EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Mathematisch-
Naturwissenschaftliche
Fakultät

Fachbereich Biologie · Institut für Neurobiologie
Lehrstuhl für Kognitive Neurowissenschaft

Compound Eyes:
From Biology to Technology

Workshop, Tübingen, Germany
March 26 – 28, 2013

CURVACE
CURVED ARTIFICIAL COMPOUND EYES

Program

Tuesday, March 26

    14:00   **Mallot, H.A.** (Tübingen): *Welcome*

    14:10   **Floreano**, **D.** (Lausanne): *CURVACE Overview*

Session 1: Compound Optics and Imaging

14:30	**Scharf**, **T.** (Neuchâtel): *Concepts for miniaturized vision systems based on micro-optics*
15:15	*Coffee*
15:45	**Brückner, A., Leitel, R., Dannberg, P., Bräuer, A.** (Jena): *Artificial compound eye vision*
16:15	**Leitel, R., Brückner, A., Buß., W. Dannberg P., Bräuer A.** (Jena) *Microoptics fabrication and integration*
16:45	**Belay, G.Y.** (Brussels): *Multi-channel, multi-resolution smart imaging system*
17:00	*Posters*
19:30	"À la carte" Conference Dinner at the Restaurant "Museum" (for address and location see p. 28/29)

Wednesday, March 27

Session 2: Motion Detection and Circuits

9:00	**Dickinson, M.** (Seattle) *Gain modulation in motion-sensitive neurons of Drosophila*
9:45	**Viollet, S.** (Marseille): *Active vision and hyperacuity*
10:15	*Coffee*
10:45	**Expert, F.** (Aix-Marseille): *BeeRotor arial robot: Altitude and speed control based on optical flow*
11:15	**Franceschini, N.** (Marseille): *Elementary movement detectors in insects and robots: Old and new analyses and developments*
11:30	*Poster Clips* (1-2 slides / 5 min. per poster)
12:30	*Lunch break*

Session 3: Optic Flow

14:00	**Srinivasan, M.V.** (Brisbane) *Of bees, birds, and flying machines*
14:45	**Yuan, C.** (Köln), **Mallot H.A.** (Tübingen): *Visual motion analysis for robotic perception and navigation*
15:15	**Stürzl, W.** (Oberpfaffenhofen): *What does a bee see? Modelling the visual input of flying insects*
15:45	*Coffee*
16:15	*Tour of the University Museum*
17:30	*Posters*

Thursday, March 28

Session 4: Applications

| 9:00 | **Zufferey, J.-C.** (Lausanne) *On the use of optic-flow in commercial minidrones* |

9:30   **Pericet-Camara, R.** (Lausanne) *CURVed Artificial Compound Eyes with fixed panoramic field of view: Characterization and applications*

10:00   Coffee

10:30   **Dobrzynski, M.** (Lausanne) *Towards wearable vision: promises, challenges and recent development*

11:00   **Briod, A.** (Lausanne): *Ego-motion estimation from optic-flow and inertial sensors fusion*

11:20   **Philippides, A.** (Brighton): *Insect-inspired route navigation*

11:40   **Wittlinger, M.** (Ulm) *Visual odometry in the desert ant Cataglyphis*

12:30 Lunch, End of Workshop

Poster Presentations

1. Oswald **Berthold** (Humboldt Universität, Berlin) *Self–supervised learning of visuo-inertial sensory-motor relationships*

2. Wolfgang **Buß** (FHG Jena) *Special topics of assembly and integration*

3. Fabien **Colonnier** (Aix-Marseille University) *Implementation of the 'time of travel' scheme on an artificial compound eye*

4. Hansjürgen **Dahmen** (Universität Tübingen) *Ego-motion detection with a panoramic sensor built on optical mouse chips*

5. David **Fleer,** Michael **Horst** (Universität Bielefeld) *Biologically inspired visual navigation system for an autonomous mobile robot*

6. Raphael **Juston** (Aix-Marseille University) *Bio-inspired hyperacute position sensing device for the control of mirco-aerial robots*

7. Jens Peter **Lindemann** (Universität Bielefeld) *Contrast normalizing extension of correlation motion detection*

8. Thomas **Linkugel** (AirRobot AG, Arnsberg) *Model-based 3D real simulation of micro-UAS*

9. Hanspeter A. **Mallot**, Till **Becker**, Gregor **Hardieß**. (Universität Tübingen) *Ego-motion from optic flow: Evidence for a matched filter mechanism*

10. Guillaume **Sabiron** (Aix-Marseille University) *Bio-inspired low-speed optic flow sensor tested flying over fields*

11. Annette **Werner** (Universität Tübingen) *3D-object recognition in bees*

ABSTRACTS

CONCEPTS FOR MINIATURIZED VISION SYSTEMS BASED ON MICRO-OPTICS

Toralf Scharf

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Miniaturized vision systems are all around us and used today in almost every nomadic device like smart-phones and tablet-computers. In mass products, exclusively single eye cameras are used. In research, concepts exist to parallelize the optics with consequences on the performance indicators like resolution and sensitivity. In this paper we discuss different aspects of miniaturized vision systems including the aspect of parallelization. Our main concern is the thickness of the vision system and its complexity. When imaging systems get miniaturized the level of components that can be implemented will be limited and correction of the aberrations becomes more and more difficult. Parallelization of the optical path with arrays and recombination of multiple images can help to design thin optical systems. We will introduce the main performance parameters to critical discuss the performance of optical systems presented hereafter. On a few examples we will show how one can improve properties of the optics by design and when it is just not needed because corrections can be done by post-processing of images. In particular we will discuss a system based on an array of lenses with landscape design arranged to correct the field curvature. In such a very simple system with limited field of view the recombination of several images improves the resolution for larger fields. The concepts will be revisited concerning parallelization in space and serial shooting in time to provide an outlook.

ARTIFICIAL COMPOUND EYE VISION

Andreas Brückner, Robert Leitel, Peter Dannberg, Andreas Bräuer
FRAUNHOFER INSTITUT FÜR ANGEWANDTE OPTIK UND FEINMECHANIK, JENA

The application of miniaturized cameras for portable electronic communication devices and sensors demands not only the shrinking of opto-electronic and electronic but also optical components. The basic requirements to achieve that goal are (1) a short focal length and (2) a low-complex optical system. However, the ongoing miniaturization of the image sensor size causes a demand for a higher image resolution and light sensitivity. Wafer-level fabrication techniques for camera lenses turned out to be promising candidates for the high-volume production in the low cost regime. The existing concepts for wafer-level optics apply complex aspherical lens profiles and vertical integration techniques which put limits to the process yield so far.

We propose an alternative approach using a multi aperture imaging system which captures different portions of the object field of view within separated optical channels. These different partial images are joined together digitally to form an image of the full field of view. The segmentation of the field of view partly decouples focal length from the size of the field of view. Therefore, a short total track length is realized for each optical channel. On the other hand, simple optical components such as reflow microlenses with small sags can be applied due to the short focal length and small size of field per channel. These may be fabricated with well-established microoptical fabrication techniques such as UV-lithography, reflow and UV-molding which show sub-µm precision and are cost-efficient due to wafer-level manufacturing. Alignment and assembly may at least partially be done on wafer-level which further reduces production costs.

Aspects of camera scaling limits and the realization of such artificial compound eye imaging systems are discussed at the examples of an apposition compound eye and the electronic cluster eye, the latest development towards higher resolution.

MICRO-OPTICS FABRICATION AND INTEGRATION

Robert Leitel, Andreas Brückner, Wolfgang Buß, Peter Dannberg, Andreas Bräuer

Fraunhofer Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, 07745 Jena

With increasing mobility and the request of manifold data acquisition and processing, compact devices are our constant companions. The miniaturisation of optical systems for imaging, sensing, and even projection purposes is of great interest not only for consumer, automotive, and healthcare applications but also for autonomous devices like robots and drones. This talk gives an introduction into the field of micro-optics manufacturing and shows how current fabrication can benefit from established semiconductor production. As an advantage, micro-optical systems can be generated by highly automated processes in parallel by wafer level technologies while allowing for a high precision. The process chain is exemplary demonstrated for the apposition compound-eye optics that has been designed for the curved optical navigation sensor (CURVACE). It includes the photo-lithographic patterning of thin absorption layers as diaphragm arrays, the generation of microlens masters by reflow of photoresist, as well as the fast replication of microlenses by UV curing. Finally, a short overview over the assembling and integration techniques links to a poster presentation which deals explicitly with the CURVACE system.

OPTICAL DESIGN OF A MULTI-CHANNEL, MULTI-RESOLUTION SMART IMAGING SYSTEM

Gebirie Y. Belay, Heidi Ottevaere, Youri Meuret, Hugo Thienpont

Vrije Universiteit Brussel, Department of Applied Physics and Photonics, Brussels Photonics Team (B-PHOT), Brussels

Miniaturized multi-channel smart imaging systems are interesting for several potential applications including surveillance, medical imaging and machine vision. In our research, we investigated the design of a multi-channel imaging system where the different optical channels have a different angular resolution and field of view. Such an imaging system is able to resolve fine details in a small region of interest through the channel that has the highest angular resolution (0.0096°) while controlling the surrounding region through the channel that has the widest field of view (2x40°). An interesting feature of such a multi-channel, multi-resolution imaging system is that different image processing algorithms can be applied at different segments of the image sensor. We have designed a three channel imaging system where each optical channel consists of four aspheric lens surfaces. These three imaging channels share a single image sensor with 1440x960 resolution and 10 µm pixel size. All imaging channels have diffraction limited performance ensuring good overall image quality. The channel with the largest resolution has a focal length of 29 mm and a full field of view of 7 degrees, whereas the widest field of view channel has a focal length of 2.65 mm and a full field of view of 80 degrees. In a next step the two lens arrays made out of PMMA were fabricated by ultra precision diamond turning. In the near future, we will characterize the optical surfaces of the lenses and verify the design experimentally in a proof-of-concept demonstrator.

GAIN MODULATION IN MOTION-SENSITIVE NEURONS OF DROSOPHILA

Michael Dickinson

Dept. of Biology, University of Washington, Seatlle

Large field motion sensitive-neurons in the lobula plate of flies have served as cellular models for visual processing for over 40 years. Although these neurons are thought to be largely specialized for the detection of ego motion during flight, most prior physiological studies have been conducted in quiescent flies. Recently, my laboratory developed a technique for conducting whole cell patch recordings in tethered, flying flies. The results indicate that the gain and temporal frequency tuning of both horizontal and vertical system neurons is enhanced during flight. The genetic tools available in Drosophila have made it possible to trace the source of this modulation to a population of octopamine-containing neurons that are activated during flight. The ability to record from lobula plate cells during flight has also made it possible to more accurately compare the responses of motion-sensitive neurons with the change in wing motion that they are thought to regulate. The results suggest that the circuitry linking lobula plate neurons with flight motor circuits may be more complicated that previously supposed. In summary, the ability to record from visual interneurons during active behavior is leading to new insights in our understanding of visual-motor processing in flies.

ACTIVE VISION AND HYPERACUITY

Stéphane Viollet

Biorobotics, ISM, Marseille

We present the different steps that led us to implement an active version of Curvace, in which insect-based retinal micro-scanning movements are used to detect and locate contrasting objects such as edges or bars. The active CURVACE is based on the cylindrical version of CURVACE submitted to active periodic scanning movements. The aim of this active vision process is to endow CURVACE with the ability to locate contrasting features with much greater accuracy than that dictated by the interommatidial angle. This ability is also called hyperacuity.

BEEROTOR AERIAL ROBOT: ALTITUDE AND SPEED CONTROL BASED ON OPTICAL FLOW

Fabien Expert

Biorobotics, ISM / CNRS, Aix-Marseille University

The new robot called BeeRotor we have developed is a tandem rotorcraft that mimicks optic flow-based behaviors previously observed in flies and bees. This tethered miniature robot (80g), which is autonomous in terms of its computational power requirements, is equipped with a 13.5-g quasi-panoramic
visual system consisting of 4 individual visual motion sensors. These new and low-power motion sensors respond accurately to the optic flow thanks to the bio-inspired "time of travel" scheme coupled with a new sensory fusion method.

Based on recent findings on insects' sensing abilities and control strategies, the BeeRotor robot was designed to use optic flow to perform complex tasks such as ground and ceiling following while also automatically driving its forward speed on the basis of the ventral or dorsal optic flow. In addition, the BeeRotor robot can perform tricky manoeuvers such as automatic ceiling docking by simply regulating its dorsal or ventral optic flow in high-roofed tunnel depicting natural scenes.

Although it was built as a proof of concept, the BeeRotor robot is one step further towards achieving a fully-autonomous micro-helicopter which is capable of navigating mainly on the basis of the optic flow.

ELEMENTARY MOVEMENT DETECTORS IN INSECTS AND ROBOTS :
OLD AND NEW ANALYSES AND DEVELOPMENTS

Nicolas FRANCESCHINI

CNRS / ISM Aix-Marseille University

Analysis of a neural process can be carried out at the computational level and at the circuit level. Both analyses complement each other and may contribute to a complete understanding. A prominent example of this 2-level-understanding is provided by the elementary motion detector (EMD) in the insect compound eye, a subject that has led to a plethora of studies since the pioneering work by Hassenstein and Reichardt (1956).

Thirty years ago, we set out to come closer to the operation of the EMD at the computational level. We recorded from a directionally selective motion sensitive neuron in the housefly Lobula Plate while presenting apparent motion stimuli consisting of a sequence of excitations to two neighboring photoreceptor cells in a single ommatidium[1]. A major result of our analyses was that the fly EMD is split into two parallel and independent EMDs, an ON-EMD responding only to sequences of brightness increments, and an OFF-EMD responding only to sequences of brightness decrements[2]. The former would sense the motion of light edges, the latter would sense the motion of dark edges. The results of recent experiments using much coarser optical stimulation but genetic block of either one of the two large monopolar cells, L1 and L2 in the lamina suggest that the ON-EMD involves L1 neurons and the OFF-EMD involves L2 neurons[3]. This exquisite detail at the circuit level nicely complements our findings on the splitting of an EMD into ON and OFF pathways in fly motion vision.

Analysis at the computational level not only guides analysis at the circuit level but results in a functional principle that can be transcribed into any non neural technology. In the mid-80's we built electronic fly-inspired EMDs, the output of which grew monotonically with the angular velocity of a moving edge, regardless of contrast within a range of 0.15 to 0.75.

The analog circuit incorporated the newly discovered splitting of the EMD into an ON-EMD and an OFF-EMD. A curved compound eye equipped with a circular array of 114 such EMDs sensing the translational optic flow allowed a terrestrial robot to navigate among obstacles at a relatively high speed (50cm/s) while heading for its target[4]. Meanwhile, we went digital and the fly-inspired EMDs became smaller and lighter[5].Their principle gives reliable results under natural, indoor or outdoor environments[6]. The EMDs equip various kinds of aerial robots[5,7].

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2. Franceschini N, Riehle A, Le Nestour A (1989) Directionally selective motion detection by insect neurons. In: *Facets of vision*, Stavenga DG & Hardie RC, Springer, Berlin, pp. 360-390
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4. Franceschini N, Pichon JM, Blanes C. (1992) From insect vision to robot vision. *Phil. Trans. Roy. Soc.* B337, 283-294
5. Ruffier F, Viollet S, Amic S, Franceschini N (2003) Bio-inspired optical flow circuits for the visual guidance of micro-air vehicles. *Proc. IEEE Int. Symp. Circuits and Systems* (ISCAS-03), Bangkok, pp. 846-849
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7. Roubieu FL, Serres J, Franceschini N, Ruffier F, Viollet S (2012) A fully autonomous hovercraft inspired by bees : wall-following and speed control in straight and tapered corridors. *Proc. IEEE Int. Conf. Bio-inspired Robotics (ROBIO 2012)* Guangzhou, China

OF BEES, BIRDS AND FLYING MACHINES

Mandyam V. Srinivasan

Queensland Brain Institute
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University of Queensland

Flying insects and birds are remarkably adept at seeing and perceiving the world and navigating effectively in it, despite possessing a brain that weighs less than a milligram and carries fewer than 0.01% as many neurons as ours does. This presentation will describe our recent progress in understanding how honeybees use their vision to control regulate their flight speed, negotiate narrow passages, avoid mid-air collisions with other flying insects, and perform smooth landings, using computational principles that are often elegant and unprecedented. It will also outline our recent progress in understanding visually guided flight in birds, and conclude with an update of our advances in the design, construction and testing of biologically inspired vision systems for autonomous aerial vehicles.

VISUAL MOTION ANALYSIS FOR ROBOTIC PERCEPTION AND NAVIGATION

Chunrong Yuan
Cologne University of Applied Sciences

Hanspeter A. Mallot
University of Tübingen

The ability to detect movement is an important aspect of visual perception. According to Gibson (1974), the perception of movement is vital to the whole system of perception. Biological systems take active advantage of this ability and move their eyes and bodies constantly to infer spatial and temporal relationships of the objects viewed.

When an observer moves, the relative motion between the observer and the environment gives rise to the perception of optical flow. Through sensing the temporal variations of some spatial persistent elements in the scene, the relative location and movements of both the observer and objects in the surrounding environment can be perceived. This is the mechanism through which biological systems are capable of interacting with objects and navigating in the external world.

There is no doubt that that optic-flow based motion analysis can provide rich spatial and temporal information such as position, orientation, distance and motion characteristics of both the observer and objects, which can lead to meaningful and purposive action. In this talk, we will discuss vision-based techniques for building intelligent systems capable of sensing, reasoning and interacting with the real world. Particularly, we focus on theoretical investigation and algorithmic development of visual motion analysis and estimation. We will show possibilities as well as challenges in achieving autonomous perception and decision making during the navigation of mobile robots.

WHAT DOES A BEE SEE?
MODELLING THE VISUAL INPUT OF FLYING INSECTS

Wolfgang Stürzl
(Nicole Carey, Heiko Hirschmüller, Elmar Mair, Jochen Zeil)

German Aerospace Center (DLR)
Institute of Robotics and Mechatronics

Flying insects are biological examples of tiny autonomous aerial vehicles that navigate in complex environments despite limited computational resources. For the development and test of models describing their capabilities it is advantageous to know the visual input the insects experience in their natural habitats. I will report on our recent attempts to reconstruct what bees and wasps see during flight. We used a laser range finder with a rotating camera attached as well as a purely camera-based method to capture the 3D structure and the appearance of outdoor environments. While the laser range finder directly estimates distances, we used bundle adjustment to estimate the camera positions where images were recorded, followed by pair-wise dense stereo reconstruction. Both approaches produce coloured point clouds for rendering image sequences with the spatial resolution of flying insects.

Besides brightness and colour contrasts, the polarization of light is another important source of information for flying insects. For example, it is known that insects use skylight polarisation as a compass cue. We recently built a polarisation sensor that, due to its hemispherical field of view, allows to measure the full polarisation pattern of the sky. Because of its low weight and compact size it is also well-suited as a biomimetic sensor on-board a UAV. We also developed an efficient method for estimating both azimuth and elevation angle of the sun, even in the presence of clouds.

ON THE USE OF OPTIC-FLOW IN COMMERCIAL MINIDRONES

Jean-Christophe Zufferey

senseFly Ltd – a Parrot company

The Paris-based Parrot group, which now includes the Swiss EPFL-spinoff senseFly, has pioneered the use of optic-flow in commercial mini-drones.

The AR.Drone is 400-gram quadrotor that can be flown both indoor and outdoor for entertainment and filming. As the AR.Drone has no beacon-based positioning system, Parrot engineers had to develop a means of controlling its velocity in order to keep the drone from drifting away during flight. To do so, they decided to rely on optic flow extracted in real-time from a down-looking VGA camera. Together with an ultrasonic distance sensor, also pointed downwards, the drone is able to estimate, its 3D velocity with reasonable accuracy. This estimate is subsequently used to keep the velocity of the drone close to zero when the operator releases the controls.

A few years later, senseFly developers were confronted with the problem of designing a 600-gram fixed-wing platform named eBee for professional mapping, which could land in small clearings. Since GPS and barometric sensors cannot provide an accurate height-above ground estimate, it has been decided to equip the eBee with a down-looking optical mouse sensor to achieve height estimation before touchdown. In this case the weight constraints were so tight, that any other distance sensor such as LIDARS, ultrasonic, or radars were not an option.

In this talk, I will present these two products, describe the development choices, the algorithms that are employed as well as the calibration procedures. I will also compare the two approaches, namely using a standard miniature camera with additional image processing versus relying on self-contained optic-flow sensors.

CURVed ARTIFICIAL COMPOUND EYES WITH FIXED PANORAMIC FIELD OF VIEW: CHARACTERIZATION AND APPLICATIONS

Ramon Pericet-Camara

EPFL Lausanne

Compound eyes present significant advantages over single-aperture vertebrate eyes, such as a wide field of view free of distortion and spherical aberration in a very small size, very high ability to detect motion and versatile morphologies to adapt to different head shapes and functionalities, with the cost of a lower spatial resolution. Artificial vision systems inspired by compound eyes present a radically different alternative to conventional cameras, providing more efficient visual abilities for embedded applications that require motion analysis in low-power and small packages. The new CURVed Artificial Compound Eyes (CurvACE) have taken an unprecedented step beyond available compound cameras by integrating a number of key characteristics of insect compound eyes, such as panoramic undistorted field of view, high temporal resolution, local adaptation to luminosity as well as embedded data processing in a variety of morphologies and compact package.

In this talk, I will present the first prototypes of CurvACE bearing a fixed panoramic field of view. The results of the characterization experiments to capture their distinctive properties will be shown and the first steps towards their validation as smart vision sensors for mobile robots will be discussed.

TOWARDS WEARABLE VISION: PROMISES, CHALLENGES AND RECENT DEVELOPMENTS

Michal Karol Dobrzynski

EPFL Lausanne

Mechanically flexible, vision sensors promise interesting features with respect to conventional, single-lens rigid cameras, such as adjustable field of view, multi-directional vision, thin packaging, or the possibility of integration onto non-planar or even dynamically deformable substrates. Thin flexible imagers can be used in numerous applications, to mention obstacle avoidance and navigation systems for soft and rigid mobile robots or wearable collision alert systems for visually impaired people.

In this presentation I will show the flexible imager developed within the CURVACE project - the Vision Tape. I will discuss the processing of an image formatted on the flexible sensor along with sensor's characterization date. To present capabilities of the imager I will discuss the wearable application where Vision Tape, in combination with a vibrotactile feedback system, is integrated with cloths and used to alert blind or visually impaired people against surrounding obstacles. Challenges related to the wearability of the system, its unnoticeable textile integration, limited payload and battery operation will be addressed.

EGO-MOTION ESTIMATION FROM OPTIC-FLOW AND INERTIAL SENSORS FUSION

Adrian Briod

EPFL/STI-IMT, LIS, Lausanne

A common challenge in optic-flow based ego-motion estimation is the scale ambiguity. In this talk, I will present a novel method to fuse optic-flow information with inertial sensors that allows to obtain an absolute value of the 3D speed. The solution is adapted to environments of any geometries, and is particularly accurate when changes of direction are present in the trajectory. Results of experiments on a flying robot embarking several mouse sensors, an IMU and a micro-controller will be presented, and a closed-loop autonomous control of a miniature quadrotor will be demonstrated.

INSECT-INSPIRED ROUTE NAVIGATION

Andrew Philippides, Bart Baddeley and Paul Graham

Centre for Computational Neuroscience and Robotics, University of Sussex, Brighton

Despite low resolution vision and relatively simple brains, ants can learn to navigate long routes robustly after only a single trial of learning, making them attractive to engineers seeking to emulate their behaviour. Here we present a model of visually guided navigation in ants that captures the known properties of ant behaviour whilst retaining biological plausibility and thus mechanistic simplicity. For an ant, the coupling of movement and viewing direction means that a familiar view specifies a familiar direction of movement. Since the views experienced along a habitual route will be more familiar, route navigation can be re-cast as a search for familiar views. This search can be performed with a simple scanning routine, a behaviour ants have been observed to perform.

We test our model in a realistic simulation of a desert ant's environment using a resolution typical of the ant's eye (~4 degree acuity). Our results indicate that, not only is the approach successful, but also that the resultant behaviour shows characteristics of the paths of ants. As such, we believe the model provides a general demonstration that visually guided routes can be produced with parsimonious mechanisms that do not specify when or what to learn, nor separate routes into sequences of waypoints. Further, computational parsimony and low resolution sensors makes our approach viable for low power and weight autonomous robotic navigation.

VISUAL ODOMETRY IN THE DESERT ANT CATAGLYPHIS

Matthias Wittlinger
Institute of Neurobiology, University of Ulm

Desert ants *Cataglyphis* employ path integration to return to their nest, a navigation feat that requires continuous updating of a home vector. The angular component of this vector is provided by a celestial compass (Wehner 2003 J Comp Physiol A 189: 579). Distance estimation is performed by a stride integrator (Wittlinger et al. 2006 Science 312: 1965). However ventral optic flow, if present, does also provide distance information to the odometer. It has been challenging to separate both inputs to the odometer experimentally, stride integration and optic flow integration, in a behavioral paradigm.

Here I present an experiment where the role of the ventral optic flow integrator on odometry can be tested without interference with the stride integrator. Experienced foragers of *Cataglyphis bicolor* regularly transport indoor workers between two nest locations of a colony. When separated during transport, the transported ant returns to the nest of origin. Although it has previously been shown that the transportees gain directional information during their transport (Duelli 1973 Rev Suisse Zool 83:413), the odometer mechanism was still unclear. In a formicine fashion, the head posture, and notably head angle, of the transportee correspond to the head posture of the transporter, only the looking directions are opposite. Hence the ventral optic flow field during transport appears to be the same for both animals, even though pointing into opposite directions.

Transportee/transporter pairs that travelled in a channel set-up were caught and separated after approximately 10m of transport and the transported ants were tested in a parallel test channel. The tested ants searched for the nest entrance after the corresponding distances that they were carried.

In summary, the ants' distance estimator can work without any active locomotion and hence without stride integration exclusively relying on optic flow integration.

Registered Participants

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Nearby Restaurants:

A: Restaurant Museum   Wilhelmstraße 3 · 72074 Tübingen
     Tel. 07071-22828 ·   www.restaurant-museum.de

B: Weinstube Forelle   Kronenstr. 8 ·   72070 Tübingen
     Tel. 07071-24094   ·   www.weinstubeforelle.de

C: Al Dente-Cafe Spaghetteria Bursagasse 72070 Tübingen
     Tel. 07071-25157 ·   www.aldente-pino.de

D: Restaurant Mauganeschtle   Hotel am Schloss, Burgsteige 18,
72070 Tübingen   Tel. 07071-92940   www.hotelamschloss.de

E: Restaurant Hotel Hospiz   Neckarhalde 2, 72070 Tübingen
     Tel. 07071-9240   www.hotel-hospiz.de

F: Gasthausbrauerei Neckarmüller Gartenstr. 4, 72074 Tübingen
     Tel. 07071-27848   www.neckarmueller.de

G: Restaurant Hotel Krone   Uhlandstr. 1, 72072 Tübingen
     Tel. 07071-13310   www.krone-tuebingen.de

H: Alte Weinstube Göhner   Schmiedtorstr. 5, 72070 Tübingen
     Tel. 07071-567078

INNENSTADT

Maßstab 1 : 5000

0   50   100   150m