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A Low-cost Mobile Urban Environmental Monitoring System

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***Abstract*—The increasing pace of economic development and urbanization around the world has led to serious problems of environmental pollution, particularly from automobile emissions which contributes to Global Warming. In this paper, a low-cost mobile urban environmental monitoring system is proposed using off-the-shelf open source hardware and software. The system can be installed or used in public transport vehicles, particularly in school and college buses in countries like India. A pollution map of local and regional environments can be built from the data acquired, and displayed online leading to increased awareness of urban pollution problems. The system can also be used *in situ* in school and college buses to educate children and youth on emerging technologies like computer hardware, software, and web technologies. Results of prototype implementation are presented to illustrate the effectiveness of the approach.**

Keywords-air quality sensors; open source hardware; web server; database

I. INTRODUCTION

In recent years, economic development and urbanization have been on the rise in developing countries of Asia, Africa, and Latin America, compared to the more stabilized developed countries. In particular, the so-called BRIC countries (Brazil, Russia, India, and China) have continued to exhibit relatively impressive growth even during the recent global economic recession. However, in much of the developing world this economic progress has been accompanied by the dark side of rampant pollution, especially in urban areas. Lack of strict environmental regulations and capital for implementation of pollution controls has led to a devaluation of the need for air, water, and soil quality as basic requirements for quality of life in these countries.

Though not well recognized, pollution is one of the biggest global killers, though the solutions to pollution are fairly well-known and of low cost [1], [2]. Pollution affects children and pregnant women particularly hard, and results in chronic illnesses and other diseases that can impair the people's lives, reducing their economic productivity and potential. It can significantly lower longevity, and conversely pollution control and intervention effects have led to improvements in life expectancy, e.g., [3]. India has a particularly acute problem of environmental pollution, with indoor air pollution a leading cause of reduction in life expectancy of its citizens, and was ranked last among 132 nations in the recent Environmental Performance Index 2012 study of the effects of air quality on human health [4]. While pollution is often associated with contamination by chemical substances, energy type of pollution, e.g., noise, also contributes to acute health issues such as heart diseases [5].

In developed countries, pollution control efforts have historically accompanied increasing affluence in response to public demand for remediation, based on environmental literacy or awareness of the presence, causes, and effects of pollution. Therefore, in developing countries too serious efforts must be made to educate the public on the extent of pollution of their environment and its resulting costs to the individuals as well as society. Monitoring of the quality of the environment, recording, and dissemination of the pollution data to the public can go a long way in raising environmental awareness among the population.

In this paper, an innovative low-cost mobile urban pollution monitoring system is introduced for use in public transport vehicles, or in school and college buses widely deployed for transportation in countries like India. The system is based on use of open source microcontrollers, off-the-shelf air quality sensors, and web technologies for display and storage of acquired pollution data on the Internet. The system can be readily replicated, so that pollution maps and environmental geographic information systems (GIS) can be developed at local and regional levels to raise environmental awareness among the citizens, and to guide public officials in environmental management for effective pollution control. Results of prototype implementation are presented to illustrate the effectiveness of the method.

II. REVIEW OF TECHNOLOGIES FOR ENVIRONMENTAL MONITORING

There are several technological trends that have made environmental monitoring and literacy campaigns easier and more effective to achieve in the present scenario: the spread of the Internet, the popularity of social networking and multimedia, and the decreasing cost of cell phones and smart phones with free or inexpensive mobile apps. In the field of electronics and computers, Moore's Law continues

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to prevail, so that hardware in the form of computers and computer controllers is becoming faster, smaller, more powerful, and less expensive. Likewise, actuators and sensors are also becoming smaller, more versatile, and cheaper, so that they can be incorporated in everyday appliances, resulting in *embedded systems.* The increasing popularity of low-cost network technologies such as wireless Ethernet, Bluetooth, Xbee, GSM/GPRS, and wireless sensor networks, has also resulted in powerful new devices and systems in the field of networked and embedded control systems (NECS) [6].

A promising new development in the area of computer technology has been the rise of *open source hardware*, exemplified by inexpensive microcontrollers such as Arduino [7], Raspberry PI [8], and Texas Instruments' MSP430 LaunchPad [9]. The availability of low-cost 3D printing and rapid prototyping technologies and the integration of software with inexpensive hardware has led to innovative new products, so much so that it has been remarked that "hardware is becoming the new software" [10]. An advantage of open source hardware is that a wide variety of ready to use – with few modifications – software is available for them on the Web making development times shorter. A wide range of low-cost interfaces, accessories, and sensors are also available on the Internet, along with useful instructions.

In the area of software too, valuable *open source software* tools are available in the area of web technologies – such as data bases and web servers – and microcontroller-based systems. Therefore, it has been possible to design and operate inexpensive systems that can be used to monitor physical systems or control them, and display the data over the Internet in real-time, e.g., [11].

The increasing availability of powerful open source hardware and software makes it possible to popularize among the public the creation of innovative technological solutions to socio-economic problems. For example, in developing nations in Africa, these tools are being used to introduce school children and youth to the power of the Do-It-Yourself (DIY) movement, so that a technologically savvy generation can be groomed [12]. This approach is similar to the use of robotics competitions such as FIRST (For Inspiration and Recognition of Science and Technology) among high school students in the United States to encourage the younger generation to pursue careers in science, technology, engineering, and mathematics (STEM) disciplines.

As mentioned in the previous section, pollution monitoring of air, water, and soil environments has become a major economic, social, and academic concern. This is in large part due to the damaging effects of Global Warming, agricultural and industrial pollution, and overuse by population growth, and urban sprawl. Educating the public in general, and the children and youth in particular, about the importance of our environments, and the need for environmental monitoring and pollution control, can help them cultivate life-long environmental stewardship and activism. It will also lead to effective reforms and major improvements at other social and personal levels: e.g., minimizing the use of fossil fuels, conservation of energy, and responsible environmental use.

Traditional environmental monitoring methods are typically stationary, labor-intensive, time-consuming, prone to human errors, and expensive [13]. As a result, mobile environmental monitoring is becoming more prevalent. In the case of monitoring by mobile workers, GPS and GIS tools are widely used [14]. More recently, smart sensors and wireless sensor networks are being used for environmental monitoring with a range of applications in agriculture and automotive emissions monitoring [15].

A greenhouse gas monitoring station at provincial level has recently been established in China. It monitors the concentrations of carbon dioxide, methane, ozone, carbon monoxide, sulfur dioxide, oxynitride, and particulate matter [16]. Researchers at the University of California in Berkeley have developed an urban sensor network to provide real-time, neighborhood-by-neighborhood measurements of carbon dioxide. The prototype network employs 40 sensors spread over a 27 square-mile grid, most of them mounted atop local schools to engage students in the project [17]. Though the system uses off-the-shelf environment sensors to lower the cost from $250,000 for a traditional monitoring station to $12,500, it is still prohibitively expensive to use in developing countries.

An efficient mobile environmental monitoring technology has of late emerged in the form of mobile robots [18], [19]. Similarly, robots are also used as significant tools in surveying technology, e.g., [20]. One of the authors was involved in the design and development of a prototype remotely operated vehicle (ROV), a type of teleoperated underwater robot, as a low-cost alternative to fixed station-based environmental monitoring of local water bodies in New Orleans, USA [21]. Mobile robots are also widely used for indoor environmental monitoring in the case of communication rooms, warehouses, power stations, and so on [22]. The robot is fitted with a data acquisition system, indoor air quality sensors, temperature, wind, and humidity sensors, on-board camera and laser range finder, and a wireless network for communication with a remote client.

In this paper, our earlier method of ROV-based mobile water quality monitoring is adapted to air pollution monitoring. However, it is not feasible to use robots for this purpose. On the other hand, in urban centers in India buses and vans are widely used for transporting students to schools and colleges every day. Buses too are a widely used mode of transport for the public. Therefore, a novel approach is taken of deploying in these buses air quality monitoring kits equipped with on-board GPS and a microcontroller-based system for data acquisition. The monitoring system containing carbon dioxide, carbon monoxide, and methane sensors as well as an electret microphone for measuring ambient noise can then be used for recording air quality data during the time of travel along the routes of the bus, which in many cases cover substantial areas of a city. For wider coverage areas during much of the day, the systems can be installed in public transport means, such as buses and suburban trains.

III. A MOBILE ENVIRONMENTAL MONITORING SYSTEM

The basic concept of the proposed mobile environmental monitoring system is illustrated in Fig. 1. A low-cost Arduino microcontroller is used for data acquisition from the air quality sensors, temperature sensor, and microphone. A GPS (global positioning system) module is used to determine the geospatial coordinates at the points of measurement while on the bus.

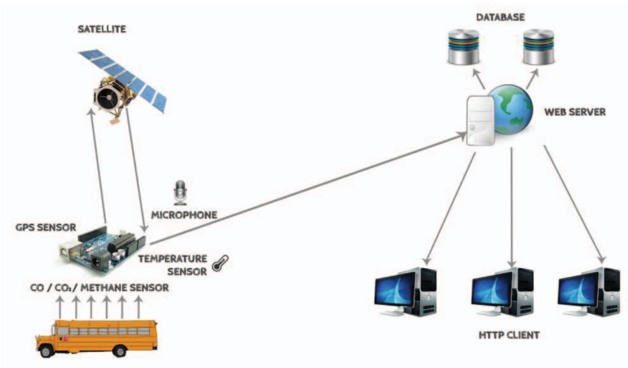

Fig.1. Concept of mobile urban environmental monitoring

Common air pollutants in the urban milieu include hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM), sulfur dioxide (SO_2), ozone, volatile organic compounds (VOCs), hydrogen sulfide (H_2S), and toxic air contaminants such as lead (Pb). In this work, as a proof-of-concept prototype, CO, CO_2, hydrogen, and methane sensors have been used. Additional sensors are being deployed in ongoing work. The main characteristics of the measured variables are as follows:

- *Carbon dioxide (CO_2) Sensor*: CO_2 is the primary greenhouse gas, resulting from human activities. Measuring carbon dioxide is important in monitoring indoor air quality and many industrial processes, as well in assessment of vehicular emissions. The most common types of CO_2 sensors are infrared gas sensors and chemical gas sensors.
- *Methane (CH_4) sensor*: CH_4 is the second most important greenhouse gas after CO_2 and contributes to global warming. Measurements of CH_4 concentrations can help identify and locate methane *hot spots*, from which most of the methane flux originates.
- *Carbon monoxide (CO) sensor*: CO is a colorless, odorless, toxic gas. In urban environments, it is largely a result of emissions from incomplete combustion in automotive engines. It also arises in developing countries as a byproduct of operating wood stoves.

The major features of the proposed system are:

- The system is built using inexpensive, yet reasonably accurate, off-the-shell components to monitor pollution at an affordable low cost in an efficient manner.
- The pollution monitoring system tags the changes in the environmental measurements by tracking the position of the vehicle in which the sensors are installed, using on-board GPS.
- The pollution information is then uploaded and updated in a web server.
- An easy-to-understand website is created for students, the public, and public pollution control officials to access and share updated information about the environment.
- As the monitoring is done while transporting students to and from schools/colleges, the monitoring results will be displayed in the bus in real-time to raise the consciousness of the students.
- The technology and methodology will be shared with local school/college teachers, so the bus trips can be used to offer innovative and interactive lessons *in situ* to the students on the environmental issues faced by their neighborhoods.
- The students and the public will be encouraged to enlighten themselves about the remedial measures to deal with environmental pollution-related issues raised by the results of the project implementation.

IV. METHODOLOGY OF IMPLEMENTATION

A photograph of the environmental monitoring kit is shown in Fig. 2. The system uses Arduino, a popular open source single board microcontroller, which is based on an Atmel AVR processor, with on-board support for analog inputs, pulse width modulation (PWM) outputs, and digital input/output [23]. The advantages of Arduino include simplicity, ease of use, low cost, availability of a wide range of inexpensive, well-documented compatible hardware, and extensive software code available from a large user community for other users to reuse and adapt, so that users can focus on rapid system integration and development, with value added. Customized Arduino boards, known as *shields,* are available for applications such as Ethernet and Bluetooth communication, motor control, etc. The microcontroller is interfaced to a personal computer for programming and data acquisition purposes through a USB port.

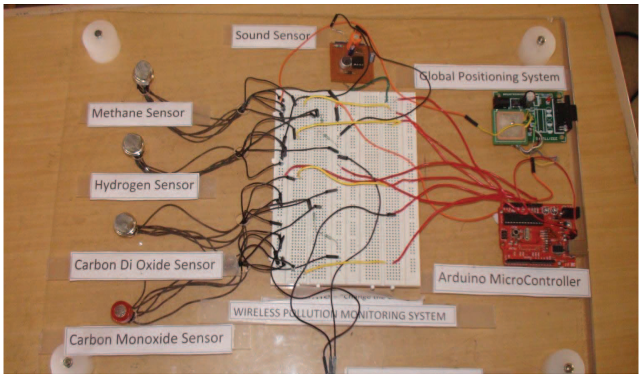

Fig.2. Environmental monitoring kit assembly

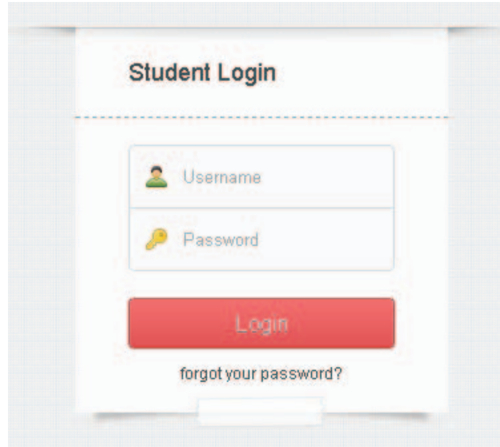

Fig.4. Authorized login to database

The Arduino board is programmed in a C++ like integrated development environment (IDE), with built-in example code known as *sketches*. Extensive built-in libraries are available with custom code for various applications and compatible hardware made available by user community.

A graphical user interface (GUI) is developed for storage and retrieval of the environmental data. For ease of understanding, the values can be shown graphically for periodic intervals (weeks, months, etc.), and comparative summaries provided as column/bar charts or in tabular form.

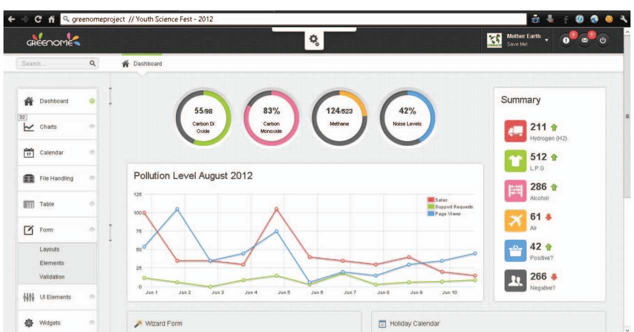

Fig.3. Graphical user interface for display of sensor data

Figure 3 shows a typical GUI window display of the environmental sensor data. At the end of the bus trip culminating in a college/school, the sensor data are uploaded manually (e.g., from a micro SD card installed in an Arduino Ethernet shield), or wirelessly using a Bluetooth shield or other means such as Xbee, or by Wi-Fi connection in the institution.

For educational purposes, student users can log on to the web site with authorized user ID and password (Fig. 4). Others, such as members of the public, can log on to the site for guest access to selected data.

The database is developed using MySQL, the open source relational database management system. MySQL is a part of the open source web application software stack, LAMP (Linux/Apache/MySQL/PHP). The web server hosting the database is developed using PHP, another open source software for web development.

The process of uploading the sensor values to the database is shown in Fig.5.

Fig.5. Updating the sensor values database

The GPS position data are logged using the Arduino microcontroller and Trimble GPS Studio. The Studio is a free software used for tracking the vehicle/sensor kit positions in real-time over the Web. A Google Maps tracking of the GPS data around the authors' college grounds is shown in Fig. 6.

Fig.6. Remote GPS monitoring over the Web using Google Maps

V. RESULTS AND DISCUSSION

Preliminary results have been obtained using the proposed system for the city of Madurai in Tamil Nadu State, India. Madurai is the third biggest city in the state and a major urban center. Like many other cities in the world, it has been increasing temperature caused by urbanization, growth of vehicles, and industrial activity [24].

A trial observation of urban air quality using the proposed mobile environmental monitoring system was recently conducted. The results are categorized in terms of low, medium, and high pollution as shown in Figure 7.

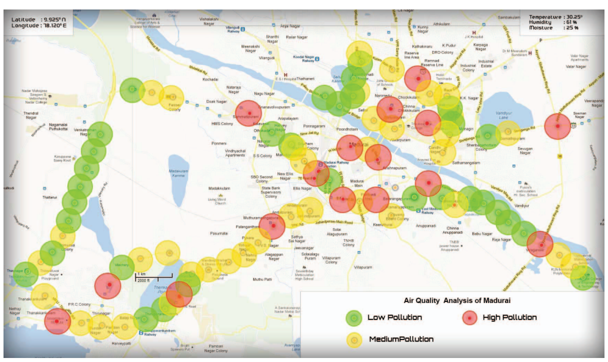

Fig.7. Air quality monitoring in and around Madurai city

It can be noted that the air pollution levels are high in and around the city center. This is where the Periyar Bus Terminal is located and commercial and public transit traffic is heavy and congested. As one moves away from the city center, the air pollution levels tend to decrease. As can be seen, there are a few locations in the outlying areas with higher pollution. Some of these higher measurements were measured at places of traffic congestion. These geospatial variations in air pollution level are similar to the variations in SO_2 and NO_2 values obtained at three sampling sites in the city, obtained by Vijaybhaskar, et al. in a 2003 study [25].

The authors plan to implement the low-cost monitoring system on local school and college buses which ply among the major routes of the city and outlying areas, except partly through the city center which is mainly a business district. This will provide a long term collection of air quality data that could then be used to develop a GIS data base of air quality in the city and its surrounding areas.

The authors are collaborating with local schools on the details of implementation of the proposed system for *in situ* and classroom environmental education. Innovative lesson plans will be developed using the existing environmental science curriculum, along with coverage of additional topics of relevance. By providing student-friendly visual presentations and summaries of the air pollution data in correlation to their geospatial locations, the students will be encouraged to understand, explain, or speculate about the causes and correlations behind spatial variations in the pollution data. A photograph of an actual demonstration of the prototype system to local school students in their bus is shown in Fig. 8.

Fig.8. Live demonstration on a bus for school students

The sensor kits developed are quite inexpensive, costing as little as $200 only. They can be installed permanently on the buses with suitable weatherproofing of the kits, or depending on the sampling requirements for a given neighborhood, the kits can be installed and operated on an as needed basis. Moreover, it is possible to develop kid-friendly kits that the children can use around their neighborhood for data collection and visualization [26].

Environment data collected over distributed neighborhoods and over a period of time can be organized into *environment clouds* [22], or color-coded pollution maps, as well as environmental geographic information systems (GIS). This will allow students and citizens to go online and look up the air quality levels in their neighborhoods. It will encourage them to investigate the potential causes for any high pollution levels in their localities, and hopefully motivate them to undertake remedial measures.

The proposed system can also be used in other innovative ways: for example, the microphone sensors on the bus can be used to collect time series data on noise from the bus (e.g., honking of horn by the driver) which can be analyzed to reward prizes for drivers for responsible, quite driving. Similarly, microcontroller-based kits can be installed in buses or vehicles with fuel-injection type engines to provide real-time displays of the fuel consumption patterns to the drivers, as well as comparative periodic summaries of fuel consumption performance, thereby encouraging fuel-efficient driving behavior among the drivers [27].

Moreover, the experience gained with the open source hardware-based environment monitoring systems can also be used to provide high school and college students with valuable lessons on hands-on experiences in building their own kits for environmental monitoring or other applications. It will have the merit of introducing these students to latest developments in emerging technologies in computer hardware and software, embedded and networking systems, and information and communications technologies. Similar projects are employed with hands-on ROV building summer camps and design competitions [28].

VI. Conclusions

This paper has presented a novel low-cost urban environmental monitoring system for installation and operation on college/school buses or public transport vehicles in countries like India. The data acquired are displayed over the Web for raising environmental awareness among the public. They can be used *in situ* for educating the traveling school/college students on the need for environment preservation and stewardship. Given the ease of development and use of the underlying technologies based on open source hardware and software, the project can be replicated elsewhere so that environmental databases of entire cities and regions can be readily developed.

References

[1] Blacksmith Institute Pollution Blog, 2011, http://www.blacksmithinstitute.org/blog/?m=201110

[2] J. Fenger, 1999, "Urban air quality - their physical and chemical characteristics", *Atmospheric Environment*, **33**, pp. 4877-4900.

[3] A.W. Correia, C.A. Pope, D.W. Dockery, Y. Wang, M. Ezzati, and F. Dominici, 2012, "Effect of Air Pollution Control on Life Expectancy in the United States: An Analysis of 545 U.S. Counties for the Period from 2000 to 2007", *Epidemiology*, **24**, pp. 23-31.

[4] M. The Hindu, 28 January 2012, "India has the most toxic air: Study", http://www.thehindu.com/sci-tech/energy-and-environment/article2837739.ece

[5] M. Sorensen, Z.J. Andersen, R.B. Nordsborg, S.S. Jensen, K.G. Lillelund, R. Beelen, E.B. Schmidt, A. Tjønneland, K. Overvad, and O. Raaschou-Nielse 2012,"Road Traffic Noise and Incident Myocardial Infarction: A Prospective Cohort Study", *PLoS ONE*, 7, pp. 1-7.

[6] R. Alur, K.-E. Arzen, John Baillieul and T.A. Henzinger (Eds), 2005, "Handbook of Networked and Embedded Control Systems", Birkhäuser. Boston, MA.

[7] www.arduino.cc

[8] www.raspberrypi.org

[9] Texas Instruments,www.ti.com/msp430

[10] New York Times, 25 August 2012, "Silicon Valley's Hardware Renaissance", www.nytimes.com/2012/.../silicon-valleys-hardware-renaissance.html.

[11] Open Energy Monitor, http://openenergymonitor.org/emon/

[12] F. Graham, 23 July 2012, "Can robotics change the face of a nation?", http://www.bbc.co.uk/news/business-18956031.

[13] G.B. Wiersma (Ed), 2004, "Environmental Monitoring", CRC Press.

[14] M. Christl, 2009, "Location-Aware Environmental Monitoring For Mobile Workers", GRIN Verlag.

[15] S.C. Mukhopadhyay (Ed), 2012, "Smart Sensing Technology for Agriculture and Environmental Monitoring", Springer.

[16] Emissions monitoring system launched in Shanxi province, http://www.thehindu.com/sci-tech/energy-and-environment/emissions-monitoring-system-launched-in-shanxi-province/article3654088.ece

[17] UC Berkeley installing first CO2 sensor network in Oakland, 2012, http://newscenter.berkeley.edu/2012/06/27/uc-berkeley-installing-first-co2-sensor-network-in-oakland/

[18] M. Dunbabin and L. Marques, 2012, "Robotics for environmental monitoring", *IEEE Robotics and Automation Magazine*, **19**, pp. 24-39.

[19] M. Trincavelli, M. Reggente, S. Coradeschi, A. Loutfi, H. Ishida and A.J. Lilienthal, 2008, "Towards Environmental Monitoring with Mobile Robots", *Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, Nice, France, pp. 2210-2216.

[20] S. Williams, L.T. Parker, A.M. Howard, 2012, "Terrain Reconstruction of Glacial Surfaces : Robotic Surveying Techniques", *IEEE Robotics and Automation Magazine*, **19**, pp. 59-71.

[21] B. Xu, S. Abe, and S.R. Pandian, 2005, "A low-cost prototype ROV for monitoring of New Orleans aquatic environments", *Proc. Int. Conf. on Underwater Intervention*, New Orleans, LA.

[22] J. Wu, Z. Huang, Y. Guan, C. Cai, Q. Wang, Z. Xiao, Z. Zheng, H. Zhang and X. Zhang, 2011, "An Intelligent Environmental Monitoring System Based on Autonomous Mobile Robot", *Proc. IEEE Int. Conf. on Robotics and Biomimetics*, Phuket, Thailand.

[23] M. Schmidt, 2011, "Arduino: a quick start guide", The Pragmatic Bookshelf, Raleigh, NC.

[24] The Hindu, 21 April 2010, "Temperature is on an increasing trend in Madurai during summer", http://www.hindu.com/2010/04/21/stories/2010042156460100.htm

[25] B. Vijaybhaskar, R.V.Jebarajasekhar, and P.Muthusubramanian, 2003, "Out Door Air Quality And Health Effects: A Case Study" in *Proc. Third Int. Conf. on Environment and Health*, Chennai, India.

[26] E. Gertz and P. DiJusto, 2012, "Environmental Monitoring with Arduino: Building Simple Devices to Collect Data About the World Around Us", Make Press.

[27] D. Schneider, 2009, "A fuel-economy gauge for the rest of us", *IEEE Spectrum*, 2009, **40**, pp. 20-21.

[28] J. Zande and D. Sullivan, 2003, "ROV competitions for students: developing the next generaton of ocean explorers, scientists, technologists, and engineers", *Proc. Oceans 2003 Int. Conf.,* pp. 1563-64.