Introduction

Pattern matching problem (Lewis, 1995; Ouyang et al., 2010) can be thought of as the matching of feature points representing an object or a pattern to an instance of that object given in a scene. It has extensive applications in object tracking and detection (Viola and Jones, 2001), shape matching (Lampert et al., 2008), image retrieval and industrial applications in automotive machine vision. For example, pattern
matching can be used for finding a pattern in a scene contains large number of objects, finding a particular face in a scene of crowd face images, finding a missing part of an object in some industrial products by inspecting on assembly line, etc. In those applications, a priori information about the target pattern is determined in the form of deformable shape, texture, boundary information, etc. The task of pattern matching is to find the pattern in the scene with some priori information. Moreover, the features which constitute the target pattern make the correspondence with features determined from a window in a scene by maximizing the similarity function. Fig. 1 shows an example of a scene where the input pattern to be searched.


In this paper, we are interested to develop a pattern matching algorithm which would be computationally efficient as well as it would find the target pattern as an instance in the given scene in faster way. In order to accomplish this task, the proposed algorithm uses Image Integral model (Ouyang et al., 2010) as Haar transform manipulator. As most of the pattern matching algorithms are not proved to be memory efficient, therefore large memory space requirement could be disastrous and at the same time performance can be degraded. Though the authors of Ouyang et al. (2010) use Haar like features to compute Haar Projection Values (HPVs) and for cumulative computation, Image Integral and Image Square Sum techniques are used. This particular combination (Ouyang et al., 2010) achieves the desired results and behaves like fast pattern matching algorithms. However in our paper, cumulative computation is performed using arithmetic operations, such as subtraction and division.

Rectangle sum (Ouyang et al., 2010) and Haar like features (Ouyang et al., 2010) are successfully applied in object detection (Viola and Jones, 2001), object classification (Lampert et al., 2008) and pattern matching (Tombari et al., 2009) problems. On the other hand, Integral Image (Ouyang et al., 2010) can be used to find rectangle sum and the corresponding Haar Projection Values (HPVs) (Ouyang et al., 2010) from an image using Haar wavelets. This paper suggests a novel pattern matching algorithm with two different variants to find the rectangle sum and HPVs using Image Cumulative Subtraction and Image Cumulative Division operations. Prior to apply cumulative operations, Haar like features are applied to both target pattern and windows of given scene to determine HPVs separately.

The rest of the paper is organized as follows. Section ‘Pattern matching techniques’ discusses the proposed pattern matching algorithm with two different variants. Concluding remarks are made in the last section.

**Pattern matching techniques**

**Image Cumulative Subtraction**

To compute HPVs (Ouyang et al., 2010) from both the target pattern and the candidate window, we apply Image Cumulative Subtraction (ICS) method. HPVs for any spatial location \((x, y)\) can be computed using ICS method is shown in Fig. 2 where the updated value (after cumulative subtraction) of spatial location \((x-1, y)\) and HPVs of all the spatial locations from \((x, 0)\) to \((x, y-1)\) are subtracted from the HPV of \((x, y)\). The Image Cumulative Subtraction algorithm is shown in Fig. 3. After computing HPVs, a correlation based metric is used to find a correspondence between the input pattern and a candidate window, and a predefined threshold decides whether the candidate window to be accepted or rejected. The cumulative subtraction operation is expressed by the following equation:

\[
ICS(x, y) = (g(x, y) - ICS(x-1, y)) - \sum_{i=0}^{y-1} g(x, i)
\]
Algorithm 1 Image Cumulative Subtraction (ICS) Algorithm

1. Let, IC(0,0) = g(0,0) and d, c are two matrices having all zeros with size h x w.
2. for x = 0 to h – 1 do
3.   for y = 0 to w – 1 do
4.     b(x,y) = g(x,y);
5.   end for
6. end for
7. for x = 1 to h – 1 do
8.   Compute ICS(x, 0) = g(x, 0) – ICS(x – 1, 0);
9. end for
10. for y = 1 to w – 1 do
11.   for k = 0 to y – 1 do
12.     d(0,y) = d(0,k) – d(0,y);
13.   end for
14.   Compute ICS(0, y) = g(0, y) – d(0, y);
15. end for
16. for x = 1 to h – 1 do
17.   for y = 0 to w – 1 do
18.     for k = 0 to y – 1 do
19.       c(x, y) = b(x, k) – c(x, y);
20.     end for
21.     ICS(x, y) = (g(x, y) – ICS(x – 1, y)) – c(x, y);
22. end for
23. end for

Image Cumulative Division

In this section, we present another method that calculates HPVs by computing the rectangle sum and we call this method Image Cumulative Division (ICD) as it uses arithmetic division operation. HPV calculation at any spatial location (x, y) using cumulative division method is shown in Fig. 2 where the HPV at (x, y) is divided by updated HPV (computed using cumulative division) of the spatial location (x – 1, y) and also divided by the values of all the locations from (x, 0) to (x, y – 1). The algorithm is given in Fig. 4. The cumulative division operation is expressed by the following equation

\[ ICD(x,y) = \frac{(g(x,y)/ICD(x-1,y))}{g(x,i)} \]

where \( i = 0, 1, \ldots, y – 1 \) (2)

Algorithm 2 Image Cumulative Division (ICD) Algorithm

1. Let, ICD(0,0) = g(0,0) and d, c are two matrices having all ones with size h x w.
2. for x = 0 to h – 1 do
3.   for y = 0 to w – 1 do
4.     b(x,y) = g(x,y);
5.   end for
6. end for
7. for x = 1 to h – 1 do
8.   Compute ICD(0, 0) = g(x, 0)/ICD(x – 1, 0);
9. end for
10. for y = 1 to w – 1 do
11.   for k = 0 to y – 1 do
12.     d(0,y) = b(0,k)/d(0,y);
13.   end for
14.   Compute ICD(0, y) = g(0, y)/d(0, y);
15. end for
16. for x = 1 to h – 1 do
17.   for y = 0 to w – 1 do
18.     for k = 0 to y – 1 do
19.       c(x, y) = b(x, k)/c(x, y);
20.     end for
21.     ICD(x, y) = (g(x,y)/ICD(x-1,y))/c(x, y);
22. end for
23. end for

The rectangle sum is computed using Image Cumulative Subtraction (ICS) can be expressed by

\[ Rect(ICS) = ICS(x + h, y + w) + ICS(x, y) – ICS(x, y + w) – ICS(x + h, y) \]

and rectangle sum using Image Cumulative Division (ICD) can
be expressed by $\text{Rect}(\text{ICD}) = \text{ICD}(x + h, y + w) + \text{ICD}(x, y) - \text{ICD}(x, y + w) - \text{ICD}(x + h, y)$, where $0 \leq x, x + h \leq H - 1$, $0 \leq y, y + w \leq W - 1$, $h > 0$, $w > 0$. To compute rectangle sum, both the cumulative operations need two subtractions and one addition. Further, HPV needs one more subtraction between two rectangle sums. Finally, the algorithm needs seven operations which include five subtractions and two additions.

**Conclusion**

This paper has presented a novel pattern matching algorithm which uses two different variants, such as Image Cumulative Subtraction (ICS) and Image Cumulative Division (ICD). The aim of these two methods is to compute rectangle sum using arithmetic operations. Further, in order to obtain HPVs from Haar like features, rectangle sum is found very effective method. Cumulative operations ICS and ICD can be used to compute orthogonal Haar transform (OHT) and then OHT is used as HPVs for equivalent pattern matching where ICS and ICD methods represent input image in small values compared to values calculated by cumulative sum in image integral. Moreover, the rectangle sum of a particular rectangle region calculated by cumulative sum for image integral is much higher than the rectangle sum calculated by the proposed cumulative operations.

**References**


