A Real-Time Smart Sensor System for Visual Motion Estimation

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Abstract

We present a new smart sensor architecture for visual motion - optical flow - estimation. As the system operates in real-time it is very well suited for collision avoidance on autonomous mobile platforms. The core of the system is an ASIC in standard digital CMOS technology, which forms a pipeline with feedback path for on-line image processing. The presented implementation was tested on image frames of 128 x 128 pixel size.

An autonomous vehicle - as MORIA [6] - augmented with visual motion sensors should be capable to navigate through an unknown and changing environment. It must identify a possible collision danger with a dynamic object to correct its navigation track in real-time. The important visual information needed is first any movement and second the speed and direction of it - represented through the optical flow field. From the optical flow a possible area of collision and the time-to-impact can be estimated that on its turn triggers an avoidance manoeuvre.

For a collision avoidance system a short processing time is a major constraint. As a consequence, the integration of low-level image processing tasks, like optical flow estimation, on a special purpose sensor is essential. In addition the sensor output has to fit commercially available modules for further high-level processing steps mentioned above (e.g., time-to-impact). To be integrated on a mobile platform, the sensor needs to be small, robust, and of low power consumption. Taking into consideration these requirements we developed our new hardware architecture.

Current developments of optical flow sensor systems are focused on two different approaches: First, biologically motivated sensors with processing and sensor elements integrated on a single chip [5], where only prototypes with a few pixels (max. 26 x 26) have been fabricated; second, computer systems augmented with special circuits like correlation processors (e.g., [4]), which are quite complex and hence, not suited for mobile vehicles.

Based on an overview over optical flow algorithms presented by Barron et al. [1], we review these methods again under hardware related aspects. The algorithm of Horn and Schunk [3] is chosen as best suited for an efficient implementation. The velocity vectors are iteratively calculated from the spatio-temporal derivatives of the image. Given that the sensor works continuously, the iteration count can be reduced to one. Hence, the algorithm is implemented as a pipeline with feedback path.

The major advantage of our implementation is, that we process image data synchronously, pixel by pixel, while we read out the sensor's front end. This reduces the response of the sensor to the time needed to read less than 5 image lines. Various efforts were necessary to fit all processing steps into the pipeline structure:

- shift registers before mask operations
- dual ported SRAMs for temporary frame memory
- parallelization of datapaths

Following a top-down methodology we synthesized the ASIC using VHDL. A VHDL-testbench modelling the system's behaviour was developed to handle the high throughput of data and to visualize the sensor's output for verification.

The area of the fabricated ASIC is 47 mm^2 in 0.7 µm CMOS. The test results confirm the simulations. A throughput of 50 frames/s is achieved with the used seeing surface FUGA15 [2].

References

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