Citizen Assisted Environmental Pollution Measurement in Developing Cities

Md Yusuf Sarwar Uddin and Rezwana Rafiq

Abstract—**Measuring pollution in a city is vital for maintaining its living standard and healthy environment. Pollution in land, water, and air of a city is attributed to motorized vehicles, construction works, human and industrial waste and so on. Measuring pollution is, however, expensive in terms of human efforts, resources and costs. For cities in developing countries, such as Dhaka where the authors live, these challenges are severe because of lack of infrastructure and financial capacity. As a functional alternative, in this paper we propose citizen assisted pollution measurement techniques that leverage voluntary participation of city dwellers in collecting pollution-related data and evidence using their mobile phones and other suitable digital gadgets. To this end, we propose techniques for measuring three types of pollution: i) sound/noise pollution, ii) solid waste pollution, and iii) air/carbon emission pollution. We propose schematic system architecture for these measurements and also put discussions on relevant side issues, such as accuracy of these measurements, willingness and incentives for people participation.**

Index Terms—**Environmental pollution, measuring pollution, mobile phones, participatory sensing.**

I. Introduction

Measuring the level of pollution in a city is vital for maintaining its living standard and healthy environment, and also to help city authorities for taking actions to mitigate and prevent these pollutions. Pollution in land, water, and air of a city is attributed mainly to motorized vehicles, construction works, human and industrial waste and so on. Measuring pollution is, however, expensive in terms of human efforts, resources and costs. For developing cities, such as Dhaka where the authors live, these challenges are severe because o lack of infrastructure and financial capacity. As a functional alternative, in this paper we propose citizen-assisted pollution measurement techniques that leverage voluntary participation of city dwellers in collecting pollution-related data and evidence using their mobile phones and other suitable digital gadgets. This technique is popularly called as participatory sensing [1], [2]. In these techniques, smart phones possessed by average individuals are harnessed for capturing and reporting data about certain events experienced by ordinary citizens. Thanks to enormous proliferation of these devices that have sophisticated computation and communication capabilities featured with a set of rich sensors. Sensors range from physical sensors, such as accelerometer, magnetometer, gyroscope, and GPS (Geographic Positioning Systems), to environmental sensors, namely temperature sensor, light sensor, and humidity sensor. There are also other components such as audio recorders and video cameras that are capable to capture/record rich and hi-fidelity media data. Possession of these devices effectively instruments people for measuring various environmental indicators or metrics as they live-by and travel around in a city.

To this end, we propose techniques for measuring three types of pollution: i) sound/noise pollution, ii) solid waste pollution, and iii) air/carbon pollution. In all cases, people who agree to volunteer—with the help a special software pre-installed in their devices—automatically collect data of certain modality (such as sound, image and video) and deposit them into a server system for necessary processing in order to measure pollution. For instance, for measuring noise pollution, phones record sound samples in their vicinities where the sound samples are timestamped with the current time and labeled with geographical location obtained through GPS of the phones. Solid waste pollution, which is due to improper disposal of trash items, is measured by allowing people to take pictures of littered objects by their phones' cameras and have them analyzed to extract prevailing pollution incidents. Finally, carbon emission pollution caused by flying vehicles can be measured from video data that people could have taken to capture those vehicles that emit black smokes. In the paper, we propose overall system architecture to enable these measurements as well as put discussions on relevant side issues, such as accuracy of these measurements, possible trade-offs, willingness of people participation and incentives for participation.

The paper is organized as follows. Section II describes various pollution and their causes. Section III proposes citizen assisted pollution measurement techniques for various pollutions. The proposed techniques have issues that are concerns for their success. These issues are discussed in Section IV. Finally, Section V concludes the paper.

II. Pollution: Its Causes and Effects

In this section, we describe the major causes and their associated effects of various pollutions.

A. Vehicular Noise Pollution

Noise is unwanted sound that creates annoyance, discomfort and can induce damage to health. Noise is considered to be a serious threat to human health. It leads to

Manuscript received on August 1, 2013; revised September 4, 2013. This work was conducted at Bangladesh University of Engineering and Technology (BUET) and was supported in part by a grant obtained from BUET.

Md Yusuf Sarwar Uddin is with the Department of Computer Science and Engineering in Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh (e-mail: yusufsarwar@cse.buet.ac.bd).

Rezwana Rafiq is with the Department of Urban and Regional Planning in Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh (e-mail: rezwana@urp.buet.ac.bd).

emotional and behavioral stress and in some cases may produce permanent deafness [3]. A sudden loud noise can cause damage to the eardrum. It may also cause startle or fright phenomena and can result in harmful effects on various parts of the body such as brain, heart and liver [4]. Exposure to constant high level of noise may cause severe stress on the auditory and nervous system of people, particularly the children. The increasing urbanization in cities has contributed to the mounting volume of noise and intruding upon the quiet life of urban dwellers [4]. There are many sources of noise such as industries, construction works, and indiscriminate use of loud speakers. In most popular opinion, motorized traffic is the predominant source of noise in urban areas [5], [6]. Vehicular traffic noise is contributed by various kinds of vehicles such as heavy, medium trucks or buses, automobiles and two wheelers. In order to reduce the detrimental effects of traffic noise public awareness should be raised and necessary measures should be taken. One important task in this regard is to measure the level noise in a city.

B. *Solid Waste Pollution*

Solid waste management is an essential public service which provides benefits to all urban residents. Rapid population growth and continuous rise in community living standards have accelerated the rate of generation of municipal solid waste and thus causes its management to be a challenging one [7]. In the areas of concentration of intense human activities, such as in urban centers, appropriate and safe solid waste management is of utmost importance to ensure healthy living conditions for the population. This fact has been acknowledged by most governments around the globe. However in urban cities of developing countries, solid waste management is still highly neglected [8], [9], which causes substantive solid waste pollution in those cities. In particular, the collection process of solid waste has been identified as a major problem behind this, since in many areas municipal authorities are either unable or unwilling to provide waste collection services to all residents in their jurisdiction [9]. Another reason is open dumps and unfortunately it is still mostly observed in developing countries, where the waste is dumped in an uncontrolled manner [8]. Such kind of uncontrolled dumping in developing cities is caused mainly by institutional deficiencies, inadequate legislation and resource constraints. Existing long and short term plans are inadequate due to capital and human resource limitations.

Most of the municipal solid waste such as domestic waste, plastic, glass and paper in low income Asian countries is dumped on land in a more or less uncontrolled manner. Such inadequate waste disposal creates serious environmental problems that affect health of humans and animals and cause serious economic and other welfare losses. The environmental degradation caused by inadequate disposal of waste can be expressed by the contamination of surface and ground water through leachate, soil contamination through direct waste contact or leachate, air pollution by burning of wastes, spreading of diseases by different vectors of methane by anaerobic decomposition of waste [8]. Considering these facts, solid waste management issue should be given much concern. There is a need for financing equipment for its management, proper training should be given for capacity building and most important factor is that people should be more aware regarding this matter.

C. *Vehicular Air/Carbon Emission Pollution*

Vehicular air pollution in metropolitan areas particularly in South Asian countries is a very common phenomenon. With the rapid increase of population the number of vehicles is also increasing rapidly which in turn becomes a major source of air pollution. The emissions of fine particles from vehicles are considered to be critical and harmful pollutants in terms of impacts on public health, particularly because they occur near ground level which is very close to where people live and work. Considering lubricant and fuel quality, two-stroke gasoline engine vehicles account for about 60 percent of the total vehicle fleet in South Asia and they emit particulate matter at a higher magnitude [10] than other vehicles. Emissions are higher in two stroke engines because of the design of the engine. Along with that, poor vehicle maintenance, the misuse of lubricant, the adulteration of gasoline, and the lack of catalytic converters exacerbate two-stroke engine emissions [11] (as of this writing, however, two stroke engine vehicles are banned in various cities).

The emission of vehicles has devastating effect on both human health and climate change issue. Three greenhouse gases, namely carbon dioxide, methane and nitrous oxide, emitted from vehicles are believed to be the potential contributors to increase global warming. The transport sector contributes 13 percent of carbon dioxide emissions in South Asia, ranging from 10 percent in Bangladesh to 48 percent in Sri Lanka [10]. Fine particulate matters (with diameter no more than 2.5 microns) are extremely damaging to public health. These particles cause chronic heart diseases, respiratory problem, exacerbation of asthma, changes in lung function and even premature death [12]. Considering its harmful effects vehicle air pollution must be monitored and controlled properly.

III. Citizen-Assisted Pollution Measurement Techniques

In this section, we outline our proposed techniques for measuring various pollutions by taking voluntary assistance from citizens in a city. In all cases, we assume that we can harness peoples' hand-held devices to collect a representative set of data and observations for measuring pollution with sufficient accuracy. While we envision such mechanism could be possible, we did not, however, build any of such systems to its completeness as of this writing that could demonstrate such possibility with great certainty. Small prototypes mainly in laboratory setup have been tested as a part of a proof-of-concept. Building a functional working system around our proposed techniques is under development and is an important future work to furnish. In the following we sketch the functional features of the proposed mechanisms for measuring various pollutions.

A. *Noise Pollution*

Noise is an unwanted sound that causes human discomfort and annoyance. Technically, sound is an energy transfer in the form *vibration* through air (or through other sound carrying material, known as sound media). This vibration effectively incites human auditory sensation, which in turn causes hearing. The pressure exerted through this vibration measures the intensity or loudness of the sound. This intensity is usually called sound level. Noise is a sound whose sound level exceeds certain threshold. While the level of noise largely depends on subjective assessment of the hearer about the perceived loudness, the sound level is rather a physical measurement that is a function of variation of pressure along time. This quantity is usually referred to Sound Pressure Level (SPL).

Sound pressure level, expressed in logarithmic scale called decibel (dB), is defined as follows [6]:

$$\text{Sound Pression Level}, SPL = 10\log_{10}\left(\frac{P}{P_0}\right)^2 \qquad (1)$$

where P is the root mean square (rms) sound pressure (in Newton per square meter), and P_0 is the standard reference pressure (20 Newton per square meter). The metric numerically indicates that for every three decibel rises of sound level, the apparent loudness of sound doubles. From practical experiences of various sound sources, sound pressure level has been reported to vary from zero (the hearing threshold) to 20-30 dB (calm rooms) to above 120 dB (e.g., jet engines and gunfire, which are threshold of pain). In order to account ear's selective responses to different pressure level, special filters/weighting are usually applied on the pressure level. While various filters are available, one, known as A-weighting, is widely accepted. The corresponding scale is then called A-weighted decibel (dBA). Usually, sound level above 60 dBA is treated as noise [6].

In traditional deployment setup, sound level at a certain location is measured by special hardware, called sound pressure meters (or sound meters). These embedded hardware measure direct sound pressure by complex circuitry and mechanics. In our approach, however, we envision to leverage mobile phones carried by users. A user can record sound for a while at a certain location by his audio recorder and save the audio clip in a file. Then special custom-made software analyzes the sound clip and derives the associated sound pressure level in dB or dBA. Usually, pressure is a function of frequency (obtained from Fourier Transform of the sound wave) and squared amplitude of the sound samples. These two can be extracted from the recorded audio file.

To date, several mobile applications (commonly known as Sound Meter or Noise Meter) are available in mobile app-stores, such as Google Play for Android platform and AppleStore for iOS (iPhone). Fig. 1 shows two such apps. Those apps may be handy, but may not have flexibility to offer all the functional features discussed above, such as sharing measured sound level to a common repository. Besides these apps, programs with raw implementation are also available[1] that can be used to write suitable software for mobile phones. Such implementation is our future work. One important limitation of using mobile phones is that mobile phones are usually designed for transmitting human voice which remains rather in low decibel. Special filters are used to optimize the corresponding performance that may not allow them to record very high loud sound, say pressure level above 100 dB. In practice, this should not make much problem, because most noises remain far below that level.

Fig. 1. Sound meter apps available in Google Play (http://play.google.com/).

In the above process, a single user can measure sound level, hence noise, around only his vicinity. In order to measure noise level of a city, we need the same done by a large pool of users scattered across the whole city. A common service platform or a repository needs to be provided so that people can share their records in a place. When sound samples from different sources are gathered, an aggregated noise level can be computed from all these observations. To collect all these noise data, widely available mass information dissemination platforms, such as Facebook and Twitter, can be used.

B. Solid Waste Pollution

Solid waste pollution, also known as urban littering, is attributed to haphazard disposal of trash items in a city. According to a survey conducted by KAB (Keep Australia Beautiful) Association [13], littered objects can be categorized into 6 main categories, namely cigarette-buts, glass, illegal dumps, metal, paper/paperboards and plastic. As per National Litter Index (NLI) 2011-2012 for Australian provinces conducted by KAB, cigarette-buts constitute the largest amount of littered objects by numbers, whereas plastic waste is the largest constituent by volume followed by glass items. In the context of Dhaka city, plastic packets used in packing light snacks, water bottles, tea/coffee cups and domestic waste (e.g., vegetable residue, torn cloths, food waste and peel of fruits) are the key constituents of urban litters. Littering can also happen due to poor handling of municipal-led cleaning of dustbins, overflowing of dumping stations, broken trash boxes, and others. In this article, however, we do not consider industrial waste, coastal waste and other forms of solid waste.

Scattered littered objects damage the soothing beauty of a clean city. Some items, such as plastic, Styrofoam and glass, have a very long degradation life, in that they either do not decompose or decompose very slowly into soil. So they remain as solid waste for a long time and ultimately cause lasting problems, such as blocking water flow and drainage, solid sedimentation in water bodies, and degradation of soil fertility. These are real bio-hazards that impact environment a lot.

[1] For example, at https://code.google.com/p/splmeter/

Fig. 2. Littered objects captured on cameras. Collected from the Internet. Copyrights hold to the respective users.

One aspect of littered objects, hence the pollution due to solid waste, is that littered objects are *visually* detectable with ease. When city dwellers walk on streets and roam around in parks, open spaces, and other public places, they, may be quite inadvertently, encounter littered objects and waste materials. It is quite easy for them at that moment to take their phones out of their pockets and hand bags, and take a *photograph* of those objects. It is found quite evident—by making a few searches in Google image search—that people indeed take pictures of such kinds. Fig. 2 shows some samples where people photographed littered objects in order to raise attention and awareness of others against those littering phenomena. If the phone has its GPS service enabled, the pictures can also be labeled with location data, in addition to the current time. This inscribes the very location and time recording where and when these objects are seen. Respective users can then upload or share these pictures onto a common image gallery. A set of human volunteers can then identify the presence of littered objects in those pictures by visual inspections. An automated image processing technique can be also run over the image collection.

1) Measuring waste pollution level

A question arises is as how to "quantify" the degree of pollution as captured by an image. The assessment obviously depends on the viewer's personal perception about pollution. In Fig. 2(a), someone may wanted to document littered cigar buts as a potential solid waste pollution source, whereas another one may be Ok with this and may not recognize the same as pollution. The degree of pollution, if even agreed, may also vary. For instance, the pollution depicted in Fig. 2(d) (a water body full of littered plastic objects and others) definitely has higher degree of pollution than the same represented by a single floating pat bottle as in Fig. 2(b). Admittedly the issue is non-trivial and involves subjective evaluation of the viewer. To unify a decision, several approaches can be considered in this regard. Firstly, the system can deploy a set of experts who would assess "pollution level" posed in pictures and assign numerical weights to them. Secondly, the pictures can be put to public review so that general people can rank them, say, by clicking "dislike" against those pictures. The number of total dislikes against a picture can be treated as its pollution index. Some scaling can be devised so that all these ranks are made in a uniform scale.

2) Issues with picture assessment and collection

One important aspect associated with measuring pollution from a picture is called *spatial span* of the measurement. A picture, when is taken, captures a certain time, so the time of the measurement is precisely the moment when the picture is taken. But what is about the space? Particularly, what extend of physical space does a certain measurement correspond to? While the time is precisely known, space seems not be bounded. A picture may contain a point shoot object (by allowing the camera to zoom in and focus onto it) within a narrow spatial coverage (e.g., a littered bottle in Fig. 2(b)), whereas some other pictures may capture objects in a larger area when the pictures are taken with a wider field of view of the cameras (e.g., Fig. 2(d)). In the later case, the picture is supposed to have a larger spatial span. Each picture thus in addition to its degree of pollution presents a spatial coverage

(a) (b)

(c) (d)

Fig. 3. A Youtube video showing a bus emitting black smoke in Dhaka city.

of its measurement. This spatial span is considered when an aggregation over pictures collected over a large geographic area is made, which we discuss next.

While a single picture containing littered objects can give us pollution measure in a certain time over a spatial span, in order to measure the same for a large geographic area, such as in a city, an aggregation over all these collections is required. As pictures are labeled with temporal point and spatial span, such aggregation can be possible. The objective of this aggregation could be to select a set of representative pictures from different times of a day and also from different locations in order to cover the whole city as much as possible. This aggregation task is a challenging research problem that the authors are currently working at.

When people are asked to upload pictures, a few issues may rise. Due to large proliferation of camera phones these days, lots of people have them. Taking pictures are inherently non-intrusive to users and do not involve human attention much, other than clicking only a button or so. As a result, pictures can be taken at a very high rate. Moreover, pictures are large digital data objects with an average size of around 2MB (1 MB = 10^6 bytes), which makes storage and transfer of these large numbers of pictures really costly. Furthermore, as many people who are mostly uncoordinated among themselves are engaged in taking pictures, it can happen that a set of people are all taking the same littered objects, say a overflowed trashed box in a neighborhood, and report them all separately, whereas one report could have been sufficient. Each individual is thinking that he/she is contributing to the pollution measure, not knowing that someone else is also doing the same. This effectively results in redundant contribution to some extent. Eliminating this redundancy without hurting the overall goal of collection is a very challenging research problem that one of the authors had worked on extensively in some of his earlier works [14]-[16].

A. Air/Carbon Emission Pollution

Next we move to measuring pollution due to carbon emission, which is mostly attributed to motorized vehicles. There are several possible ways citizens can assist in this regard. In the following, we discuss them.

The first approach relies on energy-based carbon emission calculation due to [17]. Energy based approach calculates emission directly from the amount of total fuel consumed by all vehicles in a city. In streets, there are public vehicles (e.g., buses) for public transport as well as privately owned vehicles. While fuel consumption for public vehicles can be collected from the respective offices, fuel consumption due to private vehicles is hard to gather. Hence, citizen assistance can be solicited. In that, citizens would share their fuel consumption data in some temporal granularity, say per week or months. Based on the total population of a city who possess and run vehicles, an estimate of total gasoline or diesel combusted can be obtained. According to a measurement of US Energy Protection Agency [18], average carbon (CO_2) emissions from one gallon of gasoline and diesel are 8,887 and 10,180 grams respectively. Based on this, total carbon emission can be determined by multiplying the above figures by the amount of total fuel consumed.

The second approach is activity based. Here, people share total miles they traveled in a certain time interval, say in a month. They also share their mileage, i.e., fuel consumption rate per mile or km, usually determined by the model and make of the vehicle. Mileage is usually measured in MPG (mile per gallon). Based on different vehicle models, average MPG is assumed to be as 21 [18]. Hence, CO_2 emission per mile can be computed as 8,887/21 = 443 grams.

The total miles traveled by vehicle can be measured directly from its odometer reading. Recently special sensor devices, called OBD (on board device), are available that can be mounted in the dashboard of a vehicle to record engine states, odometer readings and others. These devices have standard USB and Bluetooth connectivity options that allow them to be connected to a mobile phone. In that, custom-made software may be installed in mobile phones that would be able to communicate with the installed OBD to pull necessary records from the dashboard, including total miles traveled by the vehicle. These data can then be shared via the data connection of the phones or can be processed locally.

The first two approaches are sort of direct estimation of carbon emission in terms of real physical unit of how much carbon is emitted. The third and final approach that we present is rather indirect: assessing carbon emission from *video* data. This assessment is indirect in the sense it does not actually measure carbon emission in physical units, but generates a subjective perception of degree carbon related pollution as experienced by the citizens. The assessment is based on the assumption that people in a city are constantly exposed to carbon emissions all the time, but they do not necessarily label such emissions as pollution unless the level of emission exceeds certain level. Like as detecting waste pollution, this pollution has also a visual clue. When people watch vehicles emitting dark black smoke from their exhaust outlets, they may label these emissions to have exceeded the normal limit, hence detect them as an indication of pollution. People voluntarily become vigilant about these emissions and record these incidents by capturing an image of the vehicle emitting smoke. A still photograph is indeed evident of the fact that vehicle is making excessive carbon emission, yet it does not tell how long the emission actually lasted. For this, a video seems more appropriate.

Under the above mentioned assumption, in our proposed citizen-assisted scheme, people harness the video recording capability of their camera phones. When they watch a vehicle emitting black smoke, they record the emission, preferably placing the video camera behind the vehicle. The duration of the capture can be at least as long as the vehicle is seen to be emitting smoke or the vehicle goes beyond view or as long as the user can do recording comfortably and safely. Either way, the video contain at least one vehicle emitting smoke. A regular search on YouTube, the most popular video sharing site, reveals that there are indeed such kinds of videos available. Fig. 3 shows such a video from a YouTube user who captured a bus emitting black smoke in Dhaka city. That means such recordings are possible and are indeed quite frequent. It can be argued that the degree of pollution due to carbon emission of vehicles is positively correlated with the number of such emission incidents, as recorded and posted by users.

IV. Relevant Issues

There are a set of issues that need to be discussed in connection with peoples' participation in our proposed techniques for citizen assisted environmental pollution measurement. These issues are rather critical and largely define the success of our techniques. In the following, we discuss them.

A. *User Involvement in the Techniques*

The proposed techniques should be *non-invasive* in nature so that people can participate in them comfortably. Large advancements in UI (user interface) design for hand-held devices could be one key hope for this. Recent releases of mobile phone's UIs provide friendly interactions between user and the devices by which users can perform any operation at great ease. For example, taking a picture merely takes couple of taps on their phone screen to accomplish. Another important issue is *non-intrusive* nature of user involvement. The scheme should not seek much attention from the users, but rather a minimal interaction, such as pressing a button, should be sufficient for its operation. Other than recording video which engages users for a while, all other proposed involvements, namely capturing audio and images, are greatly non-invasive as well as non-intrusive.

B. *Accuracy of the Measurements*

Accuracy is a very important issue in people assisted measurements. Accuracy depends on how representative the collected samples are and on the presence/degree of noises/outliers in those collected data. Unfortunately, people generated data are inherently noisy due to various reasons, such as faulty devices, noisy surrounded environment, user's reluctance to conforming to accuracy, malicious behaviors of users by fabrication of false data, and individual biasness to events. The popular technique used to ensure accuracy to some extend is called “calibration”. Through calibration, user devices can be preset to known reference base for any measurement thereafter. Accuracy can also be increased by diversifying collected samples over spatio-temporal metrics. Since the data modalities that we use in our approaches are mainly media data such as sound, images, and video, there can be hardly any fabricated data. Even though some inadvertent errors can be introduced by users, it can be minimized by providing training to the users beforehand.

There are other factors that affect data accuracy and quality. Data quality can be compromised by a few factors. One is perturbation of data: modifying data content with illicit intent. Another one is to generate false data. However, media data, i.e., sound, pictures and video, are hard to fake (if not impossible) and are naturally protected from fabrication. Another way to lose data quality is to increase data volume by inserting the same observation repeatedly. This can be eliminated by examining data closely and by conducting statistical analytics, such as auto-correlation and regression fitting. There could be corroboration among users where the same data can be posted by different sets of users. Maintaining data provenance and digital signatures of content may help to combat this. Content with low significance can be posted for public review and then the number of likes and dislikes can be weighted.

C. *Willingness and Incentives for People Participation*

There is a big, but little understood problem is as to what extend people would actually ever participate in these efforts. Although the objective of the approach, that is measuring the pollution, has a collective goal serving the community as a whole, it is unclear how an individual may become highly enthusiastic about this unless his/her direct benefit is evident. This falls into the classical economic phenomenon popularly referred to as "the tragedy of the commons". Pricing and providing incentives are a few proposals made by economic researchers to circumvent this problem.

Incentives for users, who participate in measuring pollution and contribute data/observations to the repository, can be modeled as per design. For instance, users may be paid depending on the amount or the volume of data they produce. In order to reduce logistic hassles, the payment can be made in the form immediate use, not in hard currency, such as pre-paid talk time in mobile account. The volume of data, however, may not be the only decider for incentives. Another point could be the quality of reproduced data, where quality can be measured in terms of utility derived out of the contributed data.

V. Conclusion

In this paper, we outline citizen assisted environmental pollution measurement techniques. The techniques harness peoples' hand-held devices, particularly camera phones, for capturing sound, image and video in order to measure noise pollution, solid waste pollution and carbon emission pollution. While the proposed techniques are mostly conceptual, authors' future works are to be directed to build and evaluate such systems. If succeeds, the scheme can be used in developing cities.

References

[1] T. Abdelzaher *et al*., "Mobiscopes for human spaces," *IEEE Pervasive Computing*, vol. 6, no. 2, pp. 20-29, 2007.

[2] J. Burke *et al*., "Participatory sensing," in *Workshop on World-Sensor Web (WSW): Mobile Device Centric Sensor Networks and Applications*, pp. 117-134, 2006.

[3] T. Subramani, M. Kavitha, and K. P. Sivaraj, "Modeling of traffic noise pollution," *International Journal of Engineering Research and Applications* (*IJERA*), vol. 2, pp. 3175-3182, 2012.

[4] L. R. Kadiyali, *Traffic Engineering and Transport Planning*. Delhi, India: Khanna Publisher, 1997.

[5] J. B. Alam, M. J. B. Alam, M. M. Rahman, A. K. Dikshit, and S. K. Khan, "Study on traffic noise level of Sylhet by multiple regression analysis associated with health hazards," *Iran. J. Environ. Health. Sci. Eng.*, vol. 3, pp. 71-78, 2006.

[6] M. J. B. Alam, A. F. M. A. Rauf, and M. F. Ahmed, "Traffic induced noise pollution in Dhaka city," *Journal of Civil Engineering*, vol. 29, 2001.

[7] S. Seo, T. Aramaki, Y. Hwang, and K. Hanaki, "Environmental impact of solid waste treatment methods in Korea," *Journal of Environmental Engineering Div.* (*ASCE*), vol. 130, pp. 81-89, 2004.

[8] C. Zurbrugg, "Urban solid waste management in low-income countries of Asia how to cope with the garbage crisis," *Scientific Committee on Problems of the Environment* (*SCOPE*), Durban, South Africa, November 2002.

[9] I. A. Al-Khatib, M. Monou, A. S. F. A. Zahra, H. Q. Shaheen, and D. Kassinos. Solid waste characterization, quantification and management practices in developing countries. a case study: Nablus district-Palestine. *Journal of Environmental Management*, vol. 91, no. 5, pp. 1131-1138. 2010. [Online]. Available: http: //www.sciencedirect.com/science/article/pii/S0301479710000046.

[10] M. Kojima, C. Brandon, and J. Shah, "Improving urban air quality in south Asia by reducing emissions from two-stroke engine vehicles," *The World Bank*, Tech. Rep., December 2000.

[11] B. A. Begum, S. K. Biswas, and P. K. Hopke, "Impact of banning of two-stroke engines on airborne particulate matter concentrations in Dhaka, Bangladesh," *J. Air & Waste Manage. Assoc*, vol. 56, pp. 85-89, 2006.

[12] S. T. Holgate, *Air pollution and Health*, J. M. Samet, H. S. Kore, and R. L. Maynard, Eds. London: Academic Press, UK, 1999.

[13] Keep Australia Beautiful National Association, "National litter index: Annual report 2011-2012," *Keep Australia Beautiful National Association*, Tech. Rep., 2012, last accessed on 12:19am (GMT +6) July 29, 2013. [Online]. Available: http://kab.org.au/wp-content/ uploads/2012/08/8837-KAB-NLI-Report-2011-12-Final.pdf

[14] M. Uddin, H. Wang, F. Saremi, G.-J. Qi, T. Abdelzaher, and T. Huang, "PhotoNet: a similarity-aware picture delivery service for situation awareness," in *Proc. of IEEE Real-time System Symposium*, 2011.

[15] H. Wang, M. S. Uddin, G. J. Qi, T. Huang, T. F. Abdelzaher, and G. Cao, "PhotoNet: a similarity-aware picture delivery service for situation awareness," in *Proc of ACM Conference on Information Processing for Sensor Networks* (*IPSN*) (Demo), 2011.

[16] M. Y. S. Uddin, M. T. A. Amin, T. Abdelzaher, A. Iyegner, an R. Govindan, "PhotoNet$^+$: On achieving diversity in the presence of outliers in camera sensor networks," in *Proc of ACM Conference on Information Processing for Sensor Networks* (*IPSN*) (Demo), 2012.

[17] A. McKinnon and M. Piecyk, "Measuring and managing CO_2 emissions of European chemical transport," *Logistics Research Centre, Heriot-Watt University*, Edinburgh, UK, Tech. Rep., 2010. [Online]. Available: www.cefic.org

[18] Office of Transportation and Air Quality, "Greenhouse gas emissions from a typical passenger vehicle," *The U.S. Environmental Protection Agency* (*EPA*), Tech. Rep., December 2011.

Md Yusuf Sarwar Uddin was born in Chittagong, aport city of Bangladesh. His date of birth is Dec 2, 1979. He obtained his Bachelor and Masters degree both on Computer Science and Engineering from BUET on 2006 and 2004 respectively. He got his PhD on Computer Science from University of Illinois at Urbana-Champaign in 2012.

He is currently working as an Assistant Professor at the Department of Computer Science and Engineering at BUET. His research interests are in wireless and sensor networks, people-centric computation and communication, and disaster response communication.

Mr. Uddin is a Fulbright scholar to the United States, and has been award International Fulbright Science and Technology Award 2007 for PhD program. He is a member of State Alumni of US.

Rezwana Rafiq was born in Dhaka, Bangladesh.Her date of birth is February 22, 1984. She obtained her Bachelor and Masters degree both on Urban and Regional Planning from BUET on 2007 and 2011 respectively.

She is now serving is an Assistant Professor at the Department of Urban and Regional Planning at Bangladesh University of Engineering and Technology (BUET). Before joining BUET, she served as an Assistant Town Planner at RAJUK, the Capital Development Authority in Bangladesh. Her research interests are in wetland preservation, economic valuation of natural resources, environmental planning, and transportation planning.

Ms. Rafiq is a member of Bangladesh Institute of Planners (BIP). She had been awarded with University Grand Commission Scholarship, Dean List Award, Board Scholarship and University Technical Scholarship.