The FischFITMonitor – A New System for Monitoring Multiple Physiological and Behavioural Parameters in Fish

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ABSTRACT

The presented work reflects the scientific research on and development of the FishFITMonitor (FFM), an innovative telemetric system for simultaneous monitoring of multiple physiological and behavioural parameters of free swimming fish. The miniaturization of the developed sensor system allows the integrated measurement of temperature, DC resistance of the direct cell environment, cellular electrical potential, electromyography (EMG), three dimensional swimming acceleration, heart rate and breathing rate.

The FishFITMonitor is a new approach for the combined evaluation of physiological and behavioural parameters. The assessment of the fish status is carried out by the mean of chronobiological regulation diagnostics. Therefore a set of time series analysis functions is applied to prepare the sensor signals as input for an artificial neural network (ANN) which then analyses distribution, stability, changes and synchronisation of the chronobiological regulation states of all measured parameters. At the first developmental stage the system will be usable in restricted size aquaria, basins or smaller ponds.

Author Keywords

telemetric sensor system, multiple parameter monitoring, physiological and behavioural parameter, pattern analysis, neuronal network

INTRODUCTION

MacIntyre [6] suggested that animal health is a central tenet of animal welfare. A reliable evaluation and monitoring of health and welfare in laboratory, domestic or farm animals is still one of the most challenging issues in animal behaviour research and even for the development of appropriate measuring techniques and evaluation methods. Especially for fish the natural borders between us as human observers and the individuals of interest limit the access to behavioural and physiological data on which health and welfare estimations can be based. Therefore welfare in fish has not been studied to the same extent as in terrestrial animals. Deviations of measures from normality enable us to say that fish are stressed and have impaired welfare and health, but it is still difficult to evaluate the extent of impairment or forecast if the animals might return to normality or show mortality [4].

Following these considerations and based on the experiences with conventional telemetric systems (5; 7) and the methods of chronobiological regulation diagnostics in humans and mammals [1; 2] we decided to develop a miniaturized integrated sensor and evaluation system for the simultaneous online monitoring of several physiological and behavioural parameters in fish.

SYSTEM DESIGN

Mechanical Design

The design goals of the FFM-sensor node had to ensure a size small enough for implantation into the peritoneum of fish to pick up the vital parameters without impairing the observed individual. Therefore we constructed the FFM sensor node of water resistant bio-compatible material build in a rapid prototyping process. We gave it the shape of a flattened ellipsoid with embedded flat electrodes avoiding sharp edges. With eight micro screws and a rubber seal we obtain an absolute water resistant packaging. The screws

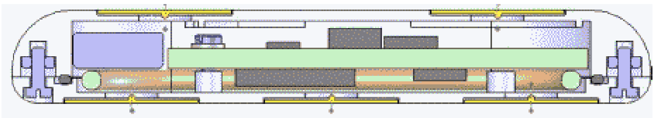

Figure 1. Cross sectional scheme of the sensor node.

Figure 2. Photo of the opened sensor node.

are covered on top and bottom with a plastic faceplate to ensure hermetic encapsulation. The overall dimensions of the sensor node are recently 50x20x12 mm and its weight is about 10 g therefore applicable for fish of about 1 kg weight [3]. Figure 1 and 2 show the main design of the sensor node.

Electric Design

We are recently using a 1 Ah battery as a power source. With a sample and communication rate of one second the lifetime is about 40 days. Within the next year we are planning a further miniaturisation as well as an already tested wireless power recharging technology.

To ensure a high data rate of 250 kbps required by a sample rate of once per second with eight analogue channels we decided to use digital radio frequency (RF) communication.

Because of the limited energy resources we optimised the system for low power consumption. Therefore we use an energy saving microcontroller MSP430F147 and a RF transceiver CC1101 from Texas Instruments. For a dataset of eight channels containing 16 bytes of data, the transceiver is only busy for one millisecond. Because of a small bandwidth of the vital parameter signals we applied two instrumentation amplifiers and seven operational amplifiers with a low gain bandwidth but even very low power consumption. Despite of an high signal attenuation through the fish and the water we can cover a volume of one cubic meter of the swimming tank with an average signal level of -70.52dBm.

Sensors

We integrated five gold electrodes of 1 cm diameter into the flattened upper and lower sides of the sensor node to measure the electrophysiological signals. For the DC resistance of the direct cell-environment we use two electrodes with a distance of 2.5cm. The measurement current is limited to 5µA thus avoiding a stimulation of the nervous system of the fish. The three electrodes at the other side measure the cellular electrical potential and the EMG whereas the middle electrode is the reference connected to the circuit ground. All sensors are sampled by an ADC with a resolution of 12Bit. For temperature measurements from 0°C to 40°C two NTC thermistors are connected directly to the housing for minimum thermal resistance. With a 3D acceleration sensor we determine the orientation in the swimming tank and the momentary acceleration of the fish. The resolution is 2mG or 0.019N. Two recently integrated pressure sensors at the front and back end of the sensor node will measure the longitudinal pressure waves caused by heart beats and breathing of the animal.

DATA PROCESSING AND ANALYSIS

For the first experimental and developmental tests our sensor system had to cover a measurement period of a minimum of three weeks and to record one dataset every second. For the RF communication we decided to use a frequency division (FDMA) method and a point to point connection for the first implementation. This technique is very energy saving, avoiding collisions and overhearing problems. We could prove a reliable data transfer from all sensor channels to the post processing in the RF gateway and the PC software. The conversion of the digital signals to the physical units is then done by the PC software.

To avoid the problems of regular calibration of all sensors we focus on the chronobiological analysis and evaluation of datasets. Doing this the only exactly calibrated and reliable measurement we need to have is the sample timestamp of every single measurement. The chronobiological regulation diagnostics [Balzer] uses the frequency distribution of regulation states over a certain time span for the assessment of the state of the whole organism.

Therefore first a set of time series analysis functions are applied to a selected time span (normally two times 20 s) of the sensor signals during a pre-processing step. We remove trends, determine the main period lengths of the parameters oscillation by autocorrelation and power spectral analysis while stepwise moving the observed time frame through the whole dataset. Finally we determine the frequency distribution of the calculated main period lengths for each 20 s interval. These frequencies are the main input for an artificial neuronal network (ANN) which then determines regulation states according to the Periodic System of Regulation States by Balzer [2] The output of the ANN is recently composed of 42 output nodes which stand for regulation states. The node with the highest output enumerator represents most likely that of the fish during the observed time period. The working cycle of the ANN corresponds to the sensor signal sample rate, so every second the regulation state of a single physiologic/behavioural parameter is calculated.

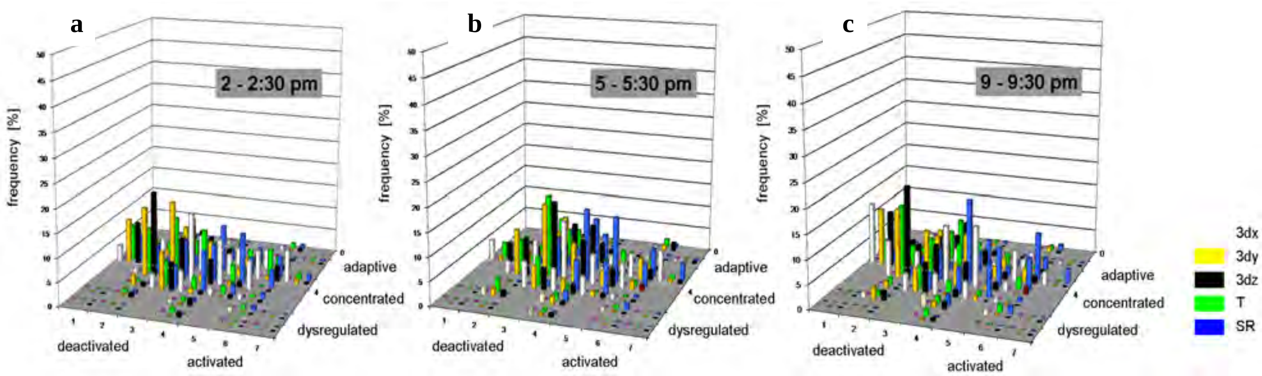

Figure 3. Frequency distribution of regulatory states for one fish at three different time periods. The data based on 3D acceleration (3dx, 3dy, 3dz), temperature (T) and skin resistance (SR).

To visualise the results achieved by this procedure we show exemplarily the frequency distribution of regulation states of one fish for the x-y-z acceleration parameters, the temperature and the tissue resistance in Figure 3. The three observation periods represent:

a) half an hour after implantation, still under the influence of anaesthetics and deactivated

b) three to four hours after implantation, fish is already recovering, in an activated state

c) three hours after light off at the evening, fish is more deactivated (relaxed) and slightly more adaptive

These are very first and preliminary results. For fish species we will still have to test and 'teach' the ANN by a human interpreter who 'informs' the ANN about the 'meaning' of the observed behaviour or status of the fish on the basis of distinct experiments with defined stress situations. Thus the ANN will learn figuratively from the fish.

CONCLUSION

With the FischFITMonitor we could present a miniaturized implantable wireless sensor node with eight sensor channels for real-time monitoring of vital parameters in fish. We could show the functionality and reliability of measurements and the possibility of an evaluation of recorded data by means of the chronobiological regulation diagnostics leading to conceivable results in the sense of health and welfare status of fish. Next steps must include a further miniaturisation of the sensor (by 30%), the wireless power supply recharge and a time division based communication (TDMA) for multiple sensor nodes.

By specific experiments we will train the ANN to recognise stress situations and health impairments in different fish species.

Ethical Statement

The experiments comply with the German Guidelines for Animal Care and were approved by the Landesamt für Gesundheit und Soziales, Sächsische Str. 28-30, 10707 Berlin, Germany, Reg-No. G 0378/08.

REFERENCES

1. Balzer, H.U. Chronobiology – as a foundation for and an approach to a new understanding of the influence of music. in: Haas / Brandes (ed.*) Music that works*, p. 1-76, (2009) Springer Wien ISBN 978-3-211-75120-6.
2. Balzer, H.U., Struwe, R., Kuhne, F. Evaluation of regulation states in comparison with behavioural analysis determining states of stress sensitivity in dogs. In *Proceedings of the 3rd European Conference on Behavioural Biology, Physiological Mechanisms in Behavioural Ecology*. (2006).
3. Baras, E., Lagardere, J-P. Fish telemetry in aquaculture: review and perspectives. *Aquaculture International*, *3* (1995), 77-102.
4. Davis, M.W. Fish stress and mortality can be predicted using reflex impairment. *Fish and Fisheries*, *11* (2010), 1–11.
5. Fredrich, F., Ohmann, S., Curio, B. and Kirschbaum, F. Spawning migrations of the chub in the River Spree, Germany. *Journal of Fish Biology*, 63 (2003), 710–723.
6. MacIntyre C., Ellis T., North B.P., and Turnbull J.F.. The influences of water quality on the welfare of farmed trout: a Review. In: *Fish Welfare* E. Branson. Blackwell Scientific Publications, London, (2008), 150-178.
7. Winter, H.V., Fredrich, F. Migratory behaviour of ide: a comparison between the lowland rivers Elbe, Germany, and Vecht, The Netherlands. *Journal of Fish Biology*, 63 (2003), 871–880.