

# Obstacle Detection Techniques in Outdoor Environment: Process, Study and Analysis

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**Abstract**—Obstacle detection is the process in which the upcoming objects in the path are detected and collision with them is avoided by some sort of signalling to the visually impaired person. In this review paper we present a comprehensive and critical survey of Image Processing techniques like vision based, ground plane detection, feature extraction, etc. for detecting the obstacles. Two types of vision based techniques namely (a) Monocular vision based approach (b) Stereo Vision based approach are discussed. Further types of above described approaches are also discussed in the survey. Survey discusses the analysis of the associated work reported in literature in the field of SURF and SIFTS features, monocular vision based approaches, texture features and ground plane obstacle detection.

**Index Terms**—Segmentation, Obstacle Detection, Feature Extraction, Thresholding, Image Processing.

## I. INTRODUCTION AND MOTIVATION

It is very much difficult for blind person to roam safely as the density of the persons and traffic on road is going on increasing day by day. Blind persons need some assistance to roam safely. This assistance can be provided by any other normal person or by any device, as it is not always possible that the blind person will get the normal person to roam safely so a device is needed by them. This device must be easy to carry and enough responsive in real time situations. The device after detecting the upcoming objects (Obstacles) will make the blind person come to know about the object in the path by using proper mode of signaling [1, 2]. Distance of the object can also be signaled to the visually impaired person i.e. how far the object is, like if the beep method is used to signal the person then pace of the beep can be increased as the distance between the person and object decreases and if the object is far from the person then beep pace will be slow.

### A. Motivation for Research

- Obstacle detection is the process of recognizing the objects in the path of the visually impaired persons and to guide them, so that they can move

easily. Therefore, this study presents a detailed analysis of different existing techniques implemented in the literature at each phase of the obstacle detection.

- We recognized the necessity of a well ordered literature study and review after considering progressive research in obstacle detection techniques. Therefore, we have summarized the available research based on a vast and methodical look in the existing database and present the research challenges for advanced research.

### B. Paper Organization

The organization of the rest of paper is as follows: Section II presents the background of obstacle detection techniques, various types of sensors present, vision based techniques, ground plane detection, feature extraction. Sect. III describes the study of the various techniques for each level of obstacle detection and analyses it. Methodical literature survey results and conclusions are presented in section IV. Section V presents the discussions of this research work. Open issues and future research directions are presented in Sect. VI. Note, a glossary of acronyms used in this paper can be found in “Appendix 1”.

## II. BACKGROUND

To tackle the obstacle detection problem many researchers have proposed various techniques. Different types of sensors have been used to capture the data. So initially we classify the various types of sensors [1] used and then we will present the various types of vision based techniques followed by the discussion on the various phases of the obstacle detection. As it is presented that obstacle detection is a process consisting of many phases in it, all those phases are discussed in this research article.

### A. Sensor Based Techniques

To capture scene related information like depth of object, color of object, distance etc. sensor is used [1]. Broad classification of sensor based techniques along with their key components is shown in Fig 1.

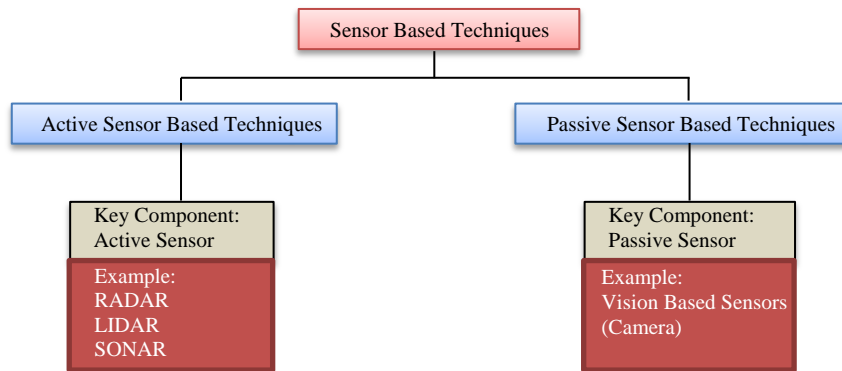


Fig.1. Various Sensor Based Techniques

1. Active Sensor Based Techniques

The sensors having their own source of energy are known as Active Sensors. For collecting the information, energy is transmitted by them only [1]. Active Sensor Based Techniques are the techniques that use the Active Sensor as the key Component.

2. Passive Sensor Based Techniques

The sensors those don't have their own source of energy are known as passive sensors. They have to take the energy from the external source, for example vision based sensors [1]. Camera is used by the vision based sensors to capture the scene.

Merits and demerits of the Active Sensors and Passive Sensors are presented in Table 1. Active sensors are costly as compared to passive sensors. Excellent measurement of positioning and speed is the main advantage of Active sensor.

Table 1. Comparison of Active Sensors and Passive Sensors

	Active Sensors	Passive Sensors
Advantages	Excellent Measurement of Positioning and Speed	Very Cheap
Disadvantages	Very Costly	Not able to generate the detailed information like active Sensors.

B. Vision Based Techniques

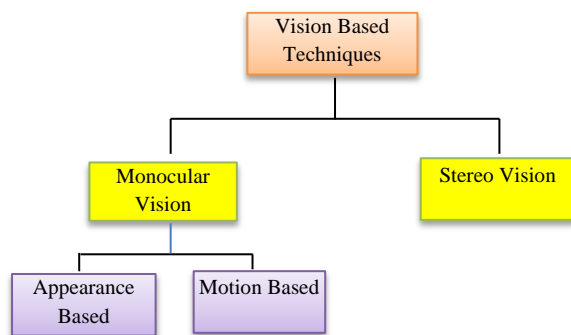


Fig.2. Various Vision Based Techniques

The technique in which camera is used to capture the information of scene to know about the upcoming objects in the path is known as a vision based technique. It is a strong mechanism. These techniques are very much cost effective as compared to the techniques using active sensors [1]. Various vision based techniques are discussed in Fig. 2.

1. Monocular Vision Based Approach

The approach that uses one camera to capture the scene is known as a monocular vision based approach. Image is captured then processing is done on it [1, 3]. Further monocular vision based technique is of two types as displayed in Fig. 2, considerations and merits of these two types are discussed in following Table 2.

Table 2. Comparison of Appearance Based and Motion Based Techniques

	Appearance Based	Motion Based
Consideration	<ol style="list-style-type: none"> <li>1. Shape</li> <li>2. Texture</li> <li>3. Colour</li> <li>4. Edge</li> </ol>	<ol style="list-style-type: none"> <li>1. Strong Displacement of object is needed.</li> <li>2. Size of object must be very large.</li> </ol>
Advantages	<ol style="list-style-type: none"> <li>1. Speed</li> <li>2. Cost Effectiveness</li> <li>3. Ability to detect very small obstacles.</li> </ol>	

2. Stereo Vision Based Approach

The approach that uses two cameras in place of one to arrest the image at the same time is known as Stereo Vision Based Approach. The depth detail of the obstacle is easily obtained accurately from the images taken. The two images taken at same time are checked that whether there are any similar pixels present, which further helps to calculate depth and is known as disparity. Calibration is properly required between both two cameras present. Stereo vision based and monocular vision based techniques are analyzed on the basis of some attributes like calibration, computational requirement, maintenance etc. as presented in the Table 3. As the Stereo Vision Based

Approach is more costly and have more computational requirements than Monocular Vision Based Approach, so it is less preferred as compared to Monocular Vision Based Approach.

Table 3. Comparison of Stereo Vision Approach and Monocular Vision Approach

	Stereo Vision Approach	Monocular Vision Approach
No. of Cameras used	2	1
Cost	More Costly	Less Costly
Maintenance	Requires more maintenance	Requires less maintenance
Use	Not used in Real Time Situations	Used in Real Time Situations
Characteristics used	Motion Characteristics	Appearance Characteristics
Computational Requirement	More	Less
Calibration	Required	Not Required

### C. Ground Plane Detection

For sensing the Environment, Monocular Vision Based Approach can be used, but more accurate and fast methods are needed for real time processing of data gathered [2]. Techniques like texture segmentation, motion, inverse perspective mapping, color and ground plane detection etc. can be used with Monocular Vision Based Approach. In real time, ground plane detection technique can be used as it is computationally very simple among other techniques. In ground plane detection, image is partitioned into two regions -> ground and non-ground, based on certain characteristics of particular area. Then reference area is matched with properties of ground area. Properties of ground matches with the reference area and properties of non-ground don't matches with the reference area. This process continues until complete image is processed. Obstacles are further checked for in non-ground area. For detecting ground plane, techniques like Thresholding and Region Growing can be used. By removing the ground plane from image, feature extraction becomes simple and consumes less time.

### D. Feature Extraction

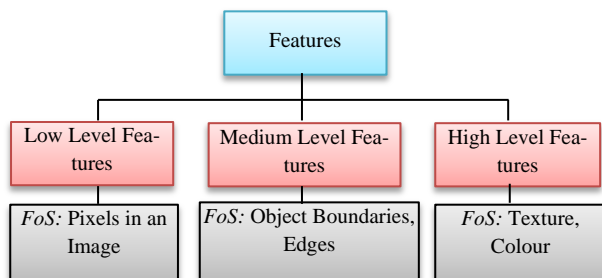


Fig.3. Various Levels of Features

After partitioning the image into ground and non-ground region, further obstacles are checked for in the non-ground region. For the obstacle checking, feature

extraction is done. Various types of features and their focus of study (FoS) are described in Fig. 3.

After extraction of features, number of methods had been proposed in the literature for obstacle detection. Lowe proposed SIFT (Scale Invariant Feature Transform) [4] in 2004 and SURF (Speeded up Robust Features) [5] were proposed by Bay et al. in 2006. As comparison with SIFT, SURF is faster. Based on points of interest like blobs, corners etc. features are extracted by SURF. Unchanging property to illumination, rotation, scale and computational simplicity are main advantages of the SURF. After extracting the features of non-ground image, they are matched with the obstacle image features to select Region of Interest.

### E. Obstacle Detection: Process

Fig 4 describes the basic steps used in an obstacle detection, which includes video as an input and then pre-processing is done to select the high quality frames followed by segmentation and feature extraction. Segmentation divides image into 2 parts, ground plane and non-ground plane, here non-ground plane will be checked further for the obstacles presence. Features will be extracted from non-ground plane and then by referring to the particular obstacle image, obstacles will be checked for.

## III. OBSTACLE DETECTION: STUDY AND ANALYSIS

Analysis and survey of most of existing techniques for each level of obstacle detection process is presented here.

### A. Monocular Vision Based Approach

Vision based approach is preferred over the other methods due to computational simplicity. Focus of Study (FoS) of obstacle detection by evolution of monocular vision based approach across the various years are described in evolution of monocular vision based techniques as shown in Fig. 7. In 2000, Ulrich et al. [2] gave a technique for ambulant robots, in which each single pixel of an image is checked and classified on its color appearance, to check that whether it belongs to an obstacle or the ground. The technique performs in real time and outputs binary obstacle image at high resolution. This technique includes four steps as described in Figure 5. In 2005, Michels et al. [6] described a supervised learning based algorithm using monocular vision to detect object i.e. obstacle. They considered remote control car for this, running at high speeds. Their algorithm using laser range finder, learns the relative depths on single images using monocular visual sign. In 2006, Yamaguchi et al. [3] gave a technique for detection of obstacles that are in motion using ego-motion approximation. First of all the image was divided into small pieces and then local measurements on each image were calculated to have an estimate of ego motion. At the end all local measurements were clubbed up. Structure from motion algorithm was used to calculate vehicle ego-motion. Feature points that don't contain obstacles were extricated from regions

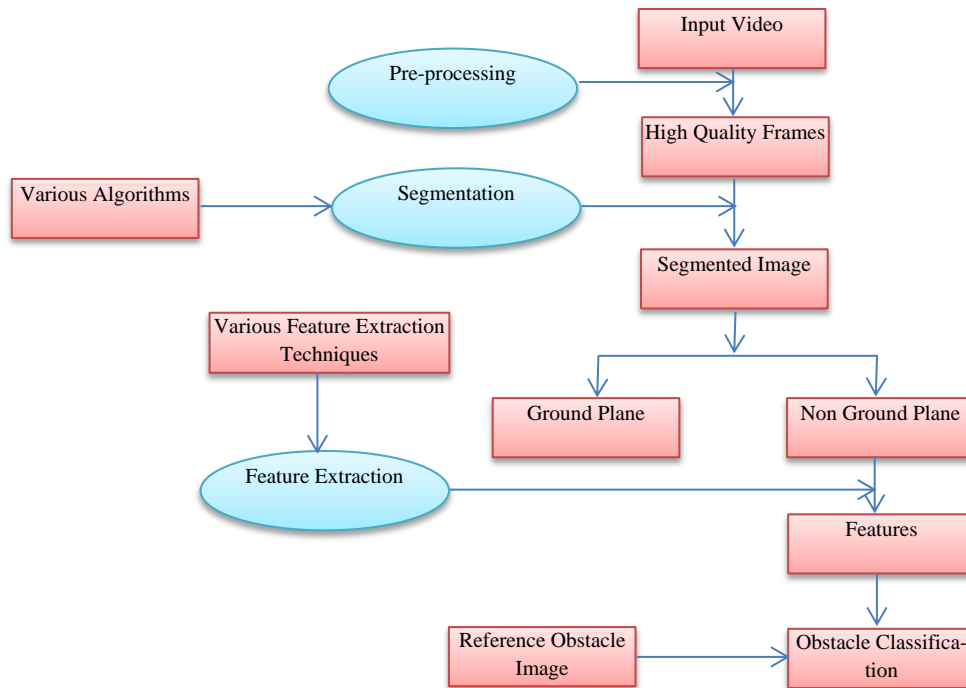


Fig.4. General Obstacle Detection Process

and feature points of various consecutive frames were followed to find obstacles in motion. In 2008, Song et al. [7] gave a technique to spot vehicles in different traffic situations. This method spotted vehicles in steps as described by Figure 6. In 2008, Zhan et al. [8] on basis of monocular vision gave a seamanship method for ambulant robots in untold habitat. Obstacle recognition, distance calculation, path organization were three tasks used in the recommended technique. For obstacle recognition, technique recommended in [2] was used. To calculate distance, variation equation between robot and image

coordinate was used and grid map was used to organize path. In 2009, Muller et al. [9] suggested a rambler identification technique. Detection range was partitioned into sub regions, known as nearby regions and afar regions. Motion segmentation was employed to recognize nearby region obstacles and Inverse perspective mapping was implemented to identify afar region obstacles. In 2009, Viet et al. [10] proposed a classifying method for recognizing obstacles using touch and color. Touch came into existence when color fails.



Fig.5. Flowchart for Ambulant Robots



Fig.6. Flowchart for Spotting Vehicles

For color attributes, histogram comparing on basis of resemblance of two histograms was considered. For touch features LBP or statistical techniques with eight histograms was implemented. K-mean clustering algorithm was used for grouping. In 2010, Lin et al. [11] gave an ego-motion evaluation technique and grouping approach to slice ambulant obstacles from videos. Ellipsoid scene shape in ambulant model was implemented and a complex ego-ambulant evaluation formula was obtained.

SURF characteristics were used for motion recovery, for motion evaluation genetic algorithm was used and pixel level probability model was used for grouping. In 2011, Cherubini et al. [12] gave a technique that aided the machine to evade the new obstacles that were not present during the preparation. Circumnavigation and collision risk were used for this objective and were evaluated from potential vector field obtained from tenancy grid.

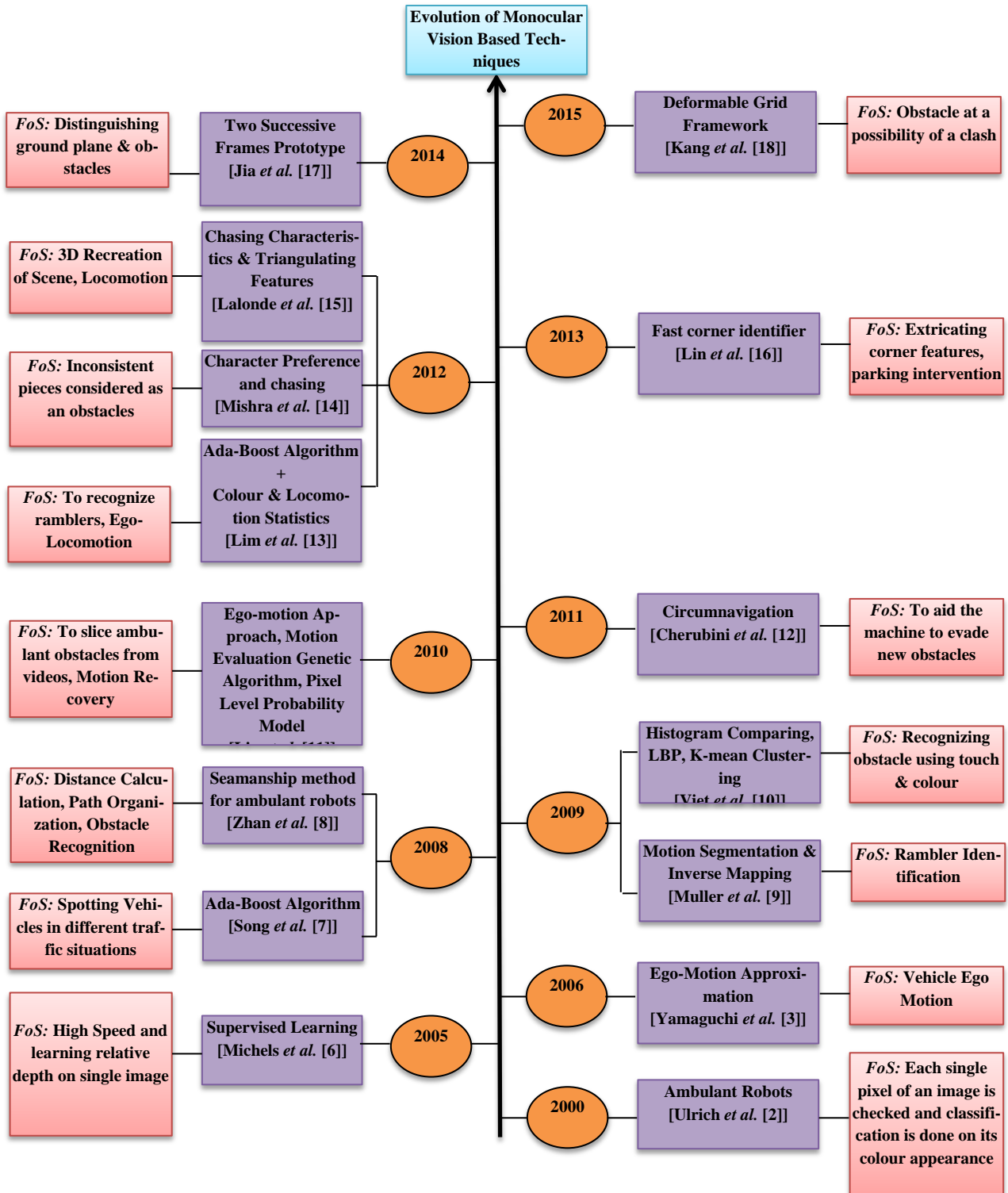


Fig.7. Evolution of Monocular Vision Based Techniques

In 2012, Lim et al. [13] by using color and locomotion statistics gave a technique to recognize rambblers. Feature set was used to calculate ego-lo-motion. By evaluating distinction between two successive images, region of interest was created. A number of feeble classifiers on basis of histogram of oriented Gaussian were uplifted using Ada-boost algorithm and block based method based on color information was used to identify rambblers.

In 2012, Mishra et al. [14] suggested a technique that worked for different characteristics extraction from environment. This technique was based on characteristics preference and chasing. Feature vector space was constructed that afterwards passed to the model. This vector space was the homographic conversion that was used to search inconsistent pieces which could be considered as obstacles. In 2012, Lalonde et al. [15] proposed a method

for parking system, in which 3 dimensional recreation of the scene was done to identify stable obstacles. Following are the 2 main initiatives used: Figuring out locomotion of vehicle then 3D recreation to identify obstacle. Locomotion was evaluated by chasing characteristics and 3D recreation was done by triangulating those features to build 3D prototype. In 2013, Lin et al. [16] gave a method for parking intervention, to identify obstacles. FAST corner identifier was used to extricate corner features and then checking was done to check that whether features belong to ground or obstacle by using IPM. In 2014, Jia et al. [17] gave a method to evaluate distinction between ground plane and obstacle using locomotion characteris-

tics and this technique was known as Two Successive Frames prototype. For matching characteristics of two successive frames KLT corner detector was used. Obstacles were distinguished from shadows and road marking, considering locomotion characteristics. In 2015, Kang et al. [18] gave a new framework known as Deformable Grid for identifying the obstacles. Initially the DG is in normal shape which changes according to the locomotion of object in scene. Measuring the amount of malformation this DG method identifies the obstacle at a possibility of clash. All the various monocular vision based techniques are analyzed in the following Table 4. Merits and demerits of each technique are discussed.

Table 4. Analysis of various monocular vision based techniques

Author/Year	Method	Description	Target/Equipment	Merits	Demerits
Ulrich et al. [2]/2000	Passive Monocular Colour Vision	Approach is purely based on appearance of pixels	(1) Mobile Robots	(1) The algorithm performs in Real Time (2) It provides a high resolution obstacle image (3) Algorithm operates in variety of Environments (4) Algorithm is also very easy to train	(1) This approach do not work properly if obstacles are present inside the trapezoidal reference area
Michels et al. [6]/2005	Supervised Learning	Algorithm learns relative depths on single images using only monocular visual cues	(1) High speed Remote Control Car (2) Laser Range Finder	(1) Problem of High Speed Navigation is Considered (2) Avoids Obstacle in Un-structured Outdoor Environment	(1) Car will crash into an Obstacle when Obstacle is less than 5m away
Yamaguchi et al. [3]/2006	Ego-Motion	Ego-motion for the vehicle is calculated	(1) Vehicle Mounted Monocular Camera	(1) Proposed method is able to detect moving obstacles (2) Pedestrians are also detected	(1) This approach does not detects stationary objects on road (2) Some false detection occurs (3) Region detection accuracy must be improved
Song et al. [7]/2008	Monocular Machine Vision System	Detects vehicles in front or behind of our own vehicle	(1) Ego- vehicle	(1) This method can detect vehicles in rear area and in front as well (2) The system successfully detects the vehicles on roads in various environmental conditions (3) The system is effective under various traffic scenarios	(1) Vehicle Candidates are generated by exploiting a fact that vehicle has vertical and horizontal lines and also rear and front shapes of vehicle show symmetry
Zhan et al. [8]/2008	Monocular Vision Based Navigation Method	Navigation Method for Mobile Robot in an unknown Environment	(1) Camera Mounted Mobile Robot	(1) Simple Computation (2) Cheap Hardware (3) Promising to Realize Real Time Navigation	(1) It outperforms when grid size is too large or very small (2) Performs only when ground is flat (3) There must be no over changing obstacles
Muller et al. [9]/2009	Pedestrian Detection Algorithm	To detect Pedestrians and to predict possible collisions	(1) Single Monocular Camera Mounted Car	(1) Computational Efficiency that enables system to run in real time (2) Robustness against Environment (3) Improved detection in vertical direction	(1) It is difficult to track pedestrians in close proximity to car (2) Detection of Head of Pedestrian is very difficult
Viet et al. [10]/2009	Classification Algorithm	Presented new Classification Algorithm using colour and texture for obstacle detection	(1) Outdoor Robots	(1) Very good classification rate (2) Average run time for classification is very fast (3) Good trade-off between performance and efficiency	(1) With small $K$ texture classifier becomes unreliable (2) Training set should represent real population as learning algorithm can only model variations presented in training set

Lin et al. [11]/2010	Ego-motion Estimation and Background/Foreground Classification	To effectively segment moving objects from videos	(1) Moving Camera on Moving Platform	(1) Proposed method can be applied to detect moving obstacles with irregular camera movement (2) Effective detecting performance (3) Performs effectively in complex detecting environment	(1) Some Initial guesses are generated (2) Difficulty in estimating 10 degrees of freedom
Cherubini et al. [12]/2011	Circumnavigation and Collision Risk	To aid the machine to evade new obstacles	(1) Robot	(1) It can also deal with unavoidable obstacles (2) It guarantees path following, obstacle bypassing and collision avoidance by deceleration	(1) Moving obstacles are not considered (2) Visual occlusions provoked by obstacles are not considered
Lim et al. [13]/2012	Block Based Method	To detect pedestrians using colour and motion information	(1) Single camera on Mobile or Stationary System	(1) It can track pedestrians with possibly partial occlusions (2) It has detection rate of 93.5% (3) Able to track multiple pedestrians	(1) It cannot track pedestrians those who have recently entered in image frame (2) Interaction between detection and tracking is not considered
Mishra et al. [14]/2012	In-motion detection	To detect and track moving obstacles	(1) Mobile Robot	(1) Computationally Simple (2) Better Time Response (3) Robust to Low Level Intensity Variations (4) Robust to Shadow Effects	(1) This method fails when surface is plain and doesn't have distinguishing feature
Lalonde et al. [15]/2012	3D Reconstruction Algorithm	Detection of static obstacles from single rear view parking camera	(1) Car having rear mounted parking camera	(1) Very High Detection Rate (2) Reliable and Efficient (3) Low Cost	(1) Least amount of disparity for given camera displacement
Lin et al. [16]/2013	Method for Parking Intervention	Obstacle detection for parking assistance	(1) Car having rear mounted parking camera	(1) Low Computing Power (2) High Detecting Rate (3) Detects both moving and stationary	(1) The system will only work at driving speed under 30 km/hr (2) Detectable distance is up to 6 metres
Jia et al. [17]/2014	Two Successive Frames Prototype	To evaluate distinction between ground plane and obstacle	(1) Autonomous Navigation Vehicle- Mobot	(1) It meets real time requirement (2) It is effective in various conditions (3) No calibration or any prior knowledge of the camera is required (4) Cost Effective	(1) Too many miss detections and mismatched feature points in obstacle region may fail the system (2) Far away objects are considered as no obstacles
Kang et al. [18]/2015	Deformable Grid	Detecting obstacles at the risk of collision	(1) Smart Phone (2) Tablets (3) Wearable Devices	(1) Robustness towards motion tracking and ego-motion of the camera (2) Suitable for ETA systems using consumer devices like smart phones	(1) Unable to detect collision in region where the accurate motion vector is not easily computed like walls, doors

### B. Key Frame Extraction

For detecting the obstacle we need an image, we are using camera to take the video, key frame must be extracted from the video sequence. The excessive grade frame that is enough capable of portraying and is able to reflect the obstacle clearly present, in a video sequence is considered as key frame. Focus of Study (FoS) of obstacle detection by evolution of key frame extraction across the various years is described in evolution of key frame extraction techniques as shown in Fig. 8.

In 1998, Zhuang et al. [19] proposed a technique on the basis of unsupervised clustering. For mastering the cluster density, threshold and color histogram of each frame of video computed in HSV color space was used. Key frame election was done only to clusters which were huge enough to be considered as key cluster. From every

cluster a representative was picked as a key frame. In 2000, Zhao *et al.* [20] proposed a technique based on the concept of Nearest Feature Line. Both Feature Extrication and Distance Computation are considered as a whole process. Breakpoints of feature trajectory of a video shot are used as key frames and lines passing through these points are also used to represent the shot. In 2000, Doulamis et al. [21] proposed a frizzy based election technique. Every frame was depicted in form of frizzy color and locomotion histogram. Shortest spanning tree algorithm was used to part every frame. For every part a frizzy color and locomotion histogram was extricated and saved as a presenter. In 2000, Gong et al. [22] gave a method in which clusters were constructed using feature vectors. First of all 3D histograms were created for every block to assimilate spatial data of every frame and then theses histograms were clubbed up to form feature vector. The frame that was closest to the center of cluster was

elected as a key frame. In 2007, Mukherjee et al. [23] gave a method on the basis of strayness of representation of the frames, to elect key frame from video shots. Spatial and Haar wavelet based characteristics were extricated for every frame. Individual characteristics were used to evaluate the strayness between frames and the frames with huge strayness were elected as key frames. In 2013, Liu et al. [24] proposed a technique to elect key frame for every action sequence of human using Ada-Boost learn-

ing algorithm. For key frame selection, correlated pyramidal locomotion-characteristics for human action recognition were used. In 2014, Raikwar et al. [25] proposed a key frame extraction method that consists of two phases, in first step, size of input video shot is reduced by removing the frames that are not distinguishable and in 2nd step motion energy between the remaining frames is calculated for checking optical flow and the frames having maximum optical flow are only retained.

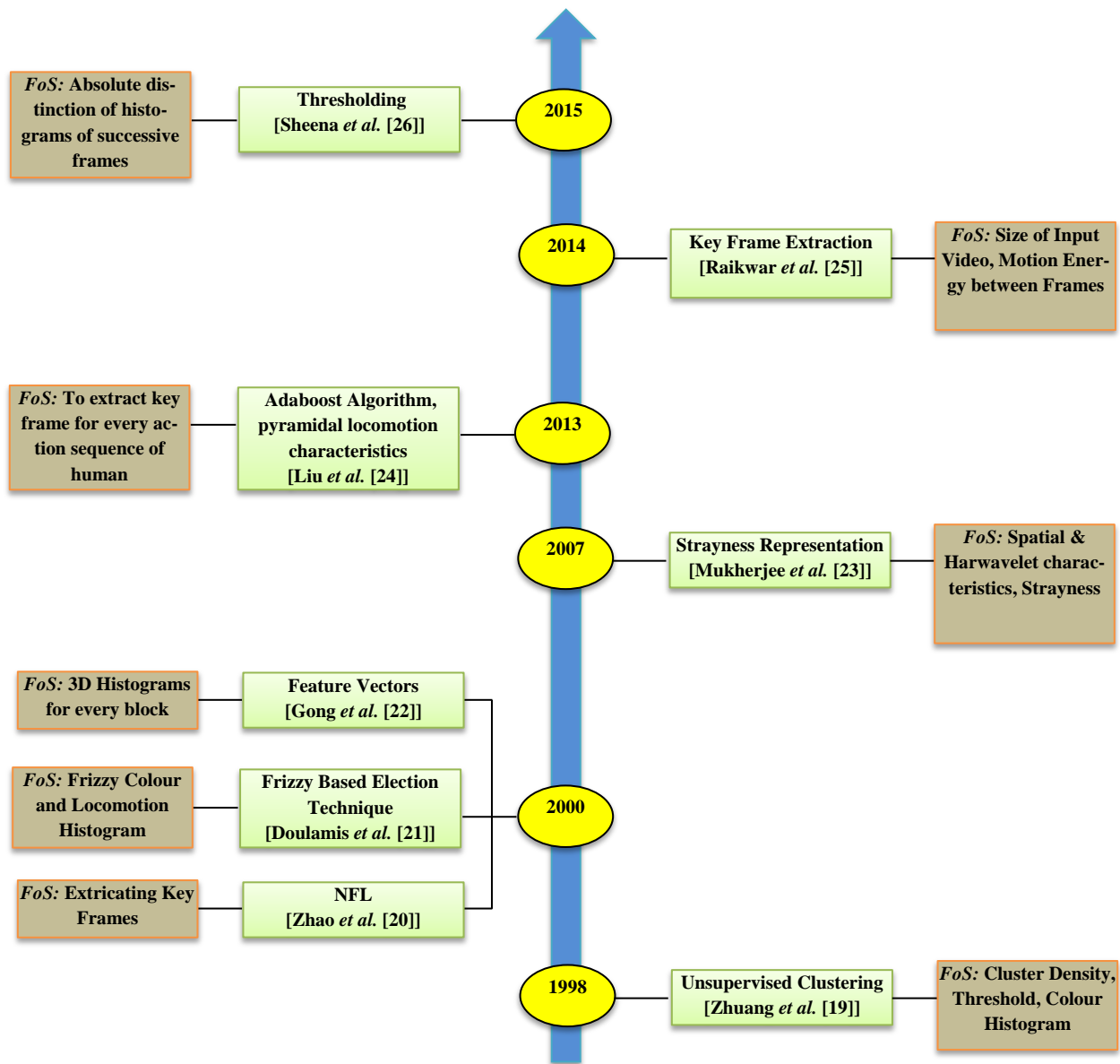


Fig.8. Evolution of Key Frame Extraction Techniques



Table 5. Analysis of various key frame extraction techniques

Author/Year	Method	Description	Merits
Zhuang <i>et al.</i> [19]/1998	Unsupervised Clustering	Key frame election was done only to clusters which were huge enough to be considered as key cluster. From every cluster a representative was picked as a key frame.	(1) Computationally Simple (2) Able to adapt to visual content (3) Efficiency and Effectiveness tested on real world videos
Zhao <i>et al.</i> [20]/2000	Nearest Feature Line	Breakpoints of feature trajectory of a video shot are used as key frames	(1) Used in Face Recognition and Video Classification and Retrieval (2) Better than methods such as NN and NC (3) Effective
Doulamis <i>et al.</i> [21]/2000	Frizzy Based Election Technique	Multidimensional fuzzy histogram is constructed for each video frame based on a collection of appropriate features, extracted using video sequence analysis techniques	(1) It is suitable for new emerging multimedia applications like video browsing, video summarization. (2) High Accuracy and Computational Efficiency (3) Natural Interpretation of the visual content
Gong <i>et al.</i> [22]/2000	Singular Value Decomposition	For input video sequence a feature frame matrix is created and SVD is performed on it.	(1) Little Redundancy (2) Support different user requirements for video browsing and content overview
Mukherjee <i>et al.</i> [23]/2007	Dempster-Shafer theory of evidence	Works on basis of inter-relationship between different features of image frames in a video	(1) No Previous knowledge is required in decision fusion process (2) Promise of real time use
Liu <i>et al.</i> [24]/2013	Boosted key-frame selection and correlated PMF + Ada-boost Algorithm	A method for human action recognition	(1) Accuracy of 95.5% (2) Robustness towards determination of Bounding Box
Raikwar <i>et al.</i> [25]/2014	Key Frame Extraction Method	Two phase method in which in 1 <sup>st</sup> step size of video shot is reduced and in second optical flow is calculated for maximum	(1) Very less time required for extraction of key frames (2) Uncompressed surveillance video shots are also handled
Sheena <i>et al.</i> [26]/2015	Absolute distinction of histograms of successive frames	Two phase method to extract key frames in which in 1 <sup>st</sup> step threshold of absolute distinction of successive frames is calculated and then in 2 <sup>nd</sup> step threshold was analysed	(1) Computationally simple (2) High Accuracy

In 2015, Sheena *et al.* [26] gave a technique to extract key frames on the basis of absolute distinction of histograms of successive frames. This technique consist of 2 passes: threshold of absolute distinction of successive image frames was calculated in 1st pass and then in 2nd pass key frames were extracted by analyzing the threshold against absolute distinction of successive image frames. All the various key frame extraction techniques are analyzed in Table 5. Methods, merits and description are discussed.

### C. Ground Plane Detection

Ground plane detection is a technique that can be incorporated to identify the obstacles. Evolution of ground plane detection techniques along with their Focus of Study (FoS) is discussed in Fig 9. In 2006, Zhou *et al.* [27] proposed an algorithm based on homography evaluation between 2 frames extracted from a chain. To evaluate homography, H-Clustering algorithm was implemented. In 2010, Conrad *et al.* [28] proposed a modification to EM (Expectation Maximization) algorithm for grouping of pixels in images as ground and non-ground pixel categories. Expected value on the basis of the ongo-

ing specifications of a probability task was evaluated by E-step. LM (Liebenberg-Marquardt) and simplex method were considered for M-step. Simplex method was better than other. In 2010, Jamal *et al.* [29] gave an obstacle identification method for ambulant machine seamanship by combining segmentation and optical flow methods. GMM (Gaussian Matrix Model) was implemented to learn stable characteristics of ground level. Then by using learned signatures, ground level was partitioned. If piece matches with ground level characteristics, it was parted as ground plane else was considered as non-ground level. This method was very simple. In 2010, Lin *et al.* [30] gave the method to evaluate distance between obstacle and machine on the basis of IPT. Homography was used to distort images. Pixels equating to the ground level were emulated in the considered images. Numerous cues were used to evade flaws and attain ruggedness. To categorize characteristics as ground and non-ground among successive frames, homography was used. First images were transformed to HSI color space and were parted using color homogeneity. Ground or non-ground region was categorized by matching pieces with distorted images. In 2012, Benenson *et al.* [31] gave a method to evalu-

ate obstacle frontiers without evaluating depth map. To make the algorithm fast, dynamic programming was implemented. To evaluate ground level, v-disparity map-

ping was considered. For identifying objects GPU rate was boosted.

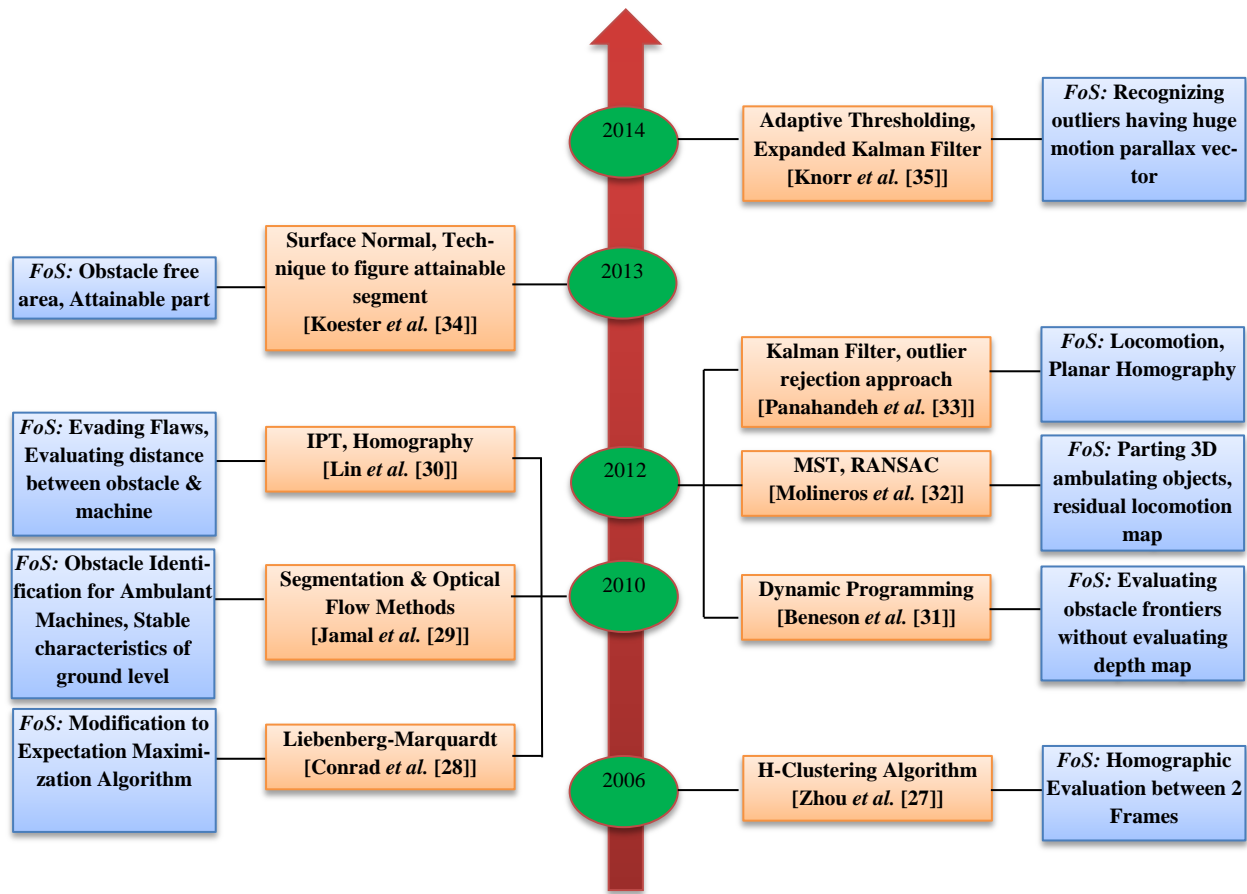


Fig.9. Evolution of Ground Plane Detection Techniques

In 2012, Molineros *et al.* [32] attained ego-locomotion in integration with soupy optical flow that results into a residual locomotion map which was implemented to part 3D ambulating objects. For electing ground points, MST (Minimum Spanning Tree) was executed. To separate outliers RANSAC was implemented. Using disparity of optical flow evaluation, a residual locomotion map was generated. Algorithm also performed well when ground level in images was less. In 2012, Panahandeh *et al.* [33] figured locomotion by executing an IMU (Inertial Measurement Unit) and ground level in the images was identified in 2 steps. 1<sup>st</sup> on the basis of kalman-filter (non-linear), planer homography was generated. Secondly on basis of evaluation of plane normal, outlier rejection approach was suggested. In 2013, Koester *et al.* [34] gave a

technique to correctly figure the attainable segment (obstacle free area) of ground ahead of visually impaired person. Surface normal were evaluated by considering gradients in disparity maps and were used to figure the attainable part. In 2014, Knorr *et al.* [35] gave an approach in which large field of view of fish eye camera was used to ruggedly recognize outliers, where huge motion parallax vectors were present. They clubbed adaptive thresholding with expanded kalman filter for better execution. Results were upgraded by distorting images into a common frame to evade deformity. All the various ground plane detection techniques are analysed in Table 6. Methods, merits, demerits and description are discussed.

Table 6. Analysis of various ground plane detection techniques

Author/Year	Method	Description	Target/Equipment	Merits/Applications	Demerits
Zhou et al. [27]/2006	Homography Based Ground Detection Approach	To detect ground in mobile robot applications	On-Board Camera	(1) Robust (2) Practical Deployment (3) Obstacle Avoidance (4) Cost Efficient	(1) This method fails when the object is very close and occupies large portion of the image (2) Unhandled Noise in the points correspondence (3) Absence of guiding a robot
Conrad et al. [28]/2010	Modified Algorithm	EM Indoor Navigation	Mobile Robot	(1) Classification rate of 99.6% (2) Can be used in outdoor settings where ground plane is not smooth (3) Target Following (4) Obstacle Avoidance	(1) No detection of multiple planes for indoor navigation (2) Ground plane data have to be manually maintained
Jamal et al. [29]/2010	Combination of segmentation and Optical flow techniques	Mobile Robot Navigation	Camera mounted on an in-house developed mobile platform	(1) Navigation in outdoor structured and dynamic environment (2) Very low computation time (3) Real time moving obstacle detection	(1) Fails when colour of the path is not uniform
Lin et al. [30]/2010	Vision based obstacle avoidance	To estimate distance of objects and avoid obstacles in an indoor environment	Wheeled mobile robot	(1) Various obstacles with various colours and sizes were detected and avoided (2) Cost effective (3) High performance processors	(1) When object is far away, it can't be distinguished due to limited resolution of image (2) As camera provides 60 degree wide view angle therefore robot might not avoid obstacles in blind zone
Benenson et al. [31]/2012	Fast Stixel Computation	To estimate ground obstacles boundary without calculating depth map	Stereo Image	(1) Focuses on computing exactly what we need (2) High Speed	(1) Wrong quantization (2) Ignores horizontal gradient
Molineros et al. [32]/2012	Novel Image Registration Algorithm - VOFOD	To detect obstacles from moving vehicle particularly children when backing up	Moving vehicle using monocular wide angle camera	(1) Works in cases with very few ground points present (2) Better Registration (3) Better ego motion estimation	(1) Arbitrary pose detections still needed to be improved (2) To eliminate false positives
Panahandeh et al. [33]/2012	Kalman filter + outlier rejection approach	To determine ground plane features	Mobile camera mounted on inertial measurement unit (IMU)	(1) Proposed approach is scene independent (2) No restriction on camera movement is their (3) Can be used for pedestrian navigation systems (4) Can be used for mobile robot navigation	(1) False detected ground features located around edges (2) Virtual plane false detection
Koester et al. [34]/2013	Computer vision approach to detect accessible section	To determine accessible section in front of walking person	Walking person	(1) Guiding users more smoothly around obstacles (2) Computationally light weight and simple (3) Consistently good performance	(1) Large parts of ground section cannot be recognised (2) More false positives as compared to other techniques (3) Reliance on good stereo reconstruction (4) Fail to detect small obstacles
Knorr et al. [35]/2014	Adaptive thresholding + expanded kalman filter	Robust homography estimation	Fish eye cameras	(1) More sensitive data based on consolidated estimates is processed (2) Robustness and high accuracy	(1) Identification likely to be incorrect for more distant points (2) Less degree of freedom

D. Texture Features

For categorization of objects, texture features are utilized. By evaluating characteristic values, it can be checked that whether the considered area belongs to obstacle or not. Pits, manholes etc. can be identified by collaborating texture feature techniques with obstacle identification technique. Characteristics of an image are evaluated and matched with citation characteristics to search for parallel characteristics. Further categorization of obstacles can be done. Different texture based techniques are present that we can use to do so. Some of the techniques present are- Local binary Patterns (LBP)[36][37], Grey Level Co-occurrence Matrix(GLCM)[38][39], kernel methods[36], feature combination[40], histograms based methods[41][42], Gabor filters[43]and boosting and baseline methods[44]. Best output can be attained by clubbing some of these techniques. Evolution of texture feature techniques along with their Focus of Study (FoS) is discussed in Fig 10. In 2000, Zitova et al. [45] proposed a technique to identify multi frame characteristic

points that remains constant towards rotation and noisy and unfocused images were also properly handled. This technique checked for common contents in various images to extract characteristics. Personal dataset of size 180 x 180 pixels was created and these images were rotated several times by different angles. These images were also softened using square convolution masks of varying sizes. They compared these techniques with another approaches and found that it gives best results in case of huge softening and minimum rotation. In 2001, Saisan et al. [46] proposed a technique that identifies and categories dynamic textures, where every touch was depicted specially, in lively structure. For PCA (Principal Component Analysis) and ICA (Independent Component Analysis), 3 distances were analyzed. They got best output in martin distance used for PCA. In 2006, Woolfe et al. [47] gave a technique to represent the locomotion of water, smoke etc. i.e. organic locomotion. They narrated sequence as multivariate AR (Autoregressive) structures. To figure

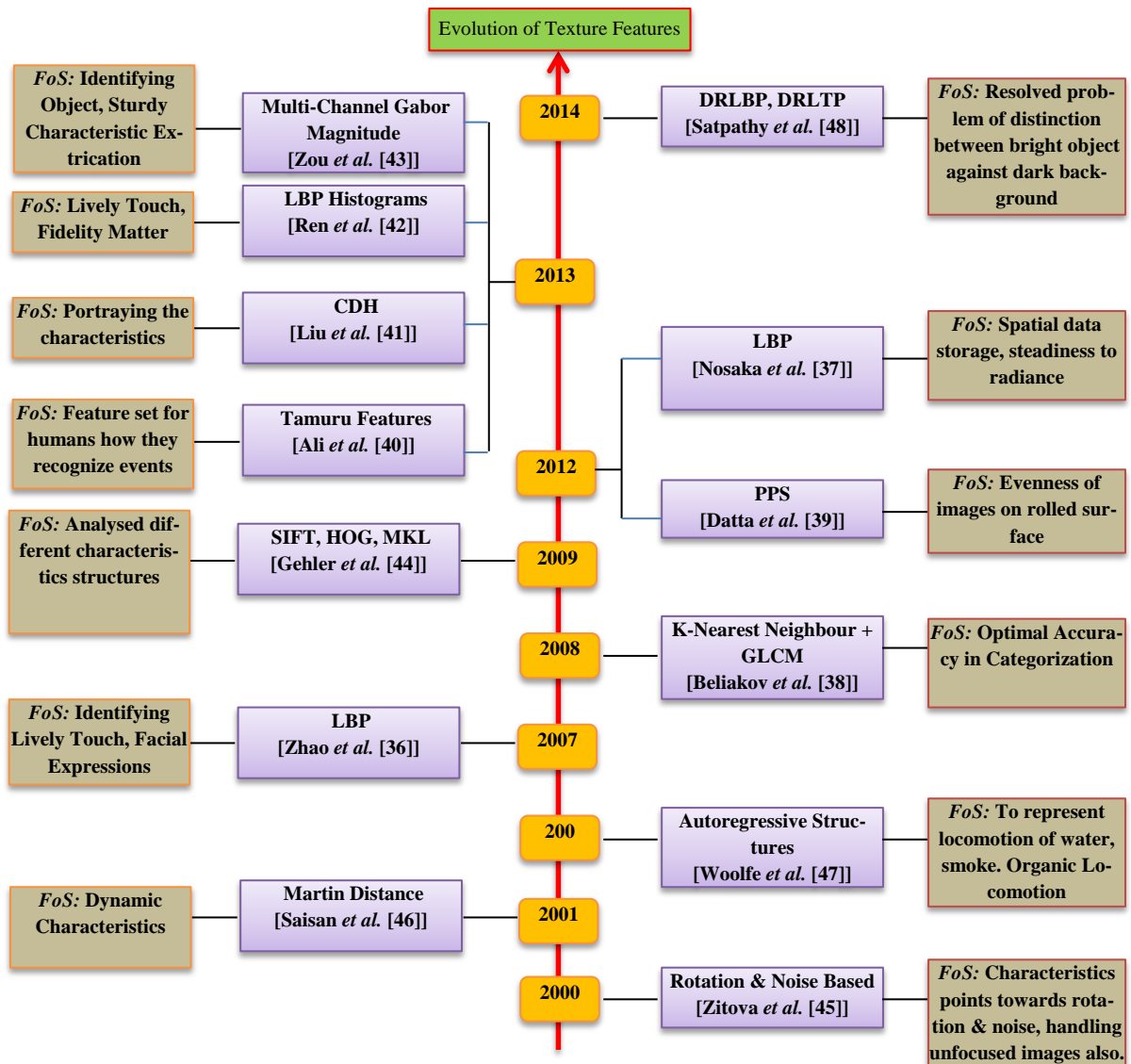


Fig.10. Evolution of Texture Features

the distance betwixt AR models, KL metric and chern off distance were evaluated. In 2007, Zhao et al. [36] proposed a technique using LBP to identify lively touch. Volume LBP was implemented to club locomotion and impression to structure touch. This method delivered an application for identifying facial expressions. As in comparison with other methods, authors obtained huge identification rate. In 2008, Beliakov et al. [38] merged the GLCM entries with benchmark metrics and analyzed these metrics with various other aggregation approaches to check for optimal accuracy of categorization. GLCM metrics were expendable; converting arithmetic mean to quadratic mean notably upgraded the effectiveness. K-nearest neighbour on basis of GLCM results best in noise absence. In 2009, Gehler et al. [44] analyzed different characteristics structures like single features as shape, color, SIFT, HOG and combination characteristics like product, averaging and MKL. Different techniques were discovered on basis of uplifting. Simple baseline techniques resulted equally well in contrast to its equivalents and were very simple. These techniques can be implemented in real time framework. In 2012, Datta et al. [39] by analyzing the outcome of disparity PPS (Pixel Pair Spacing), evaluated the evenness of images of a rolled surface by GLCM technique. In 2012, Nosaka et al. [37] suggested a LBP based new image feature that was steady to radiance also. Real and co-occurrence of adjoining LBPs both were present in it. More spatial data was stored by this technique. Due to radiance results of gabor, raw was not appropriate. In 2013, Ali et al. [40] gave a new feature set on the basis of how humans recognize the events. Organic events were categorized in this suggested approach. For this tamuru features were used by roughness features and openness features used histograms. First of all, image was quantal into eight color levels and for color characteristics; canny edge identifier was executed to figure direction characteristics. Better output was obtained in this technique as comparable to others.

In 2013, Liu et al. [41] gave a method known as CDH (Color Difference Histogram) that concentrated on portraying of characteristics for retrieving images. Color distinction betwixt 2 points in respect of color and edge locations were ciphered in it. It showed better results for content based image retrieval techniques. In 2013, Ren et al. [42] used LBP histograms to identify lively touch on basis of temporal and spatial characteristics. On the basis of PCA (Principal Component Analysis), 2 approaches were suggested on learning to handle fidelity matter by histograms of LBP. They suggested super histograms also. In 2013, Zou et al. [43] suggested an approach to identify object by interpreting multichannel Gabor magnitude co-occurrence matrices. Gabor magnitude touch equality was its basis. For sturdy characteristics extrication, learning algorithm to rescale images was advised. In 2014, Satpathy et al. [48] proposed new set of edge touch characteristics, Distinctive Robust Local Binary Pattern (DRLBP) and Ternary Pattern (DRLTP). These features removed the limitations of the other Texture Features like LBP, LTP and Robust LBP. They solve the problem of

discrimination betwixt a bright object against a dark background and vice-versa inherent in LBP and LTP. DRLBP also resolves the problem of RLBP whereby LBP keys and their complements in a like block are plotted to similar key.

#### E. SURF and SIFT Features

In 2004, David G. Lowe discovered distinctive image characteristics for comparing various images and was also steady to scaling and spinning of images [4]. This approach was known as SIFT (Scale Invariant Feature Transform). In 2006 Bay et al. discovered SURF (Speeded up Robust Features), which were very much fast and better than all other approaches proposed [5]. Object recognition can also be done by using SIFT features. Individual characteristics were compared with huge database of characteristics which contained object features using fast nearest neighbour approach. SIFT features from cited images were extricated and stored in the database. Evolution of SURF and SIFT feature techniques along with their Focus of Study (FoS) is discussed in Fig 11. In 2006, Bay et al. [5] discovered SURF (Speeded up Robust Features), that was steady towards spinning and scale. First of all, interest points were nominated at various locations in image. For this Hessian based detectors were executed. In 2nd step, interest points were presented as characteristic vector. In 3rd step characteristic vector in various images were compared. In terms of sturdiness, individuality, rapidity and clarity, this technique comes out to be better than all other approaches. In 2008, Zhang et al. [49] implemented SURF for identification of indicator points from image in SLAM (Simultaneous Localization and Mapping) technique. Landmarks extricated by using SURF features and EKF (Extended Kalman Filter) figured the position of camera and landmarks. For comparison of SURF features, Euclidean distance was utilized. In 2009, Lampert et al. [50] resolved the problem to categorize objects when training and test sets differ. Objects were identified by human described elucidation that contained color or any other geographic data. Categorization was done by direct and indirect feature prediction. In 2009, Ta et al. [51] gave a technique to recognize image and predict characteristics in a video by optimizing the interest points. Alternative of computing feature descriptors of 2D images, candidate features were explored and compared in community neighbourhood within the 3D image pyramid. In 2009, Yu et al. [52] resolved the steadiness of SIFT features associated with angles those describe camera axis spinning. Transition tilt, a new framework was discovered. It managed more transition tilts than its equivalents. In 2010, Besbes *et al.* [53] suggested a SVM and SURF based technique to identify the rambler. For categorizing SURF features, RNN was utilized. For fastening the extrication of features, stratified codebook was utilized. That boosted the categorization output along with the upgradation of characteristic extrication. In 2010, Sande *et al.* [54] gave color rubrics to boost steadiness against radiance and discerning power. For various datasets, various descriptors must be utilized.

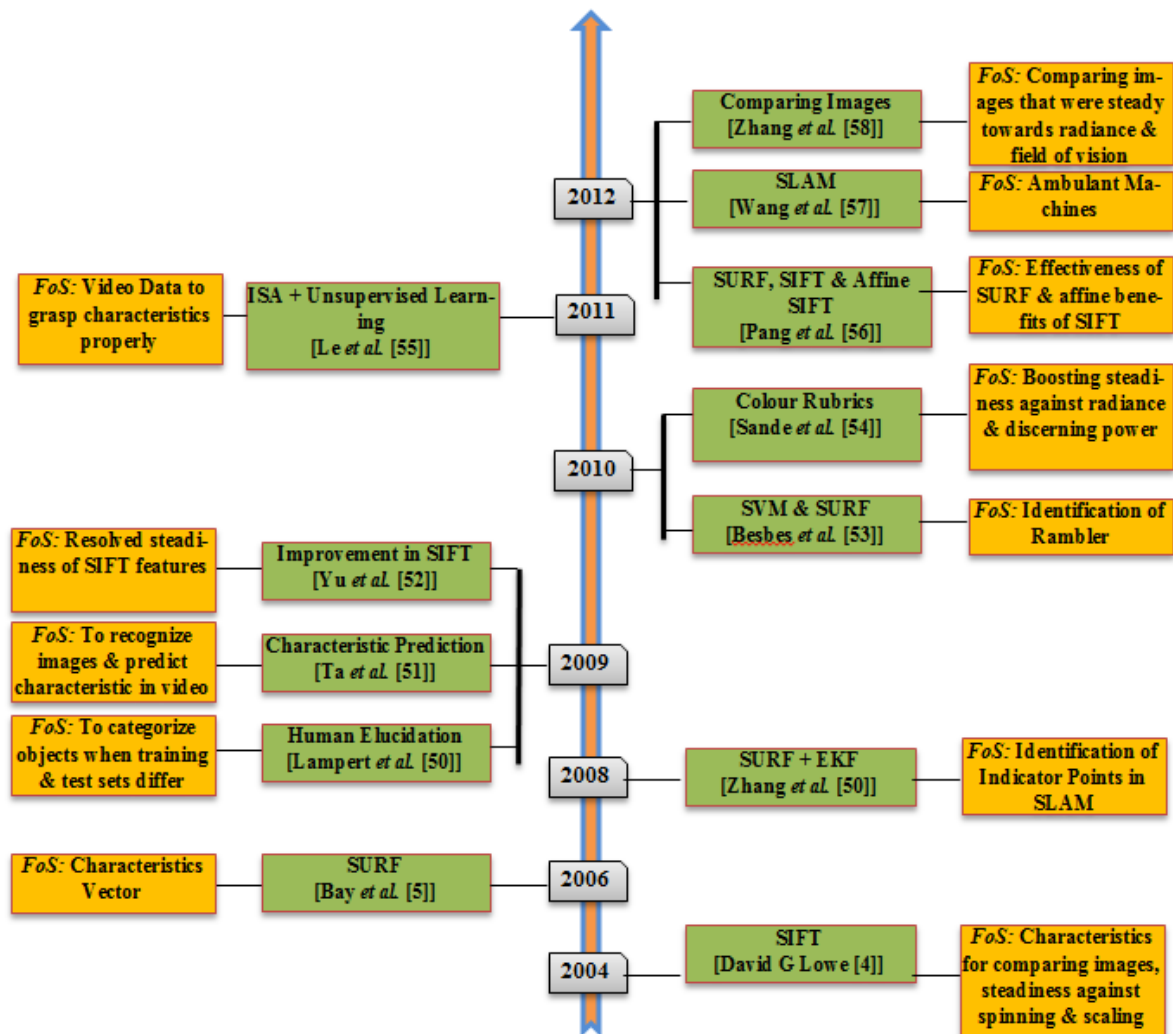


Fig.11. Evolution of SURF and SIFT Features

Instead of discrete rubrics, proper amalgamation of colour descriptors gave better results. In 2011, Le et al. [55] suggested a technique on the basis of video data to grasp characteristics rightly from it. Unsupervised learning was utilised as an addition to ISA (Independent Subspace Analysis) algorithm. This approach in collaboration with approaches like stacking and convolution gave better results. In 2012, Pang et al. [56] predicted that SURF, SIFT and Affine Sift, none of them were fully affine. They gave a wholly affine steady algorithm on basis of SURF. Effectiveness of SURF and affine benefits of SIFT were considered by evading their limitations. This advanced SURF technique comes out with fewer complications than ASIFT. In 2012, Wang et al. [57] suggested technique in SLAM (Simultaneous Localization and Mapping) for ambulant machines. For equivalent characteristic points, epi-polar constraints were explained and SURF features were exploited for having good and sturdy identification. In 2012, Yu et al. [58] gave a technique to compare images that were steady towards radiance and field of vision. Normalization of radiance, conversion of images field of vision, evaluation of relative view and radiance was done to boost fidelity, steadiness and exactness of the system. If initial field of

vision and radiance approach fades, this approach also fades, so valid angle and valid radiance were suggested.

#### IV. RESULTS AND CONCLUSIONS

Exploring the existing research in field of obstacle detection is the main objective of this review. Out of 58 research papers, 23 are publicized in eminent journals and the remaining are publicized in workshops, conferences and symposiums on obstacle detection. It is merit expressing about the publication for that research articles on ground plane detection, monocular vision approach, key frame extraction, feature extraction and SURF and SIFT features are published in comprehensive variety of journals and conference proceedings. We observed that IEEE conferences/symposiums like IEEE Intelligent Vehicles Symposium, IEEE Conference on Robotics, IEEE/RSJ International Conference on Intelligent Robots and Systems, IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), IEEE International Conference on Fuzzy Systems, IEEE 12th International Conference on Computer Vision contribute large part of research articles. Prime

journals like International Journal of Computer Vision, The Visual Computer, Journal of signal processing, Pattern Recognition, Neuro computing, EURASIP Journal on Advances in Signal Processing, contributed significantly to our review area. Figure 12 depicts the percentage of research papers analyzed at various phases of the obstacle detection process like as the figure depicts 26% in Monocular vision based approach, 14% in key frame extraction, 16% in ground plane detection, 23% in texture features, 21% in SURF and SIFT features. Study consists of 45% research articles publicized in conferences and 40% in eminent journals, 7% literature appeared in workshops and 9% of the study publicized in symposiums. Conferences acquire major part of publications (26 papers) followed by 19 papers in journals. Fig. 13 depicts the number of research papers published in the various areas

against the different steps included in obstacle detection from year 1998 to 2015.

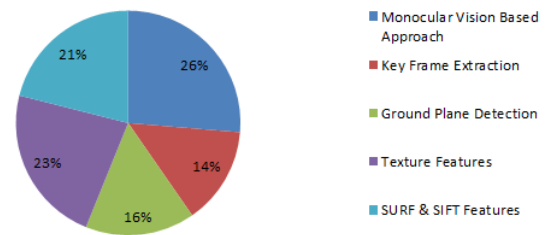


Fig.12. Obstacle detection mechanism

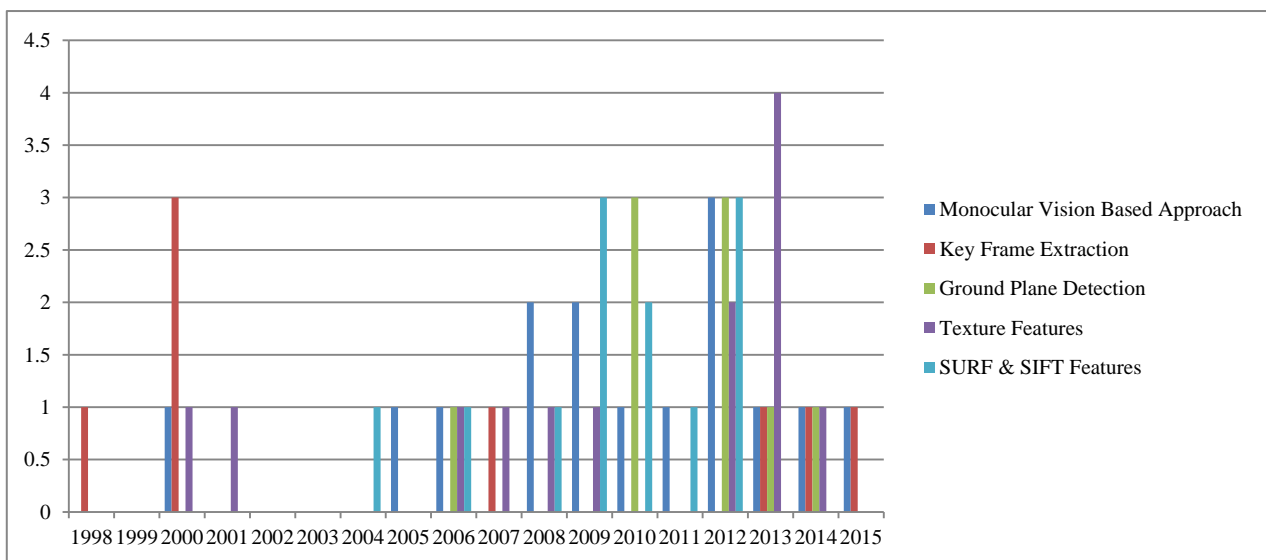


Fig.13. Time based count in obstacle detection against various fields

From year 2000 – 2015, no. of research papers against monocular vision based approach are described in the Figure 13. Maximum 3 research papers were published in year 2012. In the field of key frame extraction, research is discussed from year 1998 – 2015, with maximum research done in year 2000, leading towards 3 research papers. Ground plane detection is also discussed over years from 2006- 2014, having maximum research articles published in year 2012 and year 2010 with the count of three. Maximum 4 research articles in field of Texture Features in year 2013. SURF and SIFT originated in year 2004 with maximum research done against this filed in the year 2009 and year 2012 leading towards 3 research articles.

After analyzing all the research carried in various fields, conclusions are presented like in field of monocular vision based approach, it is concluded that deformable grid proposed by Kang et al. [18] is a good method for detecting obstacles at the risk of collision, where as to evaluate distinction between ground plane and obstacle, two successive frames prototype proposed by Jia et al. [17] comes out to be appropriate as no calibration or any

prior knowledge of the camera is required and is cost effective also. For detecting and tracking moving obstacles, in-motion detection method proposed by Mishra et al. [14] is concluded to be the appropriate one as it is computationally simple having better time response. Block based method by Lim et al. [13] can be used to detect the pedestrians. For key frame extraction, if fast processing is required, method proposed by Raikwar et al. [25] is the appropriate one as it requires very less time for extraction of key frames, where as if high accuracy and simplicity is considered then absolute distinction of histograms of successive frames method proposed by Sheena et al. [26] comes out to be appropriate one. In ground plane detection phase, to determine ground plane features, kalman filter and outlier rejection approach proposed by Panahandeh et al. [33] is concluded to be a good method. To detect obstacles from moving vehicles, novel image registration algorithm VOFOD by Molineros et al. [32] is the appropriate one. To guide the walking person about the obstacles around, computer vision approach to detect accessible section by Koester et al. [34] is the appropriate method.

## V. DISCUSSIONS

Total 58 research articles out of 761 have been reviewed to study Obstacle Detection techniques and to provide a surmised summary. Unlike erstwhile reviews, our supreme emphasis is on the research done at each phase of Obstacle Detection process, and existing research work from diverse main sub-topics is categorized. We have used quality analysis procedures and have done a wider literature survey on obstacle detection up to 2015. Research issues of monocular vision based approach, key frame extraction and ground plane detection are explored. We explored the obstacle detection mechanisms and their subtypes in detail for each and every phase of obstacle detection and compared the various mechanisms. No such survey has been proposed that consist of the literature of each and every step included in the obstacle detection process. From this survey, authors can easily find the recent research carried out after year 1998, all the existing studies are logically categorized into various sections.

## VI. FUTURE RESEARCH DIRECTIONS

This research article presents a well ordered survey on obstacle detection techniques. As obstacle detection is a complete process having various phases in it. Study is done for all of the phases. First of all various Monocular vision techniques are discussed and are analyzed. Then various key frame extrication techniques are studied and analyzed, after that various ground plane detection techniques are also discussed. Feature extrication is also discussed along with the SIFT and SURF features. Various vision based approaches are also discussed in the research conducted, like Stereo Vision based approach and Monocular Vision based approach. It is concluded that Monocular Vision based approach is less costly then Stereovision Based approach and also have low complexity leading towards fast processing in real time. The main objective of this research is to find the suitable technique at every phase having low cost and fast operating in real time environment with high accuracy. We have also identified a number of open issues that would benefit from further studies. To the best of our knowledge, such an analysis has not been done so far and could lead to identifying novel areas for the application of obstacle detection techniques in the context of aiding the visually impaired persons.

Though a lot of progress has been achieved in the obstacle detection techniques, at each phase of obstacle detection process, various techniques are applied, still there are many issues and challenges in this field that needs to be addressed. Future research directions have been identified for monocular vision based approach and ground plane detection phases of obstacle detection process. The following research directions have been identified from the existing literature [Ulrich et al. [2]; Michels et al. [6]; Yamaguchi et al. [3]; Song et al. [7]; Zhan et al. [8]; Muller et al. [9]; Viet et al. [10]; Lin et al. [11]; Cherubini et al. [12]; Lim et al. [13]; Mishra et al. [14];

Lalonde et al. [15]; Lin et al. [16]; Jia et al. [17]; Kang et al. [18]] of monocular vision based approach.

- Monocular vision based approach must work properly if the obstacles are present inside the trapezoidal reference area.
- Obstacles less than 5m away must be detected and avoided, preventing the car crash.
- Stationary objects present on road must be detected.
- Region detection accuracy must be improved.
- Outperformance when grid size is too large or too small, performing only when ground is flat, detecting the over changing obstacles are open research issues.
- Based on existing research, we found that tracking pedestrian in close proximity to car and detection of head of pedestrian are open research issues.
- Training set should represent real population as learning algorithm can only model variations presented in training set.
- Visual occlusions provoked by obstacles must be considered.
- Tracking pedestrian those who have recently entered in image frame is also found to be an open research issue.
- Interaction between detection and tracking must be considered.
- Further research when surface is plain and doesn't have distinguishing feature is an open research issue.
- Disparity for given camera displacement must be considered automatically.
- Too many miss detections and mismatched feature points in obstacle region may fail the system.
- Far away objects are considered as no obstacles.
- Detecting collision in region where the accurate motion vector is not easily computed like walls, doors is also found to be an open issue.
- Developing the system working at driving speed more than 30 km/hr and increasing the detectable distance beyond 6 metres are also found to be an open research issues.

The following research directions have been identified from the existing literature [Zhou et al. [27]; Conrad et al. [28]; Jamal et al. [29]; Lin et al. [30]; Benenson et al. [31]; Molineros et al. [32]; Panahandeh et al. [33]; Koester et al. [34]; Knorr et al. [35]] of ground plane detection.

- Considering the objects that are very close and occupies large portion of the image is an open research issue.
- Handling noise in the point's correspondence.
- Guiding a robot is found to be an open research issue.
- Multiple plane detection for indoor navigation.



- Extending the system to detect ground plane when colour of the path is not uniform.
- Increasing the resolution of the image to distinguish very far away objects is also found to be an open research issue.
- Avoiding obstacles in blind zone by increasing the view angle.
- We found that considering horizontal gradient and quantization is also an open research issue.
- Improvement in arbitrary pose detections is still needed.
- More degree of freedom is required.
- Improvement of virtual plane detection and ground features located around edges is needed.
- Recognising large parts of ground section.
- Identification of more distant points and very small obstacles is also an open research issue.

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#### Appendix 1: Acronyms

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SURF	Speeded up Robust Features
SIFT	Scale Invariant Feature Transform
FoS	Focus of Study
RADAR	Radio Detection and Ranging
LIDAR	Light Detection and Ranging
SONAR	Sound Navigation and Ranging
LBP	Local Binary Patterns
GLCM	Grey Level Co-occurrence Matrix
PPS	Pixel Pair Spacing
CDH	Colour Difference Histogram
DRLBP	Distinctive Robust Local Binary Pattern
DRLTP	Distinctive Robust Local Ternary Pattern
SLAM	Simultaneous Localization and Mapping
ISA	Independent Subspace Analysis
RLBP	Robust Local Binary Patterns
EM	Expectation Maximization
GMM	Gaussian Matrix Model
IMU	Inertial Measurement Unit
MST	Minimum Spanning Tree
PCA	Principal Component Analysis
EKF	Extended Kalman Filter

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