SEVENTH FRAMEWORK PROGRAMME PRIORITY: ICT FET Open

CURVED ARTIFICIAL COMPOUND EYES

Participants List:

Role*	Name	Short name
CO	**École Polytechnique Fédérale de Lausanne** Laboratory of Intelligent Systems, School of Engineering	EPFL
B 3rdP	**Université d' Aix-Marseille** **Centre National de la Recherche Scientifique** Laboratory of Biorobotics, Institute of Movement Sciences (ISM) & Centre de Physique des Particules de Marseille (CPPM)	AMU CNRS
B	**Fraunhofer Institute of Applied Optics and Precision** Department of Micro-Optical Systems	FRAUNHOFER
B	**Eberhard-Karls-University Tübingen** Laboratory of Cognitive Neuroscience, Department of Neurobiology, Faculty of Biology	UTUB

*CO = Coordinator, B = Other Beneficiary, 3rdP = Third Party

Project Coordination:

Project Coordinator:
Prof. Dario Floreano, Tel. +41 (0)21 693 5230, dario.floreano@epfl.ch
Project Manager:
Dr. Claudio Bruschini, Tel. +41 (0)21 693 3911, claudio.bruschini@epfl.ch

Project Website: http://www.curvace.org/

Project number FP7-2009-ICT-23794

Project context and objectives

CURVACE (CURVed Artificial Compound Eyes) is a collaborative research project supported by the Future and Emerging Technologies (FET) programme within the Seventh Framework Programme for Research of the European Commission. Herein, we design, develop, and assess artificial compound eyes, which are composed of microlens arrays arranged on curved and flexible surfaces where each microlens is integrated with one or more aVLSI adaptive photoreceptors. The output of these artificial compound eyes is processed by adaptive vision filters implemented in programmable devices, such as microcontrollers or FPGAs, for fast extraction of motion-related information. Compared to conventional cameras, artificial compound eyes offer a much larger field of view in a smaller size and weight with negligible distortion and higher temporal resolution. Furthermore, some versions of the artificial compound eyes offer space within the concavity for embedding processing units, battery, or additional sensors that are useful for motion-related computation.

In order to reach the desired goals, we are taking leverage from a novel combination of micro-optics fabrication, neuromorphic engineering, microelectronics on bendable surfaces and insect-inspired active vision and motion detection. We adopted a progressive approach by developing a set of flexible artificial ommatidia units that will serve as mechanical and functional basic elements. We built on these units the four versions of artificial compound eyes, i.e., cylindrical, active, spherical and tape, which allowed us to incrementally tackle the technical and scientific challenges and at the same time develop different prototypes that suit the needs of various applications.

4th Year activities and main results

The fabrication of all CURVACE versions was completed in this period with the final assembly and activation of the first spherical CURVACE prototype, bearing an omnidirectional field of view. Additionally, a second version of the tape CURVACE has been assembled. This new prototype presents various artificial ommatidia units connected in chain configuration, which increases the photosensitive length of the device and makes its attachment onto larger objects possible.

In this period, the implementation of various optic flow (OF) extraction methods on-board the controlling units of the CURVACE prototypes was achieved, which makes CURVACE not only a visual sensor, but also a smart self-contained device with embedded data processing functionalities. For the cylindrical CURVACE prototype, a modified version of the Lucas-Kanade algorithms was developed, which exploits the high temporal resolution of CURVACE. For the tape and cylindrical CURVACE, several OF extraction procedures inspired by the I^2A algorithm were produced. OF on-board implementation was achieved not only in the microcontrollers of the cylindrical, tape and spherical versions, but also in the FPGA units of the fully cylindrical CURVACE, which yield higher computational power, and thus, much faster motion extraction capabilities. In addition, the inertial sensing units embedded in the CURVACE prototypes to assist in data processing and navigation were calibrated and activated.

A number of additional characterization experiments have been realized in this period. Namely, the angular sensitivity of the tape and spherical CURVACE ommatidia, which consist of three photodiodes under a single microlens, has been measured. After this, the motion detection capabilities of the tape and spherical CURVACE versions have been tested, validating the developed methods for extraction of OF vectors from the visual signals of the three photodiode ommatidia of these versions. Additionally, the extracted OF by the microcontrollers of the three CURVACE versions has been characterized and validated.

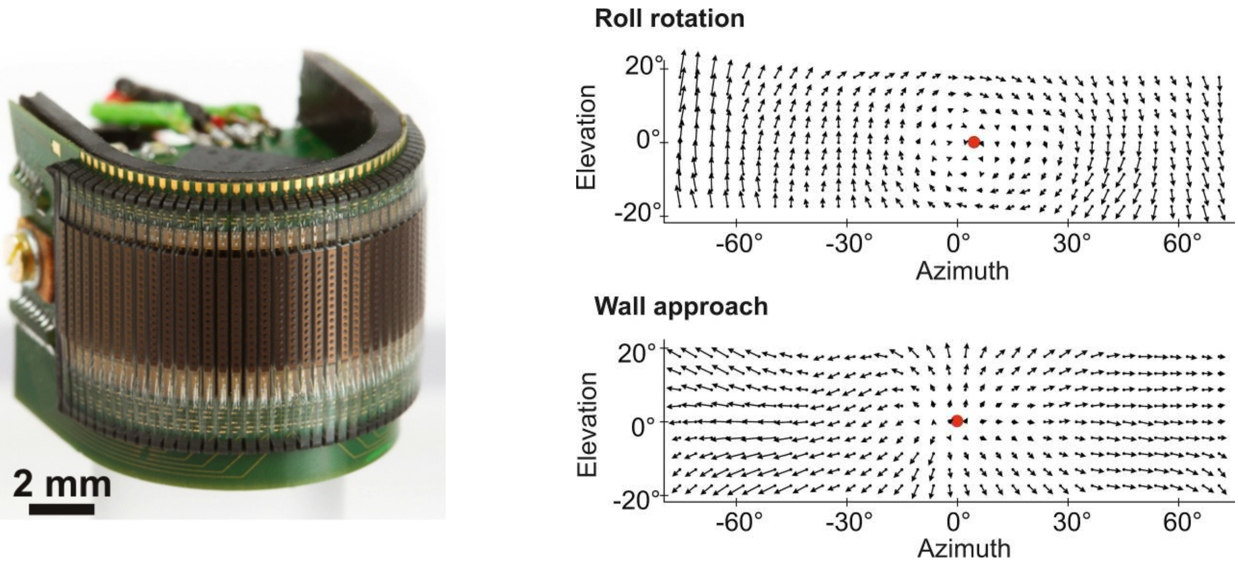

Figure 1. Left, image of a semi-cylindrical CURVACE prototype. Right, extracted optic flow maps across the field of view of the CURVACE prototype during roll rotation (top) and translation towards a wall (bottom). The red circles mark the center of rotation and the focus of expansion, respectively.

We characterized the performance of active CURVACE prototype indoors and outdoors under various lighting conditions, demonstrating that is highly valuable for position sensing endowed with hyperacuity. We have also shown that active CURVACE runs as an optical incremental coder since it is able to measure its relative orientation with respect to the visual environment with very high accuracy. For this characterization, the visual signals of a full line of CURVACE were extracted in order to measure its orientation.

In this 4th year of activities, the validation tasks of the CURVACE prototypes have been continued. We have demonstrated the performance of the CURVACE sensor placed inside the feedback loop of the control of an autonomous 80-gram flying robot. In particular, we have shown its ability to extract accurate optic flow in a stationary or moving environment. This measurement has been used to control the altitude and the forward speed of an aircraft in an unknown unsteady environment. All the processing during these experiments was carried out on-board this 80-gram robot, showing that the CURVACE sensor can assist in flying strategies based on optic flow despite the limited computational power available on Micro Aerial Vehicles. The CURVACE performance assisting collision-free navigation has been demonstrated at illuminance values as low as 3 lux. Similar navigation strategies assisted by the cylindrical CURVACE have been implemented in wheeled robots, which are able to efficiently perform collision-free navigation tasks like corridor following or collision avoidance.

The active CURVACE prototype was mounted on-board an aerial robotic demonstrator called HyperRob in order to assess the ability of the vibrating eye to stabilize a robotic platform in hover. In this robotic application, active CURVACE was able to yield both an estimation of the robot's linear speed and position. The linear speed control was tested by moving (translating) the pattern over which the HyperRob was hovering. The robot was able to follow faithfully the movement imposed to the pattern by hand. The closed-loop position control of the robot was tested by applying perturbations onto the rotating arm supporting the twin-engine robot HyperRob. The latter was able to compensate for these perturbation and remained still in space.

Finally, a novel wearable collision-alert system assisted by tape CURVACE was developed and validated. Named the *VisionHat*, it is an Electronic Travel Aid (ETA) system that aims at supporting visually impaired users in indoor and outdoor navigation. The system intends to increase their awareness of objects present in close proximity that may pose a danger of collision. These collision threats are estimated based on perceived relative motion. The VisionHat bears a tape CURVACE prototype with a scalable modular structure that allows for motion detection in a wide field of view. Subsequently, the system transfers extracted motion information to the user through a head-attached vibrotactile system. All these elements are integrated into a hat, which provides them with wearability and comfort during long-time use. In this period, we have developed not only the design of this collision-alert system, but we have also carried out validation experiments to prove its operability indoors and outdoors. In particular, the system has been tested in a natural outdoor scene and in an office-like room. The occurring relative motion with respect to surrounding objects is successfully detected and an appropriate feedback signal is triggered.

Final results and Impact

During the fourth year of project, the consortium has succeeded in fabricating the four versions of the CURVACE prototypes. Through novel fabrication methods and assembly approaches, we have been able to engineer a unique family of sensors that mimic the physical characteristics of animal compound eyes in an unprecedented way. After characterizing the CURVACE prototypes, the consortium has focused on the validation of the CURVACE prototypes and assessed their added value in applications such as navigation of flying robots and wearable sensing. We have demonstrated the validity of the CURVACE technology integrating it with mobile robotic platforms or as a wearable tool to assist in various tasks, such as collision avoidance, corridor following, or flight stabilization in rough terrains.

Our aim has been to offer an assortment of self-contained devices to be used as compact, wide angle fast operation vision sensors on a variety of platforms with an undemanding implementation procedure. The range of potential applications goes from their use in mobile robots as a smart sensor for obstacle avoidance or egomotion estimation, to miniaturized cameras in endoscopes for medical inspection or wearable visual sensors for handicapped people. Extending beyond mere application examples, CURVACE provides a radical alternative that aims at a paradigm shift from conventional cameras inspired by vertebrate vision towards compound eyes inspired by insect vision. This step-up will lead to further miniaturization of manufactured cameras while maintaining unparalleled sensitivity, very large field of view with no distortion and rapid response with lower power consumption, among other advantages.