State of the art of smoke and fire detection using image processing

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State of the art of smoke and fire detection using image processing

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Abstract: In this paper we present a comprehensive review of the state of the art of smoke and fire detection techniques using image processing. Smoke is a good indicator of a pre-fire condition and many fires are indicators of subsequent dangerous situations due to the spread of fire. In this paper we first start our comparison of smoke detection methods and different types of approaches for the classification of smoke. Furthermore we analyse different types of technologies and various models involve in detection techniques such as RGB and HSI models for detecting smoke and fire. Generally, the false alarm rate can be reduced by image processing through effective types of detection techniques such as vision-based or sensor-based methods. Mainly in this paper, we focus on optimised technologies in order to detect smoke and fire at the earliest possible stage of the event, and smoke and fire detection by satellite vision methods.

Keywords: edge detection; flame detection; RGB-HSI model; satellite vision based detection; smoke detection; vision-based motion.

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1 Introduction

There are many technologies available for smoke and fire detection but still society is lacking reliable and accurate methods to predict smoke and fire at early stages, this deficiency may then lead to dangerous situations. This paper describes state of the art of different techniques used for smoke detection, fire detection and classification which may help to better understand the problem in hand. In addition to preventing disasters, this study of smoke and fire detection and classification can be incorporated into bio-mass gasification and other real- time applications (Samantaray and Mohanta, 2015; Li et al., 2013) for commercial use.

Various techniques involved in image-based processing are more effective than utilising specialised sensors to detect smoke. In image processing, smoke can be identified using image data and information of smoke shape. Smoke identification techniques are very important for testing in open environments (Ko et al., 2011), for example, in ports, in power plants, etc. as they can hurt users, whereas generic smoke sensors are capable of recognising smoke effectively in closed spaces.

The image information source may be a 2D image source which can be considered as parameters and it is difficult to extract the features or the qualities of smoke features (Costantini et al., 2008). Different methods of extracting arrangements of the elements can be performed by utilising the image handling techniques. Distinctive smoke identification strategies and their examination are essential for accuracy of image of smoke detection. We discuss more about this topic in Sections 4 and 5.

Video recognition can also play a vital role in fire security. Video handling is used for detecting wood fires, because these are harmful fires compared with building fires and can easily spread to neighbouring places to make harm to human life. Flares and/or smoke are generally the main initial signs of flame. Flares may not be supported by the camera while the flares are obscured by obstacles such as mountains or structures. Also, it can be hard to recognise smoke in images since it does not have a particular shape or shading pattern.

Smoke or flame can be detected by advanced sensors and image processing. Image processing can be used for recognition and to measure the smoke produced, i.e. intensity of the condition where the flame is produced. In this way, a pixel-level examination is required (Cappellini et al., 1989). Details are discussed in Section 7.

When using image processing to detect smoke and fire, motion and edge processing are important. Initially, the fire edge frames are considered as fire trademark parameters. Second, the fire edges are used for measuring information for clearing undesirable data, for example noise inside the picture (Razmi et al., 2010). The edge processing can be used to check for multi-burner framework. We discuss more about motion and edge of the fire in Section 6.

In this paper we discuss various technologies to predict smoke and fire at its earliest stages using image processing. Figures 1 and 2 show the different types of technologies which are used in detecting smoke and fire. Generally smoke and fire detecting technologies are used as applications
which involve various purposes in energy plants, chemical plants, etc. (Sazzad et al., 2015; Korhonen et al., 2015; Li et al., 2013). Furthermore, we discuss about the different methodologies to detect and classify smokes as well as fires.

Figure 1 Block diagram of different types of smoke and fire detection approach (see online version for colours)

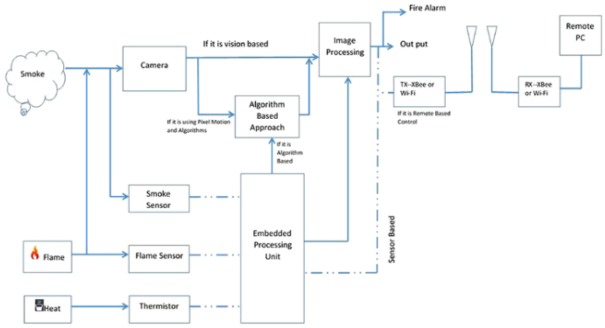
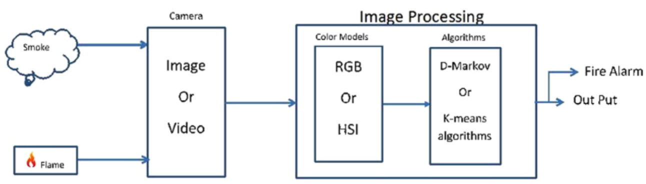


Figure 2 Block diagram of smoke and fire detection by image processing (see online version for colours)



2 Smoke detection and classification approaches

2.1 Covariance approach

These methods are frequently used to detect smoke. In this method, spatial and domain information are combined using covariance descriptors. When smoke is near to the camera then the output produced by this approach is highly effective but not very effective if the smoke is further away from the camera. Therefore, in many cases, this method may fail because the smoke issuing point too far away from the camera (Tuzel et al., 2006).

2.2 Mehdi Torabnezhad approach

To improve the rate of detection (Torabnezhad et al., 2013), vision-based smoke detection is proposed. In this approach, both vision- and thermal-based information are taken into account in order to improve its efficiency in estimating the smoke detection when compared with other detection approaches.

2.3 Fractal encoding method

Smoke has an indefinite boundary line and this is difficult to detect. The boundary of the smoke region is not clear; therefore, it becomes difficult to extract the smoke region using fundamental image processing. To address this limitation (Fujiwara and Terada, 2004), the shape of the smoke which has fractal properties and extracted the smoke region using fractal encoding is focussed.

In this method, the authors incorporated K-means algorithms which is an effective machine learning technique to fix the initial point in the domain region. The image is completely black while all pixels are in the initial point and through an image segmentation process, the image of the smoke shape then develops self-similarity properties. The positional relationships of pixels extracted from a single brightness is used to finally apply the fractal encoding techniques used for detecting smoke images.

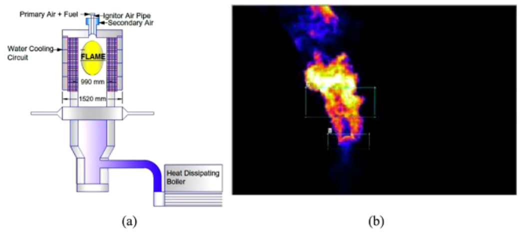
2.4 Smoke based on machine vision

In this method to improve the image quality of the smoke, fuzzy logic is employed for image enhancement. Then the smoke area is extracted by a Gaussian mixed model and this is then used for analysis of the static and dynamic features of the smoke. A hyper parameter of support vector machine is established for smoke recognition online (Yuanbin, 2016).

3 Flame detection and classification approaches

Flame identification plays a vital role in commercial applications like gasifiers especially for pulverised fuel flames. In this method flame images are acquired by charge coupled device (CCD) cameras, and used for extraction of the relevant flame features (Boucourt et al., 2001). The combustion test monitoring by image processing systems is illustrated in Figure 3a and b. This method focusses on the relationships between image features, monitoring the performance of parameters such as swirl number or NOX emissions in both gas and pulverised fuel flames (Samantaray and Mohanta, 2015). Generally, digital image processing can be used to extract the statistical and spectral features of the flame in gasifiers and can be graphically represented as two-dimensional distributions covering the root flame area. The fast Fourier transform is then used to obtain the flicker calculation. This approach gives a good performance to analyse the flame characteristics.

Figure 3 (a) Flame in combustion furnace. (b) Flame in camera vision (see online version for colours)



Source: Samantaray and Mohanta, 2015

This approach has two disadvantages: It cannot measure the heat, and also cannot synchronise with the flame image output and smoke sensor. It can only work when the CCD camera is at a distance of up to 400 mm from the flame.

Integrated gasification and combined cycle plants are powerful alternative frameworks for energy production. This method reduces steam and utility consumptions, stabilises H_2S removal and minimises environmental impact using flame identification by image processing. The method enables the production of clean gas, equivalent to natural gas even if it is of a lower heating value, from inferior fuel with expected reduction of CO_2 emissions by the use of high-performance gas turbines (Abela, 2007).

4 RGB-based fire and smoke detection techniques

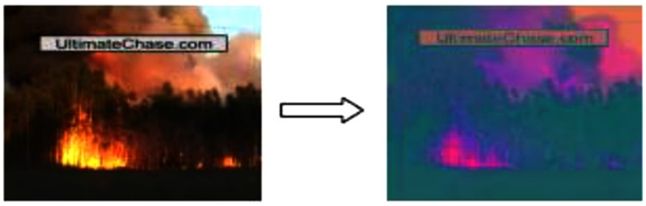
The RGB model is an additive model in which red, green and blue light are added together in various ways to reproduce a broad array of s. The RGB model is primarily used in image display systems.

Different types of extracted models can be used in complete fire/smoke detection systems and these also combine colour information with motion analysis such as the *YCbCr* colour model and the YUV model. The *YCbCr* colour model suitable for fire and smoke detection using image processing. Vision-based systems generally make use of three static characteristic features of fire: colour, motion, geometry and dynamic features such as irregularity, diffusion and direction (Alsultanny, 2010; Pagar and Shaikh, 2013). It is a low cost method to detect smoke and fire.

The *YCbCr* colour space model which makes it possible to separate luminance/illumination from chrominance is important. If RGB colour space model is used the illumination of image changes with each capture, then the fire pixel classification rules cannot perform well. The fire pixels show the characteristics that their R intensity value is greater than G and the G intensity value is greater than B same such as *Y*(x, y) is greater than *Cb*(x, y) where (x, y) refer to pixel's spatial location as shows in Figure 4. The following mathematical notation is used to separate illumination from space.

$$Y = Y / I_{max}, Cb = Cb / I_{max}, Cr = Cr / I_{max}$$

Figure 4 Digital video image into RGB planes (see online version for colours)



Source: Pagar and Shaikh, 2013

where I_{max} is the maximum intensity value defined by the combination of *Y*, *Cb* and *Cr* channels. For smoke detection, a statistical analysis is carried out using the idea that the smoke shows greyish colour with different illumination.

Practical smoke and fire detection methods mainly employ an image sampling system and use software analysis based on RGB values. Finally the system sends an alarm after detecting image or smoke towards detected fire. The YUV model used for video-based fire detection can be divided into two groups, based on smoke and flame features (Pu and Lee, 2011; Jinghong et al., 2012; Hauser et al., 2016). Finally, a fire danger index provided by the prediction algorithm is utilised to detect fire and reduce false alarm rates. It is seen that in some regions to reduce the other moving objects from being selected, algorithms like the K- means algorithm are used. Often smoke occurs before the fire is detectable and the smoke image can be more easily captured by a camera. To achieve this, one can use vision-based field programmable gate array (FPGA). Some FPGAs can meet the needs of high-speed image processing with its hardware features (Jinghong et al., 2012; Chettibi et al., 2012; Sazzad et al., 2015).

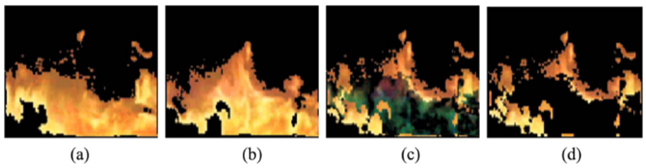
5 HSI-based smoke and fire detection

HSI is a very different three-dimensional space compared to RGB or CYM for the purpose of detecting objects. A fast and practical real-time image-based fire flame detection method based on analysis has been proposed (Ma et al., 2010; Toulouse et al., 2015). The method first builds a fire flame feature model based on the HSI space by analysing 70 training flame images. This method is effective for flame analysis because of fast vision compared with pixel analysis. The authors introduced a type of fire classifier: No fire, small fire, medium fire and big fire. Based on the knowledge that the fire flames usually display reddish, emit light and heat, and change shape rapidly. They employed the separation method for flame image according to the mathematical notation:

$$C([h_1, h_2], [s_1, s_2], [i_1, i_2]) = \left((h, s, i) \mid h_1 \le h \le h_2, s_1 \le s \le s_2, \text{ and } i_1 \le i \le i_2\right)$$

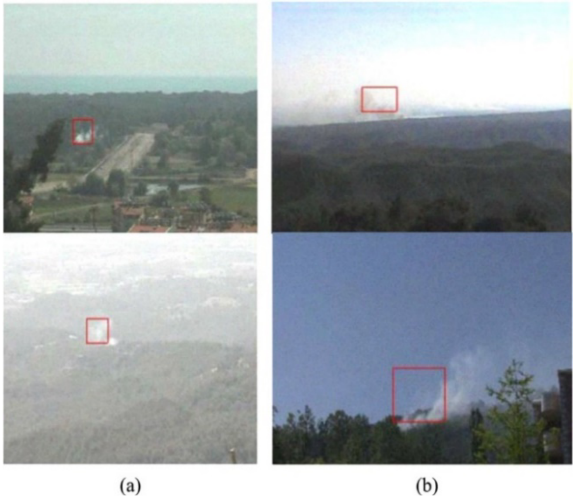
Figure 5 shows the analysis by the separation method. The method mainly focused on the detection of the lower temperature fire flames and the method is unable to accurately detect higher temperature flames.

Figure 5 Fire grayish with different illumination as of Horng and Peng (2008). (a) and (b) Two consecutive, artificial fire images after separation. (c) Result after image difference of (a) and (b). (d) Result after performing separation again (see online version for colours)



In other methods used for extraction of information and real-time analysis of video captured by a high-speed camera, the image frames of the video are compressed into a sequence of image features. Then, these image features are mapped to a sequence of symbols (Akshata Patil, 2014; Shi and Cao, 2009). Finally, a Markov model is used to train the method for both flame and non-flame pixels and compare with a pre-determined of flame boundaries. In this way, the model not only learns the flame boundary's flicker during a period of time, but also uses the parameters to simulate the spatial characteristics of flame regions. This training reduces the false alarm rates. D-Markov machines are constructed to extract features of the dynamic characteristics in such a way that the image features analysis can be used to detect a fire more quickly (Horng and Peng, 2008; Patel and Tiwari, 2012). This approach is suitable for wildland fire using colour segmentation algorithms introduced for the analysis of HSI space. The wildland fire dataset contains images in different contexts: fuel, background, luminosity, smoke, etc. All images of the dataset are characterised according to the principal of the fire, the luminosity and the presence of smoke in the fire area as illustrated in Figure 6a and b. With this characterisation, it has been possible to determine which kind of images and algorithms have the highest efficiency. Also a new probabilistic fire segmentation algorithm is introduced and compared, to the other techniques, a high performance for flame detection processing can be obtained (Rafiee et al., 2011; Patil et al., 2015).

Figure 6 (a) slow moving objects, gray regions and (b) rising regions, shadows. Wild land smoke and fire detection as of (see online version for colours)



Source: Kim and Wang (2009)

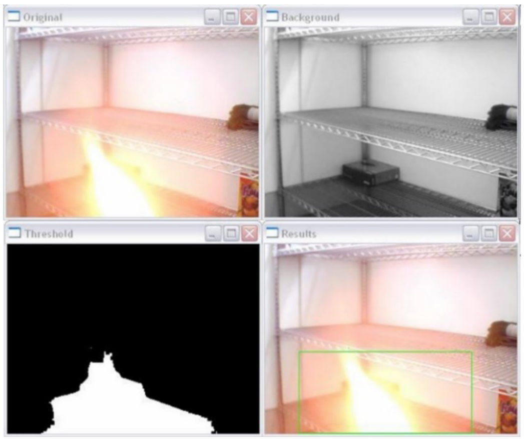
6 Motion and edge detection based flame detection

In this method, the types of fire are classified as Jet fire, Pool fire and Flash fire. Jet fires are generally found in the oil and gas industry, most of the fires that occur are caused by high pressure fuels. A Pool fire is defined as a fire that occurs from a combustible spill of liquid fuel. Once a pool of liquid is ignited, the radiation and convective heat of the flame causes the gas to evaporate and continue to feed the flame. A Flash fire is a vapour plume arising when released combustible gas is not ignited immediately (Razmi et al., 2010).

Motion and edge detection of flames are two different methods to detect a flame. In the motion detection of a flame, ‘background estimator’ technique is used for the first frames of the video stream to estimate the background image. It subtracts the background from each video frame to produce the foreground image and only the portion of the background that is revealed by the moving objects. Edge detection is an analysis on the contrast of an image to get the quality of the illumination level and is widely used in image interpretation. Figures 7 and 8 show motion and edge detection of the fire model.

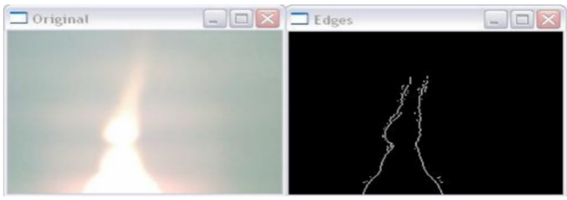
For the Edge Detection method, the pixel differences of images can be used; hence, this method can be used to detect the shape of a flame and recent detection algorithms are employed to identify fired pixels. Then, this is combined with motion and edge detection to build a flame detection system (John and Prince, 2014; Sazzad et al., 2015). In addition to ordinary motion and clues, the flame flicker process is also used by the hidden Markov model. Markov models are used to indicate the flame flicker process from the motion of flamed moving objects. Spatial variations in flame are also evaluated by the same Markov models also. These clues are combined to reach a final decision (Alamgir et al., 2015).

Figure 7 Motion detection of flame as of (see online version for colours)



Source: Razmi et al. (2010)

Figure 8 Edge detection of flame as of Razmi et al. (2010) (see online version for colours)

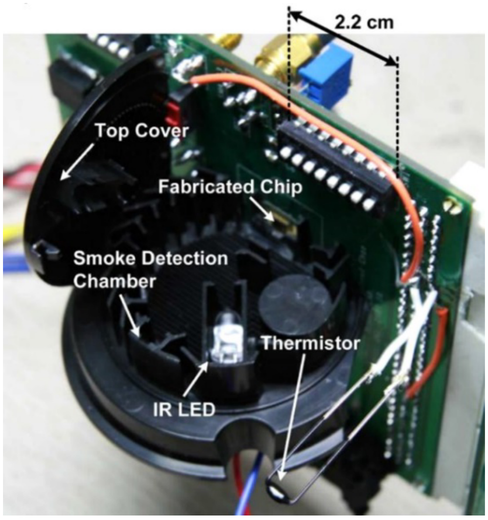


7 Smoke and fire detection by Image processing through satellite vision

In this technique, images from satellite vision are used to recognise irregular temperature transference when contrasted with the surroundings in a small location (Prasad et al., 2013; Shi and Cao, 2009; Cappellini et al., 1989). This methodology utilises k-mean bunching and Haar wavelets, and obtained an accuracy rate of 89.5 %. This method is mainly used on woodland fire location frameworks. Diverse methodologies are utilised for timberland fires. They can recognise fires without direct vision of the fire, e.g. behind a slope. Pictures have been created to compare different surfaces or movement examination by image processing using wavelet investigation among others methods (Patil et al., 2015).

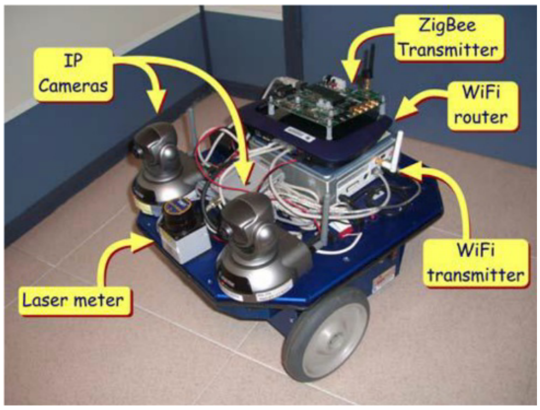
Satellite vision methodology may be used for fire location by making use of the surface temperature pictures acquired from NASA earth perception satellites by watching for unusual temperatures (Giglio et al., 2016). The images are sectioned into groups utilising a k-means algorithm and Haar wavelet. Two parameters are utilised from the close view image to separate fire regions from those of smoke by image processing and separation algorithms. The illuminations for the most part show glowing types and its shading model could be processed to observe flares. But, some flame-like areas in images may have the same types as a flame, and these non-flame regions are normally removed from images with an intelligent fire detector as shown in Figure 9. This can be extended to multipurpose sensors which are commercially used for various purpose such as object identification, smoke detection, flame detection, gas detection, IR detection, Wi-Fi detection, shortwave detection, etc., and some of the available methods use vision cameras. Moreover, in the sensor networks community, one can find several low cost localisation methods (Mobin et al., 2016; Prasad et al., 2013), several of which have recently been proposed for determining the position of mobile nodes by measuring radio signals such as: time of arrival, time difference of arrival (TDOA), angle of arrival. In particular, the TDOA method can use a radio signal combined with sonar (Islam et al., 2013; Aviles and Prades, 2011). By measuring the difference of time of flight of both the radio and the sonar signal, the distance between the transmitter and the receiver can be estimated in a very accurate manner.

Figure 9 Intelligent fire detector as of Cheon et al. (2009) (see online version for colours)



The Wi-Fi framework is normally present in broad daylight structures, and even in private ones, this might be utilised without additional cost, this will be the low-exactness area framework. ZigBee requires particular instruments; however, it gives better precision over Wi-Fi because of the more prominent number of measures changing the transmitter power and channel-taken for each position as shown in Figure 10. Ultra wideband (UWB) is a recent innovation that has been seen to satisfy the necessities for ease and fast computerised home systems (Giglio et al., 2016; Viittala et al., 2006). Ultra wideband innovations are giving information rates of 110 Mbps at a separation of 10 m and 480 Mbps at a separation of 2 m, yet much higher information rates are coming. These technologies are used for smoke and fire detection using transmitter and receiver sections of Wi-Fi, ZigBee and UWB.

Figure 10 Smoke detector control by remote systems as of Aviles and Prades (2011) (see online version for colours)



8 Conclusion

Vision-based and sensor-based detection of flame using image processing play vital roles in detecting fires at earlier stages to help towards giving a safer society. Different methods to detect the smoke and fire as well as the classification of flame using various techniques are discussed. The HSI model achieved high efficiency in background classified and subtraction types, which is used for application in aircraft fire detection systems. Motion- and edge-based detection is more suitable for continuous video sequencing and it often fails due to a large area of fire. Satellite vision images and video have given the best information to detect smoke and fire in any area of the globe but has the disadvantage in identifying the fire region quickly enough. In future, these various techniques will become suitable to use in real-time smoke and fire detection by remote monitoring systems.

The survey works are summarised in Tables 1 and 2.

Table 1 Comparison of smoke and fire detection research by application areas

	Type of smart detection	*References*
1	Smoke and fire detection for chemical plants	Butterman and Castaldi (2011), Toreyin et al. (2005), Costantini et al. (2008), Byreddy and Raghunadh (2014), Figueroa et al. (2014), Samantaray and Mohanta (2015)
2	Smoke and fire detection for power plants	Fischer and Muller (1995), Tyner et al. (2011), Mobin et al. (2016), Chettibi et al. (2012), Korhonen et al. (2015)
3	Smoke and Fire Detection for Biomass Grassfires	Abela (2007), Butterman and Castaldi (2011), Samantaray and Mohanta (2015)

Table 1 Comparison of smoke and fire detection research by application areas (continued)

	Type of smart detection	*References*
4	Smoke and fire detection for forrest fires	Akshata Patil (2014), Toreyin and Cetin (2007), Prasad et al. (2013), Toulouse et al. (2015), Cappellini et al. (1989)
5	Smoke and fire detection for constructed buildings	Fischer and Muller (1995), Ko et al. (2011), Seebamrungsat et al. (2014), Aviles and Prades (2011), Mobin et al. (2016), Prasad et al. (2013)

Table 2 Comparison of smoke and fire detection research by activity detection methods

	Technique used for activity detection	*References*
1	Video based techniques	Ko et al. (2011), Razzazi and Seyedabadi (2014), Kim and Wang (2009), Pu and Lee (2011), Jinghong et al. (2012), Torabnezhad et al. (2013), Chettibi et al. (2012), Patil et al. (2015), Patel and Tiwari (2012), Sazzad et al. (2015), Pagar and Shaikh (2013), Shi and Cao (2009), Li et al. (2013), Zeng et al. (2008)
2	Motion and edge based techniques	Fischer and Muller (1995), Boucourt et al. (2001), Costantini et al. (2008), Byreddy and Raghunadh (2014), Razzazi and Seyedabadi (2014), Giglio et al. (2016), Poobalan and Liew (2015), Hauser et al. (2016), Tuzel et al. (2006), Thirukovalluru et al. (2016), Razmi et al. (2010), Li et al. (2013)
3	Sensor based techniques	Abdulbaqi et al. (2016), Cheon et al. (2009), Viittala et al. (2006), Islam et al. (2013), Seebamrungsat et al. (2014), Aviles and Prades (2011), Torabnezhad et al. (2013), Hauser et al. (2016), Tuzel et al. (2006), Prasad et al. (2013), Figueroa et al. (2014), Sazzad et al. (2015)
4	Pixels and algorithm based techniques	Rafiee et al. (2011), Poobalan and Liew (2015), Ma et al. (2010), Torabnezhad et al. (2013), Chettibi et al. (2012), Fujiwara and Terada (2004), John and Prince (2014), Patil et al. (2015), Toulouse et al. (2015), Li et al. (2013)
5	Without sensor-based techniques	Kim and Wang (2009), Pu and Lee (2011), Hauser et al. (2016), Patil et al. (2015), Patel and Tiwari (2012), Pagar and Shaikh (2013)

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