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Pixel-level APS Sensor Integration and Sensitivity Scaling for Vision Based Speed Measurement

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Abstract

A dual-pixel APS sensor architecture is proposed in this paper, for vision based speed measurement applications, based on a novel double exposure method. The sensor integrates two type of imaging elements on pixel level, and is designed to generate two spatially and temporally coherent images. The primary sensor generates a good quality image for vehicle identification, while the output of the secondary sensor is used to calculate speed estimates, based on the intra-frame displacement of the vehicle's headlight. A scaling process has also been developed for the sensitivity of the secondary sensor, based on photodiode parasitic capacitor discharge time.

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Keywords: CMOS sensor; Quantum efficiency; Multi exposure, Speed estimation, Dual-pixel

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1. Introduction

Traffic management plays an important role in the smart city concept, enabling the authorities to observe and control the traffic flow. The key elements of such system are the sensing nodes, which provide information regarding the speed of each individual vehicle. Current speed measurement devices use separate sensors for speed estimation (RADAR/LIDAR), and vehicle identification (camera). These are expensive devices, and thus not suitable for

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example, to monitor the whole road network of a city, which would require a large number of sensing nodes. In this paper, we propose an alternative solution, a vision based speed measurement concept, which offers a single CMOS imager for both speed measurement and license plate recognition. Vision-based displacement calculation methods can be divided into two categories: inter-, and intra-frame methods. The intra-frame methods measure the displacement of certain objects based on motion blur, appearing during the exposure time interval. These methods are capable of providing speed estimates based on a single image. There are only a few publications related to intra-frame speed measurement [1], [2]. In these cases, a deblurring method is necessary to improve the image quality for vehicle identification. Our approach provides better overall image quality, while the motion blur appears only in the high intensity regions of the image. The paper is composed in the following way. The measurement concept and the double-exposure method is described in Section 2. Section 3 contains the description of the dual-pixel architecture, and the design considerations related to sensitivity scaling. Section 4 gives a short summary of the work.

2. Intra-frame speed measurement concept

The intra-frame speed measurement concept is based on a double exposure method, where each phase of the exposure is defined with different Quantum Efficiency values. Quantum Efficiency (QE) [3] describes the photon to electron conversion efficiency of a sensor in the following way:

$$\eta = \frac{Jh\nu}{\Phi q} \tag{1}$$

where J is the incident photon generated current density, q is the elementary charge, Φ is the optical power density, while $h\nu$ represents the energy of one photon. This means, that in the case of the secondary exposure, more incident photons are required to generate the same voltage swing in a pixel. As a result, we expect a good quality image of the scene, and a secondary image, where only the brightest spots will be visible (the headlights). Because of the relatively long secondary exposure time, light traces will appear on the image, which represent the movement of the headlights during this exposure stage, and the length of the trace is proportional to the movement speed of the vehicle. Hence speed measurement can be interpreted as length measurement. In our preliminary works [4], [5], we emulated the double exposure with a low shutter efficiency sensor. The theoretical background of the speed measurement, the exposure control scheme, along with the measurement results can be found in [4] and [5]. The fundamental problem with this method is that the length measurement of the traces has an inherent uncertainty. The localization of the trace starting point is difficult, because of the saturated area around it (Fig. 1). The proposed sensor in Section 3, is capable of separating the saturated region of the headlight and the light trace on hardware level.

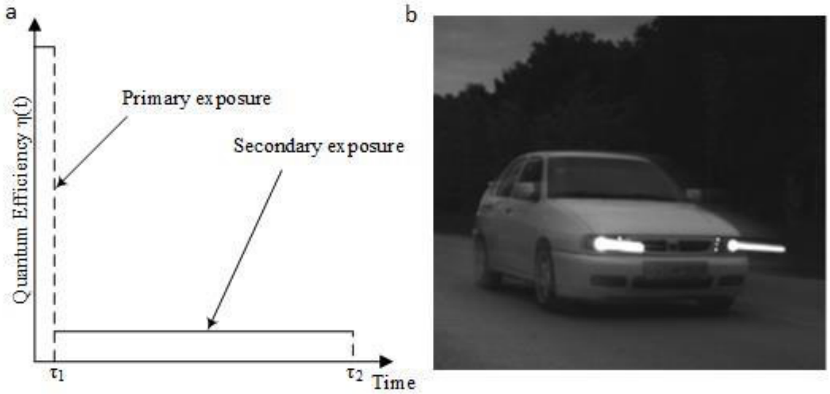

Fig. 1. (a) Exposure-control scheme of the proposed method, the primary $[0,\tau_1]$ and the secondary $[\tau_1,\tau_2]$ exposures are modelled with different QE values; (b) Superimposed image acquired with a low-GSE sensor. The saturated trace represents the movement of the headlights during the readout phase.

3. Sensor architecture

CMOS imaging technologies enable the realization of single chip imagers, where the timing and control functions as well as other pixel level innovations can be integrated on the image sensor, along with the pixel array. Our goal is the design of an imager, which consists of two separate pixel arrays, where each array corresponds to an exposure phase of the double exposure method. The pixel-level integration is important, because of the integrity of the spatial and temporal features of the scene. Since the integration times are different in the two cases, the sub-imagers need to be operated separately.

3.1. Dual-pixel structure

The proposed dual-pixel structure is based on a conventional 5 transistor (5T) APS pixel, described in [5], featuring global shutter. Every pixel in the array contains two subpixels, with the same architecture (Fig. 2). The primary subpixel is responsible for the good quality image of the scene, while the secondary sensor generates the intra-frame motion information. As a result of this dual structure, the proposed imager has two independent output images.

3.2. Sensitivity scaling

In the case of the secondary sensor, the exposure conditions remain similar for every measurement situation. Our goal is to set the sensitivity of this sensing element in a way, that only the headlights should be indicated on the otherwise black image, so the background has to be attenuated completely, even with long exposure times, as described in [5]. Hence the most important design consideration in our case is the sensitivity scaling of the secondary subpixel. This ensures, that the intra-frame motion information is extracted only from the regions exceeding a specified luminous intensity (cd) threshold. The scaling is performed using a specific opening on the metal mask over a 5×5µm photodiode (this is the smallest photodiode (PD) size available in the 0.35µm C35O technology provided by AMS). This method makes it possible to separate the saturated region of the headlight and the light trace on a hardware level, making the trace length measurement more accurate. Based on a given luminous intensity value and PD size, we can calculate the discharge time of a PD, and the pixel response, with equation (2) and (3), respectively.

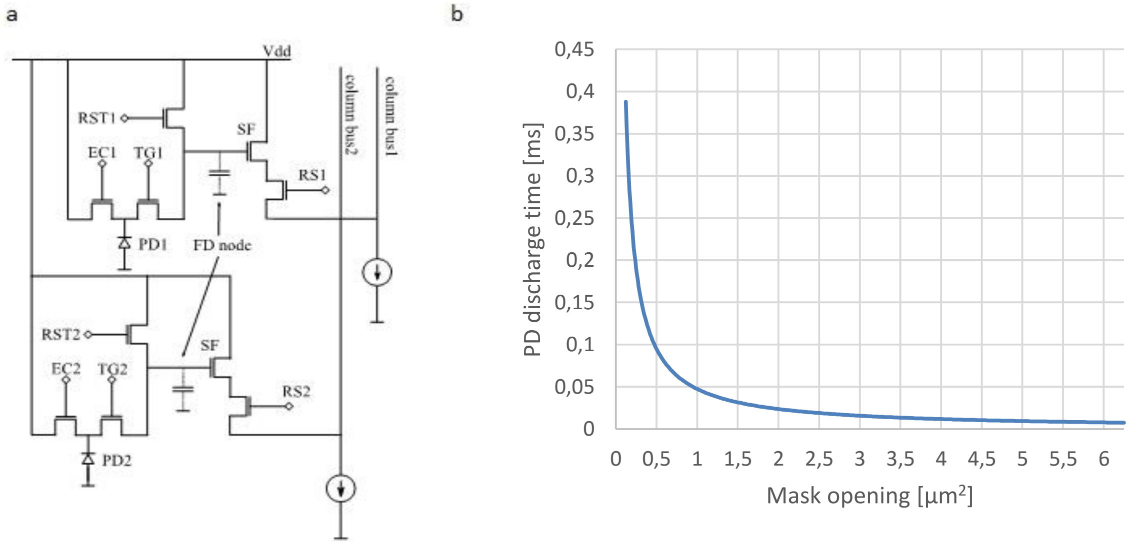

Fig. 2. (a) Pixel architecture is based on a conventional 5T APS pixel. A 5T pixel consists of a photodiode, a floating diffusion (FD - analog storage node) and five transistors; (b) PD discharge time at 26,3µW radiant power for a 5×5µm photodiode, with different mask openings

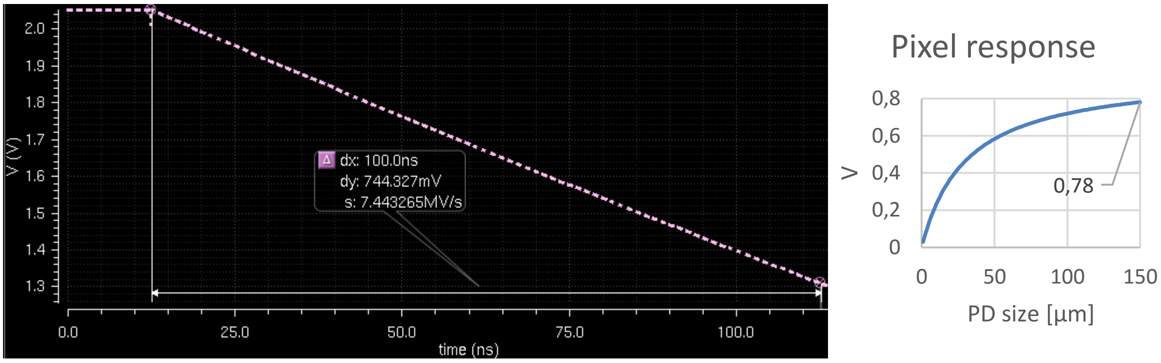

Fig. 3. Result of a simulation based on the data found in AMS C35 technology documents (a 150µm×150µm photodiode, with a light source of 26,3µW radiant power at 850nm, and 100ns integration time), and the corresponding pixel response estimation graph. The result of the simulation matches the estimation, with a tolerable difference.

$$V_d = \frac{1}{C_{jdep}} \int_{t_0}^{t} I(\tau)d\tau \xrightarrow{I=const;t_0=0} t = V_d \frac{C_{jdep}}{I} \tag{2}$$

$$V = \frac{t_{int}}{C_{jdep}} \int R(\lambda)P(\lambda)d\lambda \tag{3}$$

Where V_d is the reset voltage of the pixel, C_{jdep} is the junction capacitance, I is the photocurrent under a given illumination level, t is the discharge time, t_{int} represents the integration time, $R(\lambda)$ is the responsivity function of the PD, while $P(\lambda)$ is the incident radiant power. Fig. 2 shows the discharge time for a given PD, based on equation (2), with different mask openings, while Fig. 3 shows a simulation result compared to the pixel response estimation, using equation (3). In order to calculate the proper mask openings, we performed a reference measurement at a relatively low, 200 lux ambient illuminance level, using an Aptina AR0134 sensor and neutral density filters. In this case, we observed an average 150-200 times multiplier between the peak luminous intensity of the headlight, and the rest of the image. This value depends on the observation angle, and the headlight characteristics, defined by the isolux diagram. As stated in [5], a sufficiently long integration time is necessary for acceptable measurement accuracy, which depends on the geometry of the measurement setup. For testing and validation purposes, we will use a series of different masks throughout the pixel array, ranging from 0.12 to 1.5 μm^2.

4. Conclusion

A novel vision based speed measurement device is proposed in this paper. The theoretical results and the proof of concept measurements, published in [4] are promising. A dual-pixel CMOS imager is under development, based on these results, capable of capturing two separate images in parallel, providing information for vehicle identification and velocity measurement, using a single sensor.

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