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An embedded vision system based on an analog VLSI optical flow vision sensor

Vlatko Bečanović [a,*], Takayuki Matsuo [a], Alan A. Stocker [b]

[a] Department of Brain Science Engineering, Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu, Kitakyushu, Fukuoka 808-0196, Japan

[b] Howard Hughes Medical Institute and Center for Neural Science, New York University, USA

Abstract. We propose a novel programmable miniature vision module based on a custom designed analog very-large-scale-integrated (aVLSI) vision sensor. The sensor provides the logarithmically compressed and temporally adapted intensity image as well as a dense smooth optical flow estimate. The fully parallel and analog network architecture of the sensor guarantees efficient *real-time* visual processing. The module embeds the aVLSI sensor within commercial off-the-shelves digital hardware that controls the sensor read-out and permits additional higher-level post-processing of the intensity image and optical flow data. The combination of analog and digital processing leads to a computationally very powerful, yet small and potentially cheap vision module. It can be used stand-alone or integrated in larger vision or robotic systems. Standard interfaces guarantee easy control and programming, and make the vision module especially well suited for education as well as applied research in the robotic sciences. © 2006 Elsevier B.V. All rights reserved.

Keywords: Optical flow; Analog VLSI (aVLSI) sensor; Embedded vision system; XScale architecture; Robotics

1. Introduction

Vision is crucial for many real-world applications. Yet, vision is expensive. The high bandwidth and the variable and ambiguous visual environment typically require large computational power—even to solve relatively simple low-level visual processing tasks. Particularly, this becomes a problem for smaller robots where size and power restrictions severely limit the available computational resources for visual processing. Some low-cost vision modules based on a traditional camera/microprocessor approach have been proposed (e.g., see Ref. [4]), yet because of the aforementioned restrictions, processing is either slow or limited to computationally not highly demanding tasks such as color segmentation and

* Corresponding author. Tel./fax: +81 93 695 6160.
E-mail address: vlatko@brain.kyutech.ac.jp (V. Bečanović).

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tracking by color. Performing higher-level vision tasks that are based on visual motion estimations in real time requires a high amount of computation and thus becomes much more difficult for such traditional approaches.

Here, we propose a novel approach in building a miniature vision module that is small and consumes little power, yet is powerful enough to solve computationally demanding vision tasks. The module embeds a computationally efficient analog VLSI (aVLSI) vision sensor within a programmable digital hardware environment. The vision sensor computes an efficient and rigorous real-time estimate of 2D optical flow. It also provides the logarithmically encoded and temporally adapted gray-scale image signal, which guarantees high contrast sensitivity over many orders of light illumination. The computational efficiency originates from the sensor's distributed analog network architecture, where all computations necessary for optical flow estimation are done in parallel and in continuous time at each pixel [1,2]. In our proposed system, data from multiple such vision sensors or other external queues, e.g., inertial sensors, various encoders, etc., can be integrated and post-processed with the digital hardware in order to solve higher-level vision tasks.

We have outlined a preliminary version of this system in [3]. Here, we describe an improved system, which also uses a new microprocessor whose digital processing capabilities are significantly increased by at least an order of magnitude. Also more flexible interfaces can now be integrated, e.g., wireless modules or a touch-screen, which is advantageous for reaching our goal of designing a powerful and user-friendly system.

2. System architecture

The aVLSI chip is a prototype (cf. Fig. 1) that implements an improved version of the gradient-based optical flow algorithm according to Horn and Schunck [13]. The algorithm reflects a typical optimization problem encountered in higher-level vision. The architecture of the chip is such that it maps the optimization problem to an integrated electronic network structure of only nearest connected processing units. Each unit in the network is identical and constitutes a single pixel that contains a logarithmic adaptive photoreceptor [6] and the necessary analog circuitry to compute the local optical flow estimate [2].

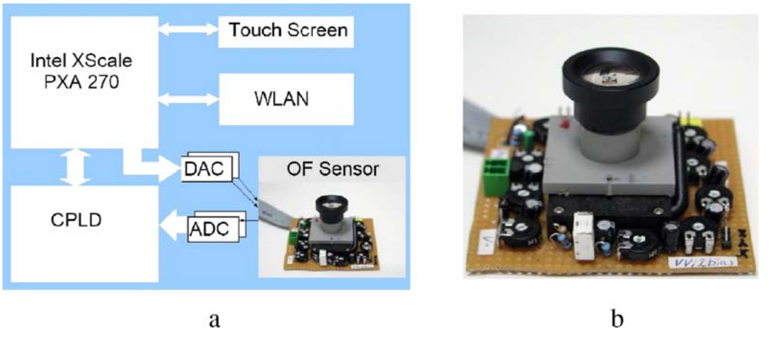

Fig. 1. (a) The system architecture with the corresponding data streams indicated. (b) The aVLSI optical flow sensor mounted on a prototype lab-board with a wide angle lens.