Visual perception of spatial objects and textures in flying pigeons

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SPATIAL PERCEPTION IN MIDDLE-DISTANCE MOVEMENTS

Level I. External spatial data

- **1.1. Environmental Information** — Boundaries between different terrains. Regions of interest and landmarks. — Remote sensing data
- **1.2. Weather Conditions** — Wind, atmospheric precipitation, poor visibility. — Weather data

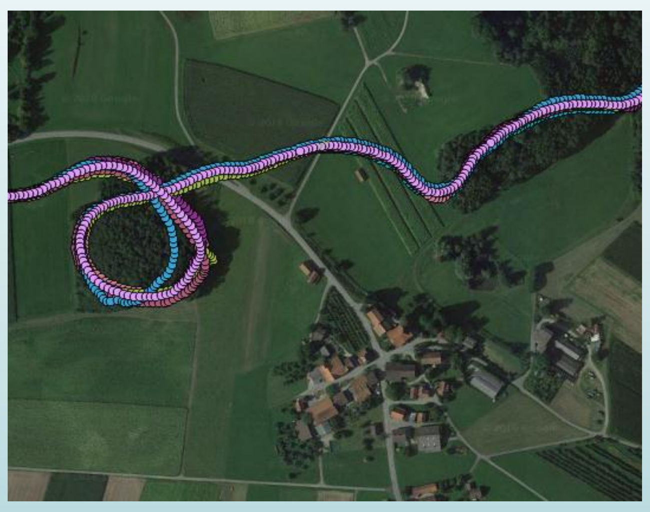
Level II. Animal Tracks

- **2.1. Collective Motion Analysis** — Group polarity. Nearest neighbour distance. — GPS logger + GIS *Processing*
- **2.2. Individual Motion Analysis** — Variety of trajectories and directions. Survey flight over unknown terrain. — GPS logger + GIS *Processing*

Level III Perception and brain reaction

- **3.1. Total Brain Activity** — EEG activity — Neurologger
- **3.2. Activity of individual brain cells** — Border cells, grid cells, place cells — Mathematical Processing

GPS TRACKS OF PIGEON FLOCK

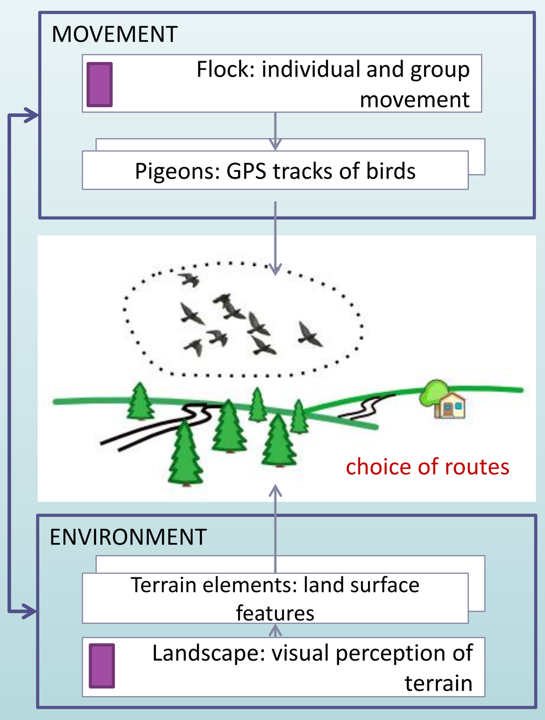


Pigeon trajectories during middle-distance flights are determined, in particular, by the visual perception of the terrain. Flight trajectories of pigeons can reflect the characteristics of terrain areas and surface objects.
In our previous works (Zaleshina 2018, 2019), we studied the properties of pigeon flight trajectories combined natural and urban terrain. The aim of studies was to find answers to the next questions:

Which properties of the terrain are guided the pigeons in flight? and
Is it possible to identify sets of significant objects and terrain based on the data about flight paths?
Spatial analysis of flight trajectories and directions was applied to identify frequently used "flight corridors" and regions of interest along the birds' flights.

The visual characteristics territories over which pigeons flew were calculated using remote sensing data. In result, distinctive areas along flight trajectories and visual features of the landscape were compared.
It was found that the "flight corridors" correspond to real objects and areas in the terrain.

DYNAMICAL CHANGES AND CHOICE OF ROUTES IN FLIGHT



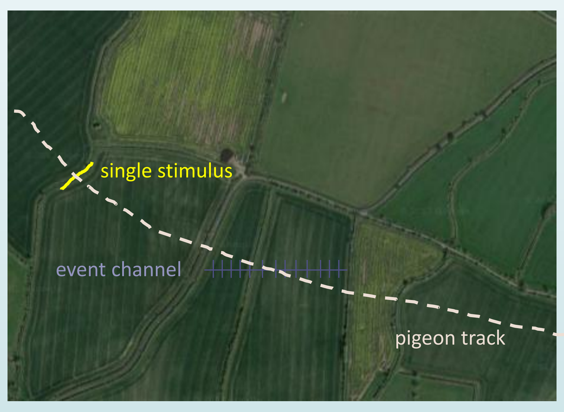
Montello and Freundschuh [5] defined "navigation" as goal-directed movement through the environment by organisms or intelligent machines, with two components:

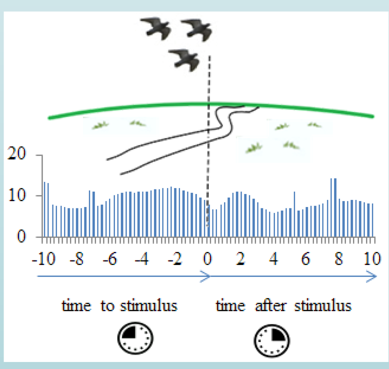
locomotion is body movement coordinated to the local surrounds;
and wayfinding is planning and decision making coordinated to the distal as well as local surrounds.

Navigational behavior is typically based on an preliminary internal plan of the route that is compared with multiple external data.
The following components can be distinguished as determining the choice of route:
I) results of perception of the environment, especially visual information about external objects, surfaces and textures;
II) final and intermediate points or areas of interest;
III) sets of natural landmarks or artificial signposts which make it possible to determine the current location and estimate distances to the next waypoints.

Although at the local level movement can be defined by paths and roads, at middle distances it is more often described by movement corridors.

STIMULI AND TEXTURES





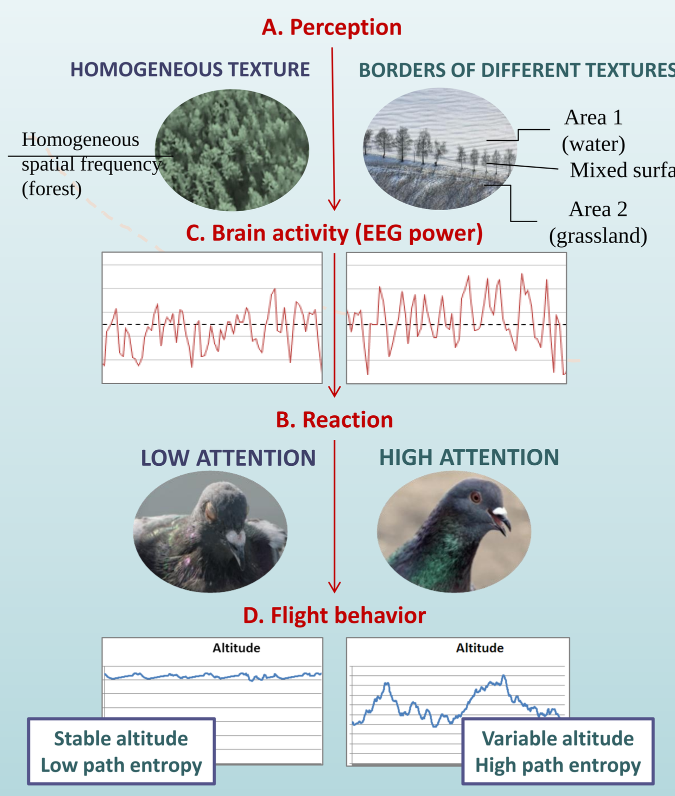
Histogram shows the change in flight parameters before and after the stimulus

Flight parameters can be calculated for each point in time, by GPS pigeon tracks
Terrain features can be calculated as visual characteristics of particular elements or areas in surface.
On the terrain over which the pigeons fly, it is possible to distinguish surfaces with different types of coverage, such as forest and ground area, as well as to select extended objects, such as roads or rivers. All of them can be stimuli in flights.

The texture characteristics and their changes during flight were represented in the form of distinct "frequency event channels". "One event occurred" means that "one proper textural elements was observed".
Textural frequency is the average number of repeating events per unit of track.
It can be calculated as temporal frequency taking into account the speed of the bird, or as spatial frequency by period of events across position in space. Spatial frequencies of textures will for different types of terrain.

It was found that extended homogeneous objects (with equal spatial frequencies of textures) – roads, rivers, or borders of dissimilar territories – can be perceived by flying birds and affect the flight path.

PERCEPTION AND BEHAVIOR



During flight pigeon can change its speed, direction, and altitude based on the varying visual information.

GPS records allow to understand how the pigeons' flock chooses the path when flying over the real terrain over important "stimuli".

Neurologgers are used to measure the brain activity of a pigeon, where multichannel EEG records from the flying and resting pigeons combine with GPS recording.

Observations made with the help of neurologgers, allow to notice that in flight over a homogeneous texture pigeons are less attentive than over a diverse surface with numerous landmarks and stimuli.

A similar effect is observed for car drivers in monotonous journey: they get tired of the monotony and begin to fall asleep.

Abstract

Many studies examine different cases of perception of visual elements as significant objects, borders, textures, as well as filtration of many of the observed elements as just noise. Spatial perception can be considered at the level of behavior and at the level of brain activity.

To understand the complex spatial orientation it is necessary to study not only short-distance movements (indoors locomotion), but also medium-distance movements, such as pigeon flights. Pigeon trajectories during medium-distance flights are determined, in particular, by the visual perception of the terrain.

This work considers hypothesis that visual perception of external environment affects reactions of birds during medium-distance flights, which is reflected in birds' trajectories.

Simultaneous comparison of data on external environment, on pigeon trajectories and on activities in the brains of birds helps to determine which elements of landscape can be a stimulus for bird navigation. Responses to basic spatial elements appear at the level of place cells, head direction cells, grid cells and a boundary cells [1]. Visual perception of more complex scenes is represented in total brain activity [2]. GPS tracks are often used to examine pigeon's ability to consider visual landmarks and to change navigational behavior [3]. Analysis of power changes in high-frequency bands of the pigeon EEG allows to identify the response of bird's brain to significant previously known visual navigational landmarks [4].

In this work, data on the flights of pigeons and remote sensing data for terrain over which these flights took place were used as primary source materials. Data packages were collected from Dryad Digital Repository (https://datadryad.org). Satellite images in the form of OpenLayers (http://openlayers.org) were used to obtain surface information.

This work showed that pigeon's flight paths may reflect specific areas and objects in terrain. Here, we calculated typical time delays in pigeon responses after perception of visual stimuli during flights, and described characteristic reactions to visual stimuli for the intervals +/- 10 seconds. As a result, it was shown that the response characteristics vary depending on the ability of the pigeon to visually detect separate elements of the terrain during flight. So, it is possible to identify the features of birds' response both to single landmarks and to boundaries of different surfaces.

Analysis of visual perception of landscapes, textures and landmarks in flying pigeons helps to better understand how spatial features are represented in the mind during motion.

GIS applications

Geographic information system (GIS) allow the handling of the flight path with reference to the locations and terrain features, including:

Process GPS data with precise spatial reference to terrain.

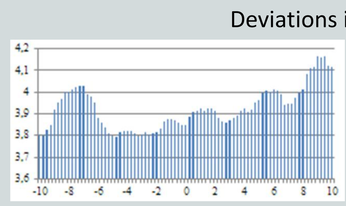
Calculate variation in directions of motion and in neighbour distances by vector data.

Build summary diagrams of the dependence of different flight parameters with reference to time and to coordinates along the flight trajectories.

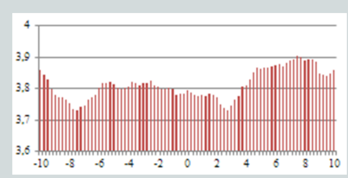
Calculate the terrain features obtained from remote sensing data-such as the boundaries between different types of terrain, or the density of special points on the surface in the form of a heat map.

Deviations near stimulus

Deviations in Distances

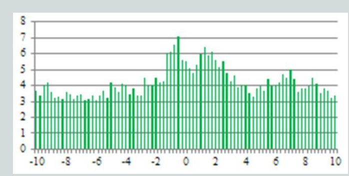


Histogram of standard distance deviations, in relation to the moments when the flock crossed the isolines.
The x axis shows the timescale in relation to events 'isoline', s. The y axis shows standard deviation of the distances between pairs of pigeons, m.

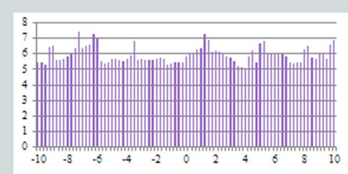


Histogram of standard distance deviations, in relation to the moments of break in flock direction.
The x axis shows the timescale in relation to events 'breakpoint', s. The y axis shows standard deviation of the distances between pair of pigeons, m.

Deviations in Directions



Histogram of standard direction deviations, in relation to the moment at which the flock flew apart.
The x axis shows the timescale in relation to events 'flock flying apart', s. The y axis shows standard deviation of the direction of pigeons, deg.



Histogram of standard direction deviations, in relation to the moments when the flock crossed the isolines.
The x axis shows the timescale in relation to events 'isoline', s. The y axis shows standard deviation of the direction of pigeons, deg.

References

1. Hartley T, Lever C, Burgess N, O'Keefe J: Space in the brain: how the hippocampal formation supports spatial cognition. Philos Trans R Soc Lond B Biol Sci 2013, 369:20120510.
2. Leeds DD, Pyles JA, Tarr MJ: Exploration of complex visual feature spaces for object perception. Front Comput Neurosci 2014, 8:106.
3. Biro D, Meade J, Guilford T: Familiar route loyalty implies visual pilotage in the homing pigeon.
Proc Natl Acad Sci USA 2004, 101:17440–17443.
4. Vyssotski AL, Dell'Omo G, Dell'Ariccia G, et al: EEG Responses to Visual Landmarks in Flying Pigeons. Curr Biol 2009, 19:1159–1166.
5. Montello, Daniel, and Scott Freundschuh: Cognition of Geographic Information. A Research Agenda for Geographic Information Science 2004, 61–91.

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