

Successful Creation of Regular Patterns in Variant Maps from Bat Echolocation Calls



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Abstract We created variant maps based on bat echolocation call recordings and outline here the transformation process and describe the resulting visual features. The maps show regular patterns while characteristic features change when bat call recording properties change. By focusing on specific visual features, we found a set of projection parameters which allowed us to classify the variant maps into two distinct groups. These results are promising indicators that variant maps can be used as basis for new echolocation call classification algorithms.

Keywords Echolocation · Algorithms · Morphometry · Fourier · Analysis
Quaternions

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1 Introduction

The identification of echolocation calls is essential to the research and conservation of bat species [1]. However, automatic classification algorithms have not yet been proven capable of providing 100% correct classifications or getting close enough to this ideal performance [2]. Since our approach of using variant maps [3] shows already promising results, we are confident that it will continue adding valuable contributions to the field of automatic bat call identification.

Automated bat echolocation call identification algorithms were developed since the late 1990s [4–7]. At that time, multivariate discriminant function analysis or neural networks were used for the classification of the calls. Since then, other methods have been applied, e.g., algorithms of pattern recognition [8], support vector machines [9], hierarchical ensembles of neural networks [9, 10], geometric morphometry [11], machine learning [12], CART [13], and random forest classification [14]. For a critical analysis of the performance of the applied methods, we refer to [2] and the references therein.

Using variant maps for the classification of bat echolocation calls differ completely from these conventional techniques. The main difference is the preprocessing step, where the recordings are transformed into variant maps. This step offers the possibility to analyze the bat call recordings from a completely different point of view. It provides additional degrees of freedom which allow a further optimization of the identification process, e.g., by supplementing the information obtained from a Fourier analysis of the bat calls.

Our method to transform the bat call recordings is based on measures proposed by Zheng [15] in the 1990s to partition special phase spaces in binary image analysis. These methods were extended in the 2010s [3, 16] and successfully used to classify quantum interactions [17, 18], differently encrypted messages [19], and noncoding DNA [20, 21].

Similar to these works, we transform the bat call recordings using variant measures to obtain variant maps. Each recording contains several calls of one bat species. We used calls of four aerial-hawking bat species in this study. Recordings were made at three types of crop fields far away from woody vegetation. The created variant maps have a regular structure, but characteristic features vary strongly with each recording. These results show that variant maps can be used to extract usable information from bat echolocation recordings.

2 Transformation

The processed bat echolocation calls were recorded with a sampling rate of 500 kHz and saved as “raw” 16-bit audio files. In the following, we describe in four steps (A–D) how we transformed these files into variant maps.

Step A: From analogue to digital audio

In a recording of data length N , the amplitude of the bat echolocation calls is stored in N samples. Each sample corresponds to a floating-point number of 16 bits. For simplicity, we transformed the floating-point numbers to integer numbers of 16 bits.

Step B: From digital audio to quaternions

Next, we transform the integer sequence into a sequence of four metastates $\{\perp, +, -, \top\}$ which resemble the quaternions {Bottom, Plus, Minus, Top}. For this step, we select the i -th sample A_i and its next neighbor A_{i+1} and define the difference $\Delta A = A_{i+1} - A_i$ and local average $L = (A_i + A_{i+1})/2$. Additionally, we require the maximum A_{\max} and minimum A_{\min} of the current sequence to define a middle value $V = (A_{\min} + A_{\max})/2$ and we define a tolerance T . Using these values, we transform the integer sequence $A_1 \cdots A_N$ into a sequence of quaternions $B_1 \cdots B_N$ using the rules

$$\begin{aligned}
 &\text{if } \Delta A < T \text{ and } L > V : B_i = \top \\
 &\text{if } \Delta A < T \text{ and } L \leq V : B_i = \perp \\
 &\text{if } \Delta A \geq T \text{ and } A_i > A_{i+1} : B_i = - \\
 &\text{if } \Delta A \geq T \text{ and } A_i < A_{i+1} : B_i = + \text{ .}
 \end{aligned}$$

As an example, the values $T = 4$ and $V = 10$ lead to the sequence

A_i	0	3	3	2	0	8	20	20	11
A_{i+1}	3	0	8	6	4	3	15	18	13
B_i	\perp	\perp	+	+	+	-	-	\top	\top

Step C: From quaternions to meta-measures

We subdivide the quaternion sequence into segments of length M and obtain, in this way, $S = N/M$ segments. For each segment, we define four meta-measures $\{M_{\perp}, M_+, M_-, M_{\top}\}$. One measure represents the number of associated quaternions in one segment. These meta-measures satisfy the relations $0 \leq M_{\perp}, M_+, M_-, M_{\top} \leq M$ and $M_{\perp} + M_+ + M_- + M_{\top} = M$. The quaternion sequence with N units is now represented by S segments where each segment contains four meta-measures.

Step D: From meta-measures to variant maps

There are many possibilities to combine meta-measures for the creation of variant maps [3, 15–21]. To transform the bat echolocation calls into 2D color maps, we defined for each segment of meta-measures the axis values $X = M_+ + M_{\perp}$ and $Y = M_{\perp} + M_- + M_{\top}$. One Z value is obtained by counting the number of segments where one specific X - Y combination was found. Each Z value is represented by a color in an $(M + 1) \times (M + 1)$ matrix.

As an example, we depicted in Fig. 1 the variant map of an echolocation call recording from the bat species *Nyctalus noctula*. It has a data length $N = 967,139$ and we chose a segment length $M = 237$. At the position $X = 80$ and $Y = 200$ marked by a white circle, the color indicates a value $Z = 10$. That is, we found 10 segments where the conditions $M_+ + M_{\perp} = 80$ and $M_{\perp} + M_- + M_{\top} = 200$ apply.

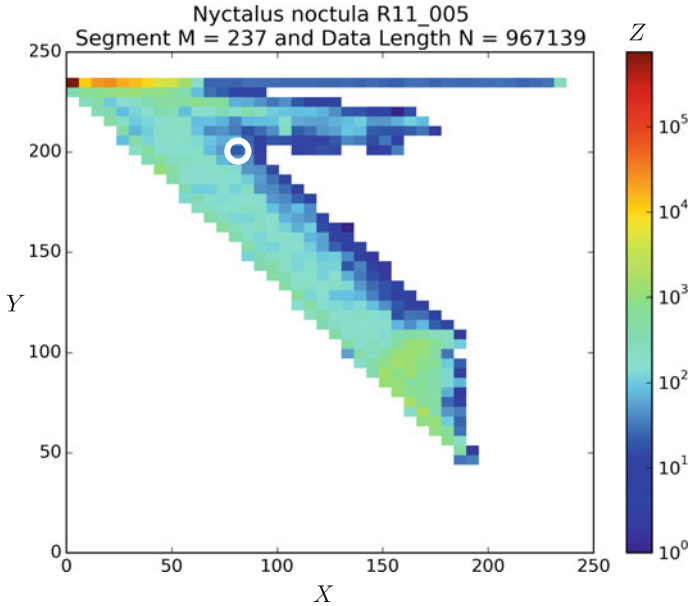


Fig. 1 The variant map of an echolocation call recording from the species *Nyctalus noctula* created by following the processing steps A–D described in Sect. 2. We highlighted the position $X = 80$ and $Y = 200$ by a white circle to illustrate the processing step D. At this position, the conditions $M_+ + M_\perp = 80$ and $M_\perp + M_- + M_\top = 200$ apply. Further visual features are discussed in Sect. 3 in more detail

White areas indicate regions without any projection point on this sequence. For a discussion of further visual features which appear in this figure we refer to Sect. 3.

These types of maps offer the possibility to visualize long data sequences with $>10^6$ samples on compact matrices. We use this scheme to transform each bat call recording into a 2D color figure. It can be optimized for the identification of bat species, recording locations or times.

3 Variant Maps

Our main result is that all variant maps created from bat echolocation calls show regular patterns while characteristic visual features vary with each recording. In the following, we describe the data we processed in detail and discuss the visual features we observed.

3.1 Data Description

We processed 44 files which were recorded in August 2012 in the Uckermark region (Brandenburg, Germany) [22]. Each recording contains only calls of one of the four European bat species *Nyctalus noctula*, *Pipistrellus nathusii*, *Pipistrellus pipistrellus*, or *Pipistrellus pygmaeus*. These files were recorded on arable fields cultivated with three different crop types: corn (C), rapeseed (R), or wheat (W). The record length varies between 30 s and 2 min.

3.2 Visual Features

We transformed all 44 files of bat calls into variant maps by steps A to D described in Sect. 2. That is, we used the axis values $X = M_+ + M_\perp$ and $Y = M_\perp + M_- + M_\top$ and a segment length $M = 237$. By focusing on the visual features, we clustered the resulting maps into two groups. A typical member of each group is shown in Fig. 2.

One group consists only of maps showing patterns which have two significant maxima with values $> 10^5$. We call members of this group **double-maxima** maps. The example shown in Fig. 2a has maxima at the positions $X=0, Y=237$ and $X=120, Y=200$. Besides these two maxima, there are distinct positions on diagonal areas with values of the orders $1-10^3$.

All other maps belong to the group of **non-double-maxima** maps. As an example, the map in Fig. 2b has its significant maximum at the position $X=0, Y=237$ while other projection regions have values of the orders $1-10^3$. In addition, most values of interest are located around a diagonal region and form a slat band on the map.

All 44 resulting maps are shown in Figs. 3 and 4. They are separated into **double-maxima** maps (Fig. 3) and **non-double-maxima** maps (Fig. 4). In principle, it is possible to further subdivide the variant maps by identifying additional visual features. However, since we did not yet find a direct connection between visual features and bat call properties, a further subdivision goes beyond the scope of this manuscript and will be the topic of a future publication.

3.3 Discussion

On all generated maps, the positions on the left-down triangle area are empty. This is because our choice of axis obeys $X + Y \geq M$. Empty positions in the right-upper area appear because the bat call recordings consist of discrete short pulses with a longer time period of silence in between.

Similarly, other visual characteristics in the colored areas can be directly related to properties of the bat call recordings. As an example, a signal of constant frequency can be transformed into a single position on a variant map by choosing suitable

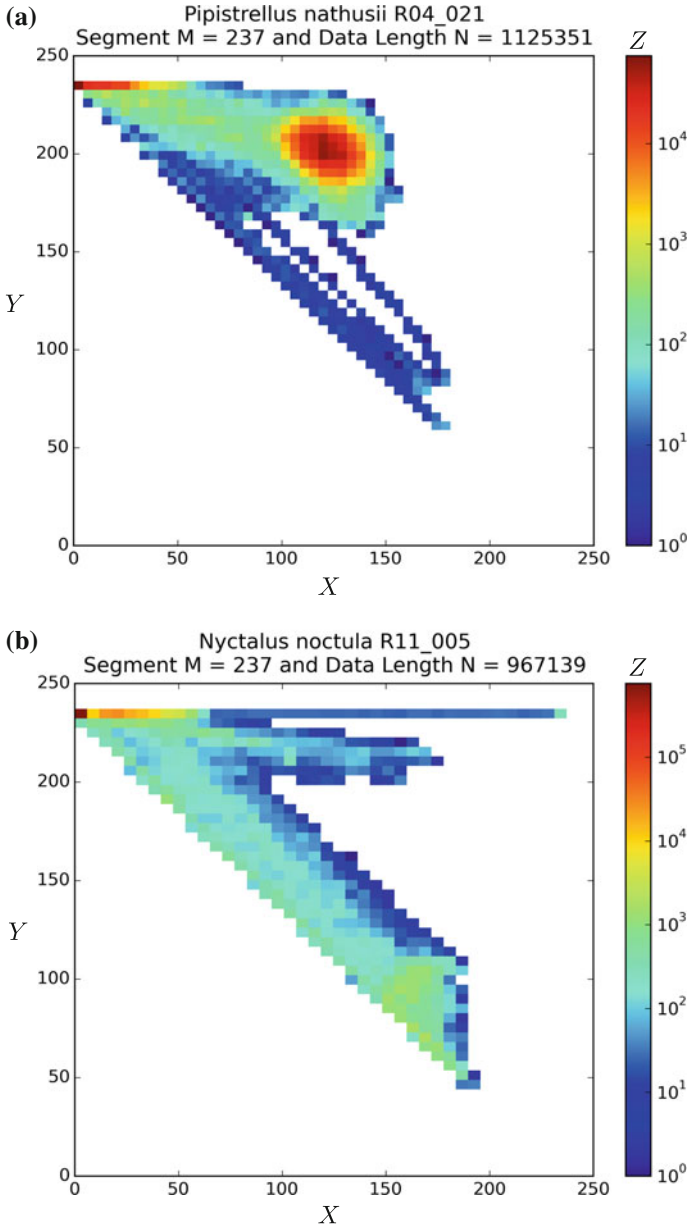


Fig. 2 Variant maps of **a** *Pipistrellus nathusii* and **b** *Nyctalus noctula*, both recorded on a rapeseed field. The figures were created by applying the transformation process described in Sect. 2. **a** which shows a typical **double-maxima** map with two significant maxima, while **b** belongs to the group of **non-double-maxima** maps

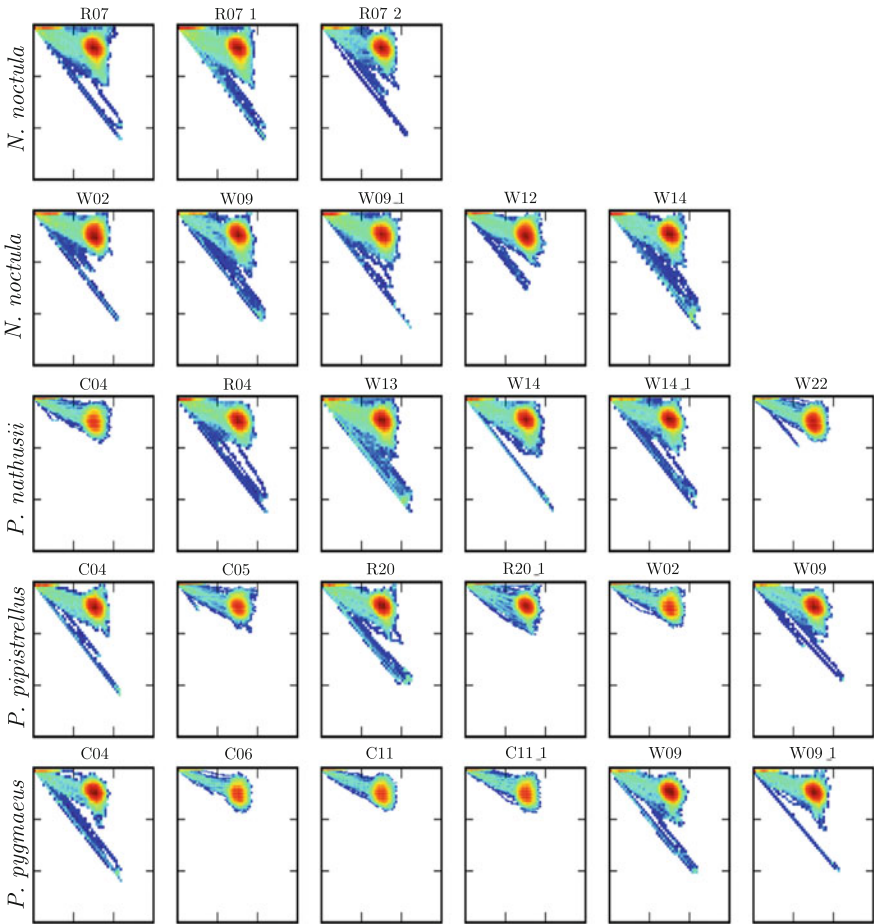


Fig. 3 These variant maps show **double-maxima** patterns. They have two significant maxima with values $>10^5$. The axis ranges are the same as in Fig. 2. Each map originates from a bat echolocation recording on a corn (C), rapeseed (R), or wheat (W) field

parameters. This means that by optimizing the variant map transformation, it is possible to focus on features of the initial bat echolocation call for the creation of variant maps.

This is the first time to our knowledge that quaternion structures have been used to transform bat calls. Our transformation process could be used to add optimizing parameters to current bat call identification schemes and in this way form the basis for a new identification algorithm.

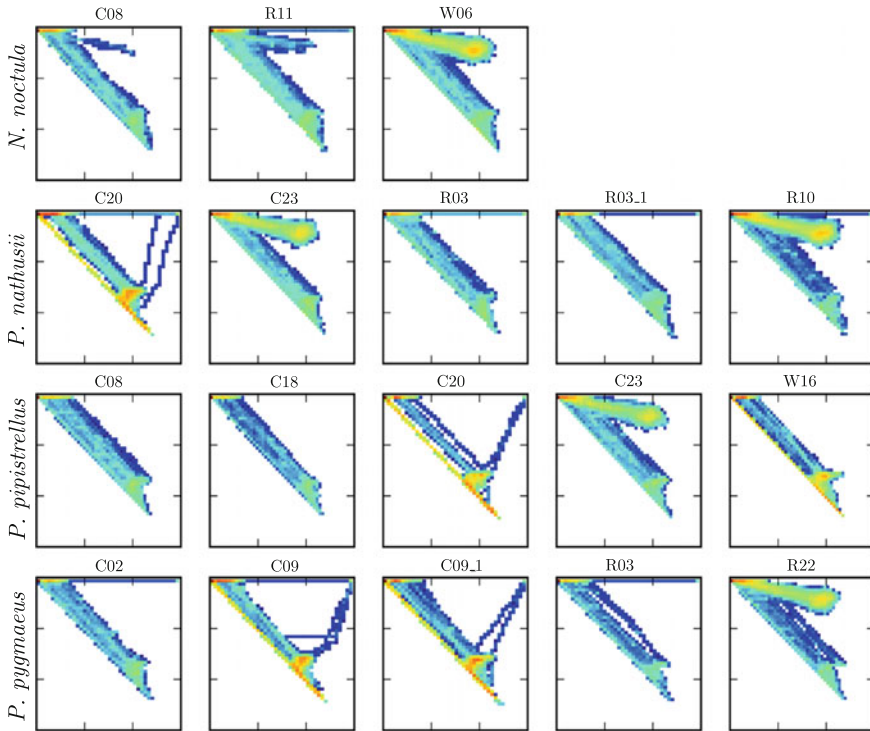


Fig. 4 These variant maps show **non-double-maxima** patterns. That is, they explicitly do not have two distinct maxima with values $>10^5$ in contrast to the **double-maxima** maps shown in Fig. 3

4 Summary and Outlook

We transformed 44 bat echolocation files into variant maps. All created variant maps have a similar structure and can be classified by focusing on specific visual features. As an example, we found a set of projection parameters which allowed us to classify the recordings into **double-maxima** and **non-double-maxima** maps.

Features like this can be traced back to the signal nature of the recordings. In this way, variant maps offer the possibility to focus on individual features of bat echolocation calls. Since there are multiple numbers of possible combinations to create variant maps, we are very positive that a suitable projection combination can be found to fulfill our ultimate goal of identifying single bat species.

In order to meet this target, it is necessary to process a much higher number of bat calls to create a sufficiently large database for the effective determination of possible projections and associated maps. This would form the perfect basis for the development of a new echolocation call identification algorithm.

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