High Precision Image Centroid Computation via an Adaptive K-Winner-Take-all Circuit in Conjunction with a Dynamic Element Matching Algorithm for Star Tracking Applications

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Abstract. An approach for implementing a high precision image target centroid—center of mass (COM) detection system via an adaptive K-winner-take-all (WTA) circuit in conjunction with a 2-D dynamic element matching (DEM) algorithm implementation for image sensor arrays is proposed. The proposed system outputs a high precision COM location of the most salient target in a programmable active region of the field of view (FOV) for star tracking purposes and is suitable for real time applications. The system allows target selection and locking with multiple targets tracking capability. This solution utilizes the separability property of the COM, and therefore reduces the computational complexity by utilizing 1-D circuits for the computation. The DEM algorithm, commonly used in ADC and DAC circuits, allows reducing the required WTA circuit precision to 5–6 bits, while still achieving a high output precision. Simulation results prove the concept and demonstrate the high precision COM result. In addition, a possible low-level hardware implementation is described.

Key Words: APS, CMOS imager, center of mass, COM, centroid, K-WTA circuit, K-Winner-take-all circuit, dynamic element matching, DEM, star-tracking, image processing

1. Introduction

Visual tracking of salient targets in the field of view (FOV) is a very important operation in star tracking and navigation applications. Several issues should be addressed in tracking of salient targets [1]: (a) the problem of selecting a target from the background, (b) the problem of maintaining the tracking engagement (target locking) and (c) the problem of shifting tracking to new targets in cases when it is decided that another target in the FOV should be selected and tracked. In such applications, the location and magnitude of the selected target must be reported in real time. For small dimension targets in the FOV (small bright spots), target locations are represented by local intensity peaks. Thus, in these cases the target can be selected using the winner-take-all (WTA) circuit which identifies the highest signal intensity among multiple inputs [1, 2]. The situation is much different when a large target consisting of a large number of pixels is acquired. In this case a target centroid—Center of Mass (COM), or the first moment of the target intensity distribution, represents the position of a target. Thus, a high precision system for COM detection of silent targets in the FOV is required. In addition to the issues mentioned above, a number of properties should be examined in such a kind of a system. These include system suitability for real time applications, hardware requirements, the possibility of implementation as a system-on-a-chip (“smart” sensor), the influence on the sensor spatial resolution (i.e. the fill factor), etc.

The significance of tracking in machine vision, star tracking and navigation applications as well as in visual attention tasks in biological systems triggered numerous efforts in these fields. Many works in this area have been published during the last two decades [1–10]. A number of different COM detection circuits in conjunction with CMOS sensor arrays have been proposed [11–16].

In most previously proposed solutions image processing is performed at the focal plane level. Most of these designs use current-mode pixels, employing
photodiodes or phototransistors to produce a current which is an instantaneous function of the incident light [17]. Typically, each pixel consists of a photo detector and local circuitry, performing spatio-temporal computations on the analog brightness signal [5]. These computations are fully parallel and distributed, since the information is processed according to the locally sensed signals and data from pixel neighbors. This concept allows reduction in the computational cost of the next processing stages placed in the interface. Unfortunately, when image quality and high spatial resolution are important, image processing should be performed in the periphery. For example, in [2] we have presented an APS with a 2-D WTA selection (performed in the periphery) implemented in 0.5 µm standard CMOS technology and achieving a fill factor of 49% with a 14.4 * 14.4 µm pixel size. In [18] the in-pixel processing strategy has been chosen. In that work, a 80 * 80 µm pixel has been implemented in the same technology reducing the spatial resolution. However, more complex functions have been achieved.

In this paper, we propose a high precision 2-D COM detection system that allows computation in the sensor array periphery without affecting the sensor properties. The proposed system can be integrated with any kind of a CMOS APS array for a system-on-chip approach. The proposed system allows selecting a target in a programmable active zone from the background, maintaining the tracking engagement (target locking) and shifting the tracking task to new targets when required. The system outputs, in real time, the coordinates of the COM location of the most salient target in the active region of the FOV. The general strategy of the active region selection, target locking and shift of tracking to new targets in our system is similar to the one proposed in [1], but the COM detection architecture described here differs from the previously proposed ones in some key features. The main features in our system are: (a) all computations are performed in the sensor array periphery, (b) the target separation from the background is performed via an adaptive, low precision mixed signal K-WTA circuit, (c) the final target COM coordinates are calculated using the Dynamic Element Matching (DEM) algorithm, commonly used in ADC and DAC circuits as a digital solution for reduction of the matching problems of analog elements, (d) the system allows COM calculation of large bright targets. In order to orient the reader better, features (b) and (c) will be briefly introduced here.

The usage of the WTA circuit in tracking systems is not a new approach [2, 5, 9, 19, 23, 24]. Generally, an analog WTA circuit, which identifies the highest signal intensity among multiple inputs, is one of the most important building blocks for neural networks hardware realizations [20–22], neuromorphic designs [5] and image processing applications [1, 2, 23]. The function of the WTA is to accept input signals, compare their values and produce a high (or low) digital output value corresponding to the largest input, while all other digital outputs are set to a low (or high) output value. Identically, the K-WTA circuit identifies the K input signals with the largest values. In tracking systems, the WTA circuit can be used for (a) target selection, by location, of the absolute maximum in the entire image [1], (b) segmentation-based peak detection, where the peak value within each target is determined by the WTA and replicated in every pixel within the target [3], (c) selection and tracking—the target with the strongest spatial contrast selection, in systems based on contrast edges target detection [5]. In our proposed system, the K-WTA circuit is used for target selection from the background, similar to thresholding and segmentation-based peak detection, as in [3]. The adaptive nature of the WTA allows selection of the bright targets independent of their size. The mixed signal WTA architecture was chosen for two reasons: (a) in this way an adaptive K-WTA is achieved in a very simple way, (b) simpler interface with the digital hardware implementation of the DEM algorithm is achieved. It will be shown, that the DEM algorithm allows reducing the required WTA circuit precision to 5–6 bits, while still achieving a high precision of the output result.

The DEM method was presented in 1975 by Van de Plassche [26] as a mean of enhancing performance of current sources. Actually, the digitally implemented DEM algorithm reduced errors caused by mismatches in analog components of current sources by appropriate selection of different current sources every time it was required. Shortly afterwards, in 1976, Van de Plassche described a Sigma-Delta A/D converter incorporating the DEM [27]. Since then the DEM method has been used primary to enhance the performance of Delta-Sigma D/A and A/D converters and is usually associated with them. In this paper we describe the DEM application to enhance performance of a COM tracking system while applying DEM in two dimensions of the sensor array. On one hand, this presents an approach different from the traditional applications of the