Bit-Plane Extracted Moving-Object Detection Using Memristive Crossbar and CAM Arrays

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Abstract. Bit-plane extraction based moving object detection approach is an extension to frame differencing method,but applied on extracted bit planes from the video frame. Firstly these bit planes are stored in a memristive crossbar array , the consecutive frames of bit-planes are compared using threshold logic based XOR gate. Post comparison these resulting bit-planes are used to reconstruct gray-scale images and then thresholded again to obtain a binary images. To find the pixel differences in first and second pairs of frames, a memristor based content addressable memory (CAM) on 2 transistor 2 memristor topology is used. pixel difference calculation process implemented using CAM gives the direction of the object movement. The New algorithm (by Dastanova et al. [1]) outperforms the conventional moving object algorithms in various metrics.

1 Introduction

In modern day computing where enormous amount of data is processed and the large part of processing the data is done on cloud, factors like latency, congestion, time sensitiveness, bandwidth are the bottle necks. To over come these bottle necks for time sensitive applications and to reduce the latency, edge computing devices play a major role.

Moving objects detection has been used for wide range of applications like video surveillance, activity recognition, road condition monitoring, airport safety, monitoring of protection along marine border [2]. Most of these applications are security and surveillance related, in such application one can't afford high latency. Edge computing devices help in reducing the latency. Moving object is a basic low-level vision activity which is a part of human visual system to learn basic information about the video scene. To implement moving object detection, camera based detection systems are more robust and reliable. There are various methods to detect motion of objects in a video scene. Most of these methods are based on three basic methods:background subtraction, frame differencing, optical flow. The method presented in [1] is based on extension of frame differencing but operated on extracted bit-planes.

In an digital image, the fundamental element is a pixel. Each pixel has a size in bits, for e.g. 8-bit pixel can have 256 colours. In a 8-bit grayscale pixel, each pixel represents intensity of light where the colours are shades of gray. The pixel with weakest intensity has value 0 representing black and pixel with highest intensity has 255 representing white. Each bit in a 8-bit pixel corresponds to a respective bit plane. These bit planes when observed only higher order bit planes convey important information in am image and the lower order bit planes doesn't convey signification information.

To store these selected higher bit planes, a device with two state storage capability is needed. Algorithm proposed in paper [1] uses memristors in a crossbar array configuration to store these bit planes. Memristor circuits are non-volatile, scalable, operates on low-power,can be integrated with CMOS circuits. In the method(by Dastanova et al. [1]), These bit-planes once stored in crossbar arrays,memristor based threshold logic gates is used for performing XOR operation and also memristor based CAM for fast data comparison. Two key highlights of the paper [1] include the following: (1) A novel approach for moving object detection by extracting bit planes in a video frame. (2) Use of memristive crossbar arrays, memristive threshold logic gates and memristive CAM arrays.

The authors of [1] claim that the system is scalable, space-efficient and can be integrated with CMOS circuits and sensor to build edge computing devices, which doesn't need a special software again to develop edge computing application for motion detection. Next sections of the paper gives a brief idea about basic methods of moving object detection, memristor based circuits then the software and hardware implementation of the proposed novel method. Following that will be details of results and conclusions of the work.

2 Background

2.1 Techniques used in moving object detection

Background subtraction: The algorithm involves separating out foreground objects by subtracting the background in present frame. It is performed by applying background models that are pre-processed. A fixed background is initialized, then the difference for each pixel is found, difference indicates the objects differing from background. If the difference is below a selected threshold, there is no change in the scene and the respective pixel is regarded as the one belonging to background. Background subtraction is extremely sensitive to environment and is based on the model that pre-processes the background. Various Performance enhancement techniques to improve the background models are available only at the cost of complexity and high power.

Frame Differencing: Frame differencing involves subtraction of two consecutive frames. If three frames are considered its called three frame differencing. Relatively three frame differencing give more accuracy than two frame differencing [3]. After the difference the resulting images are threshold-ed. Frame differencing is very similar to background subtraction but does not need an initialized background or the use of background model to pre-process the background. Even frame differncing exhibits issues with non-static camera, background noise and change in light intensity.

Optical Flow: Optical flow is the pattern of motion in a scene caused by the relative motion between an observer and a scene. Optical flow uses the change in pixel distance or pixel velocity to determine movement of objects in video frame. Two consecutive frames at time t and $(t+\Delta t)$ in a time-series are processed and each pixel's movement is calculated with a consideration that each pixel as a vector. Under brightness constancy assumption,pixel at location (x, y, t) with intensity $I(x, y, t)$ and when moved by $(\Delta x, \Delta y, \Delta t)$ between two frames.

$$I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t) \tag{1}$$

On application of Taylor series, we get

$$I_x u + I_y v + I_t = 0 \tag{2}$$

Where u,v represent components of pixel velocity at (x, y, t). Above computations in equations (1) and (2) are just for one pixel. Similar calculation for the whole frame is a very challenging and highly computationally demanding task, which makes it not really suitable for edge computing.

2.2 Pixel based movement detection

Proposed method in [1] is innovative as the reason being,it involves bit-plane extraction and manipulation of bits in respective bit planes resulting in manipulation of pixels. In the method proposed in [1], XOR operation on pixels is done to detect change in consecutive frames. As XOR is an fundamental logic operation it's realization is simple.As the method is so fundamental it can be efficiently realized using basic hardware.

3 Circuit Concepts

3.1 Crossbar arrays

Crossbar structure is an array of switches connecting M number of inputs to N number of outputs. States of the switches (ON/OFF) determine the outputs. These states can be set and reset by specific voltages. So, crossbar configuration of switches can be used to store values implying that it can be used as a memory device.

As Memristor has two states of resistance it can be used as an two state switch and its non-volatile nature of resistance is an added bonus. Non-volatile nature implies it can hold the resistance value even after withdrawing the applied voltage. so, it is possible to implement a simple memory device using memristor. Memristor voltage and current characteristics gives an insight of the two states low resistance (R_{OFF}) and high resistance(R_{ON}). It is possible to switch from one resistance to other just by applying appropriate voltages.

When a crossbar array is constructed using memristors large amount of data can be stored in a very small area. One of the biggest drawbacks of memristive crossbar is sneak path currents which pass through the path that's not selected, resulting in lower accuracy and higher power consumption.

3.2 Memristor based Threshold logic gates

Threshold logic gate is defined by a simple function, where the weighted sum of inputs is calculated and is compared with a threshold value. if the weighted sum turned out to surpass the threshold value the value of the output is set to one and zero otherwise. Memristors are used as input weights in memristor based threshold logic circuits [4].

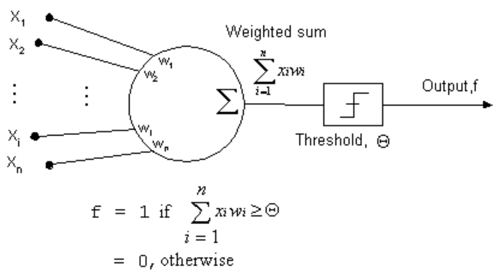

Fig. 1. TLG with n inputs x_i and corresponding weights w_i. source: [5]

3.3 Content addressable memory

CAM is like an associative array in a programming language, it compares the current input against the data that has been in CAM already. Inputs to the CAM are given by the search lines and when an input matches with a stored data, outputs are given by a match line. Search and match operation for whole CAM array is done in a single clock cycle and is very fast. Crossbar CAM has issues of high power consumption, a memristor based implementation of CAM dissipates less power.

4 Description of method proposed in [1]:

4.1 Algorithm of the method in [1]:

Two consecutive frames from a video are obtained, these frames are converted from their respective colour space to grayscale of 8-bit format. From these two consecutive grayscale images respective 8 bit planes are extracted which are nothing but 8 binary images.

These 8 binary images(bit-planes) of previous frame are used for comparison against the corresponding binary images(bit-planes) of current frame.
Steps involved in the algorithm developed for moving object detection using extracted bit planes by Dastanova et al. [1] :

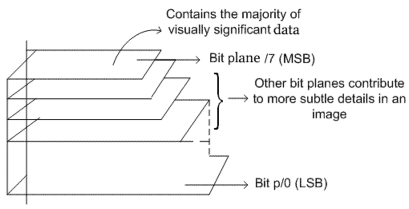

Fig. 2. Bit plane representation of an image [6].

1. Consecutive colored frames(previous and current frames as $frame_i$,$frame_i+1$) are extracted from a video
2. The extracted colored frames are converted to grayscale mode in 8-bit format ($grayframe_i$,$grayframe_i+1$)
3. 8 bit planes are generated for both previous and current grayscale frames by following the below equation. Y is the grayscale pixel value, k= bit number, mod is modulo operation, a_k is the bit value.

$$(floor(\frac{Y}{2^k})) \mod 2 = a_k \tag{3}$$

4. As mentioned in Fig.2. only higher order bit planes has more details than the lower order bit planes.Only higher order bit planes are stored.
5. The stored higher order planes(in crossbar array) of two consecutive frames(previous frame, current frame) are compared by performing XOR operation between them. a_k, b_k, c_k corresponds to k-th bit values of the pixel from previous frame, current frame and xor'ed bit value. $a_k \oplus b_k = c_k$
6. Resultant grayscale image (Y_r) is reconstructed after XOR operation is done using weighted summation of c_k and 2^k for higher order bit planes(k= 4 to 7).

$$\sum_{k=4}^{7} 2^k * c_k = Y_r \tag{4}$$

7. Resultant grayscale image (Y_r) is thresholded to observe the moving object based on the input of consecutive frames

4.2 Hardware realization

The algorithm flow mentioned can be realized using circuits after a pre-processing algorithm selects video frames samples.

Memristor based Crossbar arrays are used to store the processed frames. Only, higher order bit planes are stored in crossbar arrays using two row-by-row write cycles with help of a control unit. Memory states of an memristor can be read by applying a read voltage V_r and can be written by applying V_w. Where $V_r < V_t < V_w$ and V_t is the threshold voltage. A new modular approach

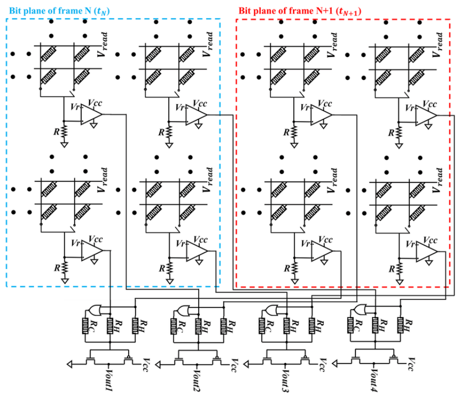

Fig. 3. Memristive Cross bar array modular approach. [1]

of memristor crossbar array is used , where the frame is split into small parts and saved in smaller cross bar arrays. Modular approach optimally reduces sneak path currents and very high power dissipation, but requires a special control unit to parallel read the data from smaller crossbar arrays. Each smaller crossbar array unit is connected to XOR Threshold logic gate using a readout circuit. The bit-planes stored in respective crossbar arrays of both frames (Previous and current) are compared using XOR TLG unit to give compared bit-planes.

XOR TLG circuit is integrated with the crossbar arrays as show in Fig.3. TLG XOR unit is a voltage controlled threshold logic gate. It is controlled by voltage V_C. Weights are stored in memristors R_H. During the XOR operation both the memristors R_H should be in high resistive state [7]. V_C is calculated by NOR gating of the input voltages to the TLG unit. Threshold operation is done using an CMOS inverter, where V_{out} is 1(HIGH) if and only if V_c is less than the threshold voltage V_{th}.
After comparison of bit-planes using Memristive TLG XOR gates, gray scale image is reconstructed using higher order compared bit-planes. Reconstruction from higher order bit planes is done using Weighted addition of bit planes. Weighted addition can be realized using operational amplifier in summing amplifier configuration as shown in Fig.4. As mentioned in the Fig.4. Weights of

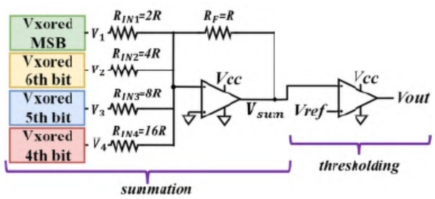

Fig. 4. Weighted sum and thresholding circuit [1]

the XOR'ed bits are realized using choosing appropriate input resistance. The ratio of feedback resistance R_F to R_{IN} gives the weights of respective input voltages. Voltage V_1 constitutes to MSB of the bits, and as it carries most details , it has to be given higher weightage. In order to provide higher weight to V_1, choose R_{IN1} in such a way that it has lowest value among the input resistances, See Equation.5. [1]. V_{sum} is the output voltage of the summing amplifier and the voltage V_{sum} thresholded using op-amp comparator w.r.t threshold voltage V_{ref}.

$$V_{sum} = -[\frac{R_F}{R_{IN1}}V_1 + \frac{R_F}{R_{IN2}}V_2 + \frac{R_F}{R_{IN3}}V_3 + \frac{R_F}{R_{IN4}}V_4] \quad (5)$$

Once the image frame is reconstructed from compared bit planes and is thresholded, it is stored in a CAM array to compare it with the result of comparison of upcoming pair of frames.

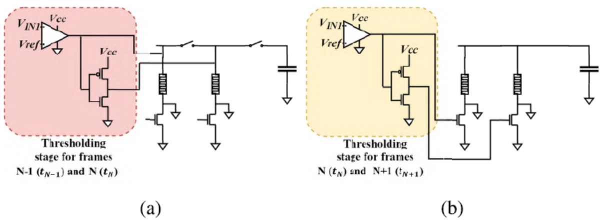

Fig. 5. Write and Read cycles of CAM array, (a) Write Cycle (b) Read Cycle [1]

CAM array is realized using 2 transistor and 2 memristor(2T-2M) cell as in Fig.5.. Each cell is for storing each bit(resulted from compared and thresholded bit-plane). During write cycle, the bits from comparison of previous frame and current frame are written into an memristor.During the write cycle, the capacitor and transistor are disconnected. During Read cycle outputs of current and next pair of frames compared and thresholded outputs are provided as inputs to transistors in the cell. If the search outcome is a match(no discharge of capacitor) and if it is a mismatch(discharge of capacitor). Based on discharge curve of the capacitor, it it possible to determine the direction of the object movement(which is based on three frames: previous,current,next).

5 Results

When compared to the conventional methods for detection of moving objects, discussed method performs equal or better in terms of accuracy,specificity,false negative rate and false positive rates etc.Apart from the performance metric, discussed method(Memristor based design) is also efficient in terms of power

Component	CMOS design		Memristive design	
	area	*power*	*area*	*power*
CAM cell	4.000 μm^2	8.880 pW	2.005 μm^2	6.250 pW
XOR gate	3.015 μm^2	30.123 μW	6.000 μm^2	0.551 μW

Fig. 6. Area,Power of CMOS based design and Memristor based design [1]

when compared to a CMOS design for both CAM cell and XOR gate. But, in terms of area Memristor based design of XOR gate occupies relatively large area than CMOS based XOR gate. Discussed method reduces the effect of sneak path currents on accuracy by following a modular approach.

6 Conclusion

Bit-plane extraction based moving object detection uses memristor based Crossbar to store images in bit planes. The respective bit planes of consecutive frames are compared using Threshold logic gates, following the thresholding process grayscale images are generated by weighted sum of compared bit planes using a summation amplifier. The generated gray scale image is thresholded to obtain a binary image of moving object. Final stage comprises of CAM used for storing for long term and also for giving direction of movement. Memristor based CAM arrays significantly reduces the power consumption and on-chip area, than the CMOS based design, it makes the whole approach appropriate to be integrated with existing image sensor units and for edge processing tasks. Memristor based design has also performed better than the FPGA based implementation. Power consumption of the memristor based approach can be further reduced by using a very low power summing amplifier and replacing resistors (in Fig.4.)with memristors.

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