A Bio-Pulsating Architecture for Object-based processing in Next Generation Vision Systems

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Abstract: A novel and robust distributed architecture for real-time object-based processing is presented for tasks such as object size, centre and count determination. This approach uses the input image to enclose a feedback loop and realize a data-driven pulsating action, ideally suited for implementation in standard CMOS technologies.

Introduction: A modern advanced image processing system uses an external camera to stream the image data to the processor; executing a software algorithm. Such a modular scheme demands huge bandwidth requirements for the video transmission and therefore heavy power requirements. Several early filtering applications can benefit from combining the phototransduction and processing at the pixel level. A new breed of vision chips have recently emerged that strive to achieve precisely this. A generic reconfigurable architecture to provide such pixel-level processing is the cellular neural network processor [1]. Other systems have been inspired by the unparalleled computational efficiency of living organisms in solving complex image processing tasks. These biologically-inspired (or retinomorphic [2]) systems have been realized to perform tasks such as image enhancement [3] and feature extraction [4]. Object-based processing is a fundamental task for many early vision applications. The segmentation of various objects in an image has been traditionally implemented in software using techniques such as the snake algorithm [5]. It has not been till recently, that dedicated hardware has been developed for such tasks as object-based attention selection [6] and

contour length measurement [7]. This letter introduces a novel scheme suitable for such object-based computation based on a distributed processing architecture. Although several of the features have been biologically inspired, the algorithm is fundamentally synthetic. By using this hybrid approach, a realistically hardware implementable system can be developed benefiting from increased computational efficiency provided by the bio-inspired analogue processing elements. The reduced power consumption enables realization of mobile diagnosis devices which would otherwise be technically unachievable.

Algorithm: The work presented uses an edge-detection technique to form the contours and trigger the data-driven processing. On detection of an object boundary, the initial state for the signal flow is set. By propagating an inward fill, the contour can be reduced until this converges to the centre. The central point is detected by utilizing spatiotemporal integration; i.e. a summation of the cells set within the receptive field within a certain time window. On centroid detection, the object is reset and output transmitted, thus realizing an inward pulsating action. The frequency of pulsation determines the size, i.e. radius of this object. Fig. 1 illustrates this interaction graphically through computer simulations.

Method: Objects are defined as regions in the image with intensity below (or above) the average level of the input image. The edges are detected by computing the difference in neighbouring cell intensities and contours are formed if a continuous edge is found; i.e. at the nodes which have two edges leading to them. The contour reduction is facilitated by setting a cells state if any of its adjacent cells have been set in addition to the object criterion being satisfied. The rate of the contour reduction is preset by a delay element being introduced in the propagation cycle. The unusual feature of this method is the

absence of any pre-defined synchronisation signal, for example, a clock. The only synchronisation is obtained through the data-driven object reset scheme but on a local, rather than a global basis. The reset is generated on detection of an object centre. As previously mentioned, this detection involves counting that all local cells have been set within a certain time period.

Implementation: The presented architecture is currently being realized into circuit blocks for implementation in a standard 0.18 μ m CMOS process provided by UMC. The representation is analogue with computation operated primarily in weak inversion for micropower consumption. In order to facilitate the contour computation, the processing must occur at the pixel corners, as illustrated in top-level-cellular architecture shown in Fig. 2. The required functional blocks; all continuous time topologies, are given below:

- a. Light detection: Active photodiode (continuous time) utilizing n+ implant p-substrate junction diode for phototransduction.
- b. Edge detection: Discrete output using current-mode winner-takes-all type circuitry with thresholding for computation of object contours.
- c. Local averaging: Narrow-field for input image smoothing and wide-field for object detection (by thresholding,) using current-mode computation.
- d. Dynamic switching: Simple MOS switching regulated by local average thresholding for object segmentation, to provide object reset path.
- e. Neuromorphic logic: Will perform synaptic (delay-and-propagate) computation for signal flow and neuronal (integrate-and-fire) computation for centroid determination.
- f. Memory: Basic 1-bit memory implemented using digital (asynchronous) RS flip-flop for storage of present cellular state.

Finally, the issue of the data readout can be achieved by employing a basic demand-driven scheme. This approach is possible due to the very low output bandwidth requirement (expected under 50 objects per second depending on tuning and input) that avoids the polling of all pixels.

Discussion: The target application for this architecture is for microscopic cellular population analysis as a microelectronic alternative to haemocytometry. The system to be developed is required to provide cellular count and size information on the microscopic image. In designing a system requiring image acquisition capabilities in standard CMOS technology, careful consideration must be taken into sources of error. Non-uniformities in the pixel array; referred to as fixed pattern noise (FPN) are mainly due to offset and gain mismatches between the in-pixel amplifiers. This error, if uncompensated for, would normally render a processing algorithm unusable; however, the method presented has proved robust. Through computer simulations, the inherent immunity to both FPN and physical defects has been verified, as illustrated in the results shown in Fig. 3. The algorithm has shown to tolerate up to $\pm 20\%$ FPN or 5 defects, continuing to provide error-free readings. For both this reason and the high lighting conditions present in the target application, the required dynamic range is limited and therefore the FPN will not pose a serious problem. However, any process variations may result in device mismatches causing other sources of error. One such error could be due to unmatched time constants for the delay elements in the data propagation path. However, the integrative nature of the analogue processing core reduces this effect and by adjusting the tolerable interval of centre arrival, this can be overcome altogether.

Conclusion: This letter introduces the concept of the bio-pulsating contour reduction algorithm. This is a parallel, distributed algorithm performing asynchronous object

recognition breaking the bottleneck of traditional, sequential von Neuman based computational paradigm. The globally asynchronous scheme is regulated by employing data-generated local synchronisation, reducing power consumption and improving the signal-to-noise ratio. By incorporating the processing in the front end, the bandwidth requirements have been reduced by at least four orders of magnitude. Both the functionality and robustness have been verified through computer simulation and by outlining an explicit architecture, the feasibility of hardware implementation has been shown. Finally, by targeting a specific application, both the efficiency and versatility will be demonstrated.

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Figure Captions:

Fig. 1 Computer simulation results of the bio-pulsating contour reduction algorithm, with snapshots taken at regular time intervals at the propagation delay of the processing.

Fig. 2 Proposed cellular architecture for object-based processing illustrating organisation and connectivity of functional blocks within a quad-pixel arrangement.

Fig. 3 Statistical data demonstrating robustness to defects (top) and FPN (bottom,) acquired through computer simulation of the bio-pulsating contour reduction algorithm.

Figure 1:

Figure 2:

Figure 3: