Realization of Low-Cost IoT System for Environmental Monitoring: Potential and Challenges

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1. Introduction: IoT concept

- The **Internet of things (IoT)** is the network of physical devices, vehicles, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data.
- Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure.
- Experts estimate that the IoT will consist of about 30 billion objects by 2020

The concept of Internet of Things creates breakthrough opportunities for seamless connectivity and ubiquitous integration of low-complex and low-cost digital systems enabling alternative cost-effective solutions for various applications.

IoT and Environmental Monitoring

- The plethora of sensors available on the market, capable to detect and measure almost every physical quantity, substantiated by the availability of affordable digital architectures with respective processing and communication power, create new developmental horizons in the area of **environmental monitoring,** which nowadays is considered as one of the key mission critical application in the next-generation ICT systems.
- Development of low-cost environmental monitoring systems is very **challenging** task, but due to huge **potential** of modern sensor systems, nowadays a lot of researchers put their efforts in order to solve such complex tasks.
- In this paper, we present analyses of low-cost IoT-based architectures and propose a solution for air quality monitoring.

2. Problem definition

- The air quality in urban areas is a major concern in modern cities due to significant impacts of air pollution on public health
- Air pollution is monitored by conventional stationary air pollution monitoring systems. These monitoring stations are highly reliable, accurate and able to measure a wide range of pollutants.
- Conventional monitoring instruments 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.
- The main goal is development of a low-cost measuring station for Air Quality Monitoring based on low-cost portable gas sensors and IoT concept using open source hardware and software.

Current “state of the art”

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.

Limitations:

- high cost (at least 20.000 EUR for each pollutant)
- high power consumption,
- large volume,
- heavy weight,
- complex maintenance

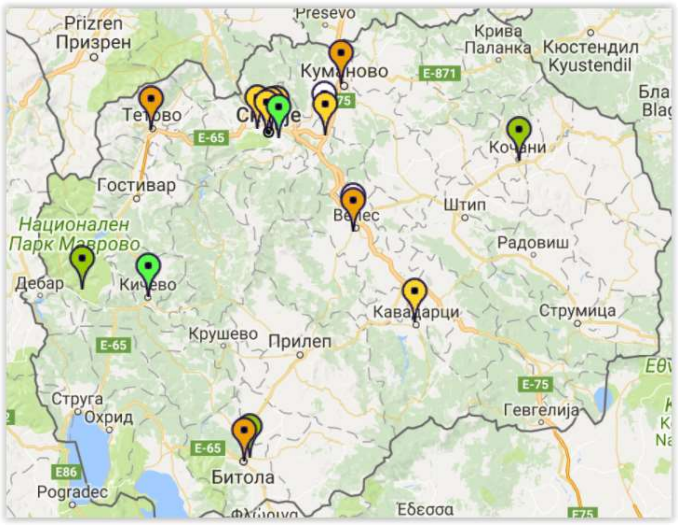
Stationary monitors in selected cities

City	Stationary Monitors	Coverage Area	Coverage per Monitor	Football Fields Per Monitor
Beijing, China	35	16000 km^2	457 km^2	64025
Hong Kong, China	15	2700 km^2	180 km^2	25210
New York, USA	44	1200 km^2	25 km^2	3820
London, UK	123	1600 km^2	13 km^2	1822

Source:
Yi, W.Y.; Lo, K.M.; Mak, T.; Leung, K.S.; Leung, Y.; Meng, M.L. A Survey of Wireless Sensor Network Based Air Pollution Monitoring Systems. Sensors 2015, 15, 31392-31427.

Skopje (Macedonia)	5	571 km^2	114 km^2	16314

Stationary monitors in Macedonia



Number of monitors:
17

Coverage area:
25.713 km²

Coverage per monitor:
1.512 km²

Football fields per monitor:
> 200.000

Stationary monitors v.s. new sensors

- Low spatio-temporal resolution is sufficient for background monitoring but **inadequate** for the public awareness and personal health risk estimation.
- Pollutant concentrations 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
- Thanks to technology advance, especially development of MEMS based ambient sensors with low cost, small size and fast response time (in the order of seconds or minutes) are available recently (price starting from 20 US$ up to couple of hundreds)

- **! No low-cost portable ambient sensor can achieve the same data accuracy and quality as conventional monitoring instruments.**

European Directive for Air Quality

The Directive establishes a framework of **methods** for air pollution monitoring for **regulatory purposes**.
In Europe, maximum levels of **measurement uncertainty** that each method shall meet at limit values, defined for each pollutant based on health effects.

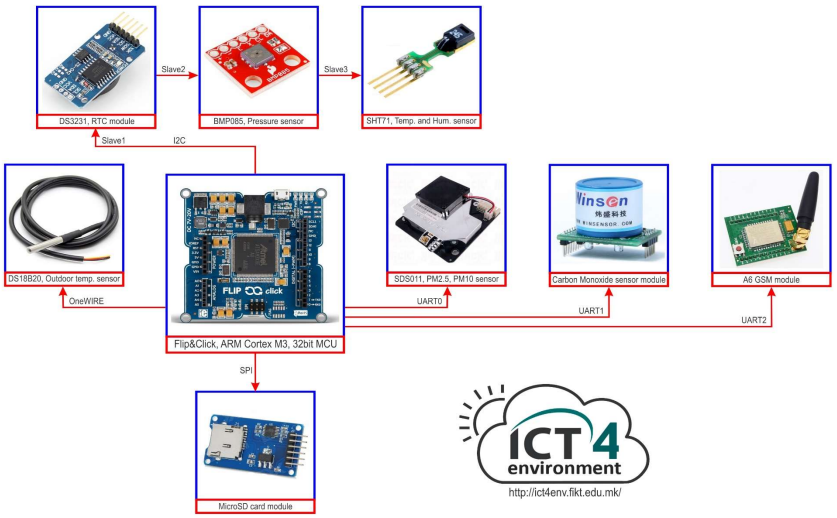
- **reference methods** that can be applied everywhere and for all purposes with a maximum measurement uncertainty of **15%** for O3, NO2, NOx and CO;
- **indicative methods** that can be applied in specific areas. Indicative methods are associated with uncertainty of **25%** for NO2, NOx and CO, **30%** for O3;
- **objective estimation** that can only be implemented in an area of low levels of air pollution with uncertainty of **75%** for O3, NO2, NOx and CO.

Several evaluations of sensor performance, shows that at this moment low cost sensors are not able to meet the uncertainty levels of reference measurements, but some sensors could reach the levels for indicative measurements.

3. Development of low-cost AQ monitor

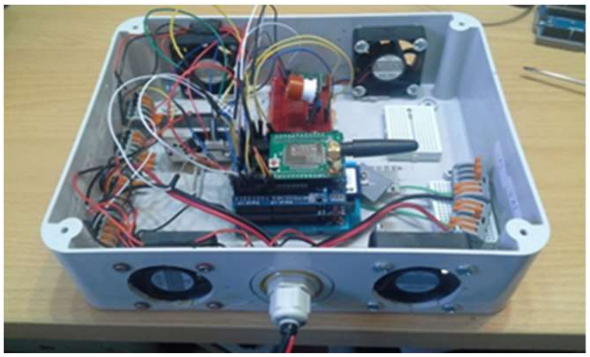
- Joint Research Centre of the European Commission (JRC Ispra) is working on the AirSensEUR project, which aims at the establishment of an affordable (under 1000 euro) open software/hardware multi-sensor platform, which is nonetheless able to monitor air pollution at low concentration levels.
- The main goal is establishment of open and transparent sensor network interconnected through the means of the IoT, with interoperable components of AirSensEUR, providing “plug-and-play” bundle capabilities.
- Our ICT4Env research group uses the experience and knowledge from JRC research group, but adapted to local condition due to numerous limitations.
- Instead of using custom made hardware (special AirSenseEUR Shield and specific connection to sensors to ensure pug-and-play capabilities) we are using the modular approach:
  - of the shelf standard microcontrollers easy to purchase
  - standard sensor boards available on the market
  - variety of available communication modules

4. AQ Monitor arhitecture



Realisation 1: Air Quality Monitor

- Arduino compatible microcontroller (MikroE Flip&Click)
- Real Time Clock module
- Micro SD card module
- GSM module (A6 ThinkerAI)
- PM2.5/PM10 sensor SDS011
- CO sensor (Winson)
- Ozone (O3) sensor (MQ131)
- temperature sensor (Dallas 1820)
- relative humidity and temperature sensor (Sensirion sht71)
- atmospheric pressure sensor (Bosh BMP 085)



System is sending SMS with measured data to the GSM Gateway (time interval: 1 hour) and after processing, the data is stored in remote MySQL database (since November 2016).

Realization 2: IoT node for PM

Main characteristics:

- Node can be connected to any available Wi-Fi network
- Measured data 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
- Simple design with only 4 components:
  1. Arduino compatible microcontroller with Wi-FI connectivity (ESP8266)
  2. PM2.5 / PM10 sensor SDS011
  3. Bosh BME280 sensor (temperature, relative humidity, atmospheric pressure)
  4. LCD display (optional)

Database table with measured data

датум	време	локација	CO	NO2	O3	PM10	PM25	SO2	id
2016-11-17	10:34:46	Bitola3	1.86	0.00	13.00	82.10	49.46	0.00	5042
2016-11-17	11:34:39	Bitola3	1.43	0.00	12.00	77.94	46.95	0.00	5060
2016-11-17	12:34:32	Bitola3	1.94	0.00	11.00	101.50	61.15	0.00	5078
2016-11-17	13:34:37	Bitola3	1.53	0.00	9.00	62.70	37.77	0.00	5096
2016-11-17	14:34:30	Bitola3	1.86	0.00	10.00	64.08	38.60	0.00	5114
2016-11-17	15:34:23	Bitola3	2.87	0.00	12.00	76.56	46.12	0.00	5132
2016-11-17	16:34:28	Bitola3	7.70	0.00	20.00	152.79	92.04	0.00	5150
2016-11-17	17:34:21	Bitola3	4.72	0.00	15.00	102.89	61.98	0.00	5168
2016-11-17	18:34:13	Bitola3	4.48	0.00	16.00	61.31	36.93	0.00	5186
2016-11-17	19:34:18	Bitola3	3.76	0.00	17.00	75.17	45.28	0.00	5204
2016-11-17	20:34:11	Bitola3	3.49	0.00	17.00	68.24	41.11	0.00	5222
2016-11-17	21:34:03	Bitola3	3.24	0.00	16.00	57.15	34.43	0.00	5240

Note: sensors for NO2 and SO2 are not yet implemented.

5. Conclusion

- Low-cost IoT system for Air Quality Monitoring was developed and tested for functionality in period of 10 months.
- System is very modular and flexible, using standard hardware solutions.
- Variety of different type of connections are available, and communication performances are on very high level.
- 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 it is not enough for regulatory purposes, but the system can be used for informative purposes providing high spatio-temporal resolution.
- Accuracy of the system can be improved in the future by “on field” evaluation and comparing the data with co-located sensors with reference methods.
- Presented concept can be implemented in other areas of environmental monitoring using appropriate sensors.

The End

Thank you for your attention!