Air Quality Crowdsensing in Smart Cities using Low Cost IoT Systems and ICT4Env Platform

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***Abstract*— Air quality in urban areas is a major concern in modern cities due to significant impacts of air pollution on public health. Conventional monitoring stations are not providing sufficient spatio-temporal resolution needed to implement abatement strategies and stimulate environmental awareness among citizens. Possible solution of the problem is development of a low-cost Air Quality Monitoring sensor system based in IoT architecture, easy to install and use, with free access to platform providing database storage and web services for presentation and visualization. ICT4Env platform and prototype of IoT hardware solution for low-cost air quality monitoring is developed and presented. After finalizing the product, design and software will be free available, in order to motivate citizens to participate in crowdsensing and providing valuable data. Presented platform and framework can be easy implemented in variety of Environmental Management Systems in Smart Cities.**

Keywords—air quality, IoT, low cost, crowdsensing

I. INTRODUCTION

Urban air pollution is monitored by several conventional stationary air pollution monitoring systems. These monitoring stations are highly reliable, accurate and able to measure a wide range of pollutants. However, conventional monitoring stations involve long-term time-consuming average models. The air pollution situation is updated hourly, so air pollution maps are with low spatial and temporal resolutions. A real-time system with high spatio-temporal resolution is essential because of the limited data availability of conventional air pollution monitoring systems.

Conventional air pollution monitoring systems are mainly based on sophisticated and well-established instruments. In order to guarantee the data accuracy and quality, these instruments use complex measurement methods and a lot of assisting tools including: temperature controller (cooler and heater), relative humidity controller, air filter (for PM), build-in calibrator. These systems are expensive (at least 20.000 EUR for each pollutant) with high power consumption, large volume, heavy weight and complex maintenance.

Development of low-cost environmental monitoring systems is very challenging task. The main goal is development of a low-cost sensor system for Air Quality Monitoring based on low-cost gas sensors and IoT concept using open source hardware and software.

ICT4Env research group uses the experience and knowledge from several research groups but adapted to local condition due to numerous limitations. In this paper, we present analyses of low-cost IoT-based architectures and propose a solution for air quality monitoring.

II. ICT4ENV PLATFORM

A. History and concept

In the last 25 years, researchers from St. Kliment Ohridski University in Bitola, Macedonia were very active in environmental protection, pollution prevention, environmental management, and development of decision support systems. Starting from activities focused on air pollution modeling and simulations following by the environmental impact assessments studies and projects focused mostly on pollution from large industrial sources and pollution from mobile sources from traffic and transportation. In the last 10 years, activities were expanded to cover all aspects of environmental pollution and protection, including water, waste and noise pollution.

Since 2015, when the new Faculty of Information and Communication Technologies was established, activities are more focused on implementation of state of the art computer technologies in environmental protection, and researchers put joint efforts into establishing a new research group: Information Communication Technologies for Environment - ICT4Env capable to cope with the highest complexities demanded by the environmental processes using interdisciplinary approach and knowledge from ICT, Environmental Engineering, Sensors and Embedded Systems.

B. Approach and strategic steps

The main idea behind of the ICT4Env group us: *solving environmental problems using state-of-the-art Information and Communication Technologies*.

Basic theoretical scientific approach is used only as a first step and foundation for development of real, practical solutions integrated in complete platform. Development of hardware and software solutions for particular environmental problem is based on framework following the 8 steps:

1. Spatial and temporal definition of the environmental problem

- macro and micro locations
- sampling intervals
- detecting the needs for efficient coverage with sensor nodes

2. Development and simulation of sensor network concept
   - selection of measured variables, selection and/or design of custom made sensor nodes
   - development of network infrastructure and topology
   - production of custom embedded sensor nodes
3. Development of database, server and cloud applications (back end)
4. Data analyses using image, signal processing and intelligent algorithms.
5. Development of GIS based visualization techniques
6. Environmental modeling and simulation using artificial and computational intelligence algorithms
7. Development of all necessary web services (front-end applications)
8. Development of simulation what-if scenarios and integration into user-friendly Decision Support System with advanced visualization concepts

C. *Arhitecture*

ICT4Env platform is based on Open Source software and hardware. Back end services are created by using LAMP stack: Linux operating system, the Apache HTTP Server, the MySQL relational database management system (RDBMS), and the PHP programming language. MySQL as an open source relational database management system is a central component in the platform, it runs as a server and allows multiple users to manage and create numerous databases capable of collecting and storing data from different sources:

- state monitoring stations (open data from stations owned and operated by government agencies)
- data from our sensor networks (sensor nodes using for research and informative purposes)
- crowdsourcing and crowdsensing (voluntary provided data from citizen "scientists").

Front-end applications and web services are also developed using open source solutions: HTML5, JavaScript, CSS, Open Layers and Leaflet (for building rich web-based geographic applications end geo tagged data presentation) and Data Driven Documents (D3.js) for visualization of measured data.

D. *Hardware solutions*

Instead of using custom made hardware (special sensor shields and specific connection to sensors to ensure pug-and-play capabilities) we are using the modular approach:

- of the shelf standard microcontrollers
- standard sensor boards available on the market
- variety of available communication modules

Hardware solutions are based on affordable, low cost controllers: various Arduino boards, Raspberry Pi, and ESP8266. Various Wi-Fi, GSM (only SMS), and NRF communication modules are used in different applications, and currently we are working on development of LoRa based systems. Also, a lot of different low cost, small size and fast response time sensors with price starting from 20US$ up to couple of hundreds are implemented in different IoT nodes.

III. IoT PROTOTYPE NODE FOR PM MEASUREMENT

Air pollution may vary over a space with magnitude of few meters and over time with magnitude of few seconds. The conventional monitoring systems cannot detect this phenomenon because of their limited data availability and non-scalability characteristics. Variety of MEMS and Laser based ambient sensors with low cost, small size and fast response times (in the order of seconds or minutes) are available recently.

Basic air monitoring IoT node (Fig1.) is measuring Particulate Matter – PM. It can be connected to any available Wi-Fi network, measured data also can be accessed by connection to mobile phone, it can send measured data to remote MySQL database, it can be used as a local web server.

Fig 1. PM IoT node prototype

Design is simple with only 4 components:

- Arduino compatible microcontroller with Wi-Fi connectivity (ESP8266)
- PM2.5 / PM10 sensor SDS011
- Bosh BME280 sensor (temperature, relative humidity, atmospheric pressure)
- LCD display (optional).

For remote locations without Wi-Fi connectivity, GSM module (A6 ThinkerAI) is used. System is sending SMS with measured data to the GSM Gateway and after processing, the data is stored MySQL database. Additional low-cost sensors for CO, SO2, O3, NOx, can be added to the base, but we must be aware of the fact that low-cost ambient sensor cannot achieve the same data accuracy and quality as conventional monitoring instruments.

CONCLUSION

Low-cost IoT system for Air Quality Monitoring was developed and tested. System is modular and flexible, using standard hardware solutions. Complete ICT infrastructure was developed in order to provide connection and data storage to practically unlimited number of sensor nodes. Accuracy of the sensor system is enough for informative purposes, and it can provide high spatio-temporal resolution. Future development and promotion is essential for motivating the citizens to participate in crowdsensing and providing large amount of usable data.