CURVACE - CURVed Artificial Compound Eyes

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CURVACE – CURVed Artificial Compound Eyes

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SUMMARY

In this project, we aim at designing, developing, and assessing CURVed Artificial Compound Eyes (CURVACE), a radically novel family of vision systems that will provide more efficient visual abilities for embedded applications that require motion analysis in low-power and small packages. Compared to conventional cameras, artificial compound eyes will offer a much larger field of view with no distortion or aberration and exceptionally high temporal resolution in a smaller size and weight. The CURVACE consortium will produce prototypes of various geometries of fixed or adaptive curvature from the same basic design to fit the requirements of a wide range of applications.

Keywords

Artificial vision; compound eyes; bio-inspired engineering; vision-based navigation.

1. INTRODUCTION

The vertebrate eye (**Figure 1**, top) has provided inspiration for the design of conventional cameras, which general purpose is to provide a faithful rendering of the visual world that can be processed by image analysis algorithms for a large variety of uses, especially for object recognition. However, such vision systems require complex computation in order to extract motion-related information from a sequence of high-resolution images. The insect compound eye (**Figure 1**, bottom), instead, consists of a curved array of ommatidia, which are individual vision units composed of a microlens that conveys photons to a separate set of one or more photoreceptors. Even with a comparatively lower resolution than the vertebrate eye, it is very efficient for local and global motion analysis over a large field of view (FOV), making it an excellent sensor for accurate and fast navigation in 3D dynamic environments. Furthermore, compound eyes take several shapes and curvatures to fit the head and viewing directions of very different types of insects while offering the same functionality.

Curved vision systems and compound eyes have recently raised the interest of the scientific and technology community. However, the design of artificial compound eyes still presents several technological and scientific challenges. This is because the most common approach drastically departs from the design of conventional cameras for what concerns the components, fabrication procedures, packaging, and visual processing. This fact frequently leads to misalignment of the fabricated devices, and thus, poor correlation between the individual microlenses and photosensitive areas of the ommatidium unit, which is reflected in low-quality visual information. Additionally, most of the devices developed to date are still too bulky or heavy to be integrated in light miniature platforms, especially if we include the readout and processing electronic components.

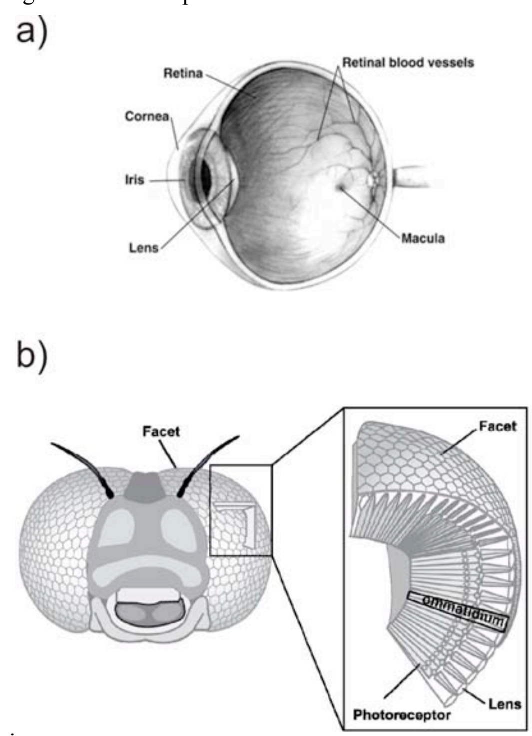

Figure 1. Schematic images of a) a vertebrate eye and b) of a compound eye.

2. PROJECT DESCRIPTION

The major goal of this project is the design, prototyping, programming, and validation of fully functional artificial compound eyes, which will be composed of microlens arrays integrated with adaptive photoreceptors made of analog Very-Large-Scale-Integration (aVLSI) circuits on flexible electronic substrates. The output of the artificial compound eyes will be processed by vision filters implemented in encapsulated programmable devices, such as microcontrollers or Field Programmable Gate Arrays (FPGA) for fast extraction of motion-related information. We call these integrated vision sensors CURVed Artificial Compound Eyes (CURVACE).

Compared to conventional cameras, the proposed CURVACE will offer much larger field-of-view, nearly infinite depth-of-field (no focusing needed) and unparalleled sensitivity. Additionally, the rendered images will feature no undesired blurring or off-axis aberrations because the distance between the optical surface and the photoreceptors will be constant over the entire field of view and because each optical channel will work under perpendicular light incidence for its individual viewing direction. Furthermore, the curved shape of the artificial compound eyes will offer space within the convexity for embedding processing units, battery, wireless communication, and inertial sensors, such as accelerometers and rate gyroscopes, which will be used for motion-related computation.

In order to reach the grand goal of artificial compound eyes and the measurable objectives listed above, we will take leverage from the completely novel combination of micro-optical fabrication technologies, adaptive photoreceptors in aVLSI chips, micro-electronics on bendable substrates, and motion detection on bendable imaging surfaces. In addition to the development of a library of motion-related filters for compound eyes, we will also study and develop novel visual filters that self-adapt to the changing curvatures of the surfaces where the compound eyes will be attached. Furthermore, we will explore bio-inspired principles of active vision, for example by applying specific micro-movements that will greatly increase visual acuity despite the coarse resolution of the compound eye, making CURVACE the first microscopic panoramic eye endowed with hyper acuity.

In order to succeed in our objective, we will explore a novel and unique approach to the fabrication of curved artificial compound eyes, which consists of developing artificial ommatidia units that will serve as functional building blocks to sequentially fabricate various types of curved compound eyes. This strategy will allow us to incrementally tackle the technical and scientific challenges that we will encounter during the project and at the same time develop different prototypes that will suit the needs of different applications. CURVACE will provide advantages and novel functionalities in several application scenarios where motion-related processing, wide field of view, and small and skin-like packaging are important. For example, a CURVACE equipped with inertial sensors could provide flying microvehicles with collision-free navigation at unprecedented size, weight, and power consumption (see Figure 2, left), or a CURVACE tape could be sewed into the back of a jacket or the hat of a visually-impaired people to warn of incoming objects (Figure 2, right).

Additionally, we aim at making the resulting prototypes reliable and replicable so that they could rapidly spread in the research and educational community, thus triggering a new wave of research into insect-inspired vision, which in the future may have an impact in several ICT applications. We will integrate CURVACE prototypes with programmable devices to encourage the development and sharing of visual software libraries. Furthermore, we will design the readout electronics so to make them compatible with other types of processing devices, such as neuromorphic chips, which could be directly interfaced to the aVLSI adaptive imagers at the place of the programmable device.

In *f*et[11], we will show a set of available prototypes to illustrate not only the packaging and scale of the devices, but also the technological processes to achieve the specific properties of CURVACE.

3. ACKNOWLEDGEMENTS

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4. ADDITIONAL INFORMATION

For further details, please visit:

http://www.curvace.org/

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Figure 2. Exemplary images of potential applications of CURVACE as sensors integrated in flying microrobots for vision-based navigation (left) and vision-based collision-alert system for visually impaired people (right).