Challenges In Communication Assisted Road Transportation Systems for Developing Regions

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ABSTRACT

Intelligent Transport Systems (ITS) make use of communication technology to alleviate road traffic problems like congestion, accidents and unpredictable travel times. Such systems are vitally needed in developing countries where road problems are more acute due to lack of adequate infrastructure. However, based on our survey of various ITS techniques currently in use, we observe that these have been devised to cater to traffic conditions prevalent in developed countries and are not necessarily applicable to developing regions. We highlight the characteristics of the ITS techniques that need to be developed to cater to traffic conditions in developing regions and present a brief description of a few efforts being made in this direction. We then present some early experimental results of a new technique, devised by us, to estimate speed of the vehicle based on Doppler shift of frequencies for vehicular honks. The preliminary results show that the speed estimates are accurate enough to differentiate slow moving vehicles from normal flow and thus holds promise for efficient detection of road congestion. We take Indian traffic conditions as an example for our analysis but we believe that most of our claims and experimental results can be extended to other developing countries too.

1. NEED FOR ITS IN INDIA

Road traffic conditions in India have particularly worsened in recent times as is evident from one of the statistics which states that the average number of vehicles on Indian roads is growing at an enormous rate of 10.16 percent annually since the last five years [1]. The condition is particularly alarming in metropolitan cities like Mumbai, where vehicle penetration has reached over 590 vehicles per km of road stretch and in Bangalore, where about 5 million vehicles ply on a road network that extends barely 3000 kms [2, 3]. This is leading to higher levels of road congestion, longer and unpredictable travel times, wastage of time and fuel for commuters and more cases of road accidents. Growth in infrastructure has been slow due to various reasons such as high cost, lack of space, bureaucracy, etc. It thus needs to be supplemented with ITS techniques that utilize existing infrastructure more efficiently to give better traffic management. What is the congestion level at important road intersections? Given a source and a destination, what is the route that will take least travel time? How should new infrastructure such as flyovers, freeways, etc be planned to minimize congestion? There is an evident need of ITS based applications that can answer such questions to make traveling on Indian roads less cumbersome.

Many ITS applications have already been designed, implemented, deployed and are being used in developed countries. But there are some major differences between the road and traffic conditions that are prevalent there and in India. For e.g. in USA, freeways and expressways extend to over 75,000 kms [4], while [1] claims that only about 200 kms of expressways are present in India. Also Indian traffic is highly disorderly and chaotic. Roads are also generally not as well maintained, with potholes being common. Thus it is intuitive that the various techniques that have been developed in the context of traffic conditions in developed countries will not be applicable directly in an Indian context. We elaborate on this intuition in Section 2, where we present a survey of various techniques in use for different ITS applications and highlight the reasons which limit their applicability in the Indian context. Section 3 describes some recent works on developing ITS techniques in India. In Section 4, we propose the use of a new technique to detect vehicle speed, based on Doppler shift of *vehicular honk* frequencies. The preliminary results presented in the paper show the estimated speed to be accurate enough to differentiate slow and fast moving vehicle. Possible applications of this technique might be in congestion detection and redirecting vehicles to less congested roads in real time. Section 5 concludes the paper.

2. ITS TECHNIQUES: LITERATURE SURVEY AND CRITIQUE

Though ITS comprises of a wide range of applications for different purposes such as automated toll collection, safety, traffic monitoring, etc., we have focused primarily on traffic sensing applications as there is immediate need for using these in India. With this view, we present a comprehensive survey of various ITS techniques for traffic sensing and examine their applicability for Indian roads. We have classified ITS techniques into two broad categories, one making use of fixed sensors and the other making use of probe vehicles (mobile sensors). The system model typically followed for both these techniques is that the required data is collected using various sensors, which is then transmitted to a central entity using an appropriate communication technology. The central entity then utilizes the data appropriately depending on the application.

2.1 Fixed sensor based techniques

Fixed sensors include various sensors such as inductive loop detectors, magnetic sensors, etc, that are deployed on road to monitor the traffic condition. We discuss three main fixed sensor techniques below.

Dual loop detector based congestion detection: Pairs of inductive loop detectors placed on the road can be used to reidentify vehicles on the basis of vehicle length [5]. Reidentified vehicles are then used to measure travel time of vehicles between the detectors, which in turn gives an estimate of congestion.

Critique: Widespread application of the technique in congestion detection can be prohibitive in terms of infrastructure cost, as dual loop detectors need to be constructed at regular intervals along the road. As given in [6], a vehicle loop detector costs $700 for a loop, $2500 for a controller, $5000 for a controller cabinet, $300000 for fiber optic cable per mile and 10% of the original installation cost for annual maintenance as of 1999. Secondly, the algorithm in [5] assumes that consecutive vehicles often maintain their relative order within a platoon for long distances. This lane-based system assumption is unrealistic in Indian traffic scenarios where overtaking, buses and autos stopping to pick up or drop off passengers is common.

Magnetic sensor based congestion detection: [7] has suggested magnetic sensor as a low-cost alternative of inductive loops. It primarily performs vehicle identification and classification using a single magnetic sensor. Vehicle identification is further used to detect congestion by extracting information like speed and length of the vehicle.

Critique: Experiments have been performed on a road with intersection that follows a lane system [8]. This assumption makes this method unfit for Indian traffic as discussed above. Absence of a lane based system implies that vehicles need not approach the sensor in a way which will assure their detection. Secondly, [7] reports that motorcycle detection is not reliable. This is of concern because a large percentage of Indian traffic consists of two-wheelers.

Image sensor based congestion detection: Some of the studies [9, 10] make use of image sensors like CCTV, deployed on the road side and measure congestion level by image processing techniques, where slower the images change with time, higher is the level of congestion. Similar techniques [11] have been used to process satellite images.

Critique: The cost of video image detection systems ranges from $16,000 to $20,000 per direction per intersection on urban roads [12], which makes it prohibitive to deploy these in India. Proper positioning and distribution of cameras to capture images of disorderly traffic will be a challenging factor. Frame level change detection algorithms need to be modified for Indian roads so that image change due to extraneous factors like people crossing road through cars stuck at congestion should be filtered out and not incorrectly interpreted as free flowing traffic.

2.2 Probe vehicle based techniques

Probe vehicles are vehicles that are part of traffic and equipped with various sensors like GPS receiver, accelerometer etc. to measure various parameters such as speed with which traffic is moving, road surface condition etc. Below we classify probe vehicle based techniques into two categories, based on i) prediction techniques and ii) localization techniques.

2.2.1 Prediction techniques:

a) Travel time prediction: Bus arrival time prediction is a desirable application in Indian context, as public transport is widely used here. For this purpose several studies have been carried out. [13] and [14] design such systems for rural and urban road networks respectively, in the USA. [13] designs four algorithms using one or more of the following parameters - bus schedules, current position of bus, statistical data of bus travel time, stop time at stoppages and stop time at time check links. [14] also tries to predict the arrival time of buses in a mass transit system using Kalman Filter Technique (KFT). Vehicle location, time and time until arrival at destination are taken as state variables in the Kalman Filter and actual locations of vehicle at actual times are used as observables.

Probe vehicles have also been used for travel time prediction on freeways. Likewise, [15] validates the concept of probe vehicles and proposes a Bayesian estimation based model for travel time prediction. It also analyzes the communication requirements for probe vehicles and proposes an optimization to minimize the radio spectrum usage. [16] makes use of Kalman Filtering Technique (KFT) based model to integrate data from probe vehicles with that from fixed sensors for travel time prediction.

Critique: The algorithms proposed by [13] have certain drawbacks. Firstly, congestion level between current position of bus and destination is not taken into account in predicting arrival time at destination. Secondly, in India, stop times of buses at stoppages is highly variable. So getting average travel time between all pair of stoppages from time-distance graphs will be tricky. Similarly for application of KFT used by [14], the system under study, has to have some properties like process should be stochastic, all equations representing the system should be linear and modeling error should be Gaussian. Modeling a complex system as road traffic with highly variable factors like road congestion, incidents, driver behavior by a linear model of constant speed with normally distributed noise seems too simplistic. Such assumptions may hold for the mass transit system in [14], due to tight schedule maintaining guidelines. But on Indian roads, both urban and rural, such over simplistic model might not give correct predictions.

Likewise, [15, 16] estimate travel time for freeways, which comprise a negligible fraction of Indian road network. Thus techniques to predict travel time in presence of signalized intersections, where vehicles stop for unpredictable times, are needed.

b) Congestion prediction: Instead of assuming freeways as above, [6] suggests a technique for characterizing traffic by segmenting the road, delimited by traffic signals. A segment is part of road for which vehicles exhibit similar speed because they are subjected to same fundamental conditions like the same traffic signal, road length, width and number of lanes. Average temporal and spatial speeds, calculated from GPS data, are used for characterizing traffic as free flowing or congested.

Critique: Segments are bounded by signalized intersections. In India, even within such a segment, traffic conditions will vary as there will many intermediate intersections, not signalized, where drivers will follow random protocols to decide who will go first.

2.2.2 Localization techniques:

A key component of probe vehicles based techniques is localization of the probe vehicle. If cell phones are used as probes then location estimation techniques devised in context of cellular networks can be conveniently used for this purpose. Use of cell phone as probes is particularly appealing due to low deployment costs, widespread consumer base of cell phone users etc.. [17] carries out investigation to ascertain the availability of required number of cell phone users needed for reliable estimation of mean speed of the traffic and evaluates prediction error. [18] investigates the suitability of various position estimation techniques devised in context of cellular networks for estimating the location of the caller, which is mandatory in USA in the wake of E911 regulation.

Critique: These studies have carried out investigations regarding different aspects such as availability of required number of cell phone users, cellular positioning techniques in use, etc that are particularly specific to USA and need not be applicable in Indian context. It is possible to carry out similar studies in India, but since error in localization using cell phones can be quite high on dense urban roads, applications that require high precision in position estimation to measure speed of the vehicle or to pinpoint location of congestion will not benefit from cell-phone based localization. GPS based localization [6] will be preferable for this.

2.3 Summary

The techniques discussed above form a representative set of the broad categories of ITS techniques used for traffic sensing. As pointed out, each of them has some associated drawbacks that prevent it from being applicable as it is on Indian roads. Some of them might be used in India but only after modification according to traffic needs here and proper evaluation. Table 1 below categorizes these techniques on the basis of some of the main assumptions that many of them make and that are not valid in the context of Indian roads..

3. ITS RESEARCH AND DEPLOYMENT IN INDIA

We now outline some initial efforts of designing ITS techniques focused on Indian traffic conditions.

[19] attempts to predict bus travel times in Chennai, a metropolitan city of India. The authors devise a system with GPS data and linear regression techniques using bus dwell times at intersections and bus stops, number of passengers, average speed of bus, lengths of 2 lane road, 4 lane road and 6 lane road between start and target bus stops. There are three open issues with this system– (a) deviation of the system from linear regression model in case of road incidents, (b) infeasibility of collecting passenger data manually in case of practical deployments and (c) recalibrating the linear model for each different bus route. However such GPS based techniques are an attractive prospect for use in India particularly due to their low cost of deployment. This is evident by the project kick-started by Metropolitan Transport Corporation, Chennai to equip its buses with GPS devices [20].

[21] tries to characterize traffic and road conditions in the Indian city of Bangalore at low infrastructure cost using mobile phones that have several components like microphone, GPS receiver, accelerometer and camera that can be used for sensing audio, localization, motion and visual data respectively. This paper makes no unrealistic assumptions about traffic on the roads. However, accuracy and cost effectiveness of this technique for road monitoring is yet to be judged on the basis of how these mobile phone based sensors will be deployed (scale and density), how data from them will be aggregated, processed and used to infer road conditions.

These studies provide a valuable insight regarding the approach to be followed for devising ITS techniques applicable to India. But such efforts have been limited and there is tremendous scope for further exploration and deployment-based validation.

4. ALTERNATE, LOW COST TECHNIQUE FOR SPEED MEASUREMENT

In this section, we present a vehicle speed estimation technique, using low-cost road-side sensors, and exploiting a unique characteristic of Indian traffic: honks.

Vehicle speed estimation using Doppler shift of vehicular sound frequencies is a well known idea. For example, [22] suggests a low cost, low maintenance technique of vehicle speed estimation by estimating acoustic wave patterns, recorded with a single roadside acoustic sensor. It uses engine, tire, exhaust and air turbulence noise as vehicular sound, Doppler shift of whose frequencies is used to compute vehicular speed. However, presence of highly noisy traffic and a huge variety of acoustic signatures of vehicles will limit the applicability of such techniques on Indian roads.

In our technique we make use of honks, which is an omnipresent feature in India. While sound-pollution is normally a negative feature, we extract some positive benefit out of it. Honks are present, in India, under all road conditions: congested or otherwise.

They are tightly knit with the driving "protocol", so much so that honking is considered an aspect of "safe" driving. And such thinking is not without truth since in many situations honks are expected by drivers/pedestrians to avoid accidents[1].

4.1 Overall technique

If we can record the sound from vehicular honks using a microphone placed on the roadside, then based on the Doppler shift observed in the measured frequencies, it is possible to estimate the speed with which vehicle is moving. If the actual frequency of the honk is not known, then for estimating the speed of the vehicle, both the frequencies, when

[1]Anti-honking laws are there in many cities, but only on paper. If such laws are indeed implemented effectively, which is unlikely but desirable, the particular technique we have explored may not be applicable, but strict traffic-law enforcement will only lead to a brighter future for other ITS techniques in India.

Techniques	**Installation and maintenance cost**	**Lane system assumption (orderly traffic)**	**Freeway traffic assumption**	**Low variation in vehicle speed assumption**
Dual loop detector based congestion detection [5]	High	Yes	No	No
Magnetic sensor based congestion detection [7]	Moderate	Yes	No	Yes
Image sensor based congestion detection [9, 10]	High	Yes	No	No
Travel time prediction for freeways [15, 16]	Low	No	Yes	Yes
Cell phone based travel time prediction [17, 18]	Low	No	Partial	Yes
KFT based bus arrival time prediction [14]	Low	Yes	No	Yes

Table 1: Reasons for inapplicability of various ITS techniques in Indian context

the vehicle is approaching and receding the microphone can be used. If $f1$ is approaching frequency and $f2$ is receding frequency, speed of vehicle can be estimated using the following expression,

$$Estimated\ speed = \frac{f1 - f2}{f1 + f2} \ .\ speed\ of\ sound \quad (1)$$

.

4.2 Subproblems and solutions

The above technique can be divided into a set of subproblems listed below with corresponding approaches taken by us to solve them.

4.2.1 Honk detection

For detecting the presence of honk against background noises, we carry out Fast Fourier Transform (FFT) of the recorded audio, after dividing it into samples of suitably chosen window size. If two or more spikes are present in the given window, in the range 2Khz-4Khz, that are greater than (T * the average of all frequencies in that same range), where T is a design parameter, then presence of honk is detected. We have found a value of 3 for T to work well in practice. Variations of this algorithm by using a single spike instead of two or more and taking average of all frequencies in the window instead of only in range of 2Khz-4Khz as used in [21], give almost similar results.

4.2.2 Detection of $f1$ and $f2$

Once we have detected a honk, we need to find the approaching frequency $f1$ and receding frequency $f2$ of equation 1. We considered two possible approaches to solve this problem as described below.

i) Using one stationary microphone: We can use one roadside stationary microphone (a in Fig.1). We look for honks of long duration, such that part of the honk is sounded when the vehicle is approaching the sensor, and part of it when the vehicle is receding. We choose frequencies $f1$ and $f2$ as the frequencies of the honk, corresponding to maximum amplitude obtained, when the vehicle is approaching and moving away from the microphone respectively.

ii) Using two stationary microphones: A single microphone approach has a primary drawback: we need to depend on long honk, as the vehicle passes the sensor. Such instances are relatively rare. To overcome this drawback, two microphones, (b and c in Fig.2), strategically placed along

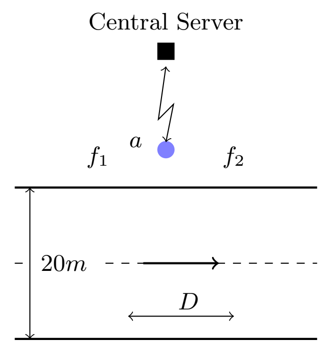

Figure 1: $f1$ and $f2$ detection with one microphone

the roadside, can be used. This increases the chances that if vehicle honks at position h in Fig.2, it is approaching one microphone, c and receding the other microphone, b. Thus even though the honk may last for short duration, both $f1$ and $f2$ are obtained, at c and b respectively. But some other issues, as given below, need to be handled for this approach.

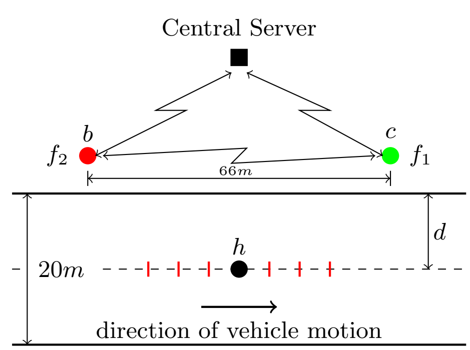

Figure 2: $f1$ and $f2$ detection with two microphones

a) Microphone Synchronization: If the microphones are WiFi or ZigBee enabled, they can be easily synchronized using wireless signals.

b) Honk matching between two microphones: For vehicle speed to be estimated correctly, $f1$ and $f2$ measured at the two different microphones, c and b respectively, should be extracted from the same honk. If the microphones record more than one honk, matching same honks across the microphones can be tricky. In our experiments, we found two main hurdles to honk matching. (1) The honk durations at the two sensors could be different; this is for the same reason as why there is Doppler effect. This means that we cannot simply depend on matching the honk durations. (2) More subtly, the honk volume levels will be different at the two sensors, making them detect incorrect honk durations (since after all the honk detection uses a decibel threshold).

To address these, we impose two constraints; we consider two honk recordings from microphones c and b to "match" (i.e. represent the same honk), if (1) the honk start times do not vary by more than 100ms, and (2) the honk lengths do not vary by more than 100ms. The first constraint bounds the differential honk travel time from the vehicle to c and b. Effectively, it constrains that the vehicle is not too near to one microphone as compared to the other. This results in approximately the same honk volume levels at the two sensors. The second constraint above is a heuristic which effectively bounds the vehicle speed to be below 54Kmph[2]. We have found this second constraint to be useful in eliminating spurious outliers. $f1$ and $f2$ are taken as those frequencies from the matched honks for which the amplitudes are maximum. The higher frequency is considered as $f1$ while lower as $f2$.

4.3 Experiments and results

We implemented the techniques described above and carried out some experiments. In our experiments, microphone on IBM Thinkpad R6li was used as roadside recorder.

Using one stationary microphone

We placed a laptop along the roadside, to record audio signals at the sampling rate of 44 KHz. We then drove a bike on the road by varying its speed from 20 Kmph to 40 Kmph, in steps of 10 Kmph. This range of speeds is used as it is the average speed of vehicles on Indian roads. Table 2 presents the estimated speeds. It can be seen that although the mechanism adopted is fairly simple, the results obtained are encouraging enough to further investigate the use of Doppler shift based method for traffic sensing, as it allows us to differentiate fast moving from slow moving traffic.

Actual speed (Kmph)	$f1$ (Hz)	$f2$ (Hz)	Estimated speed (Kmph)
20	2908	2834	15.7
30	2929	2831	20.8
40	2939	2801	29.4

Table 2: Estimated speeds using only one microphone

Using two stationary microphones

Our second experiment involved two microphones that were placed along the same side of the road with distance between them being 66m, while width of the road being 20m. Readings were obtained by varying distance of vehicle's line of motion from the microphone, d in Fig.2 as 2m, 6m and 10m. Also, now the vehicle was made to honk for small durations at positions marked by small vertical lines in Fig.2, with total number of honks adding up to 7. The speed of the vehicle was varied from 20-40 Kmph, in steps of 10Kmph. The speed estimates using value of T equal to 3 in honk detection algorithm are given in Table 3.

Distance, d (m)	Actual speed in Kmph	Honks matched	Estimated speed in Kmph (std. deviation)
2		1	15.2 (0.0)
6	20	3	15.2 (3.0)
10		2	15.2 (0.0)
2		2	19.0 (1.3)
6	30	4	20.3 (4.4)
10		3	21.9 (1.2)
2		3	28.7 (4.8)
6	40	4	31.5 (3.7)
10		3	33.8 (4.4)

Table 3: Estimated speeds using two microphones

As can be seen from the table, the speed estimates are fairly good when the vehicle is moving at 20 Kmph. Though the error in estimation increases with increase in speed of the vehicle, the results, nevertheless, are able to distinguish between low and high speeds. From the preliminary results obtained, we conclude that Doppler shift based speed estimation, using honks from vehicles, holds significant potential as a low cost technique for traffic monitoring for Indian traffic conditions.

4.4 Some comments and future work

An implicit assumption of our algorithm is presence of a single honk at a time. In real life scenarios, honks from vehicles might overlap. Effect of overlapping honks on our technique needs to be analyzed.

As seen from the results, the speed estimates obtained are not entirely accurate even in our controlled experiments, and moreover error seems to increase with speed. This might be because the algorithms used in matching the honks across different microphones, speed estimation from measured Doppler frequencies, etc, are crude and have further scope of improvement. The ground truth itself might have some errors due to malfunctioning speedometer and human factors involved. Microphone of laptops is also not very sensitive, so more sophisticated hardware might give more precise results.

The error in speed estimation does not seem to depend on horizontal distance of the vehicle's line of motion from the microphone. This behavior is counter intuitive to our expectations and we intend to explore this further. Algorithms of traffic condition classification into slow, medium or fast from individual vehicle speeds need to be developed.

Nevertheless, as our speed estimation technique can at least differentiate slow vehicle from normal flow, using it with proper classification algorithms holds promise to do traffic characterization on Indian roads at a comparatively lower cost than conventional fixed sensors.

5. CONCLUSION

Traffic scenario in India is mostly characterized by poor quality of roads, highly chaotic and disorderly traffic and heavy congestion. Several assumptions like a) presence of

[2]If $d1$ and $d2$ are the honk lengths at c and b respectively, $d1f1 = d2f2$, since the number of wavelengths (lambdas) seen by both the sensors is the same (also same as the number of wavelengths generated at source). $\frac{d2}{d1} = \frac{f1}{f2} = \frac{v+v_s}{v-v_s}$ where v is speed of sound and v_s is speed of vehicle. If v is taken as 340 m/sec and v_s as 54Kmph, maximum value of $d2 - d1 = d1/10 \simeq 100msec$ for honk length of 1 sec

freeways b) uniformity of vehicle speed c) lane based motion of vehicles, made by conventional ITS techniques in developed regions, do not hold here. These factors render ITS techniques devised in context of traffic conditions in developed countries, inapplicable in Indian scenario. Moreover conventional fixed sensor based techniques involve huge installation and maintenance cost which makes them unsuitable for India since there is paucity of funds.

Thus to cater to demanding requirements posed by Indian traffic, there is need for techniques that take characteristics of Indian roads into account. The vehicle speed estimation technique, devised by us, tries to exploit vehicular honks, a peculiar characteristic of Indian traffic. Our technique investigates the use of microphones for estimating the speed of the vehicle based on the Doppler shift of vehicular honks. Though the work done in this direction is very preliminary and a lot of challenges remain to be resolved, initial results show some promise of applicability of this technique for vehicle speed estimation and traffic condition characterization.

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