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5iD Viewer - Observation of Fish School Behaviour in Labyrinths and Use of Semantic and Syntactic Entropy for School Structure Definition

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Abstract—In this article is reported a construction and some properties of the 5iD viewer, the system recording simultaneously 5 views of a given experimental object. Properties of the system are demonstrated on the analysis of fish schooling behaviour. It is demonstrated the method of instrument calibration which allows inclusion of image distortion and it is proposed and partly tested also the method of distance assessment in the case that only two opposite cameras are available. Finally, we demonstrate how the state trajectory of the behaviour of the fish school may be constructed from the entropy of the system.

Keywords—3D positioning, school behavior, distance calibration, space vision, space distortion.

I. Introduction

THE formation of bird flocks and fish schools is in of the nature wonders [1]. Similar behaviour may be modelled using rather simple as well as by rather elaborate approaches which are comprehensively listed by Fine and Shell [2]. They conclude, that a good validation approach is strongly needed. Understanding of flocking has numerous obvious practical implications for example in agriculture but experiments in herding have been used as prototypic even in distant fields such as psychology [3]. Results of these experiments are widely hailed in simplified references in public media [4] which may have strong influence on creation of public opinion and political decision. Other interesting aspect of this phenomenon is the possibility of creation of robots with collective intelligence [5]. Thus, understanding of flocking behaviour and methods of its testing and manipulation is of rather wide general interest. As reviewed in [6] most of the approaches available for experimental observation of behaviour produce 2D analysis. The available 3D approach was based on two camera system.

The 5iD viewer is based on the same principle as multiple camera system - but it gives more credible and instantly verifiable results. It contains one camera and four mirror views. In this way we obtain effectively 5 individual camera views by which we in most cases obtain good 3D reconstruction of the position of a point in situations in which the observed object is hidden behind non-transparent labyrinth wall from some sights. Cases in which the object is observable only by two opposite views may be in most cases treated by analysis of the de-focus in combination with intensity damping by the environment. In most cases there are obtained several couples of combinations which may be mutually verified.

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Fig. 1. The image of *Puntius tetrazona* shoal in the aquarium of the 5iD viewer. Construction of the system is clearly seen.

The 5iD viewer thus enables detailed analysis of behaviour in a large variety of labyrinths constructed in the three-dimensional space and in this way also enables extensive experimental analysis of model predictions.

II. Results

A. Technical Solution

The 5iD viewer consist of the aquarium surrounded by 4 mirrors oriented to reflect the image into the camera but not into the aquarium (fig. 1). The size of the aquarium was experimentally optimised as smallest to observe school behaviour for a certain genus of the fish, in the examined case it was *Puntius tetrazona*. Image was captured using a simple Logitech HDPRO WEBCAM C920 digital camera using a custom made control software allowing simply to control the single image capture frequency.

Fig. 2 shows results of the calibration procedure. The calibration was performed using glass plates with imprinted chessboard structure. The major concern was whether using given camera optics the image will be distorted. The result showed that the observed distortion was far lower than one image point and thus considered negligible. The identification of the position in the 3D space may then be made using standard methods of analytical geometry. It may be assumed

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that in certain cases it may be advantageous to utilise objectives giving large image distortions. In such cases, the appropriate spatial geometry needs to be used.

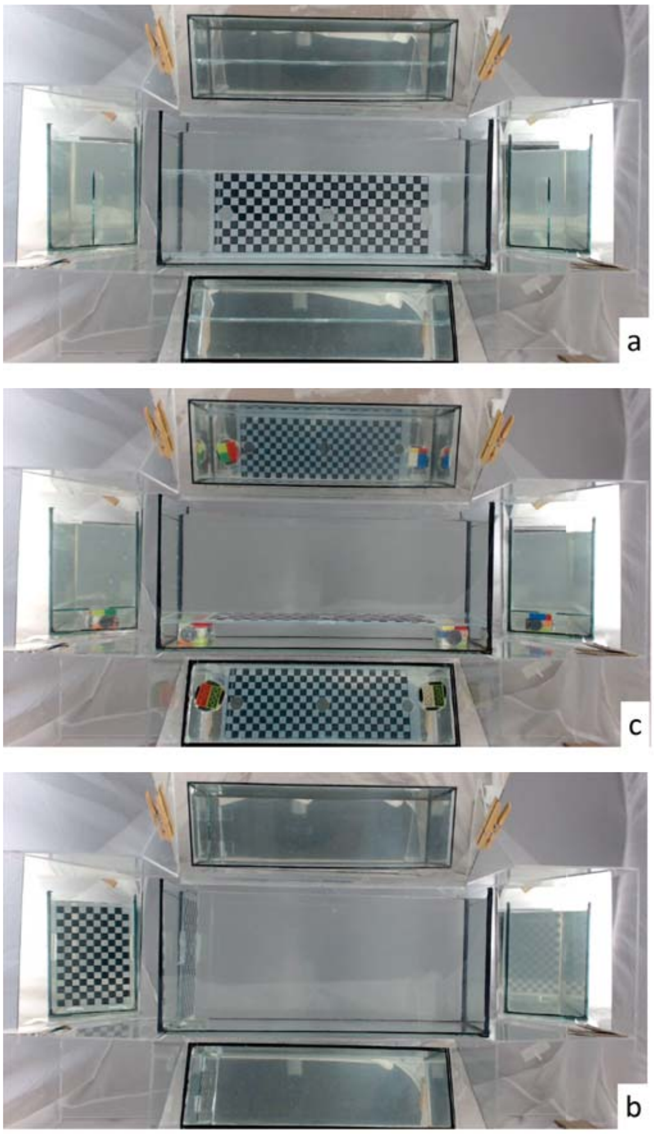

Fig. 2. Calibration of multiple views

In the Fig. 2 there are selected examples of calibration. In contrast to [7] we use calibration by chessboards precisely orthogonal to walls of the aquarium. For other applications it is interesting to consider the decay in the intensity and focus with distance which is mostly observed in the case of calibration of vertical mirrors Fig. 2c. There it is seen a fast drop of intensity - and focus - with the distance from the mirror caused by the length of the optical path. It may be used for distance calibration in cases that the object is observed only by two opposite views as if the fish is swimming through a tunnel as depicted at the Fig. 3.

In the case that the distance of the object from one side of the aquarium differs largely from the other (Fig. 2 c) we observe large differences in the intensity of the colour. This may be used for assessment of the distance in case that the object is not visible from at least two rectangularly placed views as shown at the Fig. 3 when fishes swim through a window and are thus seen only in two opposite views.

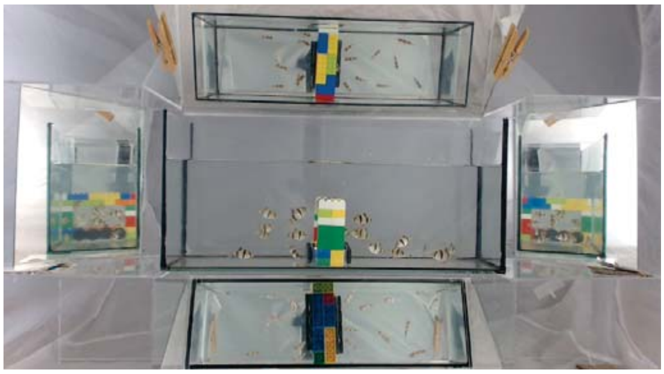

Fig. 3. Observation of behaviour in the presence of an obstacle.

At the Fig. 3 we demonstrate the case in which the simple analysis using one or multiple combinations of individual views are not available for spatial localisation of the object. Yet, still the localisation is more reliable than in other available cases when the experimenter has to rely on changes in reflectivity or de-focus for determination of the depth in which the object is located. There are 4 parameters available (intensity and defocus level from two mirrors) and there may be achieved precise calibration using animals photographed in precise locations outside the tunnel. Extensive experiments showing limits of this approach are in progress but so far we have not found limitations in distance assessment.

B. Example of Statistical Analysis of Results

The series of images may be quite extensive. It is important to find a method how to classify the behaviour of the object of study. In the fig. 4 we present one such approach. By standard methods (Pautsina et al. in preparation) we have identified fish position and reconstructed it into 3D coordinates. Since the primary action of school behaviour is the tendency of fish to occupy place close to each other in the 3D space, we sought a variable which allows us to classify the whole aquarium from this point of view. We used the Shannon entropy [11] as a possible macroscopic variable.

$$S = -\sum_{j=1}^{k} p_j \ln p_j \qquad (1)$$

For definition of system (i.e. aquarium) state j whose probability is examined we separated the aquarium arbitrarily into *primitive cubes* whose size allowed maximally three fish to be within one cube at the same time. Thus, we could have only four states of the cube - empty cube, cube occupied by one, two or three fish. The probability p_j is then given n_j/n where n_j is number of cubes in the state j and n is the total number of cubes. The entropy of the whole aquarium - referred as semantic, i.e. non-contextual, entropy in the article is then defined as

$$S = -\sum_{j=1}^{4} p_j \ln p_j \qquad (2)$$

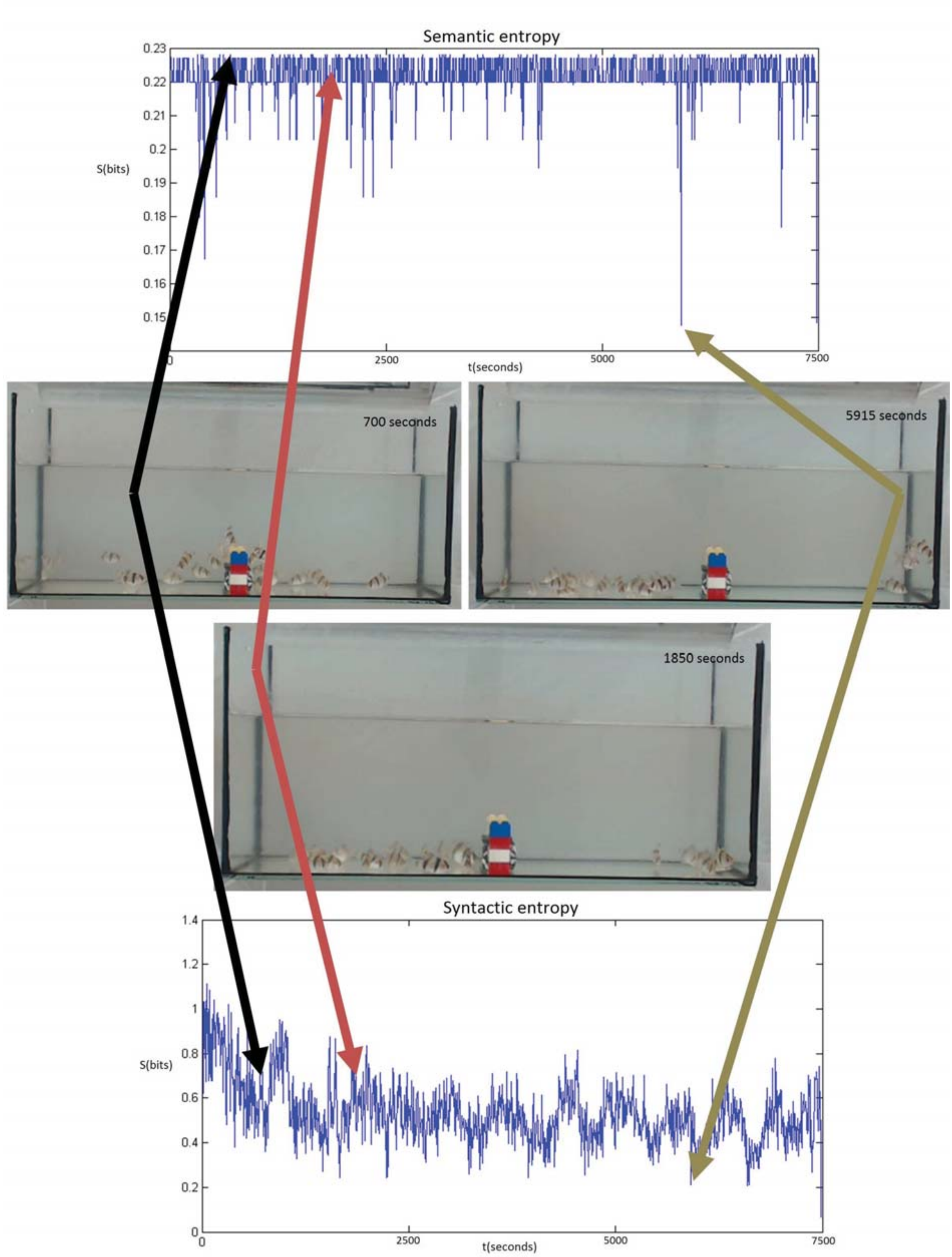

Fig. 4. Use of semantic and syntactic entropy for classification of behaviour.

and is shown at the upper graph in the fig. 4 which shows the use of entropy for the classification of fish schools. The semantic entropy S (2) characterises the overall state of the image. The drop in semantic entropy in the case of the most dense configuration of the school is clearly observed. The syntactic entropy H which is a sum of configurations in the surrounding of each of the fish (see 3 shows certain coincidences in minima with the semantic entropy but its course is much richer. The question whether for characterisation of the school the combination of S and H is sufficient will be subject of further research.

As seen, the graph has its upper limit, the case when in neither of the cubes was more than one fish. In contrast, the minimum corresponds to the state with densest and largest school observed during the measurement.

Since most models of the school behaviour are based on local interactions, it is feasible to introduce a second kind of global measure, the contextual or syntactic entropy H. In this case we examine the surrounding of each of the fish separate, i.e for each fish we obtain it own semantic entropy within an arbitrary field of sight. In the presented case the field of sight ways was defined as a box of size 10x10 *primitive cubes* as defined in the previous paragraphs. Thus for each of the n fish in the experiment we obtained using 2 its own semantic entropy S_i. From the global point of view each of these entropies corresponds to the context - or **syntax** defined by each individual fish. We may now define the syntactic entropy as

$$H = \sum_{i=1}^{n} S_i \qquad (3)$$

As seen for the fig. 4 in one case the minima of the semantic entropy S and syntactic entropy H coincide, however, in most cases they do not. The course of H is much richer and each value corresponds to a specific configuration of the school. The question whether each of the concrete configurations of the school (except, perhaps, potential symmetric cases) has its unique correspondence in a single value of H, whether the combination of H and S is sufficient to resolve the ambiguities or whether another measure would be needed will be subject of further examination.

III. Conclusion

In the article we demonstrate technical solution for the complex problem of validation of models of shoaling behaviour of fish.

Equivalent to 5iD viewer would be provided by a system of five synchronised cameras which would give smaller pixel size. There are obvious technical difficulties in synchronisation, geometric precision and stability which would increase the costs in addition to the a-priori costs of cameras and other equipment itself. Costs may not be the crucial problem, as much larger problem we consider the size of the dataset and consecutive computational intensiveness. In most relevant cases the analysis will necessarily include also research on optimisation of the dataset size, resolution or pixel size. Most of the available models give certain a-priori spatial scaling expressed as size of the virtual animal (space constant), vision etc. There is a definitive natural object size given by the physical size of the experimental animal. And this has been much bigger than pixel size in any of the mirrors in our version of the 5iD viewer experiment which we performed so far. Rather, it does not seem to be problem to analyse also fish orientation in space.

As reviewed by Fine and Shell [2] the only two models which have been extensively validated are those of Reynolds [1] and Kline [8]. The problem quite probably resides in the fact that majority of the models was developed either for unbounded free space or for periodically bounded free space. Some models, i.e. agent-based model by Wilensky [9], [10] include avoidance of obstacles but still allow collision with obstacles and agent death. This is clearly not the case in reality. Any realistic model should not only realistically simulate the formation of schools, but it should also realistically describe behaviour at borders and obstacles. The later fact may be also used in a positive way. The obstacle avoidance and corresponding influence on the behaviour of the school is method of systematic disturbing of the model and may be used for testing of the correspondence between the model an the real behaviour.

In order to obtain a testing dataset for a comprehensive model, we must provide comprehensive measurement of behaviour in a vessel which is sufficiently large to allow the school to be formed and in the same time provide sufficiently frequent sampling of border behaviour. The construction of the 5iD viewer demonstrates the solution of this problem.

We have also demonstrated two methods of classification of the school by semantic entropy S and syntactic entropy H . This approach allows sensitive discrimination between images and allows certain qualitative conclusions. The question whether the combination of S and H values uniquely characterises the school is subject of future experimentation.

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