Intelligent Transport Systems for Indian Cities

Rijurekha Sen, Bhaskaran Raman
{riju, br}@cse.iitb.ac.in
Department of Computer Science and Engineering
Indian Institute of Technology, Bombay

Abstract

Road traffic congestion is a recurring problem worldwide. In India, a fast growing economy, the problem is acutely felt in almost all major cities. This is primarily because infrastructure growth is slow compared to growth in number of vehicles, due to space and cost constraints. Secondly, Indian traffic being non-lane based and chaotic, is largely different from the western traffic. The difference can be understood fully only through experience, but some example scenarios can be seen at [1]. Thus, Intelligent Transport Systems (ITS), used for efficient traffic management in developed countries, cannot be used as it is in India. ITS techniques have to undergo adaptation and innovation to suit the contrasting traffic characteristics of Indian roads.

In this position paper, we present a comprehensive study of all available ITS systems,including both research prototypes and deployed systems. We next pose a set of interesting open research problems in the context of Indian ITS. Finally, we list a set of public and private organizations, that play a role in Indian traffic management and research, as meaningful collaboration between field practitioners and researchers is needed for efficient transfer of relevant technology. Though our paper focuses on the Indian traffic scenario because of our hands-on experience of working with it [2, 3, 4], many of the problems and solutions outlined in this paper, are relevant for other developing countries as well.

1 Introduction

India, the second most populous country in the world, and a fast growing economy, is seeing terrible road congestion problems in its cities. Building infrastructure, levying proper taxes to curb private vehicle growth and improving public transport facilities are long-term solutions to this problem. These permanent solution approaches need government intervention. The Government of India has committed Rs.234,000 crores in the urban infrastructure sector [5]. Bus Rapid Transit (BRT), metro rails and mono rails are being built in different cities to encourage the use of public transport. But still there is a steep growth of private vehicles [6]. Some cities like Bengaluru, Pune, Hyderabad and Delhi-NCR, with their sudden growths in the IT sector, also have a steep growth in population, further increasing transportation needs. Meeting such growth with infrastructure growth is seemingly infeasible, primarily because of space and cost constraints. Intelligent management of traffic flows and making commuters more informed about traffic and road status, can reduce the negative impact of congestion, though cannot solve it altogether. This is the idea behind Intelligent Transport Systems (ITS). ITS in India, however, cannot be a mere replication of deployed and tested ITS in the developed countries. The non-lane based disorderly traffic with high heterogeneity of vehicles, need the existing techniques to be adapted to the Indian scenario, before they can be used. Thus ITS in the Indian context needs significant R&D efforts.

ITS is an interdisciplinary research area. Building road sensors need embedded systems background. Using mobile phones for sensing need mobile computing background. Analyzing sensed data needs signal processing or computer vision background. Communication among sensors and traffic control authorities need wired or wireless networking background. The traffic classification and prediction algorithms need machine learning or statistics background. Applications like traffic signal management need transportation engineering background. So the ITS literature is very widespread with papers appearing in seemingly unrelated venues. In this paper, we make a comprehensive list of ITS literature, to give an overview of all existing techniques. We follow it up with a set of open research questions in the context of Indian roads and traffic. Finally, we list a set of public and private sector organizations and academic institutions, who are active in research or application in this field, as meaningful collaborations and technology transfer should happen if research has to make any practical impact.

2 ITS applications

Indian traffic can benefit from several possible ITS applications. One set of applications is for traffic management. **(1) Intersection control -** At intersections, deciding the total signal cycle and the split of green times among different flows, is one of the most basic traffic management applications [7]. **(2) Incident detection -** Pinpointing locations of accidents or vehicle breakdown is important to handle the emergency situations. **(3) Vehicle classification -** Knowing what kind of vehicles, and in what proportions, ply a certain road stretch, helps to choose appropriate road width and pavement materials. **(4) Monitoring -** Pollution and road quality monitoring are necessary for taking corrective measures. **(5) Revenue collection -** Toll taxes for infrastructure maintenance and fines for rule enforcement need to be collected. **(6) Historical traffic data -** Long term data helps to plan new infrastructure, calibrate traffic signal times, add public transport and so on.

Another set of applications can aid the commuters on roads. **(1) Congestion maps and travel time estimates -** These help commuters in route selection. **(2) Public transport information -** Information about arrival of public transport helps in choice of travel mode and reduces wait delays. **(3) Individual vehicle management -** Getting information about parking places or estimates of carbon footprint, help owners of private vehicles. **(4) Accident handling -** Emergency services after accidents are a vital necessity.

3 Sensing

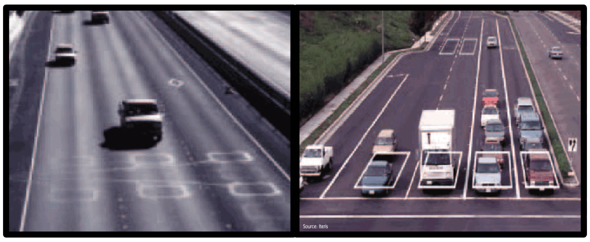
To handle any road application, the first thing that we need is information from the road. Sensors on roads can provide such information. There are several existing modes of sensing: **static sensing**, where sensors are statically placed on the road, **mobile sensing**, where sensors are placed in the moving vehicles and **hybrid sensing**, where both in-vehicle and on-road infrastructure are needed. In this section, we discuss the key technologies in each category and outline some open questions in the context of Indian roads.

3.1 Static sensing: techniques

(1) Loops and magnetic sensors - Vehicle detection and counting using magnetic sensors or loops under the road surface, has been explored in research [8, 9, 10] and deployed systems [11]. **(2) Images and videos -** Video surveillance to monitor traffic states and detect incidents and hotspots is fairly common [12]. [13] gives a comprehensive survey of the major computer vision techniques used in traffic applications. **(3) Acoustic sensors -** Some recent research is being done to use acoustic sensors for traffic state estimation, especially in developing regions, where traffic being chaotic is noisy [2, 3, 14, 15]. **(4) RF sensors -** Wireless radios placed across the road have communication signals affected by vehicular movement in between. There are commercial products [16] and research efforts [4] using this for traffic monitoring.

3.2 Static sensing: India specific questions

Adapting to chaotic traffic - Magnetic loops have traditionally been used in developed countries with lane-based orderly traffic (see Fig. 1)(a). Loops are placed under each lane. How should the placement be in absence of lanes? (Fig. 2) What methods to count and classify vehicles would work for heterogeneous traffic that move in a chaotic fashion?



(a) (b)

Figure 1. Loops and cameras in lane-based traffic

Similarly, vision algorithms exist [13] for settings like Fig. 1(b). [17] is a preliminary work on image processing algorithms for chaotic traffic. The algorithms in [17] are offline, so the trade-off between computation and communication is not understood. Also the sensing accuracy itself has been tested on only 2 minutes of video clip. [18] is another recent work to use low quality images from CCTV for traffic sensing. But computational overhead, real-timeliness and accuracy of the designed algorithms haven't been evaluated. Thus for existing sensing mechanisms like loops and images, several aspects like sensor placement, real time algorithms to measure chaotic traffic, implementability of algorithms in on-road embedded platforms, computation vs communication to remote server trade-offs, accuracy to handle different applications etc. have to be carefully designed and empirically evaluated in real settings.

New techniques for chaotic traffic - Apart from adapting traditional sensors to chaotic traffic, efforts can be made to design new sensing solutions for chaotic traffic. If these solutions are low-cost and deployable on road-side, (under road sensors like loop hamper flow during installation and maintenance), that will add greater value. We have come up with two such techniques based on acoustic sensing [2, 3] and RF sensing [4]. There are several other options to explore like passive infrared sensors, pollution sensors, vibration sensors etc. For each technique, some of the key questions to explore are - (a) what to sense, (b) how long to sense to handle the real-timeliness vs accuracy trade-off, (c) how to build sensing models for different road widths and vehicle types with minimum manual supervision etc.

Figure 2. Indian traffic (source [19])

3.3 Mobile sensing: techniques

(1) GPS on public transport or fleet vehicles - Many public transport and fleet companies have GPS installed in their vehicles for real time tracking. Several research projects have tried to exploit these as a source of road information. [20] was one of the early papers to analyze GPS traces from buses to classify road segments as free-flow and congested using threshold based classification. The Mobile Millennium Project at Berkeley [21] used GPS on a fleet of taxis and estimated travel times in London over 6 months. [22] is a recent large scale study of GPS traces of a taxi fleet in Singapore, to know fare and travel delays in real time. Another category of work using GPS on public transport has been to predict bus arrival times [23, 24, 25, 26].

(2) GPS on smartphones - With the recent proliferation of smartphones, smartphone GPS is being studied for hotspot detection and travel time estimation, after handling noise in GPS readings [27]. **(3) Sensors on smartphones -** Other than GPS, smartphones also have sensors that can provide interesting information. [28] solved the problem of reorienting the accelerometer of a smartphone to match the car axes. The accelerometer readings were then used to detect road events like bumps and brakes. A lot of braking, accompanied by honking (detected by smartphone microphone) was interpreted as congestion. [29] improves upon the accelerometer reorientation mechanism by using smartphone magnetometer. [30] uses smartphone accelerometer to detect if the phone is in a transit vehicle and if so, uses GPS to know travel times and arrival times of the vehicle. [31] uses the smartphone microphone for urban noise mapping and [32] uses the smartphone camera to predict the traffic signal ahead for automatic speed control of vehicle. **(4) Using ordinary phones -** Some researchers have tried using ordinary cell phones, instead of smartphones, for traffic sensing. Localizing ordinary phones based on only cellular tower and Wi-Fi information ([33, 34]) and adding sensors to ordinary phone hardware ([35, 36]) are two main research focus in this area This sensing using phones, popularly called *crowdsourcing* or *participatory sensing*, has related research on privacy ([37, 38]) and power ([39, 40]) issues, as these would affect user participation.

(5) Specialized hardware on vehicles - Some researchers have used specialized hardware in vehicles. [41], which detects road anomalies and [42], which tracks stolen properties are examples. [43], which uses ultrasound transceivers to find empty parking spaces and [44], which calculates fuel usage, are applications for individual vehicle owners using customized hardware. **(6) Social networking -** [45] took a fresh perspective of getting information from crowd through blogs posted via smartphones.

3.4 Mobile sensing: India specific questions

Adapting techniques for Indian roads GPS is known to have errors that affect localization of traffic information. Does this error have more impact on the dense Indian road networks? Is enhancing GPS with Wi-Fi [27, 33], feasible? To see Wi-Fi penetration and coverage, war-driving efforts might be made on Indian roads.

New social networking models - Ordinary cell-phone penetration and usage is very high in India. Blog or MMS based crowd sourcing needs GPRS or 3G connectivity. Instead, ordinary sms or voice calls can be explored for information sharing to increase the participant pool manifold.

Incentive models - Designing proper incentive models for participatory sensing is an active research area. Similar questions for the Indian population will give interesting research problems. Should we use a payment based system [46, 47]? Or should we use games? What kind of games should we design? Should low income groups like auto-rickshaw and taxi drivers be given monetary incentives whereas the middle and higher income groups are given gaming incentives? If such incentive schemes are not empirically evaluated, all the mobile sensing techniques discussed above would be rendered useless in practice.

Noise reduction - Trustworthiness of web information [48, 49, 50] is a recent active area of research. Still newer is research on trustworthiness of participatory data [51, 52]. In the context of participatory sensing for Indian ITS, similar work on data trustworthiness and noise reduction will be interesting. Paid incentive models run the risk of inducing selfish behavior among participants, who would start contributing wrong data. The system should be able to cross check data sanity, possibly through data aggregation from multiple participants. This would need high to moderate level of penetration. Another possible option is to build reputation systems using input from other sensors (say video), for parts of the data. Participants who score high in these checks can be given higher weights in future than the participants who score low.

3.5 Hybrid sensing: techniques

There are a set of techniques that use both static infrastructure and mobile sensors to gain traffic information. **(1) Teledensity -** Cell phone operators can give approximate vehicle densities in the neighborhood of a given cell tower, based on subscribers seen at that tower. There are commercial systems like [53] and research efforts [54] based on this. **(2) Bluetooth -** [55] is a system where roadside Bluetooth detectors sense Bluetooth radios in phones inside vehicles. Correlating the sensed Bluetooth addresses among different detectors, gives travel times of the vehicles between the detectors. **(3) RFID -** Similar systems are being explored using RFID tags on vehicles and RFID readers on roads [56].

4 The ITS architecture

Having discussed a set of intended applications and several possible sensing methods, the next question to ask is how to put it all together for Indian cities, so that the maximum possible number of applications are handled with ease and accuracy. Should we prioritize the list of applications, so that some are given higher importance than the others? How should we select what sensing methods to use? What should be the overall system architecture, including the communication model needed to gather sensed and/or computed data from the roads and dissipate information back to commuters on the road? Many of these lead to interesting research questions as we will see.

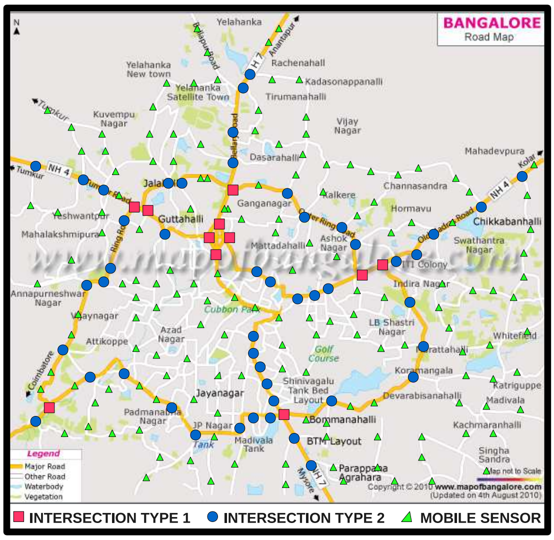


Figure 3. City-wide sensing architecture (source [57])

Choice of applications - Our discussions with the Bengaluru Traffic Police gave us insight into their ITS needs. Fig. 3 shows a road map of Bengaluru. There are two main kinds of roads, the yellow lines denote the major roads and the white lines denote minor roads. The junctions where the major roads intersect one another are shown by red squares and those where the minor roads intersect the major roads are shown by blue dots. *Traffic light control* is a vital necessity for both these type of intersections, that will govern the traffic flow pattern over the entire city. Currently, in absence of automated signal control techniques, the traffic lights are either statically calibrated, or controlled by on-road policemen, or remotely controlled by manually seeing video feeds at the traffic control room. *Localizing incidents* is another vital application, to send traffic personnels to affected areas or penalize traffic violators. The other applications described in Section 2 are also necessary, in no definite order of priority. As most Indian cities have similar road patterns, the application needs of other traffic control authorities are expected to be similar.

As for Indian commuters, the traffic applications currently available are rudimentary, with periodic updates gathered from traffic police broadcast on FM radios [58]. There are a few route planners [59] that give bus and train plans, but the plans are static, without considering the current congestion levels on different roads. Thus any application, outlined in Section 2 would be valuable to commuters.

Choice of sensing method - Participatory sensing data is inherently noisy [52]. Also probe vehicles might not be present at a given intersection at all times. Such sensing methods can thus be used for applications like travel time estimates and congestion maps to be disseminated to commuters, which can tolerate aperiodicity and noisiness. Applications like traffic light control on the other hand, need

Figure 4. Bengaluru Traffic Control Room

dedicated static sensors on the road that give highly accurate and strictly periodic updates about traffic conditions. Static sensors are costly but accurate, mobile and hybrid sensors are cheap but noisy. Based on applications, we need to make a careful choice of which mode to use when and how to mix them appropriately. The red squares and blue dots in Fig. 3 would thus be probable candidates for static sensing, while the mobile and hybrid sensors would span the city, in varying densities over time, as the green triangles in the figure. Even within each mode, choices can be made based on level of information needed and installation and maintenance costs. If vehicle classification is vitally important, videos are a must. But if only level of congestion or length of traffic queues are needed for certain intersections, RF sensors, cheaper than videos or loops, can be used.

Choice of communication model - Given a set of chosen applications and a set of sensing methods to handle them, how should the communication model be? For static sensors, the sensed data need to be transferred to traffic control rooms. At present, out of 160 cameras in Bengaluru, connected to central traffic control room by BSNL leased lines, at most 90 cameras send data at any given time [61], because of problems in the wired connections. Instead of this star topology, will a tiered architecture help, where video feeds from a subset of roads are processed at local control rooms, before the information is passed to central control? Should there be a mix of wired and wireless communication to reduce cost and overhead of laying copper, or will wireless be too unreliable? Can communication costs be reduced through in-field computation and data compression? As for mobile sensing models, quantitative analysis of 3G and GPRS performance on Indian roads, using mobile cloud for data upload and download, peer-to-peer networking among commuters with similar travel patterns, are some interesting communication problems to explore.

5 A subset of the players in Indian transport

We might know what traffic applications are needed for Indian roads. We might design and implement sensing technologies needed to handle those applications for Indian chaotic traffic. We might build robust, low-cost communication models to gather data from sensors and disseminate information to commuters. But unless we test our solutions in the field in medium to large scales, we will never come to know about practical issues. Building collaboration with the public sector is an absolute necessity for this domain as lab tests and simulations will never give the true picture of

Organization type	Website
Academic institutions	IISC - http://cistup.iisc.ernet.in/index.html IIT Delhi - http://tripp.iitd.ernet.in/ IIT Chennai - http://coeut.iitm.ac.in/ IIT Bombay, Civil - http://www.civil.iitb.ac.in/g̃patil/research.html IIT Bombay, CSE - http://www.cse.iitb.ac.in/silmaril/br/doku.php?id=proj:carts IIT KGP - http://www.iitkgp.ac.in/fac-profiles/showprofile.php?empcode=bSmUS IIIT Delhi - http://www.iiitd.edu.in/muc/
Private Organizations	Mapunity - http://www.mapunity.in/ Logica - http://www.logica.in/we-do/innovation/ KritiKal - http://www.kritikalsolutions.com/products/traffic-analyzer.html Embarq - http://www.embarq.org/en/about/about-embarq iTrans - http://www.itrans.co.in/aboutus.html Traffline - http://www.traffline.com/default.aspx
Some city traffic control authorities	Mumbai - http://www.trafficpolicemumbai.org/ Bengaluru - http://www.bangaloretrafficpolice.gov.in/ Chennai - http://www.chennaitrafficpolice.in/ Delhi - http://delhitrafficpolice.nic.in/
Government R&D lab Center for Development of Advanced Computing (C-DAC)	http://www.intranse.in/its1/
City bus authorities with GPS installed in buses	Bengaluru - http://www.bmtcinfo.com/site/index.jsp Chennai - http://www.mtcbus.org/
Research labs	Microsoft [28], IBM [15], Alcatel Lucent [55], Infosys [60]

Table 1. Players in Indian ITS

the road. Also large scale video or GPS data are sometimes available from traffic control authorities, that researchers can use in their work. In this section, we therefore list a set of key players in the Indian traffic scenario. This includes government organizations like city traffic control authorities, academic institutions, start-ups and research labs. The details are given in Table 1, where information specific to each organization can be found in the corresponding listed website.

6 Conclusion

Traffic congestion is an *important* problem in Indian cities. The characteristics of Indian roads and traffic make the problem *interesting* to solve. There is scope for evaluating existing ideas in different and challenging traffic scenarios, innovate new solutions and empirically evaluate ideas in collaboration with public and private sectors. In this paper, we make a small effort to put together the different ideas and people relevant in Indian ITS, so that it gives an overview of the problem and the available solutions and outlines a set of open questions to answer.

References

[1] `http://www.cse.iitb.ac.in/~riju/kyunqueue`.

[2] R. Sen, B. Raman, and P. Sharma. Horn-ok-please. In *Mobisys*, June 2010.

[3] R. Sen, P. Siriah, and B. Raman. Roadsoundsense: Acoustic sensing based road congestion monitoring in developing regions. In *IEEE SECON*, June 2011.

[4] S. Roy, R. Sen, S. Kulkarni, P. Kulkarni, B. Raman, and L. Singh. Wirelessacrossroad: Rf based road traffic congestion detection. In *WISARD*, January 2011.

[5] `http://www.technologyreview.in/computing/37647/`.

[6] `http://asiancorrespondent.com/39640/is-india-waiting-for-its-longest-traffic-jam/`.

[7] W. McShane, R. P Roesss, and E. Prassas. Traffic engineering. In *Prentice-Hall, Inc*, 1998.

[8] S. Cheung, S. Coleri, B. Dundar, S. Ganesh, C. Tan, and P. Varaiya. Traffic measurement and vehicle classification with a single magnetic sensor. Paper ucb-its-pwp-2004-7, California Partners for Advanced Transit and Highways (PATH), 2004.

[9] B. Coifman and M. Cassidy. Vehicle reidentification and travel time measurement on congested freeways. *Transportation Research Part A: Policy and Practice*, 36(10):899–917, 2002.

[10] `http://paleale.eecs.berkeley.edu/~varaiya/transp.html`.

[11] `http://www.scats.com.au/index.html`.

[12] `http://www.visioway.com,http://www.traficon.com`.

[13] V. Kastrinaki, M. Zervakis, and K. Kalaitzakis. A survey of video processing techniques for traffic applications. *Image and Vision Computing*, 2003.

[14] I..Magrini G. Manes A. Manes B. Barbagli, L. Bencini. An end to end wsn based system for real-time traffic monitoring. In *EWSN*, February 2011.

[15] V. Tyagi, S. Kalyanaraman, and R. Krishnapuram. Vehicular traffic density state estimation based on cumulative road acoustics, 2011.

[16] http://www.ceos.com.au/products/tirtl.htm.

[17] A. Quinn and R. Nakibuule. Traffic flow monitoring in crowded cities. In *AAAI Spring Symposium on Artificial Intelligence for Development*, 2010.

[18] V. Jain, A. Sharma, and L. Subramanian. Road traffic congestion in the developing world. In *ACM DEV*, 2011.

[19] http://www.pluggd.in/indian-traffic-entrepreneurial-lessons-297/.

[20] J. Yoon, B. Noble, and M. Liu. Surface street traffic estimation. In *MobiSys*. ACM, 2007.

[21] http://traffic.berkeley.edu/theproject.html.

[22] R.Balan, N.Khoa, and J.Lingxiao. Real-time trip information service for a large taxi fleet. In *Mobisys*, Jun 2011.

[23] J. Biagioni, T. Gerlich, T. Merrifield, and J. Eriksson. Easytracker: automatic transit tracking, mapping, and arrival time prediction using smartphones. In *SenSys*, 2011.

[24] R. E. Anderson, A. Poon, C. Lustig, W. Brunette, G. Borriello, and B. E. Kolko. Building a transportation information system using only gps and basic sms infrastructure. In *ICTD*, 2009.

[25] W. Lin and J. Zeng. Experimental study of real-time bus arrival time prediction with gps data. *Transportation Research Record*, (1666):101–109, 1999.

[26] D.J.Dailey, S.D.Maclean, F.W.Cathey, and Z.R.Wall. Transit vehicle arrival prediction: An algorithm and a large scale implementation. *Transportation Research Record*, (1771), 2001.

[27] A. Thiagarajan, L. Ravindranath, K. LaCurts, S. Madden, H. Balakrishnan, S. Toledo, and J. Eriksson. Vtrack: Accurate, energy-aware road traffic delay estimation using mobile phones. In *Sensys*, November 2009.

[28] P. Mohan, V. Padmanabhan, and R. Ramjee. Nericell: rich monitoring of road and traffic conditions using mobile smartphones. In *SenSys*. ACM, 2008.

[29] R. Bhoraskar, N. Vankadhara, B. Raman, and P. Kulkarni. Wolverine : Traffic and road condition estimation using smartphone sensors. In *WISARD*, January 2012.

[30] A. Thiagarajan, J. Biagioni, T. Gerlich, and J. Eriksson. Cooperative transit tracking using smart-phones. In *Sensys*, November 2010.

[31] R. Rana, C. Chou, S. Kanhere, N. Bulusu, and W. Hu. Earphone: an end-to-end participatory urban noise mapping system. In *IPSN*, April 2010.

[32] E.Koukoumidis, L.Peh, and M.Martonosi. Signalguru: Leveraging mobile phones for collaborative traffic signal schedule advisory. In *Mobisys*, Jun 2011.

[33] A. Thiagarajan, L. Ravindranath, H. Balakrishnan, S. Madden, and L. Girod. Accurate, low-energy trajectory mapping for mobile devices. In *NSDI*, 2011.

[34] A. Singh P. Singh K. Yadav, V.Naik and U. Chandra. Low energy and sufficiently accurate localization for non-smartphones. In *MDM*, July 2012.

[35] A. Singh V.Naik P. Singh A. Bharadwaj, P. Arjunan. Melos: A low cost and low energy generic sensing attachment for mobile phones. In *NSDR*, June 2011.

[36] Borriello G. Thies W. Chaudhri, R. Foneastra: Making mobile phones smarter. In *NSDR*, 2010.

[37] B. Hoh, M. Gruteser, R. Herring, J. Ban, D. Work, J. Herrera, A. Bayen, M. Annavaram, and Q. Jacobson. Virtual trip lines for distributed privacy-preserving traffic monitoring. In *Mobisys*, 2008.

[38] C. Cornelius, A. Kapadia, D. Kotz, D. Peebles, M. Shin, and N. Triandopoulos. Anonysense: privacy-aware people-centric sensing. In *Mobisys*, 2008.

[39] R. Jurdak, P. Corke, D. Dharman, and G. Salagnac. Adaptive gps duty cycling and radio ranging for energy-efficient localization. In *Sensys*, 2010.

[40] K. Lin, A. Kansal, D. Lymberopoulos, and F. Zhao. Energy-accuracy trade-off for continuous mobile device location. In *Mobisys*, 2010.

[41] J. Eriksson, L. Girod, B. Hull, R. Newton, S. Madden, and H. Balakrishnan. The Pothole Patrol: Using a Mobile Sensor Network for Road Surface Monitoring. In *MobiSys'08*, Jun 2008.

[42] S. Guha, K. Plarre, D. Lissner, S. Mitra, B. Krishna, P. Dutta, and S. Kumar. Autowitness: locating and tracking stolen property while tolerating gps and radio outages. In *Sensys*, November 2010.

[43] S. Mathur, T. Jin, N. Kasturirangan, J. Chandrasekaran, W. Xue, M. Gruteser, and W. Trappe. Parknet: drive-by sensing of road-side parking statistics. In *Mobisys*, 2010.

[44] R. Ganti, N. Pham, H. Ahmadi, S. Nangia, and T. Abdelzaher. Greengps: a participatory sensing fuel-efficient maps application. In *Mobisys*, 2010.

[45] S. Gaonkar, J. Li, R. Choudhury, L. Cox, and A. Schmidt. Micro-blog: sharing and querying content through mobile phones and social participation. In *Mobisys*, 2008.

[46] https://www.mturk.com/mturk/welcome.

[47] A. Ratan W. Thies and J. Davis. Paid crowdsourcing as a vehicle for global development. In *CHI Workshop on Crowdsourcing and Human Computation*, 2011.

[48] X. Yin, J. Han, and P. S. Yu. Truth discovery with multiple conflicting information providers on the web. In *SIGKDD*, 2007.

[49] J. Pasternack and D. Roth. Knowing what to believe (when you already know something). In *COLING*, 2010.

[50] X. L. Dong, L. Berti-Equille, and D. Srivastava. Integrating conflicting data: the role of source dependence. 2009.

[51] A. Dua, N. Bulusu, W. Feng, and W. Hu. Towards trustworthy participatory sensing. In *HotSec*, 2009.

[52] H. Le, J. Pasternack, H. Ahmadi, M. Gupta, Y. Sun, T. F. Abdelzaher, J. Han, D. Roth, B. K. Szymanski, and S. Adali. Apollo: Towards factfinding in participatory sensing. In *IPSN*, 2011.

[53] http://www.indianweb2.com/2008/07/live-road-traffic-details-mapunity-2/.

[54] W. Pattara-attikom and R. Peachavanish. Estimating road traffic congestion from cell dwell time using neural network. In *ITST '07. 7th International Conference on ITS*, 2007.

[55] http://www.youtube.com/watch?v=_KJBQJSpn-8.

[56] http://www.intranse.in/its1/sites/default/files/7-Congestion%20Management-Somprakash.pdf.

[57] http://www.mapofbangalore.com/maps/bangalore-road-map.html.

[58] http://www.trafficnetwork.in/.

[59] http://www.cse.iitb.ac.in/navigator2/Main.

[60] http://simula.stanford.edu/Incentive_mechanisms/Projects.html.

[61] http://www.btis.in/traffic.