# VEHICLE DETECTION METHODS FOR INTELLIGENT ROAD STUD APPLICATION: A REVIEW

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**ABSTRACT**

*Intelligent road studs are integral part of intelligent road transportation system. These are playing a prominent role to achieve the increasing demand for optimum traffic management and safety improvements with rapid increase in vehicle usage. The optimum traffic management requires to process and analysis of various traffic data such as vehicle count, classification, speed, density, occupancy, etc. For improving safety aspects the system requires to warn driver on hazardous situation in advance such as stationary vehicle presence on road, surveillance of over speed of vehicles, accident detection etc.. The key factor for all such applications is to detect vehicle, so far various approaches have been developed to detect vehicle. Among all such technologies magnetic sensor, ultrasonic sensor, acoustic sensor, infrared sensor technologies can be used in intelligent road stud network. This paper attempts to describe and analyze these methods and its pros and cons available so far for intelligent road stud applications in a systematic manner.*

***Keywords: Acoustic Sensor, Intelligent Road Stud, Magnetic Sensor, Ultrasonic Sensor, Vehicle Detection***

## I. INTRODUCTION

Road safety and traffic congestion are two of the major problems encountered by all countries, especially for developing countries. Thus the importance of intelligent road studs increasing in intelligent road transportation system. There are many possibilities of road safety measures which can be implemented, but each has its own limitations in terms of complexity, cost, power and functionality.

Reflective cat's eyes have been used to visually delineate lanes at night. The advances in electronics brought road studs a step forward by incorporating solar powered light emitting diodes in road studs. This improved road safety to some extent by reducing accidents especially during night time [1]. Further researches improved road stud capability by adding communication between road stud to road stud as well as communication with operating station through wired and wireless communication. However wired road stud networks are impractical because of their maintenance cost and complexity in deployment. Wireless road stud sensor networks with autonomous sensor nodes can be more economical.

Further in the process of improving road studs many possibilities had unfolded. Now most of the road studs are capable of counting number of vehicles passed, average speed of the road, classification of vehicles, traffic flow control, communication with the operating station etc. for efficiently managing road traffic. To improve road safety road studs are also made quite intelligent enough to identify dangerous situation such as stationary vehicle ahead on the road, probability of collision at junctions, wild animal presence on highways, over speed of vehicles, slippery road condition, snow weather ahead etc. and warning driver before accident occurs. For all of these applications to be implemented in road studs, the most important step is to detect vehicle. Accurate and fast detection of vehicle improves efficiency of road stud network.

Over the last twenty years, advances in sensor technologies enabled many ways for vehicle detection. In general according to the installation position vehicle detection sensors are classified as (I) Intrusive or Inroad sensors and (II) Non intrusive or over roadway sensors. The sensor technologies inductive loops, pneumatic road tubes, piezoelectric cables, capacitive sensors, weigh-in-motion and micro loop probes comes under intrusive sensors [2][3][4][5]. These types of sensors are embedded in the pavement or the sub grade and hence these sensor technologies require relatively high installation, repair and testing costs. Video camera, acoustic signal processor, ultrasonic sensors, infrared sensors, magnetic sensors and microwave radar comes under non intrusive sensors [6][7][8][9][10]. These sensors are placed above the surface of the roadway or poles adjacent to it or on the edges of the road, so they will not interrupt traffic flow during installation and maintenance.

Even though videos camera sensors give more accurate data and many vehicle parameters, the complex processing algorithms, high power requirements, high cost are the challenges still to be faced. Recently Wireless Sensor Network (WSN) became more popular owing to its low power, low cost. In this paper detailed study of vehicle detection sensors and its advantages & disadvantages have been discussed especially road stud based vehicle detection sensors have focused in a systematic way.

So far many articles came on vehicle detection technologies. In 1998 a paper "Traffic incident detection: Sensors and algorithms" discussed few methods to detect vehicles later diverted to incident detection [11]. In 2006 another paper “On-road vehicle detection: A review” reviewed on several algorithms for vehicle detection, but this paper especially focused on vision based sensor algorithms [12]. One more paper in 2010 “A study on vehicle detection and tracking using wireless sensor networks” described various algorithms to track vehicles along with few vehicle detection methods [13]. In this paper discussion of various sensor technologies and methods to detect vehicles in a road stud point of view besides its compatibility in wireless road stud network has provided.

## II. VEHICLE DETECTION METHODS

As mentioned earlier there are wide range of sensor technologies for vehicle detections are available. Advantages and disadvantages of various techniques are tabulated as shown in the Table 1 [14]. Apart from that the compatibility of technique in the implementation of intelligent road stud network also provided. In later sections the sensor technologies which are compatible in the road studs are described in detailed manner.

**Table1. Pros and cons of various vehicle detection technologies**

| Technology | Pros | Cons | Compatibility |
|---|---|---|---|
| Inductive loop | • Flexible design to satisfy large variety of applications.<br>• Provides basic traffic parameters (e.g., volume, pres-ence, occupancy, speed, headway, and gap).<br>• Insensitive to inclement weather such as rain, fog, and snow.<br>• Provides best accuracy for count data as compared with other commonly used techniques. | • Installation requires pavement cut.<br>• Improper installation decreases pavement life. - - Installation and maintenance require lane closure.<br>• Wire loops subject to stresses of traffic and temperature.<br>• Detection accuracy may decrease when design requires detection of a large variety of vehicle classes. | NO |
| Magnetometer (Two-axis fluxgate magnetometer) | • Less susceptible than loops to stresses of traffic.<br>• Some models transmit data over Wireless RF link. | • Installation requires pavement cut.<br>• Decreases pavement life.<br>• Installation and maintenance require lane closure.<br>• Some models have small detection zones. | YES |
| Microwave Radar | • Generally insensitive to inclement weather.<br>• Direct measurement of speed.<br>• Multiple lane operation available. | • Antenna beam width and transmitted waveform must be suitable for the application.<br>• Doppler sensors cannot detect stopped vehicles. | NO |
| Infrared | • Active sensor transmits multiple beams for accurate measurement of vehicle position, speed, and class.<br>• Multizone passive sensors measure speed.<br>• Multiple lane operation available. | • Operation of active sensor may be affected by fog when visibility is less than »20 ft or blowing snow is present.<br>• Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog. | NO |
| Ultrasonic | • Multiple lane operation available. | • Some environmental conditions such as temperature change and extreme air turbulence can affect performance.<br>• Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds. | YES |
| Acoustic | • Passive detection.<br>• Insensitive to precipitation. | • Cold temperatures have been reported as affecting data accuracy. | YES |

| | | | |
|---|---|---|---|
| | • Multiple lane operation available. | • Specific models are not recommended with slow moving vehicles in stop and go traffic. | |
| Video Image Processor | • Monitors multiple lanes and multiple zones/lane.<br>• Easy to add and modify detection Zones.<br>• Rich array of data available.<br>• Provides wide-area detection when information gathered at one camera location can be linked to another. | • Inclement weather, shadows, vehicle projection into adjacent lanes, occlusion, day-to-night transition, vehicle/road contrast, and water, salt grime, icicles, and cobwebs on camera lens can affect performance.<br>• Requires 50- to 60-ft camera mounting height (in a side-mounting configura-tion) for optimum presence detection and speed measurement.<br>• Generally cost-effective only if many detection zones are required within the field of view of the camera. | NO |

### 2.1 Detection of Vehicle with Magnetic Sensor

Magnetic sensor technology for vehicle detection is very popular, because of its low cost and low power requirement. This technology developed on the key point that everywhere on the earth surface there is a presence of earth's magnetic field. These earth's magnetic field lines are almost parallel at the equator region and perpendicular at the pole region. Various parts of a vehicle are made up of ferrous material such as engine, axel, body, etc,. A vehicle can be modeled as dipole as shown in Fig 1 [14]. As almost all vehicles made up of enough ferrous material that will influence the earth's magnetic field which can be detected by magnetic sensor to ensure vehicle passage as shown in Fig. 2.

There are two types of magnetic sensors, one is active and other is passive types. The active type is called a magnetometer. A magnetometer acts in much the same way as an inductive loop detector, except that it consists of a coil of wire wrapped around a magnetic core. This measures the change in field due to passage of vehicle hence, this type of sensors can be used for both vehicle presence as well as vehicle passage detection. But in case of passive type of sensor, it simply measures the change in the flux of the earth's magnetic field caused by the passage of a vehicle hence this can be used only for moving vehicle detection. This type of sensors having large detection range and thus can be used to multiple lane of traffic.

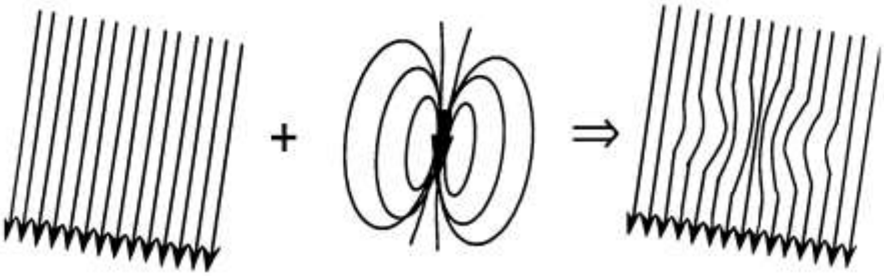

**Figure 1. Earth's magnetic field + dipole = influenced magnetic field**

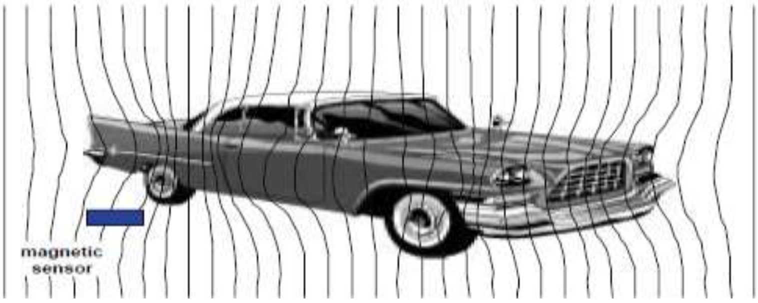


**Figure 2. Vehicle disturbance in earth's field.**

Magnetic sensor can detect the vehicles up to distances of 15 meters away depending on its ferrous content. The magnetic field signature of a vehicle passage at different distances has shown in Fig 3 [15].

One of the vehicle detection methods is to differentiate vehicle from obtained raw magnetic sensor data with a fixed threshold. Based on the typical response of a vehicle, an idea is inspired to detect vehicles by a single threshold from the raw signal sampled by magnetic sensors [16, 17]. As the obtained data through magnetic sensor consists significant noise leads to false detection of vehicle, to decrease the impact of noise Finite Input Response (FIR) filter is applied to smooth raw signal [18, 19]. A FIR filter is proposed to smooth the raw data first, then a threshold is used to detect the vehicle.

Another vehicle detection method is to identify vehicle with an adaptive threshold technique. An extra algorithm is introduced to adjust threshold dynamically [20]. A constant false alarm (CFAR) detector is applied to improve the detection performance [19]. However it is difficult to obtain noise on the road accurately.

Here is another perspective to solve the vehicle detection problem. By analyzing mass of vehicle magnetic data, it has found that most waveforms are similar to each other, it has assumed that there is a referential waveform which is similar to the majority of actual vehicle responses. Then by calculating similarity between response wave form and referential wave form vehicle can be detected [21].

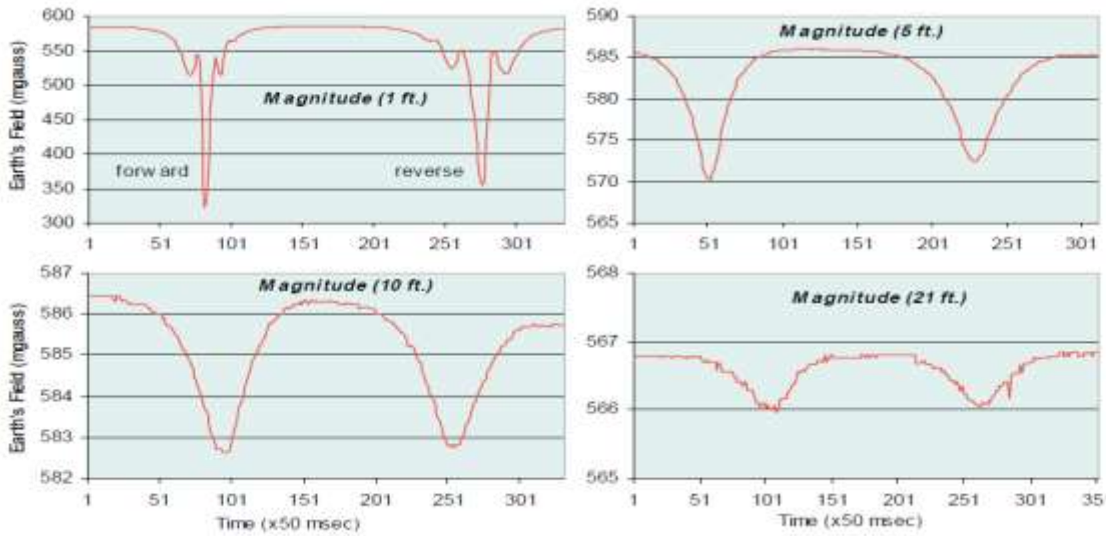


**Figure 3. Magnitude of magnetic field variations for a car traveling at distances 1, 5, 10 and 21 feet.**

One of the drawbacks of magnetic sensor technology is if multiple vehicles are moving in parallel then it assumes the presence only one vehicle. Hence accuracy of vehicle detection in dense traffic is low.

### 2.2. Detection of Vehicle with Ultrasonic Sensor

Ultrasonic sensors transmit pressure waves of sound energy at a frequency in the range 25 to 50 KHz, which are above the human audible range. The speed of ultrasonic waves varies with air temperature and can be calculated as shown in equation (1).

$$\text{Ultrasonic speed} = 331.5\ \text{m/s} + (0.61 \times \text{temperature}) \quad (1)$$

The dissemination angle of an ultrasonic sensor depends on the ultrasonic frequency. As the ultrasonic frequency decreases the dissemination angle θ increases. In addition, the condition for detecting the reflected ultrasonic wave is $\alpha < \theta/2$, where α is the angle between an ultrasonic sensor and the detection object, this has shown in Fig. 4. These characteristics of ultrasonic wave must be taken into consideration while designing vehicle detection systems.

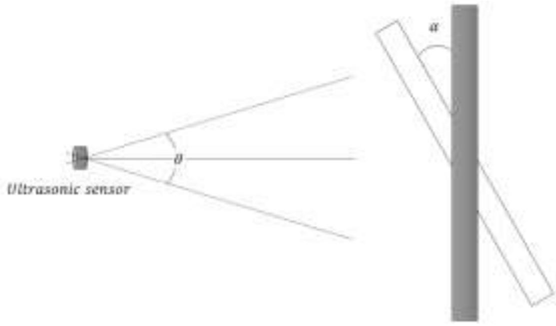


**Figure 4 Dissemination and detectable angle of an ultrasonic sensor.**

#### 2.2.1 Analysis with a Vehicle on Single-Lane

Consider a single vehicle on a single vehicle on single-lane road, as shown in Fig. 5. Assume that the vehicle length to be $l_v$ and its speed to be $v_v$ on a straight path along a lane of width $l_l$. The ultrasonic sensor is placed at a distance of $l_g$ from the road side. From Fig. 2, $l_d$ can be calculated by $2l_u \tan(\theta/2)$, where $l_u$ is the distance from the sensor to the detection point. Ultrasonic sensors generate distance data by measuring the time taken to receive reflected ultra sonic waves. The time is directly proportional to the distance between the ultrasonic sensor and the detection object. Vehicles can be detected by using the number of distance data collected from the ultrasonic sensors. Here it is important to optimize detection intervals that can collect sufficient distance data for reliable vehicle detection. The detection interval of an ultrasonic sensor is given by the ratio of detectable period of a vehicle and the number of distance data necessary for vehicle detection.

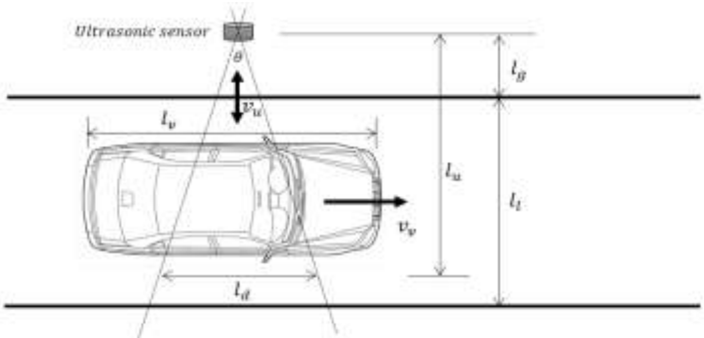


**Figure 5 Analysis of model**

The data obtained from the ultrasonic sensor is raw signal, it must be filtered for noise before applying any specific algorithm to that signal. A median filter can be selected as it combines appropriate performance with a low sampling rate. Algorithm for vehicle detection has provided in the following Fig. 6

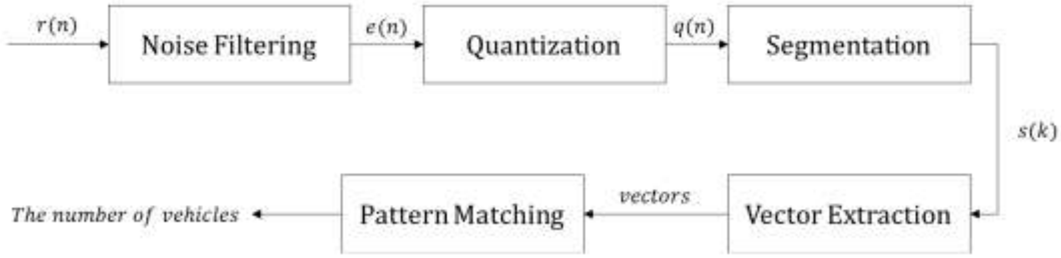


**Figure 6 Vehicle Detection Algorithm**

The raw distance data *r(n)* measured by an ultrasonic sensor are passed through a median filter which filters out noise and gives a fine output. This filtered distance data *e(n)* are then quantized according to the lane width. This quantized data *q(n)* is used for further process of segmentation. This segmented output will give vehicle information with pattern matching technique. The segmented data are then represented as vectors, for a two lane road, only four different vectors can be generated i.e., two different directions and two different sizes as shown in Fig.7. There can be a total of six patterns for the target road, with the help of patterns traffic information is generated in the final pattern matching step as shown in Fig 8.

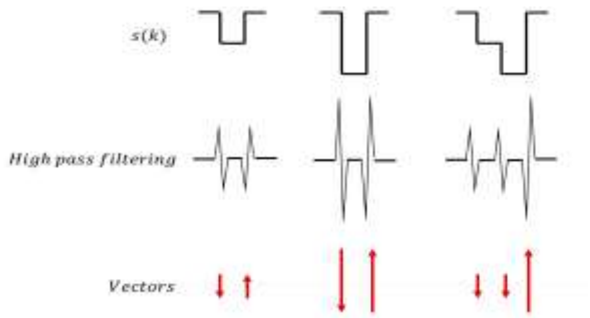


**Figure 7 Vector Extraction**

### 2.2.2 Disadvantages

Major disadvantages of ultrasonic sensor vehicle detection technique are its accuracy is influenced by temperature of atmosphere and high wind velocity. Even it is having appreciable vehicle detection accuracy it fails to detect vehicle in parallel hence shows poor accuracy for dense traffic flows. Sensors placed on a curved section of road will not work up to the expectation. Even though these problems can be overcome by implementing sophisticated algorithms, its condition to install on straight sections of road for reliable vehicle detection makes it to be less priority to choose in intelligent road stud network system.

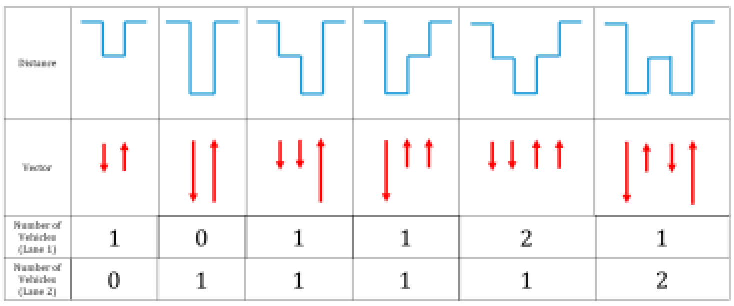


**Figure 8. Example pattern for two lane road.**

## 2.3. Vehicle Detection with Acoustic Sensor

Acoustic sensors measure vehicle passage, presence, and speed by detecting acoustic energy or audible sounds produced by vehicular traffic from a variety of sources within each vehicle and from the interaction of a vehicle s tires with the road. When a vehicle passes through the detection zone, an increase in sound energy is recognized by the signal-processing algorithm and a vehicle presence signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold and the vehicle presence signal is terminated. Sounds from locations outside the detection zone are attenuated.

#### 2.3.1 Vehicle Detection through Tire Noise

The predominant source of vehicle noise is the broadband energy radiated from the tires [22, 23, 24]. The approach to exploiting these phenomena is to cross-correlate the acoustic responses of spatially separated, roadside microphones. The noise recorded by roadside microphones is used to detect axle passages.

Sound emitted from a moving source will appear to increase in frequency as the source approaches the listener, and-decrease in frequency as the source moves away. Thus effect, known as the Doppler Effect, is caused by the compression of the sound waves as the source approaches and expansion as the source recedes. For close-in, highly dynamic, sources the Doppler Effect will cause different waveforms to appear on both microphones. Because the waveforms, at each sensor, are not alike, cross correlation without Doppler compensation will fail. The time series for a range of Doppler shifts must be compensated before cross correlation processing. The method involves scaling one phone output to correspond with the other.

#### 2.3.2. Vehicle Detection through Engine Noise

This is another attempt to detect vehicle using acoustic sensor, here it uses engine sound of a vehicle for detection as well as classification of vehicles. The acoustic signal often processed in frequency domain. The spectrum of the vehicle sound however is influenced by the structure of the vehicle body as well as its state of motion (static, moving, accelerating, etc.). A wavelet based method [25], uses a sixth order spline wavelet transform to detect arrival of vehicles of arbitrary type when other noises are present by analysis of acoustic signatures against an existing database of recorded and processed acoustic signals. To ensure least possible false matching, a training database is constructed using the distribution of energies among blocks of wavelet packet coefficients with a procedure for random search for a near-optimal footprint.

Among spectral based methods, [26] extracts the fundamental frequency associated with the engine of the vehicle, and establishes a relation between the fundamental frequency, number of cylinders of the engines and their RPM. It identifies the role of this fundamental frequency and the harmonic spectral structure in classification of vehicles. Vehicle classification algorithm using back propagation described in [27] is another spectral domain based method. A one third-octave filter bands is used for getting the important signatures from the emanated noise. The extracted features are associated with the type and distance of the moving vehicle. A fusion of harmonic features which correspond to engine noise and key features which correspond to tires friction noise have also been used in vehicle identification [28].

These acoustic sensors cannot be fully covered hence presence of dust degrades the performance of the sensor and requires regular maintenance. Noise of acoustic sensor signal is more compared to the noise of magnetic sensor hence acoustic sensor node requires more processing to eliminate noise than magnetic sensor node.

### 2.4. Vehicle detection with accelerometer (seismic) sensor

Moving vehicles emit heats, acoustic, magnetic and seismic when they run in traffic lane, which are affected by noises, Doppler effects and atmospheric. Even though seismic waves propagate in different forms, different directions and different speeds, and are also more dependent on the underlying geology, seismic method has advantages over other methods because seismic waves are less sensitive to these factors. Seismic sensors also provide non-line-of-sight detection capabilities for vehicles at significant ranges. The seismic sensors provide a good detection range, increased detection capabilities and have been extensively used in many applications.

Vehicles contact with irregularities in the road surface induces dynamic loads on the pavement. In general, seismic waves can be classified into two categories: body waves and surface waves. Research of seismic waves shows that 70% of energy of the impact is distributed in the surface waves and the remaining 30% of the energy is transmitted into the earth via body waves. Therefore, vehicles can be detected by observing the surface waves generated by the moving vehicles [29]. The seismic spectra of vehicle could be separated into two parts: a broadband component and one or more narrow band peaks. The broadband component is due to the interaction of the wheel with the randomly distributed surface irregularities. The narrow band component is due to the periodic impact of the treads. This sensor technology will be compatible with intelligent road studs but a proper mounting of this node on road is essential.

### 2.5. Vehicle Detection with Optical Sensor

This sensor technology will work only during night time because this uses vehicle head light for detection of vehicle. Now a days ultra low power optical sensor ICs are available hence these sensors will be effective in intelligent road studs to overcome power constraint. Instead of using this sensor as solo way for detecting vehicle, it can be used in the combination of any other sensor for vehicle detection in order to save power [30].

## III. CONCLUSION AND FUTURE DIRECTION

In this paper an attempt made to review various vehicle detection methods. The effort is confined to technologies which can be implemented in intelligent road stud network system. The functionalities of intelligent road studs also has described in the introduction. Pros and cons of available technologies are provided. The sensor technologies of magnetic, ultrasonic, acoustic, seismic sensors are discussed in detail.

Most of the vehicle detection methods are using single sensors, now steps are moving towards increasing accuracy by combining more than one sensors together. However this sensor fusion technologies may yield better results but it has to face power constraint, cost constraint and place constraint challenges in an intelligent road stud point of view.

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