Innovative Sensor Application: Sensor Egg in the Nest of Curlews

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Abstract

For the breeding of birds, knowledge of various breeding parameters such as effective breeding time, temperature, humidity and also rotation of the eggs during the breeding process is important. All these parameters can so far only be estimated, as they could not yet be measured directly in the nest. This paper presents the technology of the first sensor egg and the first measurement results obtained in a curlew nest with the help of a sensor egg. The battery-powered sensor egg is provided with sensors for determining temperature, humidity and acceleration and a microcontroller, memory and a Bluetooth Low Energy (BLE) module.

1 Breeding behaviour of birds

For the breeding/hatching process of birds, there are some important parameters such as temperature, humidity and rotation of the eggs so that the embryos are always well supplied with food. Knowledge of the relevant breeding parameters is indispensable for breeding and species conservation. Despite many different efforts, it has not yet been possible to measure all parameters directly in the nest over the entire breeding period. The turning of the eggs in particular has so far been a little researched process, especially since, due to the chalaza (dt. Hagelschnur), the egg yolk must not be damaged by excessive turning in one direction. In this work, for the first time in the wild, all relevant parameters of hatching of curlews (dt. Brachvögel) were measured in the nest with the help of an artificial “sensor egg”. In contrast to bird eggs, reptile eggs must not be turned, otherwise the embryo or germ cell can stick to a wall which endangers the survival of the embryo.

1.1 Requirements for the sensor egg

The aim of the development of a sensor egg is to build a sensor system the size of a quail (dt. Wachtel) egg; this is intended to monitor the essential breeding parameters of temperature (at three measuring points, each rotated by 120°), humidity and rotational movement by means of an acceleration sensor during the breeding period of at least 30 days. These data are to be measured regularly and also stored in a non-volatile memory.
Thus, the following main requirements applied:

- Size of the sensor egg: Oval structure with a height of 30 mm and a diameter of 23 mm
- Measurement of the temperature (with an accuracy of at least 0.2 K) at three points, each shifted by 120° with respect to a rotation of the sensor egg
- Measurement of the humidity, accuracy at least ±5 %
- Measurement of the acceleration in three directions, range ±2 g
- Communication with Bluetooth Low Energy (BLE)
- Recording of data at freely selectable time intervals and also event-triggered (e.g. during rotation). The data must be provided with a time stamp in order to enable a temporal allocation during later evaluation.
- At least 30 days of operation possible to record the data
- Storage of the data in a non-volatile memory.
- Various operating modes for testing and measurements (with microcontroller)
- Display of results in table format and visualisation in an app
- Charge monitoring of the battery
- Easy adaptation of other egg sizes; realisation with 3D printing
- Shape of the sensor egg must approximately correspond to the original egg (size and mass)

1.2 Design of the sensor egg

To meet all the requirements, the following components were selected – the basic design and details are shown in **Figure 1**:

- Humidity sensor HDC2080 (Fig. 1: 1) with an accuracy of 2 % with no calibration; current consumption: active: 650 µA; passive: 0.05 µA
- Connection header TMP117 (Fig. 1: 2)
- Connection header (Fig. 1: 3)
- Connection socket (Fig. 1: 4)
- Programming socket (Fig. 1: 5)
- Microcontroller with BLE and memory (Fig. 1: 6): Laird Module BL654 with Nordic nRF52840 SoC; current consumption of about 50 µA depending on activity, internal voltage supply 1.8 V
- Battery Management System (Fig. 1: 7)

ISBN 978-3-8007-5835-7

- Energy supply: VARTA CP 1654 A2 (Fig. 1: 8) with 120 mAh
- 3d-Acceleration sensor ADXL362 (Fig. 1: 9) with a measuring range of ±2g and resolution about 1 mg/LSB; current consumption: active: 200 µA; passive: 0.27 µA
- Main PCB (Fig. 1: 10)
- Dip switch (Fig. 1: 11)
- Sensor PCB (Fig. 1: 12)
- (three) Temperature sensors TMP117 (Fig. 1: 13) with an accuracy of ±0.1°C across the temperature range of -20°C to 50°C with no calibration; current consumption: active: 135 µA; passive: 0.15 µA
- Outer shell (realised with 3D printing; Fig. 1: 14)
- Charging module: TP4056 with Micro-USB interface (outside sensor egg)
- Adjusting the geometry with Blender 2.9 [1] for realisation with 3D printing

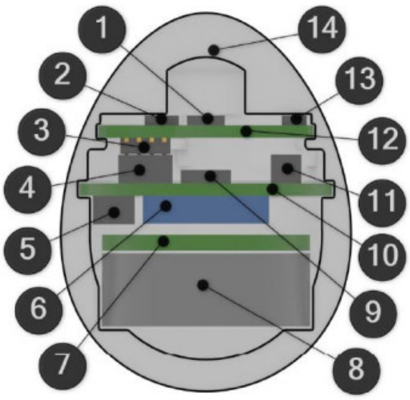

Figure 1 (Inner) Sensor egg: Principle design and details (see text above)

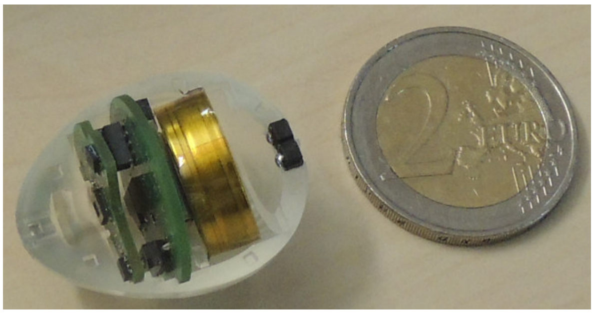

Figure 2 Inner Sensor Egg and 2 €-coin for comparison

Since bird eggs often vary in size, the approach taken here was to build the smallest possible sensor egg; this is surrounded by a larger outer sensor egg (outer shell) so that the target size is achieved. The functionality is thus determined by the inner sensor egg as depicted in **Figure 2**. In order to be able to determine the temperature at the outer shell, a thermal bridge in the form of copper stripes was built from the inside to the outside - see **Figure 3**. The air humidity can penetrate from the outside to the inside via small holes so that this can then be measured by the HDC2080 air humidity sensor in the inner sensor egg.

Both - the inner sensor egg and the outer shell - are constructed from two halves each so that they can be opened again, e.g. to change components.

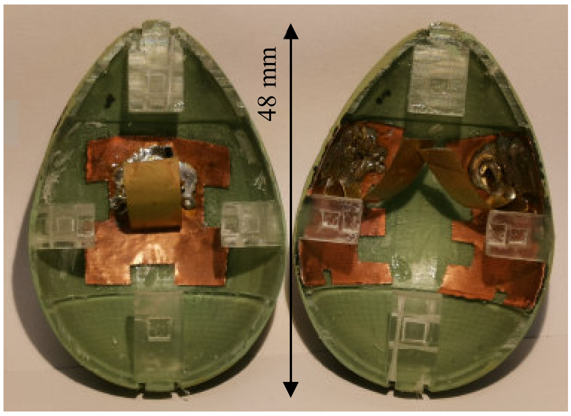

Figure 3 Outer shells with copper stripes (height: 48 mm)

For the creation of the outer shell, the software Blender 2.9 [1] software was used to create a 3D-copy of a bird's egg that is as similar as possible. In this way, the outer shell is adapted to the geometry of the original egg using Bezier curves. This makes it relatively easy to build a true-to-original sensor egg using 3D printing.

2 Results of measurements

In order to obtain first realistic data, various bird nests in the wild were equipped with sensor eggs in cooperation with Bioplan in Bühl/Baden (Germany).

2.1 Sensor egg in a lapwing nest

Figure 4 Lapwing nest with eggs and sensor egg

The first trial was carried out in a lapwing (Kiebitz) nest, see **Figure 4**. The trial had to be abandoned after a few days because a fox stole all the eggs and thus also the sensor egg. With the help of BLE, an unsuccessful attempt was made to find the sensor egg again.

2.2 Sensor egg in a curlew nest

The second experiment was carried out on a curlew's (Brachvogel) nest. These birds are threatened with extinction and strictly protected. The birds and the nest (see **Figure 5**) are observed by Bioplan/Bühl (Germany) on behalf of regional councils of Karlsruhe and Freiburg. The nest is fenced off and is not accessible to the public. The nest is located on the ground in wet meadows.

Figure 5 Curlew nest with eggs and sensor egg

The measurement in the nest took place over a period of 26 days, recording data for temperature (see **Figure 6**), humidity (see **Figure 7**) and rotation (acceleration, see **Figure 8**); the last 5 hours are shown here.

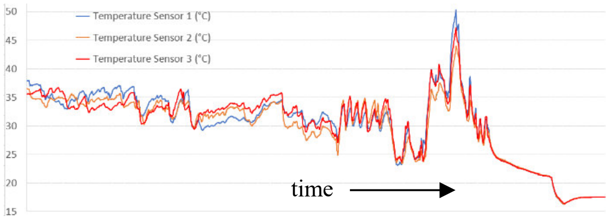

Figure 6 Curlew nest: Temperature over time

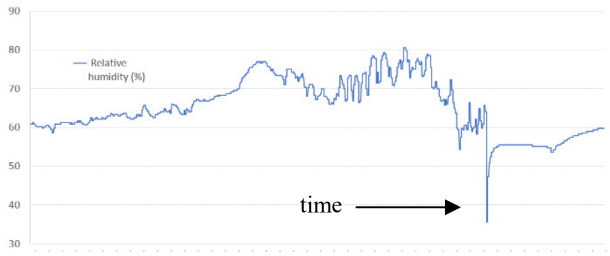

Figure 7 Curlew nest: Relative humidity over time

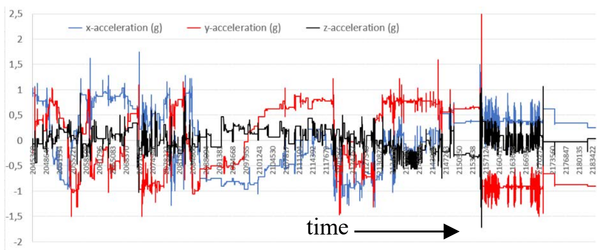

Figure 8 Curlew nest: Acceleration over time

Figures 6 to 8 show the breeding parameter in the last 5 hours: There is a fundamental change in behaviour in the last approx. 10 % of the time, as the chicks have hatched out. Then the temperature in Fig. 6 drops noticeably, the humidity in Fig. 7 decreases as well and the acceleration values in Fig. 8 each approach a constant value, as the parent birds no longer sit on the nest. Figure 8 also shows that the parent birds regularly rotate the sensor egg while they are breeding. The large acceleration value of more than 2 g in Fig. 8 is due to the removal of the sensor egg from the nest; this is also reflected in clearly reduced values of humidity in Fig. 7.

The high temperatures up to nearly 50°C in the last third of the measurement shown in Fig. 6 indicate that the sensor egg was exposed some time to direct sunlight, as these high temperatures can hardly be reached during breeding.

Likewise, when looking at the data over the entire period, it is noticeable that the parent birds left the nest regularly and then both parent birds did not breed. The data was transferred to an Android smartphone using BLE and then read out with the help of an app and evaluated on the basis of tables. A further evaluation of the data is currently still in progress.

The power consumption was very low, so that theoretically an operating time of more than 150 days would be possible. In the future, further investigations are planned to develop this technology further in order to obtain more data.

3 Summary

For successful breeding of birds (especially for protected and endangered birds), knowledge of the relevant breeding parameters is important; it is important to know the temperature, relative humidity and also the rotation of the eggs in the nest. Curlews are threatened with extinction today; in Baden-Württemberg, this species breeds - with one exception - only on the Upper Rhine in Baden in about 35 pairs. In a new approach, several sensors such as three temperature sensors, a humidity sensor and also a 3-axis acceleration sensor plus battery, data storage and evaluation electronics (microcontroller, BLE module) could be integrated into an artificial "sensor egg" with the size of a quail egg (height: 30 mm and diameter 23 mm) that was placed in a curlew's nest. The data is transmitted to an Android smartphone using Bluetooth Low Energy (BLE) and an app can then be used to read and evaluate the data.

The mechanical construction by means of 3D printing is also innovative: Starting from a miniaturised sensor egg, larger sensor eggs can now also be constructed on the basis of pictures, which show the geometry of the original egg.

With curlews, the relevant values for temperature, humidity and acceleration (rotation) could now be measured for the first time over a complete breeding period.

Acknowledgement: We thank Mr. Jürgen Wickenhäuser (GeoPrecision GmbH, Ettlingen, Germany) for his valuable support in this project.

4 Literature

[1] https://www.blender.org/download/releases/2-90/