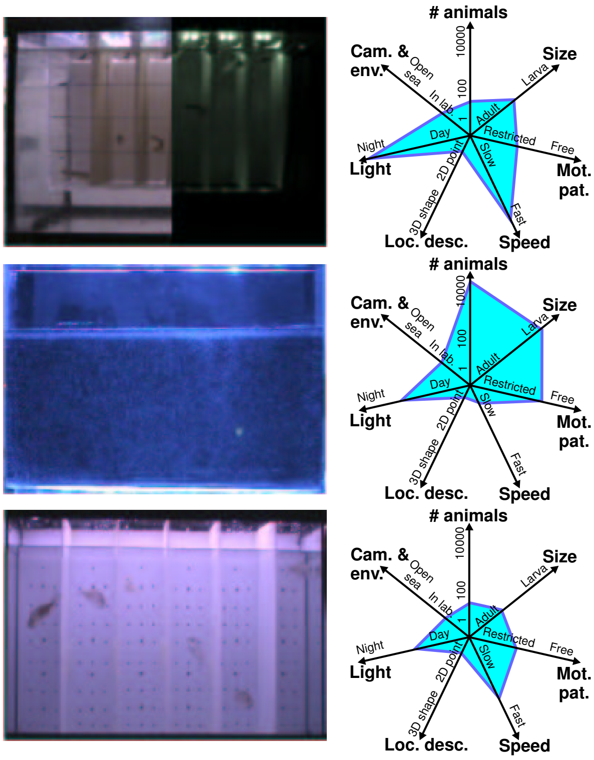

Figure 2. Sample frames and associated star charts. Up: 2D location of zebrafish at day&night conditions (left half is day, and right half is night). Center: larva motion analysis. Down: 2D location of GSB.

Our aim has been to create a method that is robust and highly accurate, while keeping it simple. The approach consists of the following four steps:

1. **Image acquisition**. It is the responsible for acquiring images at regular intervals of F fps. This way, it is possible to perform a more or less exhaustive analysis. Typically, we work at 1-6 fps.

2. **Video stabilization**. This step corrects small displacements or vibrations of the camera. The method consists of displacing every frame with respect to the initial reference frame. For this, we extract small *significant* regions of each image, and then we search them on the reference frame by using template matching. Taking the position of the best matching for each pattern, we estimate the deviation as the mode of such positions.

3. **Image segmentation**. By applying an adaptive background model, the scene is segmented into background and foreground, the last one representing moving fish. In order to achieve high accuracy in cases of good illumination and night conditions, we use an adaptive background model. It allows to distinguish fairly accurately among mobile objects, stationary background, and random noise. The main advantage of an adaptive background model is its ability to adapt to changing lighting conditions.

   We use the model proposed by Kaewtrakulpong and Bowden in [4], which models each pixel as a mixture of gaussian distributions. Then, for each new frame, all the pixels are tested and classified as background or foreground. With the new information of the classified pixels, background parameters are updated with an EM-online algorithm.

4. **Localization technique**. We use a median operator to locate each fish by determining its center of mass. After the segmentation step, each interest region may contain several blobs. Then, to locate the central point of each fish, we calculate median on x- and y-axis on the mass of pixels of the blobs. In this way, we obtain a central point at each instant that represents the resulting fish location.

   As our *tracker* is not based on a motion model, it is better suited for the fast and unpredictable movements of zebrafish. Moreover, it has shown to be extremely robust to noise.

4.2. Tests and results

The approach described in this section has been tested on real biological experiments achieving excellent results. Here we analyze both day and night mode videos. In the first case, we study the behavior of GSB at day, during one hour (3600 seconds); and in the second case, the study is focused on zebrafish at night conditions, with a total duration of 1000 seconds. In both cases we work at a sampling rate of 1 fps, a typical frequency in ethological studies.

Figure 3 shows some location results in both cases, comparing real and ground-truth positions. The main results of the achieved accuracy are presented in table 1. We consider location failures when the error is bigger than a certain threshold, which depends on the size of the analyzed animal. Thus, in the case of zebrafish night video, we use 0.5 cm (half the average size of zebrafish), while in the case of GSB light video, we use 2.5 cm. Ground-truth is given by a hand labeling.

The obtained results in day mode show a high success rate (greater that 96%) and an excellent accuracy (0.6 cm). Obviously, night mode videos present lower success rate (89.8%) and accuracy (1.50 cm) due to the poor illumination of the scene. In both cases the number of failures is low, achieving our main intention of developing a robust tracking, which satisfies the requirements of the biologists.

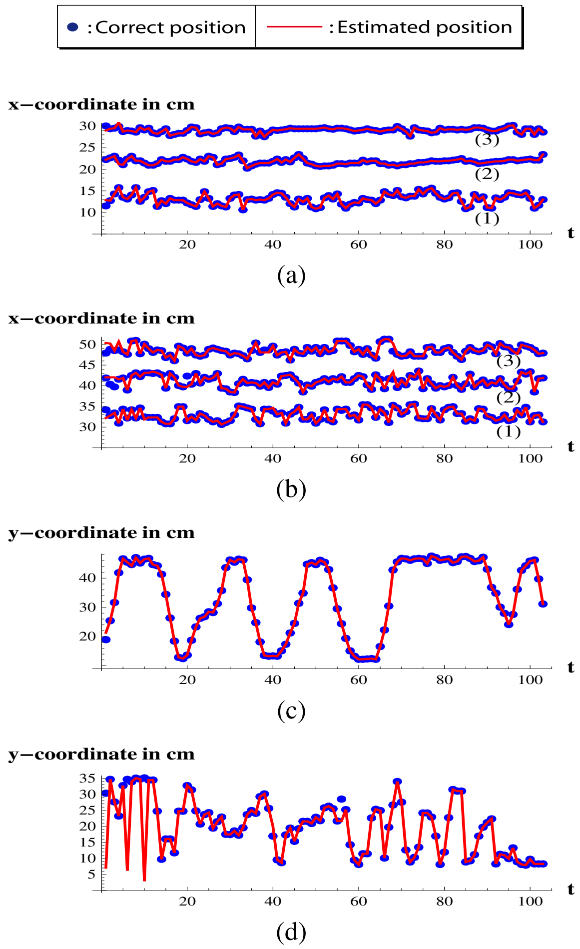

Figure 3. Some location results. X coordinates (a,b), and Y coordinates (c,d). As the fish do not overlap in X, three locations are shown in (a,b). (a,c) Day mode; (b,d) night mode.

5. Conclusion and future work

In this paper we have presented a new taxonomy for visual fish behavior analysis problems, together with an easy-to-read representation based on star charts. The proposed taxonomy is useful to quickly appreciate the difficulty of a concrete problem and to find the most suitable methods to solve it.

In the case study, we have presented a robust approach to perform visual location applied to zebrafish and gilt-head sea bream. In the experiments performed, our approach has demonstrated to be able to obtain high accuracy results, being suitable for the research into the ethology and biology areas.

Table 1. Summary of location results of the experiments with GSB (day video) and zebrafish (night video). 3600 and 1000 frames have been analyzed respectively, at 1 fps with 5 fish in each frame.

	Day GSB	Night zebraf.
Location accuracy error (cm)	0.6	1.5
Std. deviation of the error (cm)	5.27	7.33
Location failures	3.46% 625/18080	10.20% 510/5000

Currently, we are focusing our research in a more general localization method with the capability of 3D multiple tracking, without delimiters. In this case, we have to tackle the problems of total occlusions and grouping of the fish, as they tend to swim together.

6. Acknowledgments

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