Investigating the behaviour of weakly electric fish with a Fish Avatar

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Abstract: This paper is devoted to the development of a Fish Avatar, a probe designed to interact with weakly electric fish. First some information about the communication behaviour of weakly electrical fish is given, and it is discussed how a technical device can interact with the animals. The probe's hard- and software is described including some experiments with the fish.

1 Introduction

In this paper we introduce the "Fish Avatar", a small probe that is used to interact with "weakly electric" fish. First we will give some background about "weakly electric" fish. In section 2 the hardware of the fish avatar is described, followed by an overview of our experiments in section 3 and a short conclusion.

Since the 1950s ([1]), it is known that some "weakly electric" fish can produce and receive weak electric signals. They belong to two different groups, the South American Gymnotiformes and the African Mormyriformes. Both produce and receive highly stereotyped weak electric organ discharges (EODs), generated by an electric organ, in mormyrids placed in the tail. Depending on the EOD-type, fishes can be divided into pulse and wave type species.

Since the 70ties first studies of electrocommunication were carried out, for example by Moller in 1976 [2] who analysed electrocommunication in groups of intact and operated fish. In the same year, Kramer [3] reported about aggressive inter-discharge interval (IDI)-pattern in *Mormyrus rume* and *Gnathonemus petersii.*

Today it is known that weakly electric fishes use their electric organ not only for active electrolocation but also for electrocommunication ([4]), based on the stereotyped fixed EOD waveform and on the variable IDI. But until now little is known about social communication within a freely swimming group (larger than two) of electric fishes. One of the long-term goals of this work is to investigate social interactions among fishes and to use these as an inspiration in the design of collective robot systems ([5]).

This research is part of the Angels [6] project. The aim of this European project, which involves biologists, physicists and roboticians, is to develop a reconfigurable anguilliform swimming robot that can split into smaller modules. For this robot, a new sensor is developed which uses electrical fields for sensing its surrounding and for communication between independent modules. This sensor is inspired by weakly electric fish [7] which can generate electrical fields for the same purpose.

2 Setup

2.1 Probe Hardware

For interacting with the fish, a small probe with a diameter of 8 cm (Figure 1) was constructed. The probe consists of a plastic sphere that contains the electronics and bears the electrodes on its shell. The small electronic board is connected via cables to a PC through a plastic tube that is attached to the sphere.

The probe has four mainly independent sensor channels, which have the same layout. As the schematic in Figure 2 shows, each channel contains high pass filters, two amplifiers and an analog to digital converter (ADC). Each channel can measure the potential of an electric field between its two electrodes, amplify this signal and digitalize it.

The high-pass filters are used to eliminate static offset signals that could saturate the amplifiers or the ADC. Apart from that, the sensor does not use any filters and the signal is left as unmodified as

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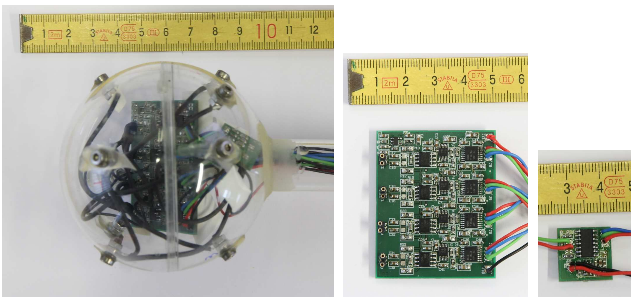

Figure 1: *Fish Avatar probe (left) with sensor (middle) and signal generator (right) PCBs*

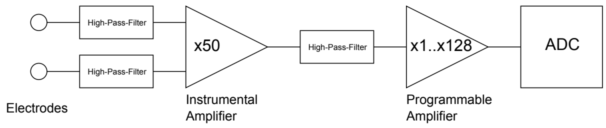

Figure 2: *Schematic of sensor channel*

possible. If filtering the signal further proves to be necessary, digital filters can be applied in software. The first operational amplifier (OpAmp) is an instrumental amplifier with a magnitude of 50. The second amplifier has a programmable gain. Its magnitude can be changed between 1 and 128, whereby the magnitude of the whole channel can be changed between 50 and 6400. The changeable gain is used in order to program the probe to detect either very weak signals of faraway fishes or to measure the EODs of close fishes without causing saturation of the ADC.

Every channel uses its own ADC rather than using a single ADC for all channels with a multiplexer to switch between inputs. This architecture enables the probe to capture the signals on all four channels simultaneously rather than working with time differences between the signals. The ratio between the four signals from the four electrode pairs makes it possible to approximate the position of the fish in respect to the probe.

The signal generator contains a digital to analog converter (DAC) and a low-pass filter. Figure 3 shows the schematic. With the DAC connected to the two transmitter electrodes, the probe is able to emit electrical fields ([8]). The flexibility of the DAC enables the device to generate signals with nearly every shape. The low-pass filters are only used to reduce the high frequency noise produced by the electric components.

The four ADCs and the DAC are connected to a PSoC board (Programmable System-on-Chip), which in turn is connected to the serial port of a PC (Figure 4). The PSoC is used to configure and control the different components. It starts the sampling process in the ADCs, reads their data and

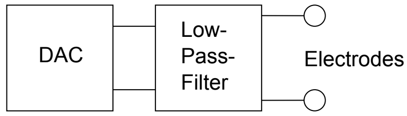

Figure 3: *Schematic of signal generator*

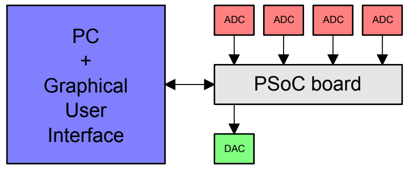

Figure 4: *Schematic of probe hardware*

transmits data to the DAC. Beyond that, it runs algorithms to detected EODs and determines their appearance in time and their amplitude. It can also be programmed to use filter algorithms to reduce the noise. The electric field measurements are than transmitted to the PC, where the results are displayed in a graphical user interface (GUI).

2.2 EOD Allocation

An important aspect in analysing EOD patterns of a swarm of electric fish is to determine which EODs belong to which individual. Until now this was done mostly manually and is very time consuming. Therefore software is developed to automatically allocate specific EODs in a recording to individual fishes in an aquarium.

By recording the EODs with four sensors simultaneously, we receive an amplitude pattern that depends mainly on the size of the fish and on the relative position of the fish in respect to the probe. Usually the fishes never stop discharging for longer than 3 seconds. This means that the amplitude patterns of a specific fish do not change essentially between two succeeding EODs.

The developed software compares an amplitude pattern of one EOD with the patterns of early EODs. Assuming that the fish's position varied only marginal since the last identified signal, its last signal can be found by calculating the difference in the patterns between the current and the last EOD.

For calculating the difference $d(a,b)$ between two patterns $a = [a_1, a_2, a_3, a_4]$ and $b = [b_1, b_2, b_3, b_4]$ (with a_i and b_i the amplitudes of the 4 sensors) the following equation is used:

$$d(a,b) = \frac{\sum_{i=1}^{4} |a_i - b_i|}{\sum_{i=1}^{4} |a_i| + |b_i|} \qquad (1)$$

The difference $d(a,b)$ is between 0 and 1, where 0 means the patterns are identical and 1 means they are completely different. The software calculates

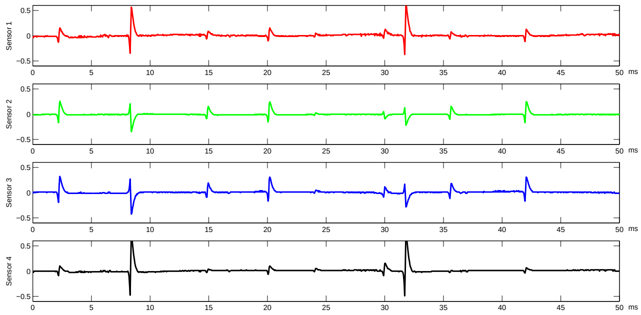

Figure 5: *Example of the recorded data (4 sensors)*

these differences between a new signal and all olc signals that are allocated to a specific fish. If the differences between the new and all the old signals are above a user defined threshold, the signal is allocated to a new fish. If not the signal is allocated tc the same fish the least different signal was allocatec to.

3 Experiments

In our first experiment which main purpose was to test the hard- and software, we recorded the electrocommunication signals in a group of five *Mormyrus rume*, an African pulse-type mormyrid. Their species-specific EOD is three-phasic, with the highest amplitude at the second negative phase, and lasts for 3 ms.
Figure 5 shows a few examples of the data recording with the four sensors. In this experiment the data collected by the sensors were transmitted directly to the PC for further analysis. It is noticeable how the different EODs are picked up differently from the four sensors. The amplifiers were programmed to a magnitude of 100 which leads to very little noise.
The recorded data were analysed, the EOD-patterns extracted and allocated to one of the five fishes. This was done on a PC, but will be implemented directly on the microcontroller in the future. Figure 6 shows some patterns in detail and a short sequence with the number of the fishes indicated by the position of the red circles.

4 Conclusion

In this paper, we described the hard- and software of a Fish Avatar, a probe to communicate and interact with weakly electric fish. The first experiments suggest that the developed algorithms will help in analysing the fishes' behaviour. Further experiments have to be conducted. We expect to learn more about the fishes' communication patterns and

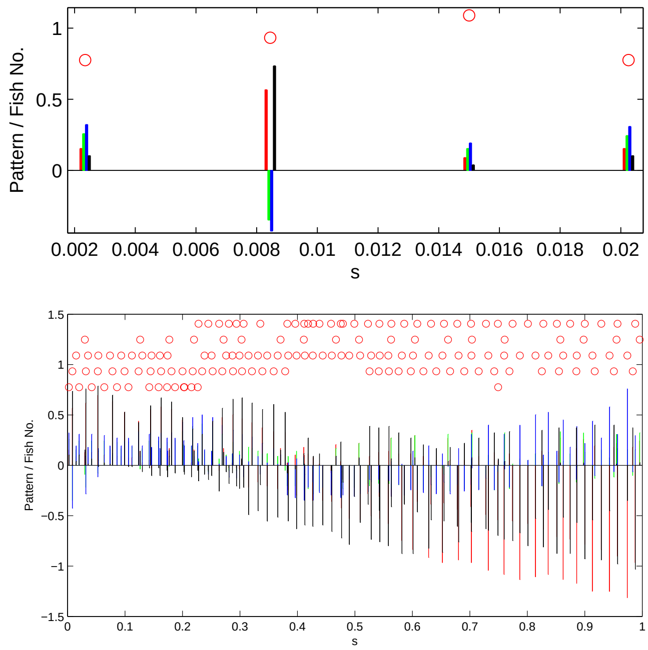

Figure 6: *Example of recorded amplitude patterns, different colours indicate different sensors, the positions of the circles show the fish numbers*

behaviours, and how their communication and interaction is related to each other.
This will be interesting not only from a biologist point of view, but from a technical point as well. The results of these experiments will be used to develop new communication protocols, based on different signal amplitudes and inter-discharge intervals. These protocols will then be implemented on the ANGELS robot.

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