

A MIXED SIGNAL ENHANCED WTA TRACKING SYSTEM VIA 2-D DYNAMIC ELEMENT MATCHING

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ABSTRACT

An approach for implementing a two dimensional dynamic element matching (DEM) technique for enhancement of a mixed signal WTA tracking system is shown to be achieved. The system consists of a version of a commonly used winner-take-all (WTA) for brightest object tracking, which is traditionally implemented as an analog circuit and suitable for integration with CMOS Active Pixel Sensors (APS). It rapidly outputs the location of the most salient object in the field of view for tracking and navigation purposes. In this WTA version, the DEM technique has been employed for compensating the matching problems of the APS and WTA, as well as compensating for errors in location of objects with finite dimensions.

This system contains an analog part together with a control module implemented as a digital circuit. This digital part enables a high level of flexibility in implementing various processing functions.

System operation is discussed and simulation results are reported.

1. INTRODUCTION

A Winner-take-all (WTA) circuit, which identifies the one of the highest signal intensity among multiple inputs, is one of the most important building blocks for neural networks hardware realizations [1] and image processing applications [2]. The function of 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 output value.

WTA circuits would be very useful in many scientific, commercial and consumer applications, where spatial acquisition and tracking of the main object of interest is sought. For example, it can be the brightest object in the case of image processing, the greatest pressure point in case of pressure sensing, etc.

Many WTA circuit implementations have been proposed in the literature [3-6]. A current-mode MOS analog implementation of the WTA function was first introduced by Lazzaro [1]. Later, this circuit has been modified by Starzyk and Fang [3] by improving resolution and speed performance. In 1995 DeWeerth and Morris have added distributed hysteresis using a resistive network [4]. Some WTA circuits were designed specially for image processing, in which inputs are not stationary [4]. Most of the works describe a one-dimensional, n-element array of WTA. Others, for example [5,6], discuss 2-D arrays.

In this work we are interested in tracking the brightest point object. Due to many reasons, such as atmosphere distortions (turbulence, etc...), high resolution of APS and matching problems, this point object is translated eventually to a number of potential

winners with the same value, which form an object which will be further referred to as the "perceived object". In this case there might be an error between the actual coordinates of the point object and the one found. We are interested in some method that can reduce the error and will yield the result that is as close as possible to the real one.

This paper presents a mixed signal architecture of a WTA circuit using the Dynamic Element Matching (DEM) method. The reason for the mixed WTA circuit choice is the high flexibility in the design of the digital parts, i.e. adaptation to different frame sizes, simple changes for enlarging the number of bits, high precision of digital data storage (no leakage from capacitors) and simplicity in re-design (technology and process changes) as well as the high speed of the analog parts.

In order to reduce the possible errors mentioned above in the winner selection results, the DEM method is proposed. There are many kinds and uses of DEM algorithms that will be briefly described later. The aim behind using a DEM method here is to find a location, which is as close as possible to the real one.

Section 2 describes the system of a mixed signal WTA circuit architecture using the DEM. The detailed description of the Dynamic Element Matching technique used is described in Section 3. Section 4 describes the performance of the system including simulation results. Section 5 concludes the paper.

2. MIXED SIGNAL WTA SYSTEM DESCRIPTION

2.1. Existing possible solution

As mentioned in Section 1, the 2-D WTA circuit finds the maximum value item out of a 2-D array, APS in our case. Suppose we have a "perceived object", as can be seen in Fig.1(a) and suppose that the APS size is $n \times n$. The figure shows one of the possible solutions of a WTA 2-D implementation. The winner selection is done row by row, finding the winner of each row and storing its value into an analog/digital memory (depending on the WTA type), as well as its address. The result is a column of n analog/digital pixel values of row winners with their column addresses. Then, amongst all row winners a global winner is selected.

A problem arises when there is more than one potential winner. It can occur in the case where the difference between potential winner values is less than the resolution of the analog/digital WTA. In this case, there is a possibility of several winners in the output of the circuit. In order to prevent this error in the output, a daisy chain solution can be used. In this solution there is a preference to the extreme pixel in the row. The worst case is when all pixels have the same value (the difference between pixel values is less than the

resolution of the WTA). This example can be seen in Fig 1 (a), where the left side pixels are chosen in the case of several potential winners in a row. As was mentioned above, the next stage is a global winner location, while using the same WTA approach, which also finds an extreme value out of all possible. Fig 1 (b) shows the final result of these operations.

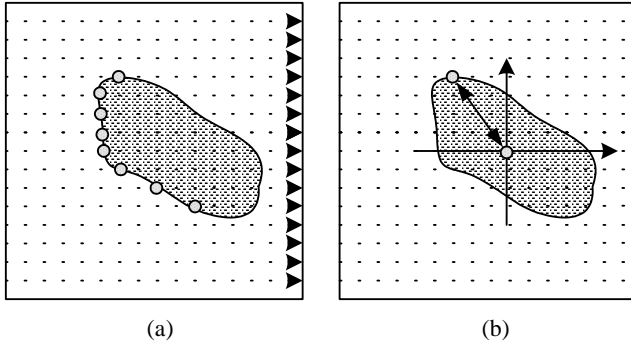


Fig.1 The possible WTA solution (a) The “Perceived image” with the extreme pixels chosen in the rows, (b) The global winner location as selected by the WTA and the real one (the difference described by the arrow).

It can be seen that there is a difference between the coordinates of the selected winner and these of the correct one. This error depends on the object form – usually larger objects would cause larger errors. The problem can be solved by using a mixed signal winner-take-all circuit with the dynamic element matching technique.

2.2. The mixed signal WTA System using DEM - description

Fig 2 shows the principle scheme of a 2-D WTA system employing the DEM approach. This system includes the scanned object (by the APS for example) with a row decoder, row comparators, a D/A controlled by a counter module, a row winner detection block, which consists of a 1-D Row DEM module and Row winners storage with a 1-D column DEM, that allows to implement a 2-D algorithm for winner detection.

In this system the object of interest is scanned row-by-row using the Row Decoder. The resulting output is a row, consisting of voltage representations of pixels brightness (as mentioned above an APS matrix is used as an example of a scanning system). The row is further fed to a row of analog comparators. These values are compared to the reference ramp levels generated by a D/A, which is controlled by the counter module. The precision of the WTA function is determined by the D/A resolution, while an analog comparator precision determines the D/A step itself.

The ramp module lowers the reference voltage applied to the comparators and when it reaches the maximum value of the current scanned row, the ramp generation stops and the maximum value detection is started. At that point, more than one comparator can detect a maximum value pixel in the row. In this case there exists an uncertainty in choosing the row winner out of several possible candidates.

As mentioned above an extreme pixel choice will cause an error in finding a row winner. Applying a DEM approach to choosing the row winner will minimize that error. Generally, DEM is a method of a dynamic choice of n objects out of m possible, where $n \leq m$. In our case $n = 1$. Since 1973 the subject of the DEM has been extensively covered in the literature [7-11] and numerous

algorithms have been described. A more detailed description of the DEM method used will be presented in Section 3. However, we

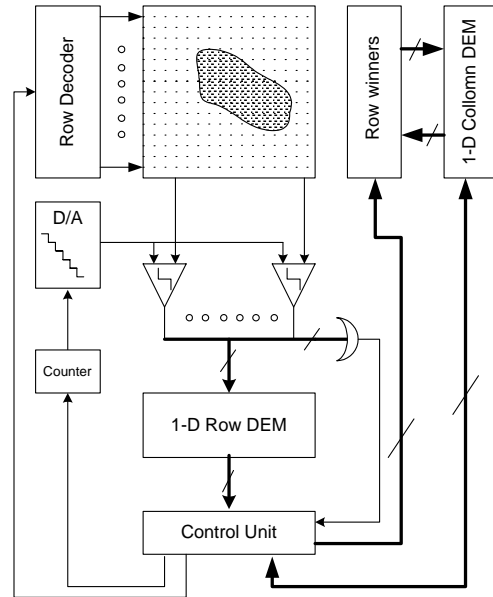


Fig.2 The principle scheme of the 2-D WTA system employing the DEM approach.

would like to mention here that the Data Weighted Averaging (DWA) based technique [11] was used in our case. A Dynamic Element Matching Row module finds the winner of a row and as a result, the control unit stores the winner’s digital value and the column address in the corresponding place in a “row winners” memory. The function of the control unit is to generate all clocks and control signals in the system. At a certain stage (after scanning the whole frame) all row winners are stored in the “row winners” memory.

Now we would like to expand the system to a 2-dimensional one. Actually we apply the same algorithm of Dynamic Element Matching in order to find the winner of the whole frame, as while finding the frame winner we face a possibility of existence of several candidates with the same value. This is done by the “1-D column DEM” block.

3. Dynamic Element Matching

An early description of the Dynamic Element Matching principle was given in a patent by Van de Plassche [7] from 1976. His system is based on a permutation circuit, which transfers to the output of the circuit, according to a cyclic permutation, a number of currents, which differ in their values due to the limited accuracy of the fabrication process. Each of the currents at the output of the permutation circuit comprises a direct current of a value equal to the average value of the currents and a ripple. The ripple is formed by the differences between the currents and can be removed by a capacitor (which acts as low pass filter) connected to each output of the permutation circuit.

Later, Van de Plassche described a high accuracy D/A converter, which employed the DEM principle [8]. Since then numerous patents and publications emerged [9-10], describing use of the DEM algorithms in current generators design, as well as for achieving high integral linearity and low total harmonic distortion

(THD) in D/A and A/D converters, without requiring precisely matched components. As mentioned above, the Data Weighted Averaging (DWA) DEM based method has been employed in our system. The DWA algorithm was developed by H. S. Jackson [11]. In this method depicted in Fig. 3, the elements, which are selected, rotate thought the array. In this example, in the first row, the 4 most left elements are selected. In the second row, the next 3 elements are selected, i.e. the column address of the first chosen element in the next row is adjacent to the last one in the previous row.

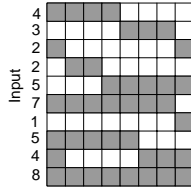


Fig. 3 DWA algorithm principle for an 8-element system: the element usage pattern.

There are a number of differences between the classic DWA method and the one that is used in our system. First, the algorithm is applied in 2 dimensions. Secondly, only one element can be chosen at a time and the elements that can be chosen are the potential winners only (all pixels that have been translated to the same value). Fig. 4 shows the effect of a 2-D DWA algorithm applied to the object (all pixels which are shown in gray are potential winners). A dotted line designates the contours of the object. As was mentioned before, the results are obtained per frame by sequentially applying a 1-D row DEM and a 1-D column DEM (described in the next sub-sections).

1-D row DEM

We introduce a winner pointer, which points to a winner of the last scanned row. The reset value of the pointer is the first column. Note that the pointer value is not reset between subsequent frames. We find a column address of the current row winner, having one or more potential winners, and a pointer to the winner of the last row. The winner of the current row is the first potential winner adjacent to the winner pointer. After tracking the next winner, the winner pointer receives its column address, moving only in one permanent direction upon which was decided up front.

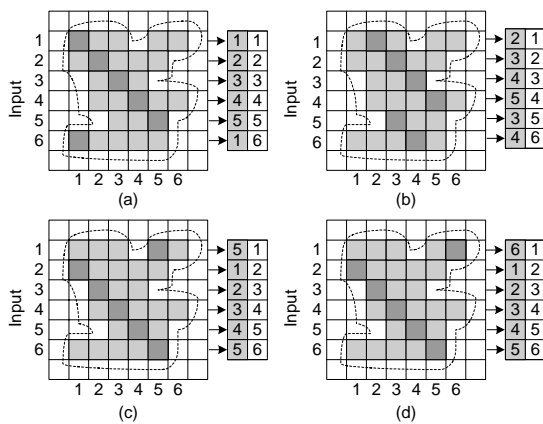


Fig. 4. 1-D row DWA algorithm stages, as applied to the APS object.

Fig. 4 shows a sequence of 4 subsequent scanned frames, where we consider a “perceived object” (where the pixels are designated in gray), the APS matrix dimensions are 6*6. The pixels that are shown in black are row winners.

1-D column DEM

The same method is used for detecting the global winner. Fig. 5 shows a process of finding it out of several candidates for 8 subsequent frame scanings. In this case a column winner pointer has an identical function to that of the row winner pointer and is initialized to the first row address.

To track the coordinates of the winner pixel we find an average of coordinates of all the global winners received after repeated scanning of the object. It must be noted that because of a possibility of a dynamic object, an image must be scanned $n*m$ times per second, where m is the video frequency and n is a factor depending on wanted precision in locating a winner pixel in the object. As can be seen from the simulation results (included in Section 4) the average coordinates limits to the coordinate of the object. The function of coordinates averaging is analogous to low pass filtering applied to the results of DEM algorithms in D/A converters designs.

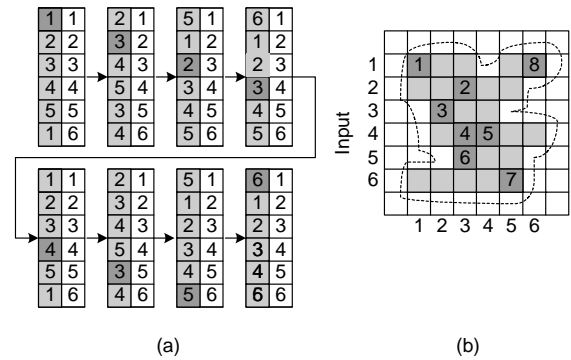


Fig. 5. The final stage: 1-D column DWA selection (following the row DWA data described in Fig. 4).

4. PERFORMANCE AND SIMULATIONS

Simulation results of the proposed algorithm are presented here. As mentioned above, the precision of the final result depends on numerous parameters such as the scanning frequency, the APS resolution, the object speed, size and the chosen DAC precision. In case of a large “perceived object”, high APS resolution and high object speed, higher scanning frequency is required. The results presented here are an example of a “perceived object” of 68 pixels. The parameter n was set to 9, i.e. the image must be scanned $9*Video\ Frequency$ times per second. A number of simulations were performed in order to estimate the influence of the regular WTA system and the proposed one, using the DEM algorithm, on the final results. Suppose the simulated system consists of a $64*64$ APS array followed by the WTA system. Fig. 6 shows the APS output from the array to the WTA system.

The high analog values correspond to a high value of the illumination intensity. A zoom of the highest values area is shown in Fig. 7(a). Due to the limited precision of analog components (D/A, comparators, etc...), these values are translated to a “perceived object” that is shown in Fig. 7(b). A WTA with the DEM Data Weighted Averaging method was applied to it. After $n = 9$ scanings, the final result was calculated as an average

of all received locations coordinates. Fig. 8 shows the distribution of the chosen locations. The vertical axes shows how many times every pixel was chosen as the global winner due to 9 scannings.

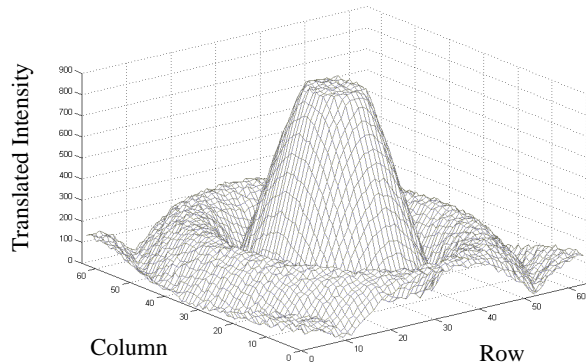


Fig.6. The APS array output (WTA input).

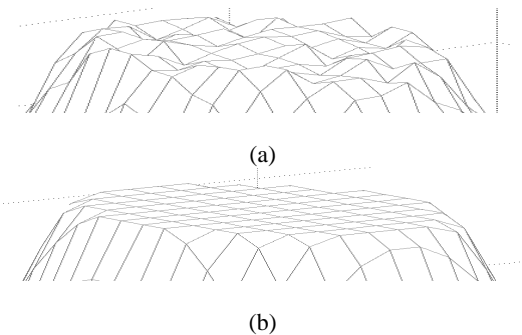


Fig. 7 (a) Zoom of highest values area, (b) The "Perceived object"

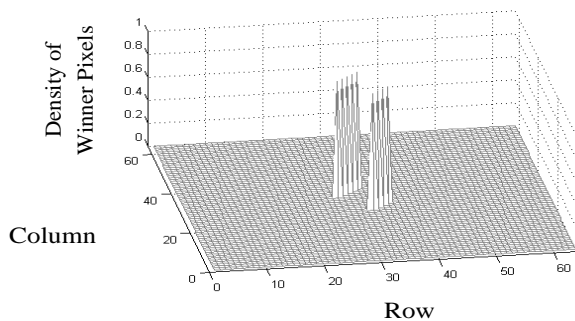


Fig.8. Distribution of the chosen locations

The ideal result for the given "perceived object" would be its center of mass, which is [32.5,32.5]. Applying an ordinary WTA method according to the configuration described above yielded the following result: [28.0,31.0]. Using the WTA with DEM Data Weighted Averaging method yielded the location [32,32.67]. As can be seen in the first case (a regular WTA circuit) the mismatch, measured from center of mass location was [-4.5,-1.5], while using the DEM algorithm yielded the mismatch of [-0.5,0.17]. It can be seen that a mismatch in the final object location is much smaller in the latter case.

5. CONCLUSIONS

System description, architecture and simulation results of an enhanced WTA tracking systems via 2-D Dynamic Element Matching have been presented. The Data Weighted Averaging DEM based method has been employed in the system. The simulation results show that the system allows minimizing an error arising in tracking a coordinate of an object of interest. It can be seen from the simulations, for example, that in the case of "perceived object" of 68 pixels and only 9 scannings per frame the mismatch in the final object location was reduced from [-4.5,-1.5] to [-0.5,0.17] when using the proposed WTA system. As a continuation of this work, the tradeoffs between scanning frequency, APS resolution, object speed, size and the chosen DAC precision will be researched in the future. As can be seen from the simulation results of the WTA with the DEM method, the global winner location approximates the object's center of mass (COM). This might enable us to implement a COM location system using only a simple WTA circuit with this suggested DEM method.

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