Comparative System Identification of the Refuge Tracking Behavior in Weakly Electric Fish ⋆

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Abstract: This study investigates the application of system identification methods to understand the refuge tracking behavior of weakly electric fish. Five data-driven methods were compared: Frequency Response Function (FRF), Recursive Least Squares (RLS), AutoRegressive with eXogenous input (ARX), AutoRegressive Moving Average with eXogenous input (ARMAX), and N4SID (subspace identification). Results showed that N4SID, a subspace identification method, exhibited the best performance as compared to other methods in modeling complex refuge tracking dynamics.

Keywords: Weakly Electric Fish, System Identification, Nonparametric Methods, Parametric Methods, Subspace Identification.

1. INTRODUCTION

System identification is the process of determining the properties and behaviour of a system by modelling the relationship between input and output data of a system based on experimental data. It is a widely used method in many branches of science, especially in engineering. The main purpose of system identification is to create a mathematical model of how a system works. This model can be used to estimate the future behaviour of the system, to optimise the parameters of the system and to design the control system of the system.

Biological systems are not suitable for modelling with traditional modelling techniques due to their complex and nonlinear structure. The flexible and adaptive nature of system identification is an ideal tool for modelling such complex systems and the use of system identification in biological systems has increased considerably in recent years. In this study, five different data-driven system identification methods [Frequency Response Function (FRF), Recursive Least Squares (RLS), AutoRegressive with eXogenous input (ARX), AutoRegressive Moving Average with eXogenous input (ARMAX), and N4SID (subspace identification)] are compared and analysed for the refuge tracking behaviour of weakly electric fish.

The application and comparison of these methods in a biological system will lead to a better understanding of the refuge tracking behaviour of weakly electric fish and shed light on the potential of system identification in biological systems.

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2. MATERIALS AND METHODS

In this study, the movement dynamics of the refuge tracking behaviour of the weakly electric fish *Apteronotus albifrons* were analysed. These fishes hide in underwater objects such as tree branches, mosses and stones to protect themselves from predators. They also track these objects by swimming back and forth very precisely depending on the movement of the objects. Fig. 1 shows an illustration of tracking behaviour.

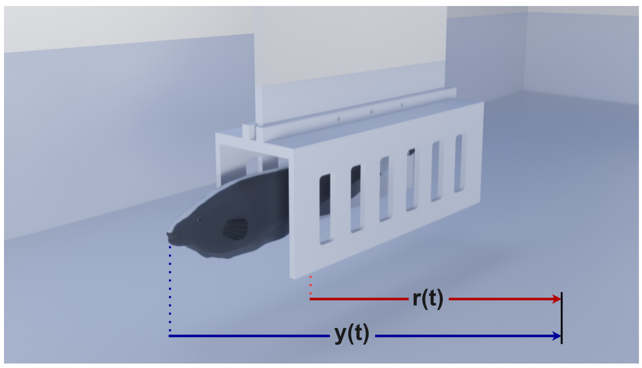

Fig. 1. Refuge tracking behaviour of weakly electric fish

In order to observe this behaviour of the fish, a flow tunnel experimental system that mimics the natural environment of weakly electric fish was designed. In this experimental setup, there is a movable refuge for the fish to hide in. The movements of the fish and the refuge were recorded by a high-speed camera and analysed by a special image processing algorithm.

All experimental data were collected at Hacettepe University Neuroscience and Robotics laboratory.

3. RESULTS

Tracking performances and error rates of the predictions of system identification methods in weakly electric fish are shown in Fig. 2 and Fig. 3.

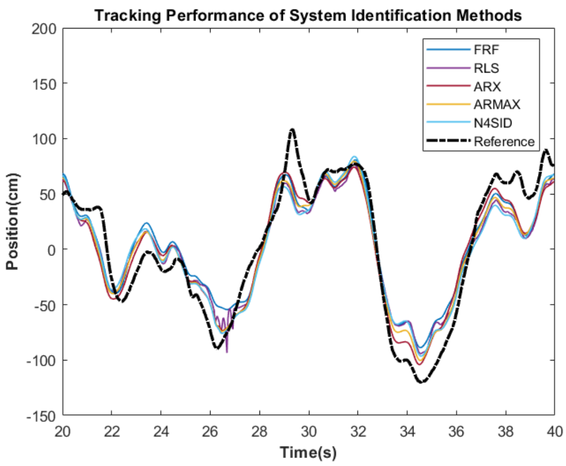

Fig. 2. Tracking performance of system identification methods

When it is enough to obtain information about the behaviour of the system in the frequency domain, the Frequency Response Function (FRF) offers a useful and simple solution. In our experiments we have observed that the FRF gives reliable results with low error mean and minimum variance. However, the use of the FRF has some limitations. This method can only be used in linear systems where we know the frequency range of the input signal. Therefore, the field of use of FRF is relatively narrow.

For system identification in real-time applications with time-varying system dynamics, the Recursive Least Squares Method (RLS) provides a useful alternative. Our experiments were conducted in an offline environment. For this reason, RLS did not produce any outstanding results compared to other methods.

The ARX model represents a system as an autoregressive model with external inputs. It is generally suitable for linear systems with known or measurable input signals. However, it is not very successful in capturing complex dynamics because it ignores noise dynamics. It also has a limited area of use because it assumes a specific model form. The ARMAX model extends the ARX model by adding a moving average component to the model structure. Therefore, it is more flexible than ARX to capture various system behaviours. However, ARMAX also assumes a linear structure and is not effective in strongly nonlinear situations. In our results, the ARMAX model performs slightly better than the ARX model, but this difference is not very large. Both models produced approximately the same results.

The N4SID algorithm combines singular value decomposition and state space methods to estimate the state space representation of a system. It is suitable for both linear and nonlinear systems with unknown or complex dynamics.

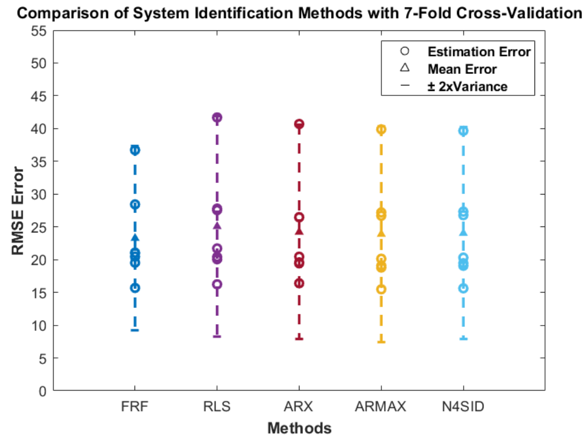

Fig. 3. Comparison of system identification methods with 7-fold cross-validation

In this way, it can be used for a wide range of system types. In addition, it has better noise elimination compared to other methods. In our results, the N4SID algorithm has shown a very successful performance. Another advantage of the N4SID algorithm is that the motion dynamics can be expressed in low-dimensional linear systems. This allows us to model the system more easily and apply many methods in the field of control theory to the system.

4. CONCLUSION

In this study, 5 commonly used system identification methods in the literature were applied and compared on a biological system. The results show that subspace identification methods are very successful in explaining the motion dynamics of weak electric fish.

Subspace identification methods stand out with their ability to model even complex systems with low-dimensional linear systems compared to other methods. The use of subspace identification methods in the study of complex systems such as living organisms will contribute to obtaining more successful and effective results.

REFERENCES

[1] Ljung, L. (2012). System identification: theory for the user. Prentice Hall PTR.

[2] Cowan, N. J., Fortune, E. S. (2007) The critical role of locomotion mechanics in decoding sensory systems. Journal of neuroscience, 27(5), 1123-1128.

[3] Uyanik, I., Stamper, S. A., Cowan, N. J., Fortune, E. S. (2019) Sensory cues modulate smooth pursuit and active sensing movements. Frontiers in behavioral neuroscience, 13, 59.

[4] Favoreel, W., Van Huffel, S., De Moor, B., Sima, V., Verhaegen, M. (1999) Comparative study between three subspace identification algorithms. In European Control Conference (ECC), pp. 821-826. IEEE.

[5] Uyanik, I., Sefati, S., Stamper, S. A., Cho, K.-A., Ankarali, M. M., Fortune, E. S., Cowan, N. J. (2020). Variability in locomotor dynamics reveals the critical role of feedback in task control, eLife 9:e51219.