SEVENTH FRAMEWORK PROGRAMME

SEVENTH FRAMEWORK PROGRAMME PRIORITY:
ICT FET Open

CURVACE

CURVED ARTIFICIAL COMPOUND EYES

Participants List:

Role*	Name	Short name
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B	**Eberhard-Karls-University Tübingen** Laboratory of Cognitive Neuroscience, Department of Neurobiology, Faculty of Biology	UTUB

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

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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 intend to design, develop, and assess artificial compound eyes, which will be composed of microlens arrays arranged on curved and flexible surfaces where each microlens will be integrated with one or more aVLSI adaptive photoreceptors. The output of these artificial compound eyes will be processed by adaptive vision filters implemented in programmable devices, such as microcontrollers or FPGAs, for fast extraction of motion-related information. We call these integrated systems CURVed Artificial Compound Eyes (CURVACE). Compared to conventional cameras, artificial compound eyes will offer a much larger field of view in a smaller size and weight, less distortion, less aberration, and less blur because the distance between the optical surface and the photoreceptors will be constant over the entire field of view. Furthermore, some versions of the artificial compound eyes will 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 optic fabrication, neuromorphic engineering, microelectronics in bendable surfaces and insect-inspired active vision and motion detection. We adopt a progressive approach by developing a set of flexible artificial ommatidia units that will serve as mechanical and functional basic elements. We are building on these units the three versions of artificial compound eyes, i.e., cylindrical, spherical and tape, that will allow us to incrementally tackle the technical and scientific challenges and at the same time develop different prototypes that will suit the needs of various applications.

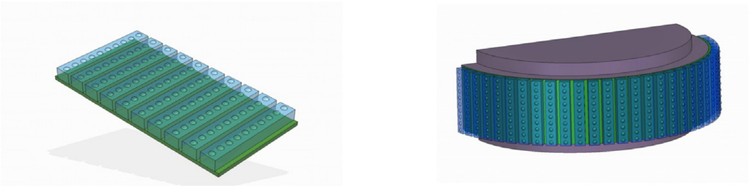
1st Year activities and main results

In the first year of work, considerable advances have been realized in the design and development of novel solutions to produce the **artificial ommatidia units**. These units consist of an array of microlenses aligned and glued onto the analog VLSI photodetectors of a specially fabricated optoelectronic chip. The stack is mounted on specially designed flexible PCBs. Thanks to a new fabrication technique, which has been introduced and successfully developed in this first year, the artificial ommatidia units can be curved to attain a wide FOV of up to 180°. This parameter is only limited by the curvature of the PCB. Two different ommatidia layouts have been designed for the various CURVACE versions. One of the layouts will be used in prototypes with a fixed and predetermined curvature, such as the cylindrical CURVACE, whereas an alternative layout will be applied on CURVACE versions whose ommatidia orientation is not predefined.

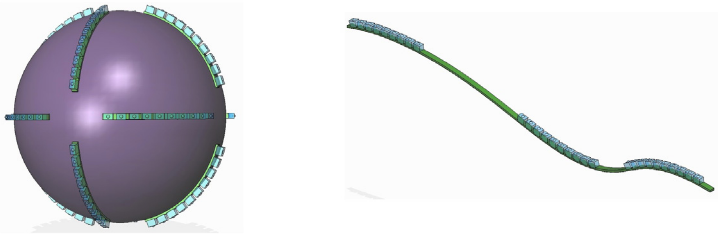
The different parts of the artificial ommatidia have also been designed in the first stages of the project. The **aVLSI vision chip** features an arrangement of photodetectors carefully aligned with an array of microlenses that focus the incident light only on the photosensitive areas. This design will provide enhanced sensitivity and available free space to place the required electronic circuitry for the read-out around the illuminated regions. Two versions of the aVLSI chip will be deployed for use in each of the layouts of the artificial ommatidia.

The ommatidia assembly, which consists of the aVLSI vision chip and the microlens array, will be mechanically glued and electrically connected to customized flexible PCBs by wire bonding. It has been proved that the flexibility of the support provides the device with its ability to be curved as a result of the specially designed novel assembly technique. The routines that are part of this method have been tested on non-functional devices. These experiments served additionally to identify potential risks for the future assembly of real prototypes. A mock-up of bendable optics-silicon-chip stacks on a flexible PCB is available and demonstrates the competence and technological ability of the consortium to fabricate artificial ommatidia for CURVACE devices starting from a planar CMOS sensor chip.

In a second stage of the project, we will rely on these artificial ommatidia units to implement four versions of artificial compound eyes, namely **cylindrical, active, spherical** and **tape** (see Figure 1). We attempt to achieve different functionalities based on CURVACE principles that will suit the needs of various applications. The cylindrical CURVACE will represent the simplest realization of the CURVACE concept and will offer a very large field of view (FOV) in the horizontal plane (up to 360°). The first prototype, which has been designed during the first year, consists of a cylindrical functional imager composed of two 2D artificial ommatidia units, which will allow to achieve the target FOV. In the concavity of the ommatidia, the necessary electronics for read-out, data processing and inertial sensing will be fitted. First fabricated mock-ups allow us to validate the mechanical packaging and further work is in progress to test the electrical connectivity of the design.



ommatidia unit cylindrical



spherical tape

Figure 1. Images of a layout of an artificial ommatidia unit for CURVACE (top left) and of the three aimed geometries of artificial compound eyes.

Furthermore, the **active** CURVACE will overcome the coarse spatial resolution of the cylindrical device by providing bio-inspired microscanning movements to obtain remarkable optical properties such as *hyperacuity*. Active vision means that an eye is submitted to small changes of its gaze direction, often at relatively high frequency (10-50 Hz). In a first step, we have accomplished a mathematical model of an elementary vibrating eye composed of only two photoreceptors placed behind a lens. In addition, we have designed an elementary visual scanning sensor that will be used to validate our model and to test different visual processing algorithms for locating a contrasting object (edge or bar) with a great accuracy under different lighting conditions. We have also revised the state of the art on potential tiny actuators that could be used for both generating micro-scanning movements and controlling the gaze orientation of a future aerial robotic platform equipped with a cylindrical CURVACE sensor.

The **spherical** version will provide truly omnidirectional field of view to the CURVACE with extra free space in the eye cavity for additional electronic components. A set of 1D artificial ommatidia units will be used for the design and fabrication of the spherical CURVACE. These units will be arranged in the longitudinal direction of the sphere. The performance of preliminary prototypes validated this arrangement by considering the distribution of ommatidia around the sphere, the number of needed parts and the electrical connectivity between ommatidia. The first version of the device will also allow the placement of the necessary electronic components, such as controlling units and inertial sensors, in the concavity of the sphere.

We will use 1D artificial ommatidia units to achieve the **tape** CURVACE. This version will feature a flexible skin-like vision sensor that can be adapted to a wide range of surfaces and validated as a wearable device. The sensor will feature a set of chained ommatidia units connected electrically and mechanically by their ends. This configuration will allow using the sensor on extended surfaces such as clothes, cars, furniture, etc. In-between the ommatidia, a suite of microcontrollers will implement the read-out and the local data processing. Prior to the tape CURVACE, preliminary prototypes have been fabricated and tested to explore the characteristics of the visual information of an imager whose shape is not known *a priori*.

Parallel to the above research on hardware specification and design of the CURVACE sensors, we have accomplished both theoretical and algorithmic advancements toward extracting meaningful visual information using such kinds of unconventional sensors. The first step of **visual processing** is to extract optic flow from CURVACE eyes. We have made a thorough analysis of the capabilities and restrictions of the CURVACE sensors with respect to the extraction of optic flow. We have investigated a large set of optic flow extraction methods from which we have selected a number of possible candidates for use in the CURVACE sensors. This selection takes into account their high temporal and low spatial resolution, as well as the special imaging geometry of the CURVACE sensor. We have also studied algorithmic extensions to these candidate methods so as to arrive at new algorithmic solutions.

In addition, we have implemented novel simulation **software** for the analysis and evaluation of optic-flow measurements obtained with CURVACE. This consists of an extendable **simulation system** that is able to simulate the sensor output of CURVACE moving freely in an arbitrary virtual environment. The simulation software has been realized according to the specifications of the CURVACE sensors, and it can currently simulate both the cylindrical and tape versions. In addition, it can render the ground truth motion data, which can be compared with the estimated one. In this regard, the simulation software provides an excellent method for checking the performance of optical flow extraction on CURVACE sensors with different complexity. Figure 2 illustrates the major components of the software system together with an example of the simulated output of CURVACE in an indoor scene.

Expected Final results and Impact

The aforementioned requirements and specifications allow meeting key project aims like high density of ommatidia, small overall size, wide field of view and available space in the CURVACE concavity for packaging. The present designs will be tested in computer simulations and in mock-ups before implementing them in a first CURVACE fabrication run. In addition, it has been conceived to consent further optimization of various factors such as size, processing power or resolution, to be applied in the second and final run of CURVACE prototypes.

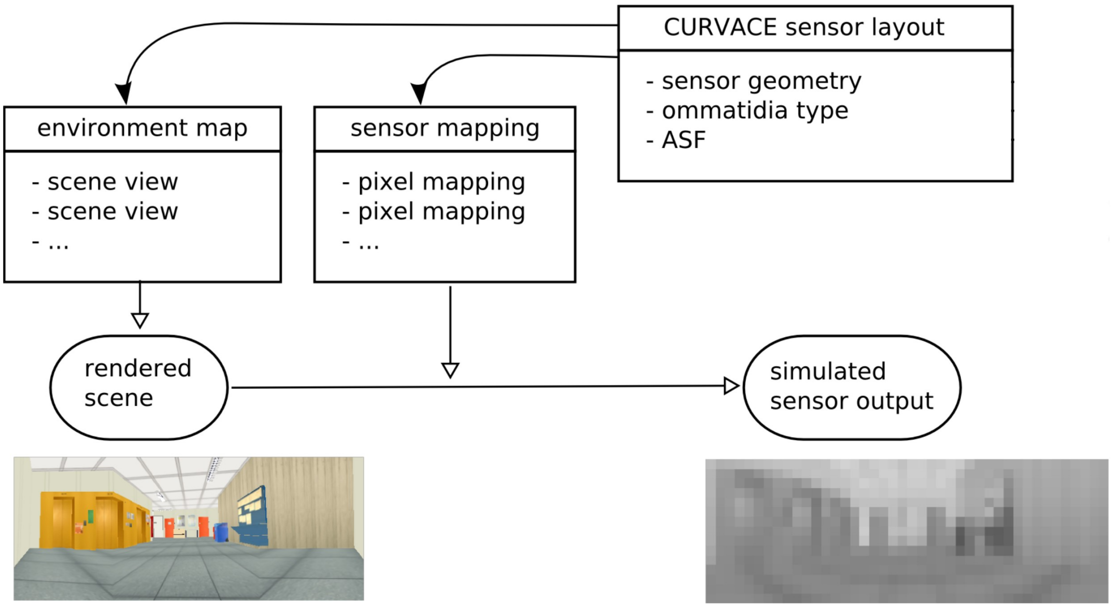


Figure 2. Illustration of the simulation software together with an example of the simulated CURVACE sensor output for a realistic indoor environment.

In the final stages of the project, we will also assess the added value of the CURVACE prototypes in applications such as navigation of micro-flying robots and wearable sensing to validate the implemented principles. Our aim is 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 an imager for obstacle avoidance or distance 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 would lead to further miniaturization of manufactured cameras while maintaining unparalleled sensitivity, lack of optical distortion, infinite depth of focus, very large field of view, and rapid response with lower power consumption, among other advantages.