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COMPARATIVE STUDY OF THE METHODS USING HAAR-LIKE FEATURES

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ABSTRACT

Object detection is a topic which takes a great extent in the field of computer vision. Is the first step in many visual processing systems like face recognition, encoding recognition and lip reading. The detection of an object passes through three stages: The first is the extraction of information that characterize the object, the second is the processing of this information and the last step is to construct the final detector. We will focus on the first stage. Various approaches have been utilized such as Haar-Like features, color information, texture, edge orientation, etc. While numerous methods have been proposed to extract information using Haar-like feature, we are unaware of any surveys on this particular topic. For this reason this paper present a comparative study of different research on Haar-Like features.

KEYWORDS: Haar-Like Feature; Asymetric Haar Features; Rotated Features; Object detection; Viola and Jones.

INTRODUCTION

Object detection has been one of the most studied topics in the computer vision literature. To detect an object in an image, the detector must have knowledge of the object characteristics. In fact, the most important step in the objects detection is the extraction of object features. For this reason, various approaches have been utilized such as color information [5][7], texture, edge orientation [5], skin approach [5][6][7] etc. The most frequently used feature is probably color histogram [6] because color is directly available from image, and histogram is fast to compute. However, there are some drawbacks of color histogram. First of all, color is very sensitive to illumination, so it is not appropriate for the situations where lighting changes frequently. Second, color histogram is not straightforward to handle spatial information, and not sufficiently discriminative sometimes. So, most researchers integrate Haar-like features instead of color information.

Haar-like features have been widely used successfully in image sensors for face detection [9][12][16], face tracking and classification problems [8][11][14]. However other problems such as hand tracking [17][21], detection of pedestrian [25][1] and vehicle detection [27][28]. etc.

The use of Haar-Like features has three challenges to be met. The first challenge is the extent of its efficiency in the detection of objects. Due to the non-invariant nature of the normal Haar-like features, classifiers trained with this method are often incapable of finding rotated objects. It is possible to use rotated positive examples during training, but such a monolithic approach often results in inaccurate classifiers [11]. For this reason Various methods have attempted to solve this problem by introducing inclined features, by 45° [12], 67,7° [15] [18] [29] [16], generic angles [30], in the learning boosting stage.

The second challenge of the use of Haar-Like features remains in how to present them practically. For normal features, their presentation is easy to achieve practically. Contrariwise, the presentation of rotated features is a big challenge because the presentation of an inclined rectangle, in an image, at an angle different to 0°, would cause a distortion of his sides, which makes the determination of integral image very hard.

The third challenge is manifested in how to calculate the integral image of a rotated feature by any angle. The normal Integral Image is very easy to be calculated, that is done by summing the pixels values above and to the left of the given pixel [9]. But for rotated Haar-like feature, their computation is practically very hard; this is due to the distortion of their sides caused by their rotation. So the

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determination of the pixels forming these sides will be very difficult, and this will lose the Integral Image its simplicity and its quickness for which is defined by Viola & Jones [9].

We present the development of the use of haar-like features since their apparition by Papageorgiou et al. [1] that they have introduced a general framework for object detection using a Haar wavelet representation until they become more famous when viola and jones [9][10] have proposed to use them for their face detection algorithm. In their work, the result of integrating a wavelet with a patch is called a *Haar-like* feature, and they proposed a new image representation for extracting these Haar-like features efficiently, which is called integral image (c.f. summed area table), Haar-like features has become an increasingly indispensable tool for extracting information in the field of object detection. Several studies have focused on this segment, for example recall; e.Lienhart et al. [12][13] who introduced an extended set of twisted Haar-like feature (twisted at 45°). Afterwards Barczack et al [15][18] proposes a new approach to detect rotated objects at distinct angles using the Viola-Jones detector. The use of additional Integral Images makes an approximation the Haar-like features for any given angle. The proposed approach uses different types of Haar-like features, including features that compute areas at 45°, 26.5° and 63.5° of rotation. Then Ramirez et al [19] introduce the use of asymmetric Haar features, eliminating the requirement of equalized positive and negative regions in a feature. They propose Haar features with asymmetric regions that can have regions with either different width or height, but not both.

We conclude with several promising directions for future research.

THE WAVELET OF PAPAGEORGIOU

Papageorgiou et al presents a novel framework for object detection in cluttered scenes, based on a wavelet representation of an object class derived from a statistical analysis of the class instances. By learning an object class in terms of a subset of an overcomplete dictionary of wavelet basis functions. [3].

They were looking for an image representation which capture the relationship between average intensities of neighboring regions [1][2][3]. This suggests the use of a family of basis functions such as the Haar wavelets for an in depth description of wavelets, see [4], which encode such relationships along different orientations. To achieve the special resolution necessary for detection and to increase the expressive power of the model, they introduce the quadruple density transform [1], an extension of the 2D Haar wavelet (Fig 1-1), that yields an overcomplete set of basis functions. Whereas for a wavelet with size 2n, the standard Haar transform shifts each wavelet by n, the quadruple density transform shifts the wavelet by (¼)*2n in each direction, shown in Fig. 1-2. Otherwise for the 1D Haar transform, the distance between two neighboring wavelets at level n (with support of size 2n) is 2n.To obtain a denser set of basis functions that provide a richer model and finer spatial resolution, we need a set of redundant basis functions, or an overcomplete dictionary, where the distance between the wavelets at level n is by (¼)*2n (Fig. 1-c).

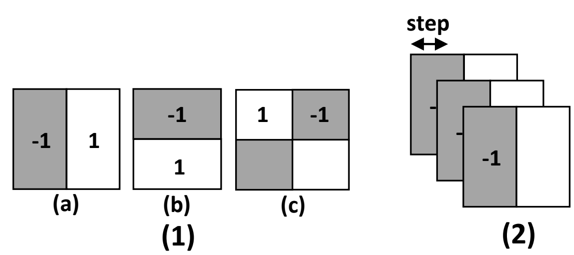

Figure 1. (1) the 3 types of 2-dimentional non-standard Haar wavelets; (a) vertical, (b) horizontal, (c) diagonal. (2) Quadruple density 2D Haar basis

Advantages

- The wavelet template have ability to capture high-level knowledge about the object class (structural information expressed as a set of constraints on the wavelet coefficients) and incorporate it into the low-level process of interpreting image intensities.
- The wavelet are independent to the variation of the illumination (instead of color).

Disadvantages

- Calculates the coefficients of wavelets by the average intensities of the pixels of a region may increase learning time
- This method gives a low detection rate, which can reach (53.8%) [3]
- Sensitive to the variation of poses (Object oriented)
- Does not allow real-time detection

THE VIOLA-JONES HAAR-LIKE FEATURES

If one were asked to name a single face detection algorithm that has the most impact in the 2000's, it

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will most likely be the seminal work by Viola and Jones [9][10]. The Viola-Jones detector has received considerable attention since its publication. It has been used mainly for face detection [11], face recognition [20] and hands detection [21]. Other uses include robot-soccer ball detection [22] and ecological applications such as wild life surveillance [23]. The work done by Viola and Jones has made face detection practically feasible in real world applications such as digital cameras and photo organization software.

Motivated by the work by Papageorgiou et al. [3], Viola and Jones have proposed a face detection algorithm based on *Haar-like features*, and new image representation for extracting Haar-like features efficiently, which is called *integral image* (c.f. summed area table) [9].

Haar-Like Features

The simple features used are reminiscent of Haar basis functions which have been used by Papageorgiou et al. [3]. They are computed similarly to the coefficients in the Haar wavelet transform. Each Haar-like feature is described by a template which includes connected black and white rectangles as shown in Fig. 2, their relative coordinates to the origin of the search window and the size of the feature. More specifically, Viola and Jones [9][10] use three kinds of features. The value of a two-rectangle feature is the difference between the sums of the pixels within two rectangular regions. The regions have the same size and shape and are horizontally or vertically adjacent (see Fig. 2). A three-rectangle feature computes the sum within two outside rectangles subtracted from the sum in a center rectangle. Finally a four-rectangle feature computes the difference between diagonal pairs of rectangles.

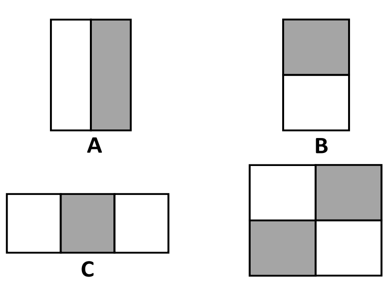

Figure 2: Example rectangle features shown relative to the enclosing detection window. Two-rectangle features are shown in (A) and (B). Figure (C) shows a three-rectangle feature, and (D) a four-rectangle feature.

Given that the base resolution of the detector is 24x24, the exhaustive set of rectangle features is quite large, 45,396 [9][10].

Image Integral representation

Rectangular two-dimensional image features can be computed rapidly using an intermediate representation called the *integral image* (c.f. summed area tables used in graphics [24]). The integral image, denoted ii(x, y), at location (x, y) contains the sum of the pixel values above and to the left of (x, y) (see Fig. 3-a), formally,

$$\mathrm{ii}(x,y) = \sum_{\substack{x' \le x \\ y' \le y}} \mathrm{i}(x', y') \quad (1)$$

Where i(x, y) is the input image. The integral image can be computed in one-pass over the image using the following pair of recurrence:

$$s(x,y) = s(x,y-1) + i(x,y) \quad (2)$$
$$ii(x,y) = ii(x-1,y) + s(x,y) \quad (3)$$

Where s(x, y) denotes the cumulative row sum and s(x,-1) =ii (-1, y) = 0.

Using the integral image any rectangular sum can be computed in four array references (see Fig. 3-b). For example, to compute the sum of region D, the following four references are required: 4+1-(2+3). Clearly the difference between two rectangular sums can be computed in eight references. Since the two rectangle features defined above involve adjacent rectangular sums they can be computed in six array references, eight in the case of the three-rectangle features, and nine for four-rectangle features.

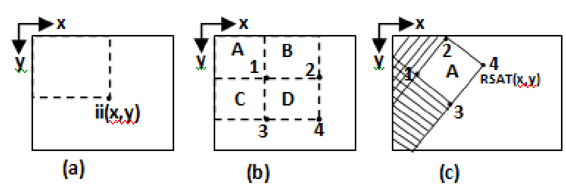

Figure 3: Integral image representation. (a) The value of the integral image at point (x,y) is the sum of all the pixels above and to the left. (b) The sum of the pixels within rectangle D can be computed with four array references. (c) calculation scheme of the pixel sum of rotated rectangles.

Jones and Viola further extended the Haar-like feature set to work on motion filtered images for

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video-based pedestrian detection. This extension called diagonal filters. These diagonal filters can be computed with 16 array references to the integral image. [11][25]

Advantages

- Haar-like features are more robust to illumination changes than color histogram
- The feature-based system operates much faster than a pixel-based system.
- The Integral Image allows the sum of pixel responses within a given sub-rectangle of an image to be computed quickly.
- Only several accesses to the integral image are required to extract a Haar-like feature response
- Allows real time detection

Disadvantages

- Haar-like features are not invariant over rotation. This means that any object that rotates is sensitive to angle changes will be difficult to solve using standard Haar-like features.

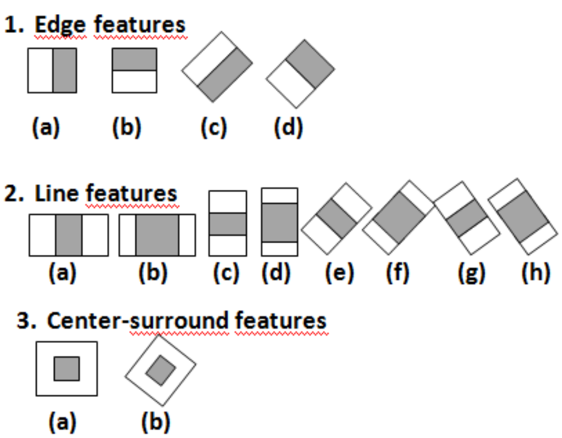

Figure 4: Feature prototypes of simple haar-like and center-surround features. Black areas have negative and white areas positive weights

ORIENTED 45° HAAR-LIKE FEATURE

Novel set of Haar-Like Features

As already mentioned above, the set of haar-like features created by Viola and Jones have one major drawback is their sensitivity to rotation of objects supposed to be detected. Therefore Lienhart and Maydt [12][13] introduced the concept of a tilted (45°) Haar-like feature (see Fig. 4). This was used to increase the dimensionality of the set of features in an attempt to improve the detection of objects in any angle. This was successful, as some of these features are able to describe the object in a better way. For example, a 2-rectangle tilted Haar-like feature can indicate the existence of an edge at 45°.

Fast Feature Computation

For 45° oriented rectangular features, Lienhart and Maydt [12][13] proposed an adaption of the integral image representation, they termed the rotated summed area table, denoted RSAT(x, y). The RSAT data structure yields the sum of pixels of the rectangle rotated by 45° with the rightmost corner located at (x,y) and extending to the image boundaries (see Fig. 3-c):

$$\mathrm{RSAT}(x,y) = \sum_{x' \le x,\, x' \le x-|y-y'|} i(x',y') \qquad (4)$$

RSAT(x, y) can be computed efficiently with two passes of the image. Rotated rectangles can be computed, like the integral image, with four table lookups. For example, to compute the sum of region A in Fig. 3-c, the following four references are required: 4+1-(2+3).

Advantages

- In addition to the advantages cited for basic Haar-Like Features, this novel set allows the detection of rotated objects at 45°.
- A new method to calculate the rotated integral image that retains the major advantage for which it was invented by Viola & Jones, which is: speed and simplicity.

Disadvantages

- But we cannot detect objects rotated at any angle other than 45°.
- We always need to calculate, for each image, two integrale images, and this infects the performance of the detector.

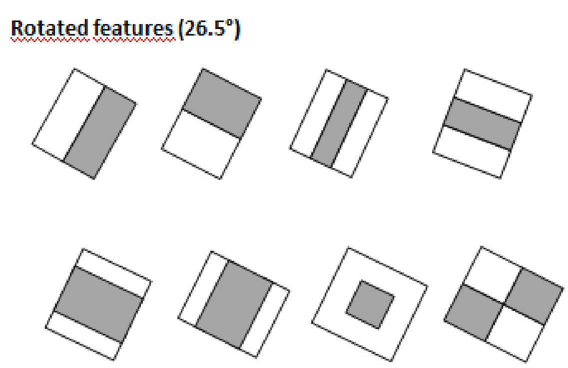

Figure 5:Additional Haar-Like features used in [15]

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ORIENTED HAAR-LIKE FEATURE FOR A GENERIC ANGLE

The extended set of haar like feature

As presented at the end of the previous section, classifiers trained with the set of Haar-Like features presented in Fig. 4, are often incapable of finding rotated objects at angle different to 45°.

For that reason the authors of [15][17] are proposed an approach that uses different types of Haar-like features presented in Fig. 4, including additional features at angles 26.5° and 63.5° (see Fig. 5).

The integral image of the feature at angle 26,57° (63.5°)

The problem of Haar-like features rotated, is to find pixels forming its sides and its vertexes in order to get the correct alignment so that the Integral Image can supply the correct sum of pixels. For the angle 45° the operation is simple but for others angles the operation becomes more and more very difficult.

Barczak et al. [15] gave a solution to 26,5° as shown in Fig. 6. Each element of the Integral Image will cover different areas of the image. There are four cases that depend on the parity of the coordinates (I1 is (even,even), I2 is (odd,odd), I3 is (even,odd) and I4 is (odd,even) coordinates). The Integral Image can be computed recursively using the following equations:

$I_{1(x,y)}=I_{(x-1,y)}+I_{(x,y-1)}-I_{(x-1,y-1)}+im_{(x,y)}$

$I_{2(x,y)}=I_{(x+1,y-1)}+I_{(x-1,y-1)}-I_{(x-1,y-2)}+im_{(x,y)}$

$I_{3(x,y)}=I_{(x-1,y)}+I_{(x+1,y-1)}-I_{(x,y-2)}+im_{(x,y)}$

$I_{4(x,y)}=I_{(x-1,y-1)}+I_{(x+1,y-2)}-I_{(x,y-2)}+im_{(x,y)}+im_{(x,y-1)}$

Where: $im_{(x;y)}$ is the pixel value.

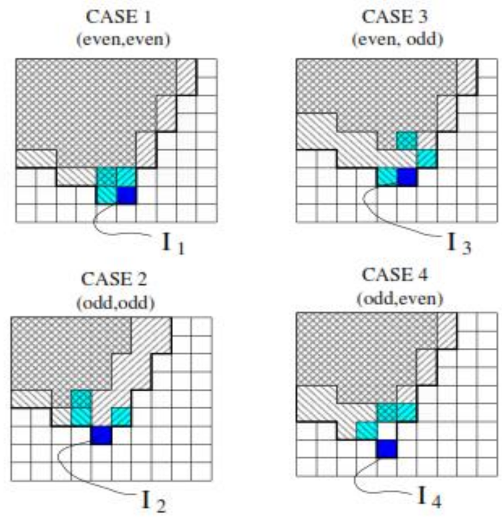

Figure 6: Computing the Integral Image for 26.56° recursively

However S.Du et al. [16] calculates the integral image of these angles without taking considerations these four cases presented by [15], they use the same method presented by [12][13]. In Fig. 7, for each pixel point (x,y), its integral image S(x,y) can be calculated by iteration:

$R_{(x,y)}=R_{(x+1,y-2)}+I_{(x,y)}$

$S_{(x,y)}=S_{(x-2,y-1)}+R_{(x,y)}+R_{(x-1,y-1)}+R_{(x,y-1)}+R_{(x-1,y-2)}+R_{(x,y-2)}$

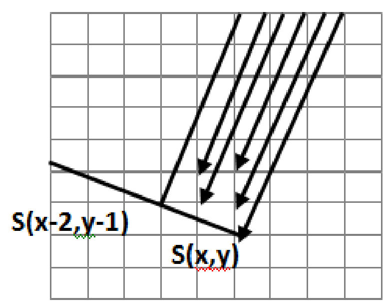

Figure 7: The calculation schedule of rotated integral images at angle 26.5◦ shown in [16]

Advantages

- In addition to the advantages cited for Haar-Like Features in previous sections, this novel set allows the detection of rotated objects at 26.5° and 63.5°.

Disadvantages

- But we cannot detect objects rotated at any angle other than 45°, 26.5° and 63.5°.
- Calculating the integral image becomes increasingly difficult; with this method we

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have to create integral image for each angle, indeed, we need 4 integral images at each computing operation, therefore this cost the technical its speed and its simplicity.

The integral image of the feature at a generic angle

Pair of equivalent features (PEF)

Barczak et al. [15] propose using a function of the values of two features to approximate the value for a feature rotated at a generic angle. They call this approach *pair of equivalent features* (PEF).This is achieved using a weighted sum of the two equivalent features and a conversion of feature positions, feature sizes and feature types.

The value of the PEF can be approximate by the following equation:

$V=V_{normal}.(26.5° - \alpha)/26.5°+V_{26}.\alpha/26.5°$

Where: V_{normal} is the Value for the normal Feature, V_{26} is the value for the feature at 26.5° and V is the weighted average that depends on the angle α (between 0° and 26°). the authors also allows the use of other intervals of angles as [0°;45°], [45°;26.5°] etc.

With this method, rotated objects can be detected without specifically training the classier for that angle.

Advantages

- With PEF technique, we can detect an object at any angle.
- Rotated features can successfully convert a normal feature to angles close to 45°.
- Oriented features used by the classifier can be found without going through the phase of training, this saves computation time.

Disadvantages

- For angles at the vicinity of 22.5° the PEFs suffer from large errors that might affect the accuracy of the classifier.[15]
- PEF of an angle always depends on the integral image of one of the following angles: 45°, 63.5° and 26.5°, so if by chance, at the stage of the training, we did not find any property trained for these angles, therefore which method will no longer useful because we cannot find any rotated feature.
- When a rotated property is long, its PEF will be calculated from two properties exceeding the limits of the picture (or frame) which leads to incorrect results.

Integer rotated Haar-like Featurs

General rotations of Haar-like features cannot be easily implemented efficiently; therefore Messom and Barczak [18] define a restricted set of rotations called integer rotations that can be easily and efficiently implemented. They introduced two new concepts: *Integer Rotated Haar-Like Feature* and *Unit-Integer Rotated Haar-like Feature*. The *Integer Rotated Haar-Like Feature* is a feature that has been rotated by an angle arctan(A/B) where A and B are integers. This means that an integer rotated line consists of all angles that have a rational tangent. A 45° rotated Haar-like feature is a special case of a feature which has been 1-1 integer rotated. A *Unit-Integer Rotated Haar-like Feature* is a feature that has been rotated by an angle arctan(A/B) where A and B are integers and either A or B is 1. For Messom and Barczak they are discussed unit-integer rotated features, which restricts the angles available to those listed in table 1.

Fig. 8 shows the use of rational number A/B to find a unit-integer rotated feature.

In order to determine the rotated integral image for a given integer rotation, Messom and Barczak [18] extended the algorithm used by Lienhart et al [12][13] that determines the integral image for a 45° twisted feature which is equivalent to the 1-1 integer rotated image.

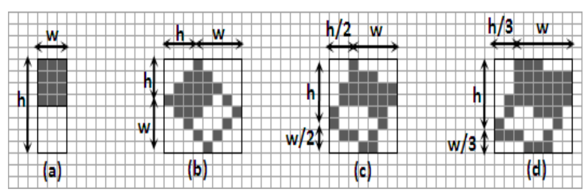

Figure 8. (a) The upright rectangle feature, and set of unit-integer rotated features (b) 1-1, (c) 1-2, (d) 1-3.

Advantages

- The use of this method can detect rotated objects by many other angles other than 45°, 63.5° and 26.5°. Each angle is equal to arctan (A/B) where A and B are integers but A or B should equal to 1.

Disadvantages

- The rotated objects by an angle arctan (A/B) such that A and B are different from 1, cannot be detected by this method.
- The calculation of the integral image becomes difficult when the angle is different from ordinary angles such as 45°, 63.5° and 26.5°.

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Table 1. Unit-Integer Rotation Angles

N-1	Angle	1-N	Angle
1-1	45°	1-1	45°
2-1	63.43°	1-2	26.57°
3-1	71.57°	1-3	18.43°
4-1	75.96°	1-4	14.04°
5-1	78.69°	1-5	11.31°
6-1	80.54°	1-6	9.46°
…	…	…	…

ASYMMETRIC HAAR FEATURE

Ramirez et al. [19] propose an extension for basic Haar features, which they call *Asymmetric region Haar features*, which are shown in Fig. 9. In contrast with basic Haar features, these new features can have regions with different width or height, but not both. They have shown that these features are able to capture defining characteristics of objects more accurately than traditional ones, allowing the development of simpler and more effective classifiers. By allowing asymmetry, the number of possible configurations for Haar features grows exponentially and is an overcomplete set. For the 6 Haar features shown in Fig. 9, there are around 200 million possible configurations for a 24 × 24 image. Using all the possible configurations is unfeasible, therefore, to deal with this limitation they propose to use a Genetic Algorithm to select a subset of features [19].

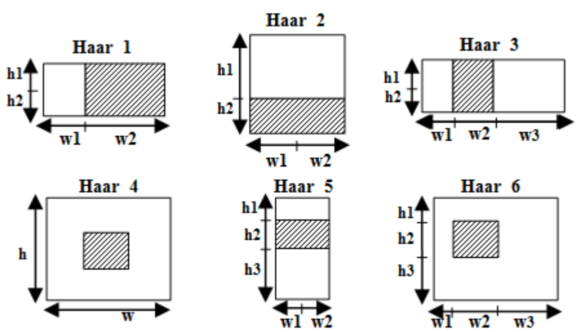

Figure 9:Assymetric Haar features.

Advantages

- This method allows extracting more Haar features than the others described above.
- Ability to detect an object in multiple poses.

Disadvantages

- Computation time is higher.
- The problem of the efficiency of Genetic algorithm to choose appropriate properties.

CONCLUSION

In this paper, we surveyed some of the recent advances in use of Haar-like features to detect an object. we try to make a comparative study of different methods with their advantages and disadvantages.

The Haar features used in the work by Viola and Jones [9] are very simple and effective for non rotated object for example frontal face detection, but they are less ideal for object at arbitrary poses. Complex features may increase the computational complexity, though they can be used in the form of a post-filter and still be efficient, which may significantly improve the detector's performance. Regarding learning, the boosting learning scheme is great if all the features can be pre-specified.

Significant progress has been made in the last decade, there is still work to be done, and we believe that a robust object detection system should be effective under the use of this type of features. We therefore believe that future work should invest in the use of the Haar-like features due to their two major advantages which are simplicity and speed and also their usefulness in real time detections. For this reason we must think of using small sets of complex features and also think of methods to calculate the integral image simpler and faster as we did in [30].

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