Personal Air Quality Monitoring

Giuseppe Anastasi

Pervasive Computing & Networking Lab (Perlab)

Dept. of Information Engineering, University of Pisa

E-mail: giuseppe.anastasi@unipi.it

Website: www.iet.unipi.it/~anastasi/

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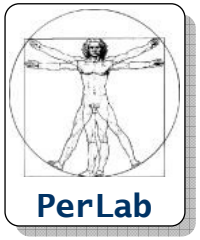
Smart Cities & Communities



Introduction

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- Air quality has a serious impact on public health, environment and economy
  - Poor air quality results in ill health, premature deaths, as well as damages to ecosystems, crops, and buildings
  - The effects are clearly more serious in urban areas
- European countries have significantly reduced the emissions of several air pollutants
  - sulphur dioxide (SO_2), carbon monoxide (CO), benzene (C_6H_6) , lead (Pb)
- Other pollutants still represent a serious threat
  - particulate matter (PM)
  - ozone (O_3),
  - Nitrogen dioxide (NO_2)
  - some organic compounds

EEA Report 2015

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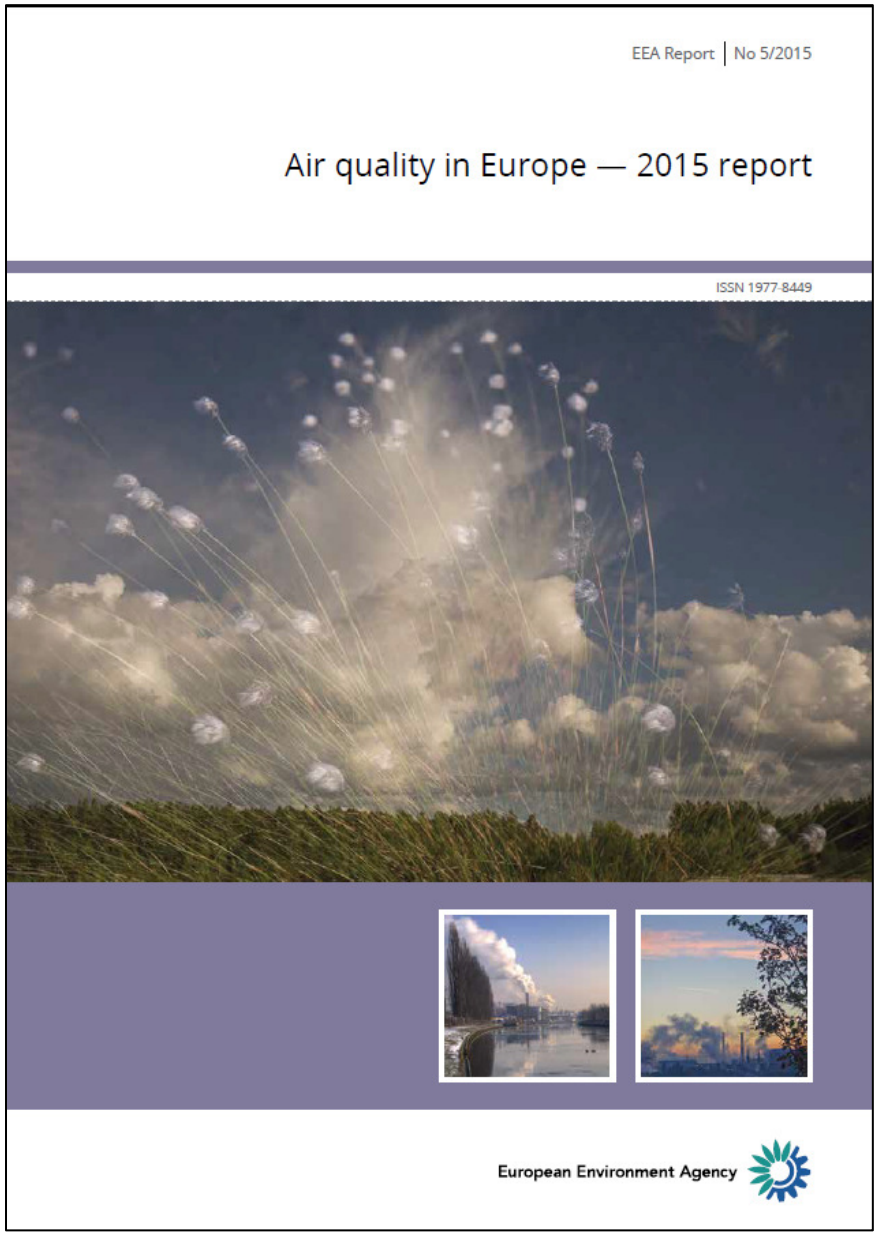

EEA Report 2015

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Contents

EEA Report 2015

Premature deaths due to PM2.5, O2, and NO2 exposure in 2012

Table 9.2 **Premature deaths attributable to $PM_{2.5}$, O_3 and NO_2 exposure in 2012 in 40 European countries and the EU-28**

Country	$PM_{2.5}$	O_3	NO_2
Austria	6 100	320	660
Belgium	9 300	170	2 300
Bulgaria	14 100	500	700
Croatia	4 500	270	50
Cyprus	790	40	0
Czech Republic	10 400	380	290
Denmark	2 900	110	50
Estonia	620	30	0
Finland	1 900	60	0
France	43 400	1 500	7 700
Germany	59 500	2 100	10 400
Greece	11 100	780	1 300
Hungary	12 800	610	720
Ireland	1 200	30	0
Italy	59 500	3 300	21 600
Latvia	1 800	60	90
Lithuania	2 300	80	0
Luxembourg	250	10	60
Malta	200	20	0
Netherlands	10 100	200	2 800
Poland	44 600	1 100	1 600
Portugal	5 400	320	470
Romania	25 500	720	1 500
Slovakia	5 700	250	60
Slovenia	1 700	100	30
Spain	25 500	1 800	5 900
Sweden	3 700	160	10
United Kingdom	37 800	530	14 100
Albania	2 200	140	270
Andorra	60	4	0
Bosnia and Herzegovina	3 500	200	70
former Yugoslav Republic of Macedonia, the	3000	130	210
Iceland	100	2	0
Liechtenstein	20	1	3
Monaco	30	2	7
Montenegro	570	40	20
Norway	1 700	70	200
San Marino	30	2	0
Serbia (a)	13 400	550	1100
Switzerland	4 300	240	950
Total (b)	**432 000**	**17 000**	**75 000**
EU-28 (b)	**403 000**	**16 000**	**72 000**

Motivations

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- Air quality typically monitored through large and expensive sensing stations
  - Located in (few) strategic locations
  - *Accurate* monitoring, but *limited* to specific areas

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- Air quality typically monitored through large and expensive sensing stations
  - Located in (few) strategic locations
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- Sensing stations are managed by public authorities
  - pollution data are often not (promptly) available to citizens
  - or they can be difficult to understand

A Typical Report

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Rete Regionale Monitoraggio Qualità Aria - AGGLOMERATO NAPOLI - CASERTA (ZONA IT1507)

PROSPETTO DI SINTESI DATI DI QUALITA' DELL'ARIA AMBIENTE RILEVATI DALLE ORE 01:00 ALLE ORE 24:00 DEL 31-03-2016

POSTAZIONI	NO2 / ora [µg/m³]				CO mob / ora [mg/m³]			PM10 [µg/m³]		PM2.5 [µg/m³]	O3 / ora [µg/m³]				BENZENE [µg/m³]			SO2 [µg/m³]			
	max	ora	media	sup.	max	media	sup.	media	sup.	media	max	ora	media	sup.	max	ora	media	max	ora	media	sup.
Caserta CE51 Ist. Manzoni	96	21	41	0	*	*	*	28	14	19	109	15	47	0	*	*	*	*	*	*	*
Caserta CE52 Sc. De Amicis	40	9	26	0	0,8	0,4	0	29	13	10	*	*	*	*	nv	-	nv	*	*	*	*
Maddaloni CE54 Sc. Settembrini	64	19	36	0	*	*	*	41	14	16	100	15	40	0	*	-	*	*	*	*	*
Napoli NA01 Oss. Astronomico	39	12	21	0	0,5	0,4	0	27	7	11	122	17	84	0	nv	-	nv	*	*	*	*
Napoli NA02 Osp. Santobono	nv	-	nv	0	*	*	*	nv	2	nv	*	*	*	*	*	*	*	*	*	*	*
Napoli NA06 Museo Nazionale	104	9	58	0	4,1	3,1	0	nv	17	27	*	*	*	*	m	-	m	*	*	*	*
Napoli NA07 Ferrovia	112	21	66	0	0,9	0,8	0	34	12	22	*	*	*	*	0,5	10	0,2	*	*	*	
Napoli NA08 Osp. N. Pellegrini	142	22	65	0	*	*	*	30	13	14	*	*	*	*	*	*	*	*	*	*	*
Napoli NA09 Via Argine	118	21	66	0	m	m	0	np	16	np	*	*	*	*	4,8	22	1,7	m	-	m	0
Napoli Epomeo (Tirrenopower)	np	-	np	0	np	np	0	np	*	np	*	*	*	*	*	*	*	*	*	*	*
Acerra Zona Industriale	nv	-	nv	0	1,0	0,9	0	38	13	17	*	*	*	*	nv	-	nv	4,2	8	1,5	0
Acerra Scuola Caporale	np	-	np	0	np	np	0	np	12	np	*	*	*	*	np	-	np	*	*	*	*
Aversa Scuola Cirillo	m	-	m	0	m	m	0	*	*	*	*	*	*	*	m	-	m	*	*	*	*
Casoria Scuola Palizzi (CAM)	np	-	np	0	*	*	*	np	17	np	np	-	np	0	*	*	*	*	*	*	*
Pomigliano d'Arco Area Asi	67	2	nv	0	1,3	nv	0	nv	21	nv	*	*	*	*	6,0	6	nv	4,5	1	nv	0
Portici Parco Reggia	m	-	m	0	*	*	*	m	*	m	m	-	m	0	m	-	m	*	*	*	*
S. Vitaliano Scuola Marconi	127	22	61	0	*	*	*	56	37	25	104	16	32	0	8,6	1	4,4	6,5	9	2,9	0
Torre Annunziata Sc. Pascoli	106	8	52	0	*	*	*	*	*	*	59	15	26	0	*	*	*	*	*	*	*
Volla (Tirrenopower)	np	-	np	0	np	np	0	np	*	np	*	*	*	*	*	*	*	*	*	*	*

LA STRUTTURA DELLA RETE DI MONITORAGGIO E' IN FASE DI ADEGUAMENTO AL D.LGS. 155/2010, L'ACQUISIZIONE DEI DATI ED I CRITERI DI VALUTAZIONE PER L'ANNO 2016 SONO DEFINITI DAL D.LGS. 155/2010.

LEGENDA
*: analizzatore non previsto
m: analizzatore in manutenzione
nv: dati non validabili
np:dati non pervenuti

ARPAC CAMPANIA

		Tempi di mediazione	
NO_2	Biossido di azoto	massima media oraria	Il valore orario di 200 µg/m³ non può essere superato più di 18 volte nell'arco dell'anno
CO	Monossido di carbonio	massima media oraria	Il valore massimo della media mobile calcolata sulle 8 ore non può superare i 10 mg/m³
PM_{10}	Polveri sosp d<10µm	media giornaliera	Il valore giornaliero di 50 µg/m³ non può essere superato più di 35 volte nell'arco dell'anno
$PM_{2,5}$	Polveri sosp d<2,5µm	media annuale	Il valore medio annuale di 25 µg/m³ non può essere superato nell'arco dell'anno
O_3	Ozono	massima media oraria	Il valore orario della soglia di informazione è pari a 180 µg/m³ la soglia di allarme è pari a 240 µg/m³
C_6H_6	Benzene	media annuale	Il valore medio annuale di 5 µg/m³ non può essere superato nell'arco dell'anno
SO_2	Biossido di zolfo	massima media oraria	Il valore orario di 350 µg/m³ non può essere superato più di 24 volte nell'arco dell'anno

Dati elaborati in data 01/04/2016

A Typical Report

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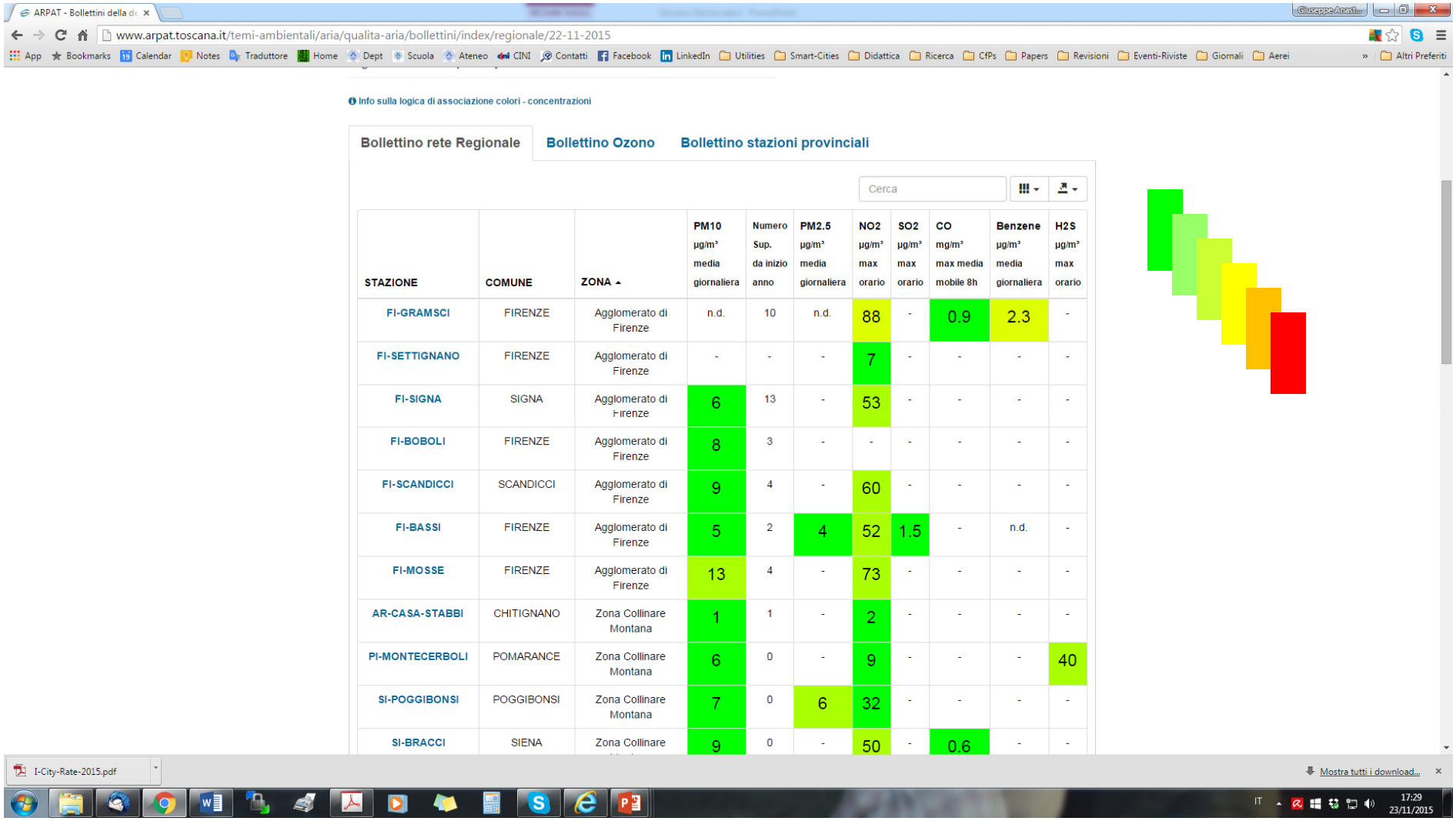

STAZIONE	COMUNE	ZONA	PM10 µg/m³ media giornaliera	Numero Sup. da inizio anno	PM2.5 µg/m³ media giornaliera	NO2 µg/m³ max orario	SO2 µg/m³ max orario	CO mg/m³ max media mobile 8h	Benzene µg/m³ media giornaliera	H2S µg/m³ max orario
FI-GRAMSCI	FIRENZE	Agglomerato di Firenze	n.d.	10	n.d.	88	-	0.9	2.3	-
FI-SETTIGNANO	FIRENZE	Agglomerato di Firenze	-	-	-	7	-	-	-	-
FI-SIGNA	SIGNA	Agglomerato di Firenze	6	13	-	53	-	-	-	-
FI-BOBOLI	FIRENZE	Agglomerato di Firenze	8	3	-	-	-	-	-	-
FI-SCANDICCI	SCANDICCI	Agglomerato di Firenze	9	4	-	60	-	-	-	-
FI-BASSI	FIRENZE	Agglomerato di Firenze	5	2	4	52	1.5	-	n.d.	-
FI-MOSSE	FIRENZE	Agglomerato di Firenze	13	4	-	73	-	-	-	-
AR-CASA-STABBI	CHITIGNANO	Zona Collinare Montana	1	1	-	2	-	-	-	-
PI-MONTECERBOLI	POMARANCE	Zona Collinare Montana	6	0	-	9	-	-	-	40
SI-POGGIBONSI	POGGIBONSI	Zona Collinare Montana	7	0	6	32	-	-	-	-
SI-BRACCI	SIENA	Zona Collinare	9	0	-	50	-	0.6	-	-

How data should presented

$$AQI = \max\left\{\frac{G_1^{meas}}{G_1^{lim}}, \frac{G_2^{meas}}{G_2^{lim}}, \frac{G_3^{meas}}{G_3^{lim}}, \ldots, \frac{G_N^{meas}}{G_N^{lim}}\right\}$$

Air Quality Index

Air Quality Index	Air Quality Classes	Color
From *0* to *0.5*	Good	
From 0.5 to *1*	Fair	
From *1* to 1.5	Moderate	
From *1.5* to 2	Unhealthy	
More than *2*	Insalubrious	

MonIQA

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http://anasim.iet.unipi.it/moniqa/

MonIQA

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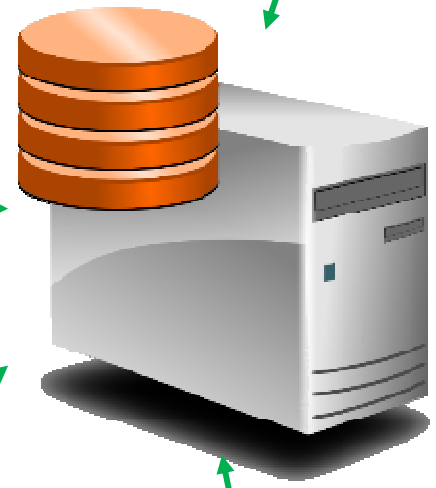

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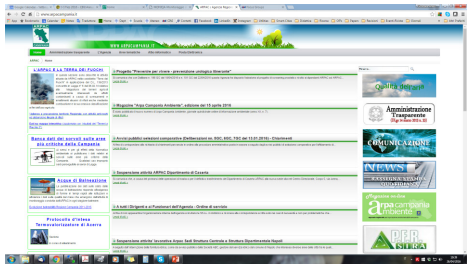

MonIQA

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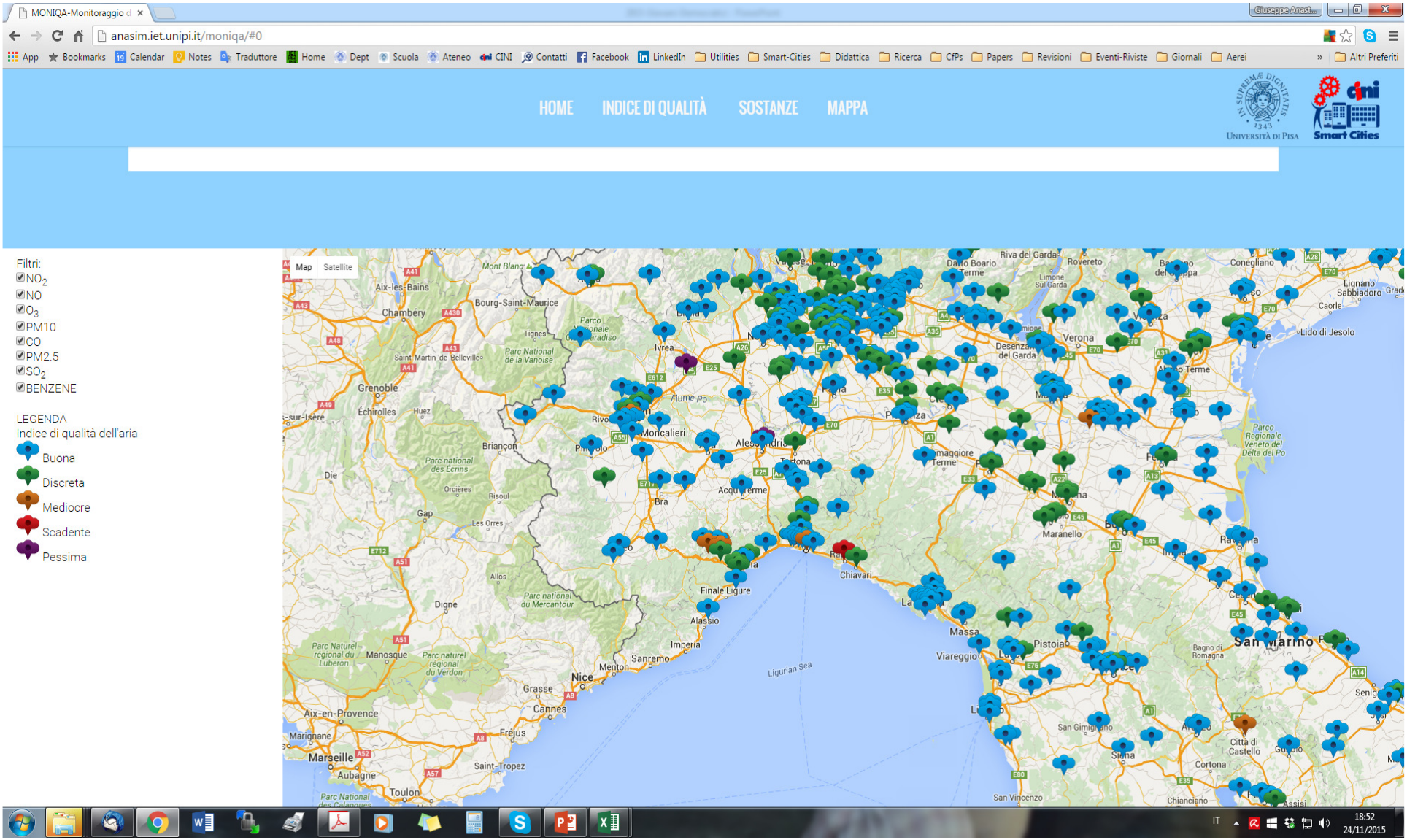

MonIQA (December 2015)

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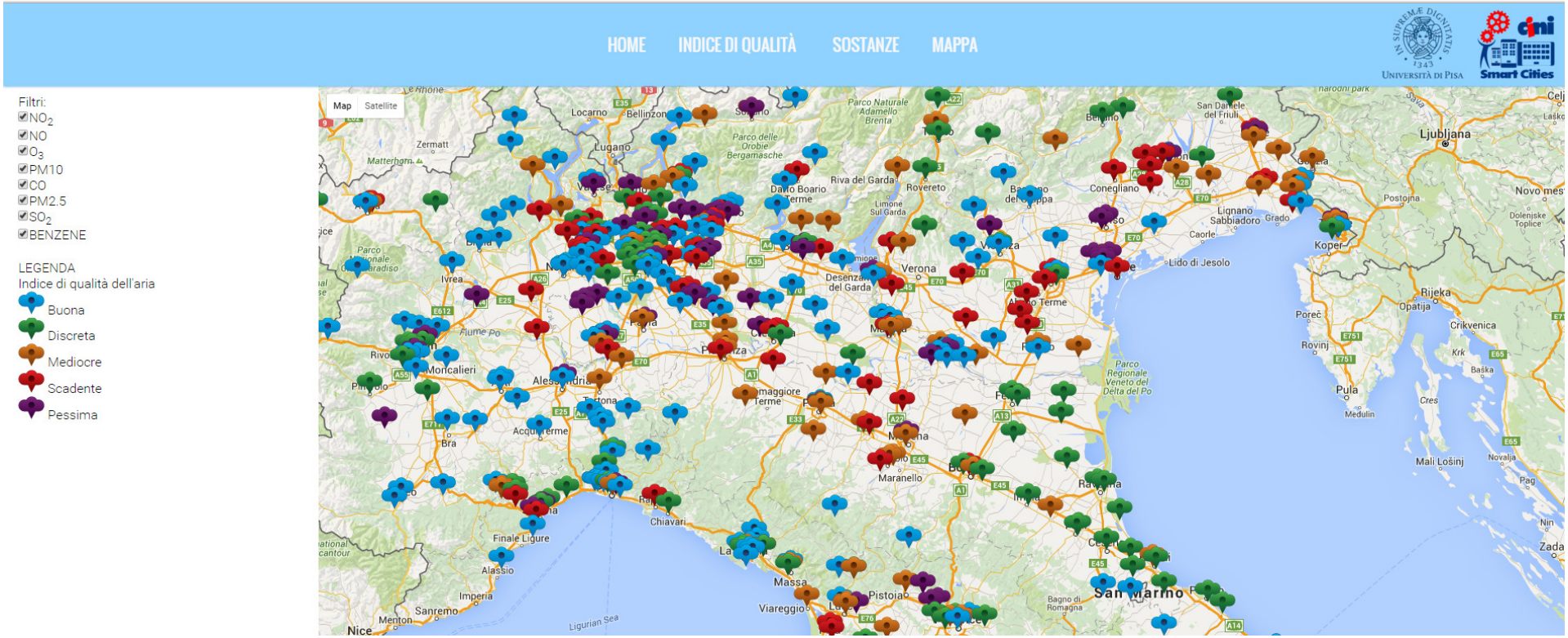

MonIQA for Mobile Devices

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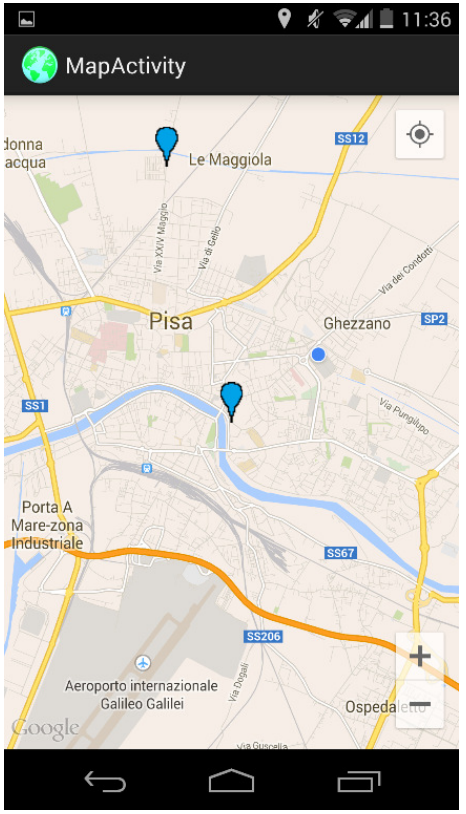
App available in Google play



Versione Web: anasim.iet.unipi.it/moniqa/

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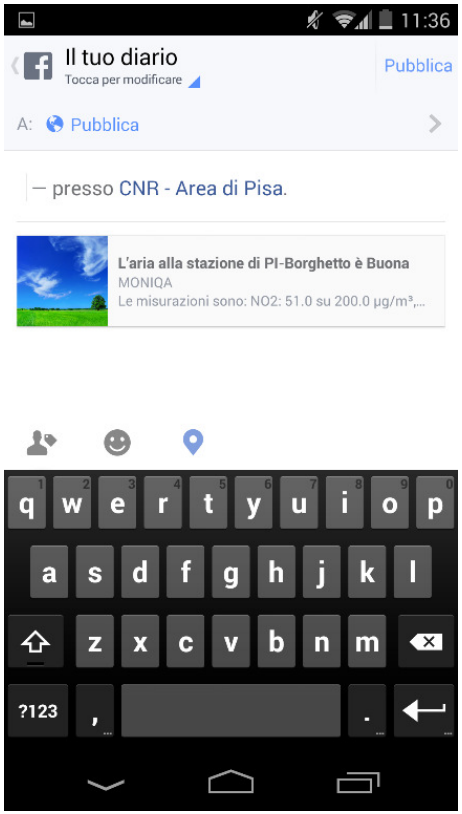

Cooperative Sensing

U-sense

Other Motivations

- Sensing stations are managed by public authorities
  - pollution data are often not (promptly) available to citizens
  - or they can be difficult to understand
- People are really interested in knowing air quality in places where they live
  - street where their home is located
  - school of their kids
  - working place
  - public gardens
  - …

uSense

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- Based on low-cost sensor nodes
  - equipped with appropriate gas sensors
  - privately installed by citizens (group of citizens)
    - ⇨ Balcony, Garden, …
- Sensor nodes are powered by batteries
  - flexible deployment and easy relocation
- Users can share their measurements
  - through social networks (cooperative sensing)
- Real-time and fine-grained monitoring
  - Many low-cost sensors

uSense: Architecture

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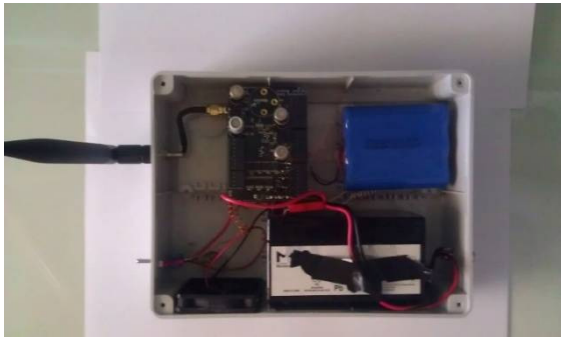
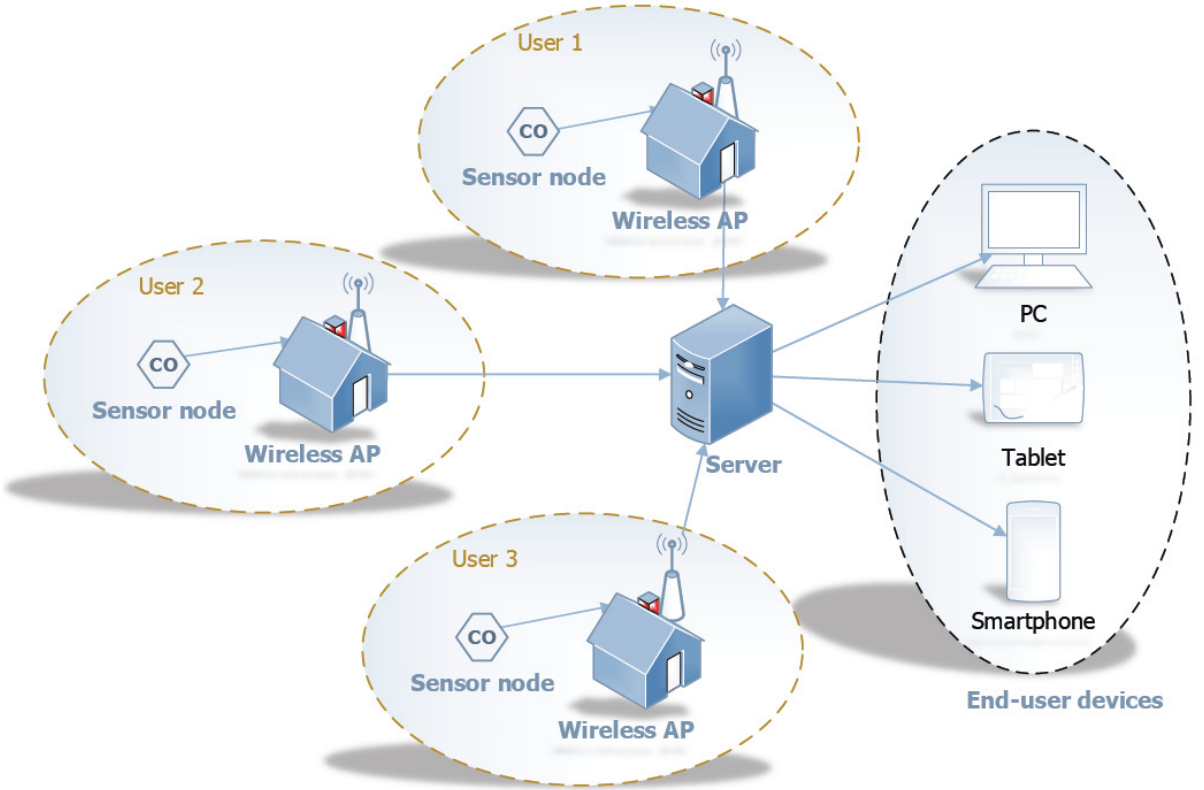
- Real-Time Air Quality Monitoing
  - Where the users really live





Services to City Users

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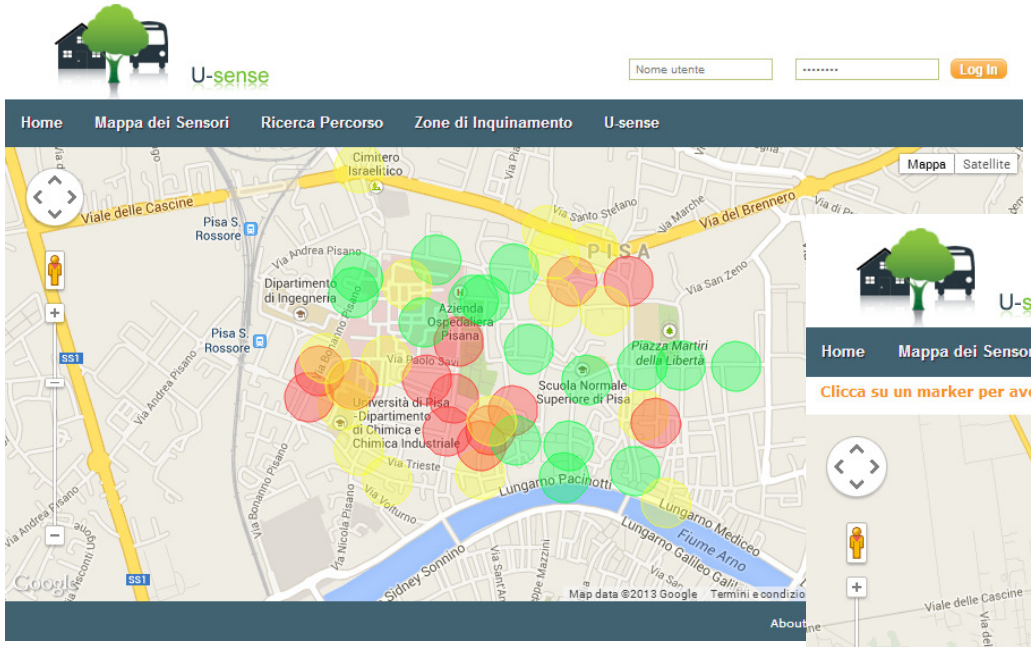
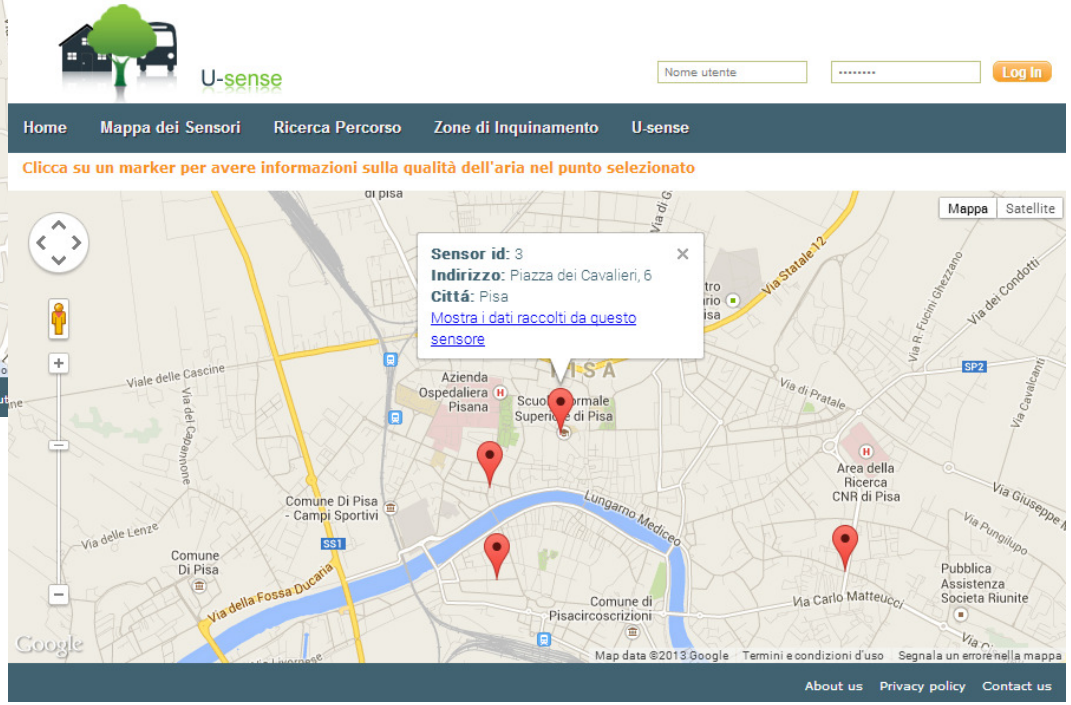
- Through a web interface, a user can:
  - View pollution map





Services to City Users

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- …Check gas concentrations in real-time

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Ora	Data	TEMP (°C)	CO (PPM)	CO2 (PPM)	NO2 (PPM)	O3 (PPB)
21:30:00	15-03-2014	12	56.172	1334.289	0.037	141.679
21:12:00	15-03-2014	12	54.003	1334.289	0.038	155.018
20:54:00	15-03-2014	12	57.994	1539.04	0.038	162.052
20:35:00	15-03-2014	12	57.46	1198.809	0.039	161.175
20:17:00	15-03-2014	12	61.743	1077.085	0.04	177.692
19:59:00	15-03-2014	12	58.265	1242.367	0.043	197.342
19:40:00	15-03-2014	12	57.46	1156.778	0.043	207.461
19:22:00	15-03-2014	12	54.706	1116.221	0.043	219.993
19:04:06	15-03-2014	12	53.32	1198.809	0.043	221.654
18:45:00	15-03-2014	12	56.937	1116.221	0.043	220.824
18:27:00	15-03-2014	12	57.197	1287.508	0.042	210.815
18:09:09	15-03-2014	12	58.265	1077.085	0.043	222.484
17:50:00	15-03-2014	13	61.743	1077.085	0.043	222.484
17:32:00	15-03-2014	13	57.46	1039.322	0.043	219.993
17:14:00	15-03-2014	13	59.661	1002.882	0.042	214.995
16:55:00	15-03-2014	13	62.053	1077.085	0.042	221.654
16:37:00	15-03-2014	14	63.005	933.792	0.041	219.993
16:19:00	15-03-2014	14	66.061	1156.778	0.042	221.654
16:00:05	15-03-2014	14	63.005	1077.085	0.041	226.626
15:42:00	15-03-2014	14	62.053	1242.367	0.041	225.799
15:24:00	15-03-2014	14	62.053	1334.289	0.041	209.978
15:05:05	15-03-2014	15	64.664	1077.085	0.04	204.94
14:47:00	15-03-2014	15	63.989	1116.221	0.038	192.25
14:29:00	15-03-2014	19	66.421	1156.778	0.036	172.506
14:10:00	15-03-2014	21	75.573	1198.809	0.033	138.986

Services to City Users

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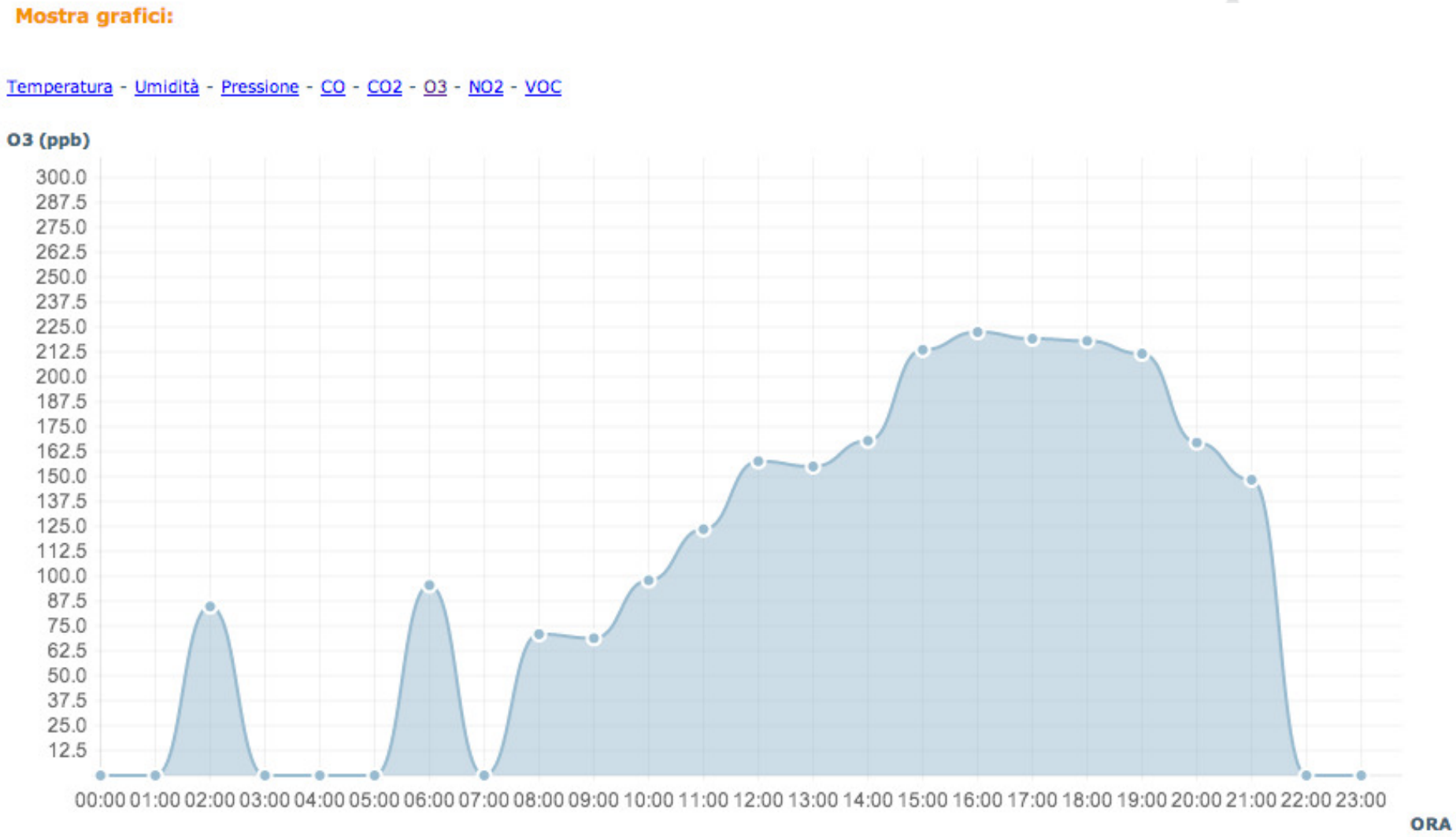
- … and plots



Services to City Users

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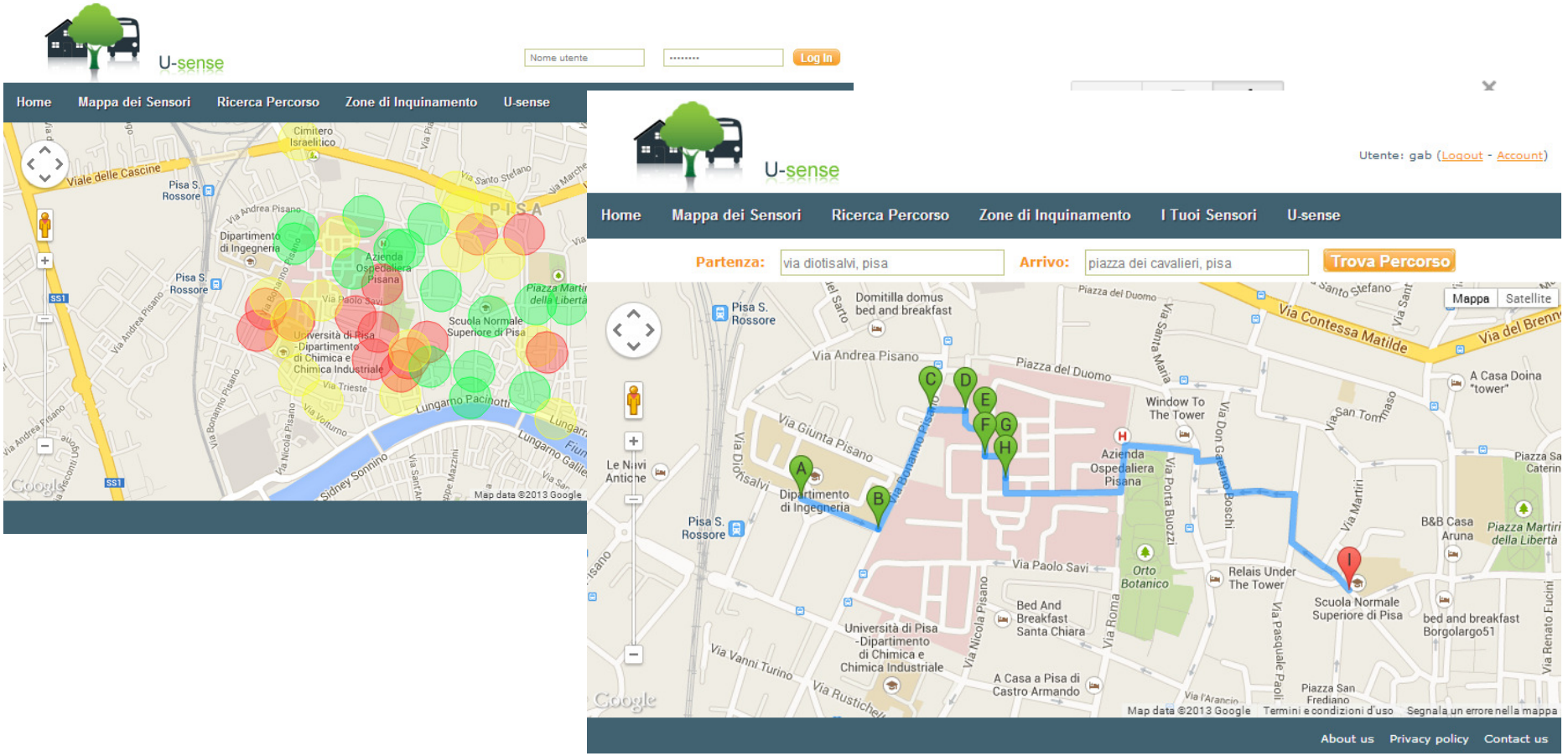
- Through a web interface, a user can:
  - Search for the less polluted route



Sensor Registration

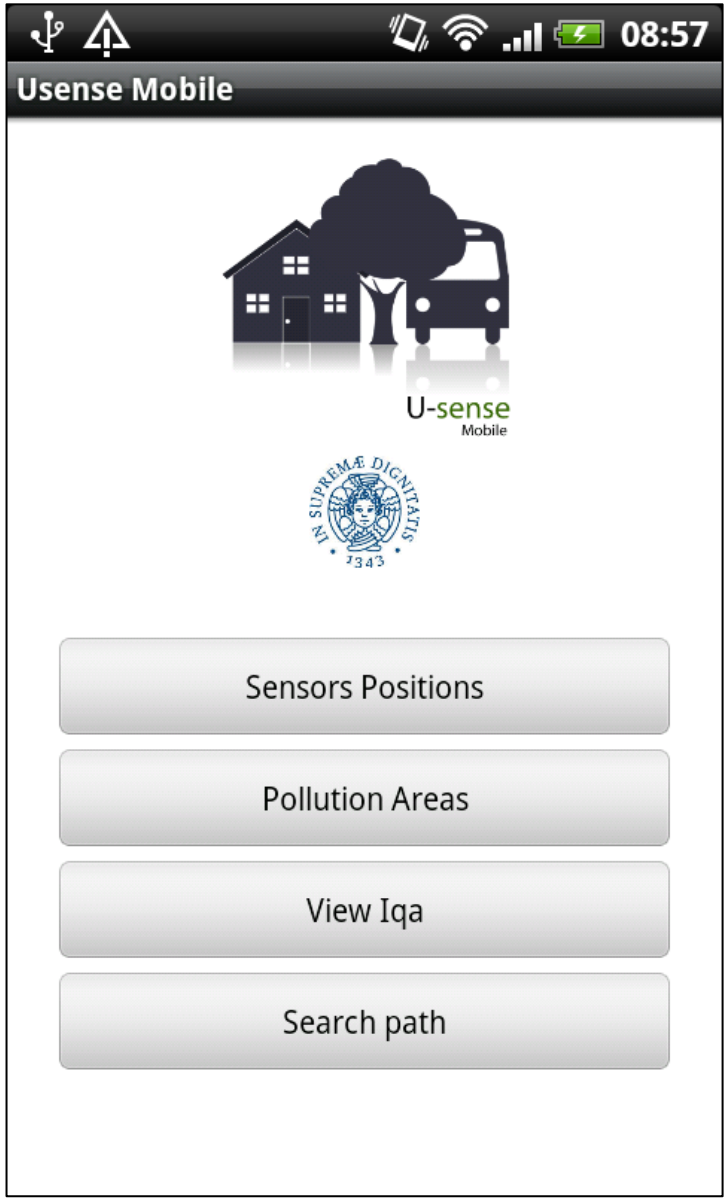
- A user with a private sensor can:
  - Create an account
  - Register his/her sensor to the system
  - Modify the sensor location
  - Remove a sensor from the system
  - View data taken from his/her sensor directly on a dedicated page

U-Sense Registration Form

PerLab

Beta version on http://anasim.iet.unipi.it

Mobile Interface



- A mobile user can
  - Visualize sensors in her/his proximity (GPS localization)
  - Check pollution areas
  - Check IQA (Air Quality Index) in real time
  - Look for less polluted paths

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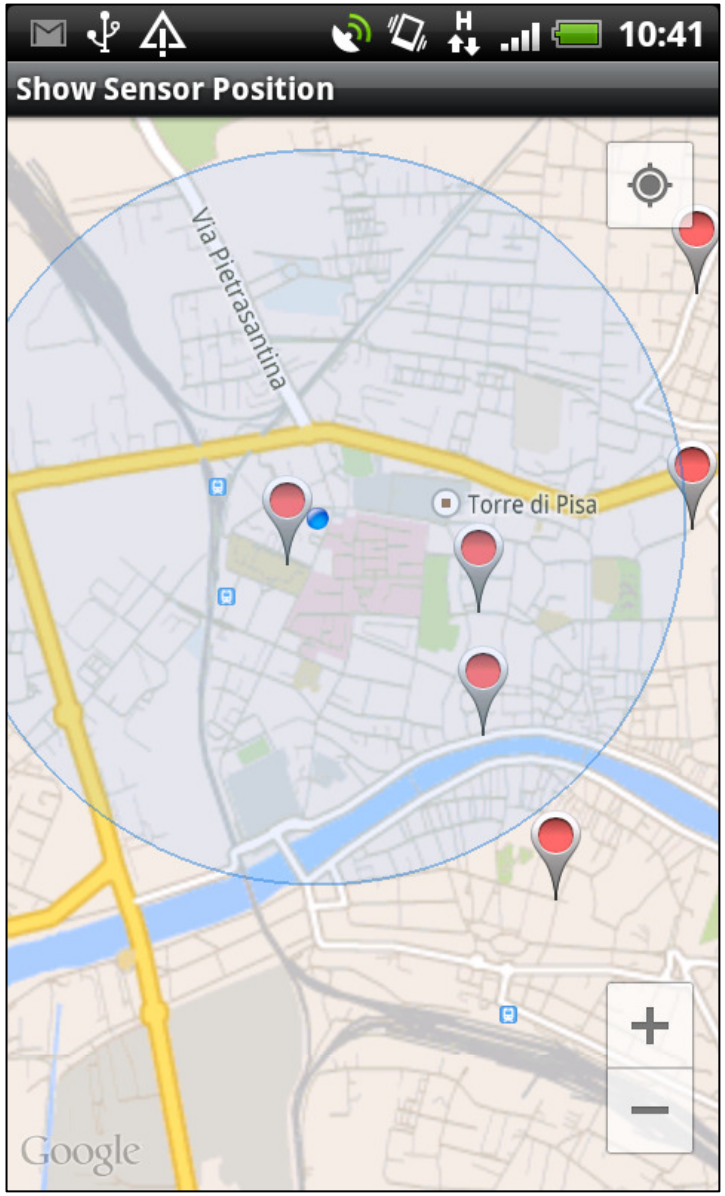
Mobile



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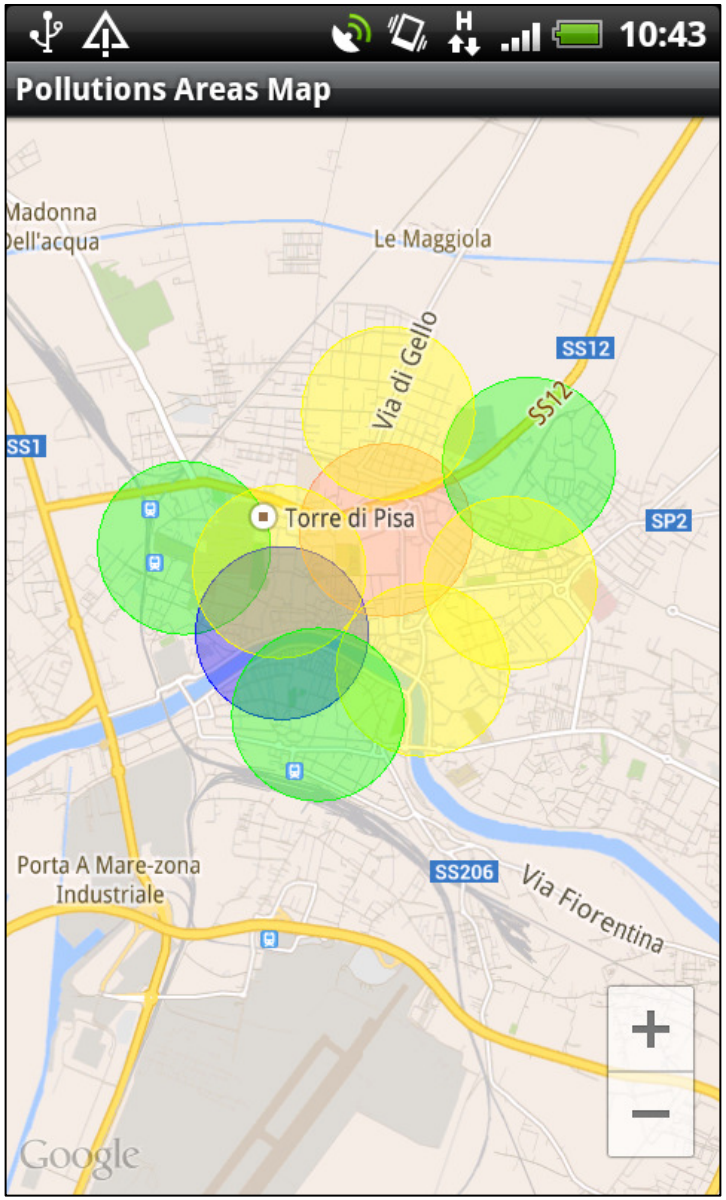

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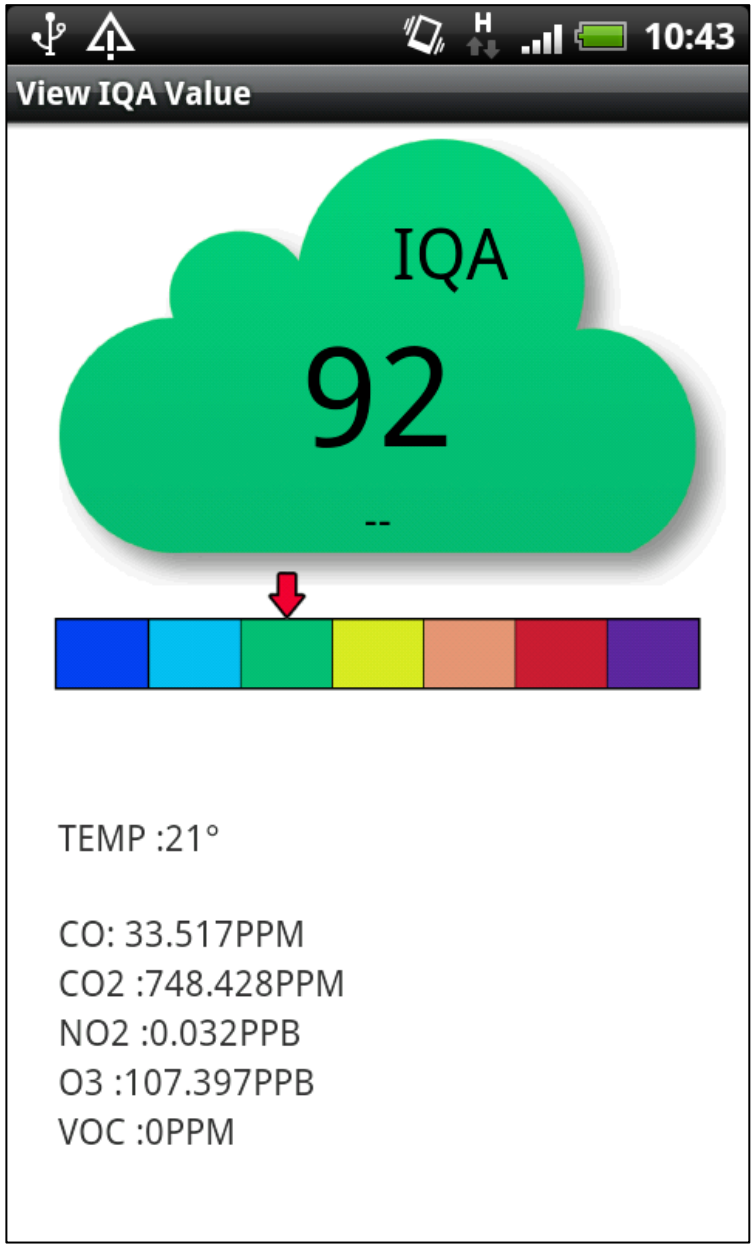

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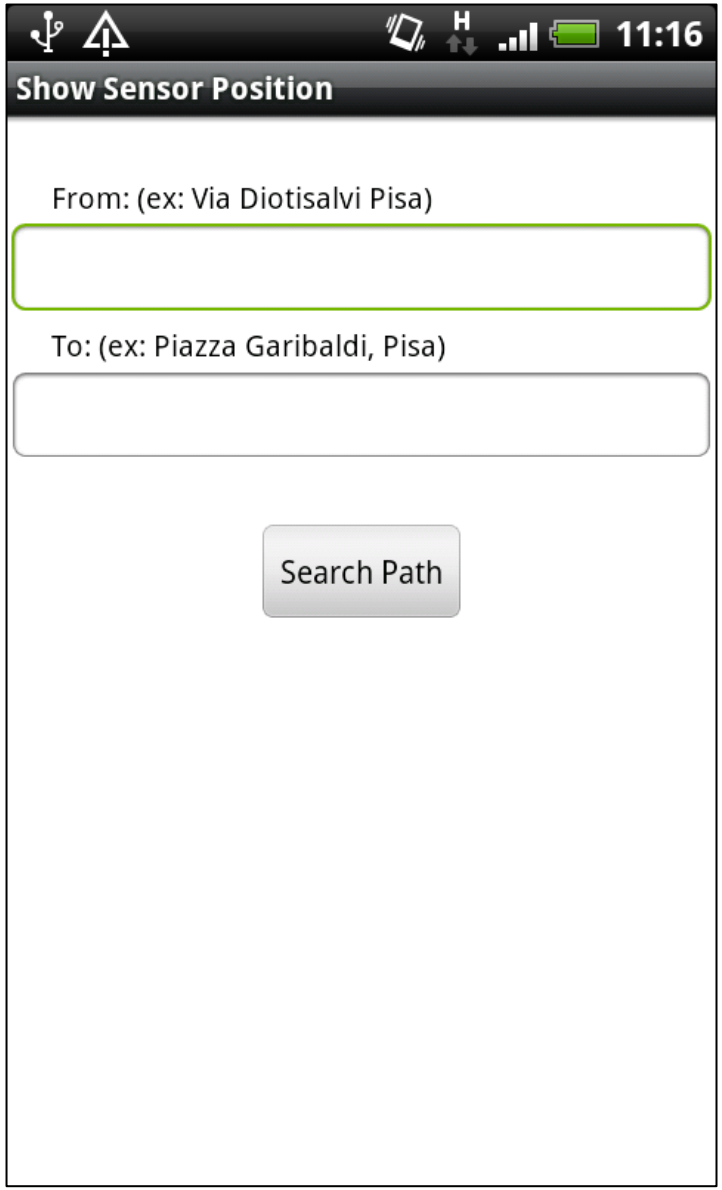

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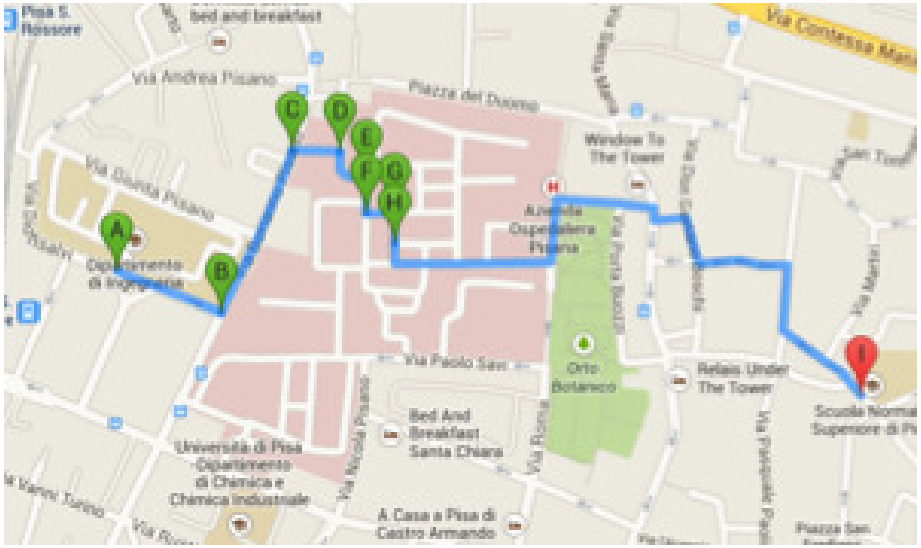

U-sense

Experimental Analysis

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Hardware

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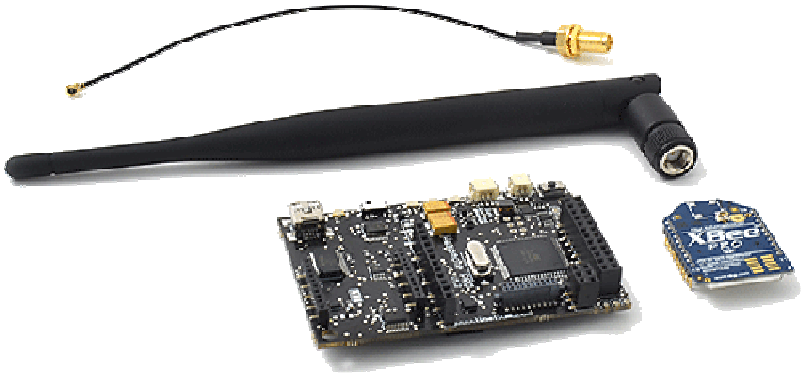
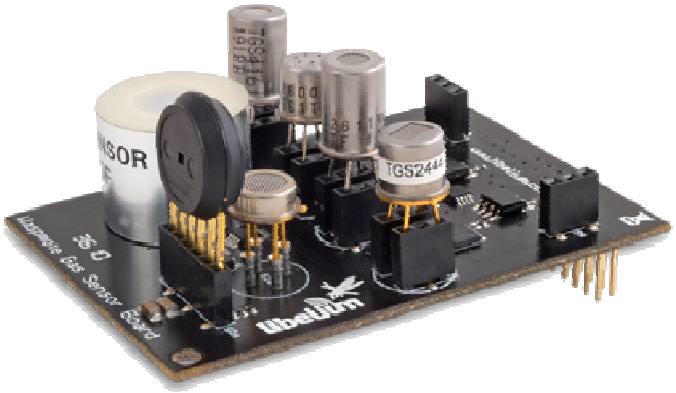
- Libelium Waspmote
  - 8-bit microcontroller
  - WIFI Communication module
- Gas sensor board 2.0
  - CO (carbon monoxide)
  - CO_2 (carbon dioxide)
  - NO_2 (nitrogene dioxide)
  - O_3 (ozone)
  - VOC (volatile organic compound)
  - Temperature
  - Humidity



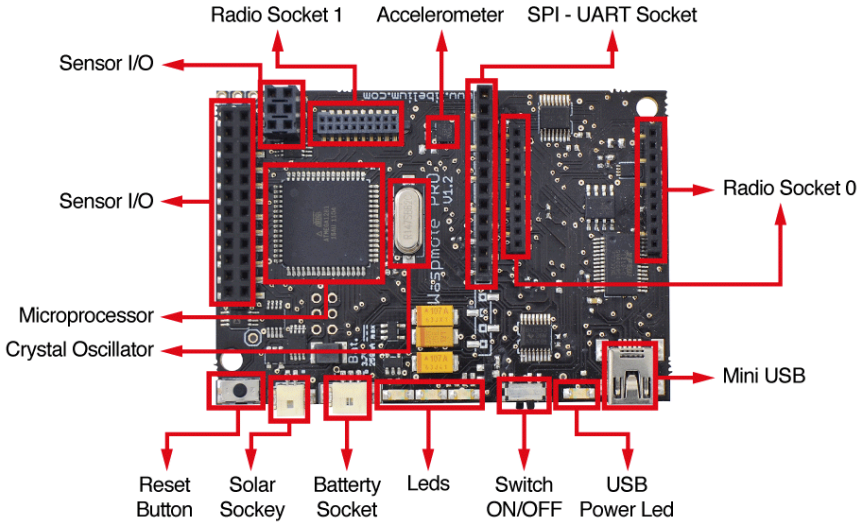


http://www.libelium.com/

Waspmote

PerLab

- Waspmote
  - 8-bit microcontroller
  - Microcontroller: ATmega 1281 (low power consumption processor)
  - Frequency: 14 Mhz
  - SO: none
  - SRAM: 8Kb
  - EPROM: 4Kb
  - FLASH: 128Kb
  - Battery: 3,7 V – 6.600 mA/h
  - Consumption:
    ON: 15 mA – Sleep: 55uA – DeepSleep: 55uA



WIFI Module

PerLab

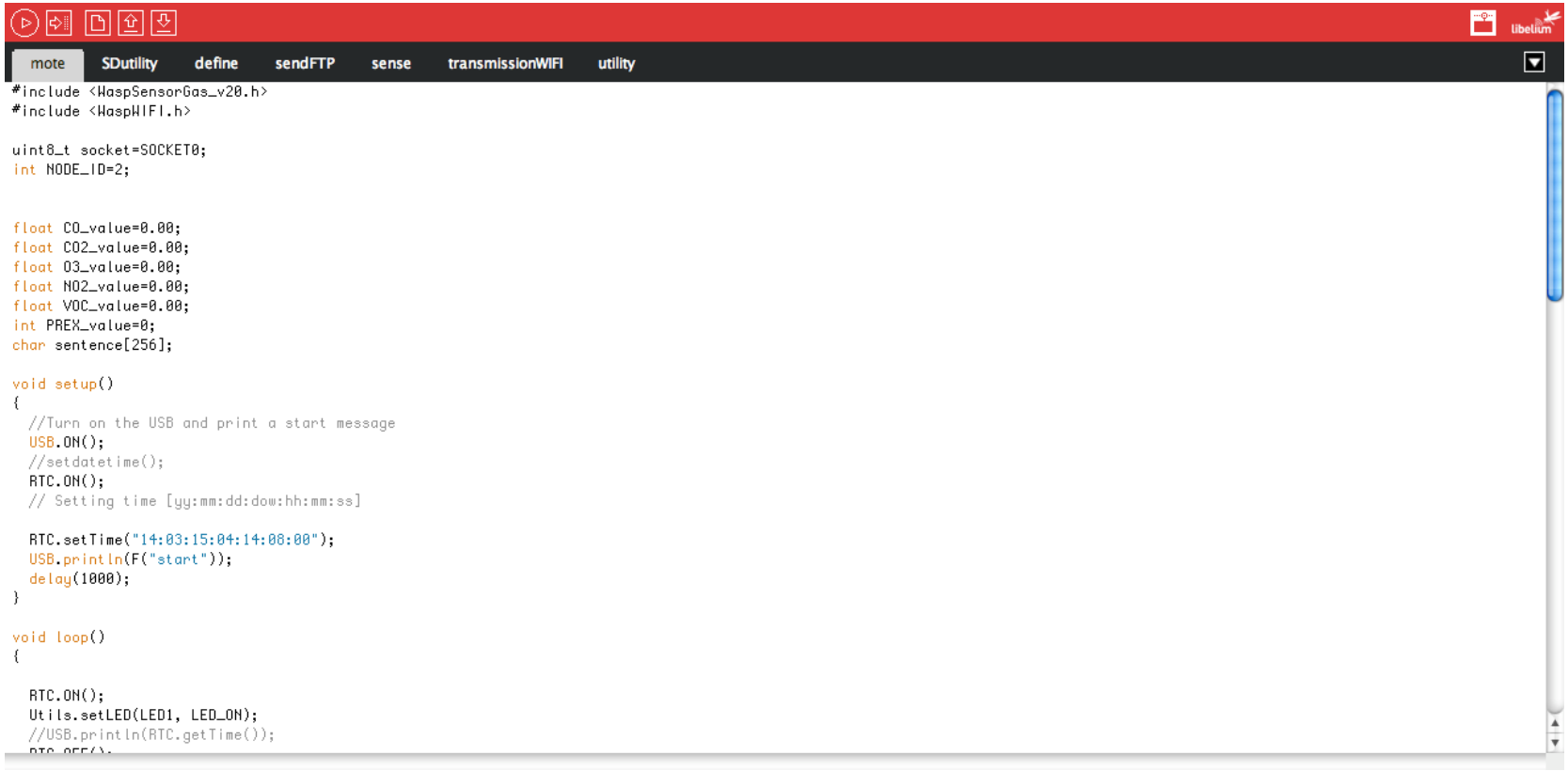
- Protocol: 802.11b/g – 2,4GHz
- TX Power: from 0 to 12 dBm, variable via software

Estate	Power Consumption
OFF	0 uA
SLEEP	4 uA
ON	33 mA
Receiving Data	38 mA
Transmitting Data	38 mA
Scanning Access Points	34 mA

Waspmote programming

PerLab

- Programming:
  - C language, procedural (non-object oriented).
  - No threads, no multitasking
  - Library for interfacing with sensors, WiFi/ZigBee module, and microcontroller.

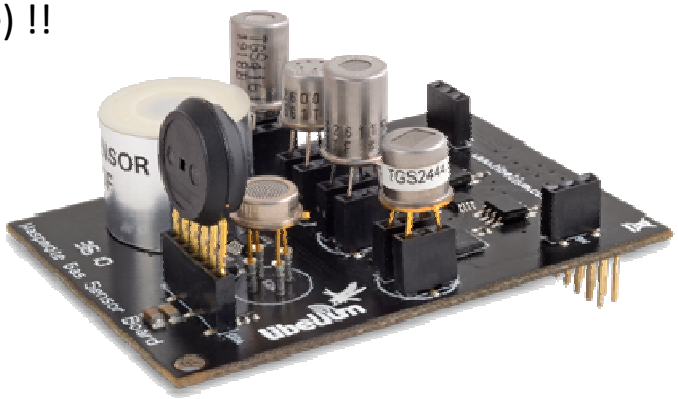



```
#include <WaspSensorGas_v20.h>
#include <WaspWIFI.h>

uint8_t socket=SOCKET0;
int NODE_ID=2;


float CO_value=0.00;
float CO2_value=0.00;
float O3_value=0.00;
float NO2_value=0.00;
float VOC_value=0.00;
int PREX_value=0;
char sentence[256];

void setup()
{
  //Turn on the USB and print a start message
  USB.ON();
  //setdatetime();
  RTC.ON();
  // Setting time [yy:mm:dd:dow:hh:mm:ss]

  RTC.setTime("14:03:15:04:14:08:00");
  USB.println(F("start"));
  delay(1000);
}

void loop()
{

  RTC.ON();
  Utils.setLED(LED1, LED_ON);
  //USB.println(RTC.getTime());
```

Gas Sensor Board

PerLab

- GAS Sensor Board
  - CO, CO_2, NO_2, O_3, VOC
  - All sensor need to be calibrated
    - ⇨ All sensors have different physical characteristics
  - From microcontroller we obtain an electrical measure
    - ⇨ Voltage or resistance value
  - Calibration is not simple, it needs a gas reference
    - ⇨ We need an artificial air with known gas concentration
  - Sensors are energy hungry
    - ⇨ All sensors have a resistance to be heated up to 400 ℃ !!!
    - ⇨ Power consumption is about 100 mW (on average) !!
    - ⇨ Duty cycling required



GAS Sensor Board

PerLab

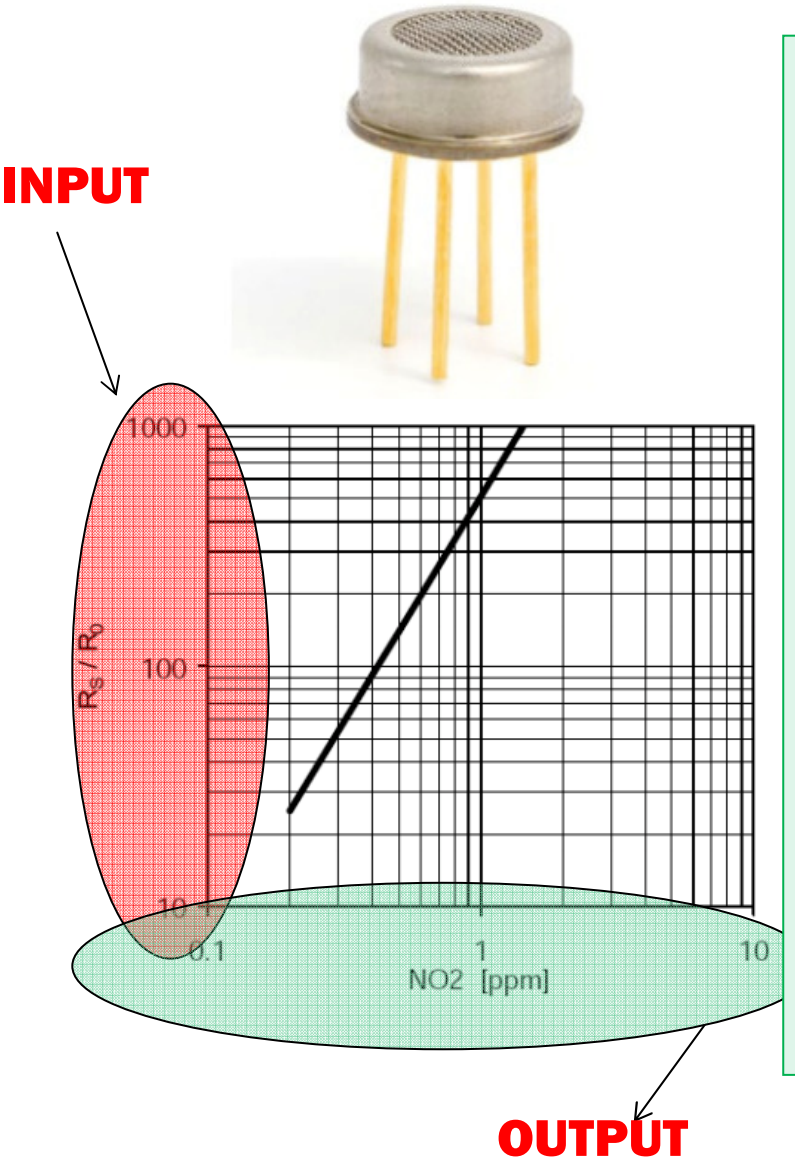
- NO_2 Sensors (MiCS-2710)
  - Specifications (from datasheet)

Maximum Ratings

Rating	Symbol	Value/ Range	Unit
Maximum sensor supply voltage	V_{CC}	2.5	V
Maximum heater power dissipation	P_H	50	mW
Maximum sensor power dissipation	P_S	1	mW
Relative humidity range	R_H	5 – 95	%RH
Ambient operating temperature	T_{amb}	-30 – 85	°C
Storage temperature range	T_{sto}	-40 – 120	°C
Storage humidity range	RH_{sto}	5 – 95	%RH

Operating Conditions

Parameter	Symbol	Typ	Min	Max	Unit
Heating power	P_H	43	30	50	mW
Heating voltage	V_H	1.7	-	-	V
Heating current	I_H	26	-	-	mA
Heating resistance	R_H	66	59	73	Ω



http://www.cdiweb.com/datasheets/e2v/mics-2710.pdf

Sensor Calibration

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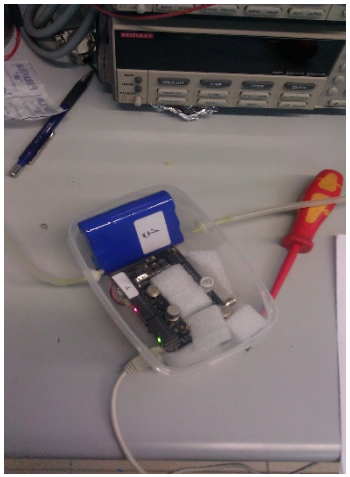
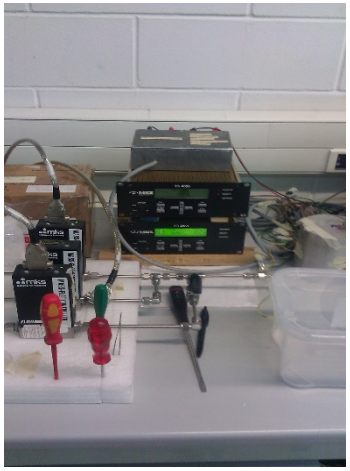
- We calibrated sensors in our lab



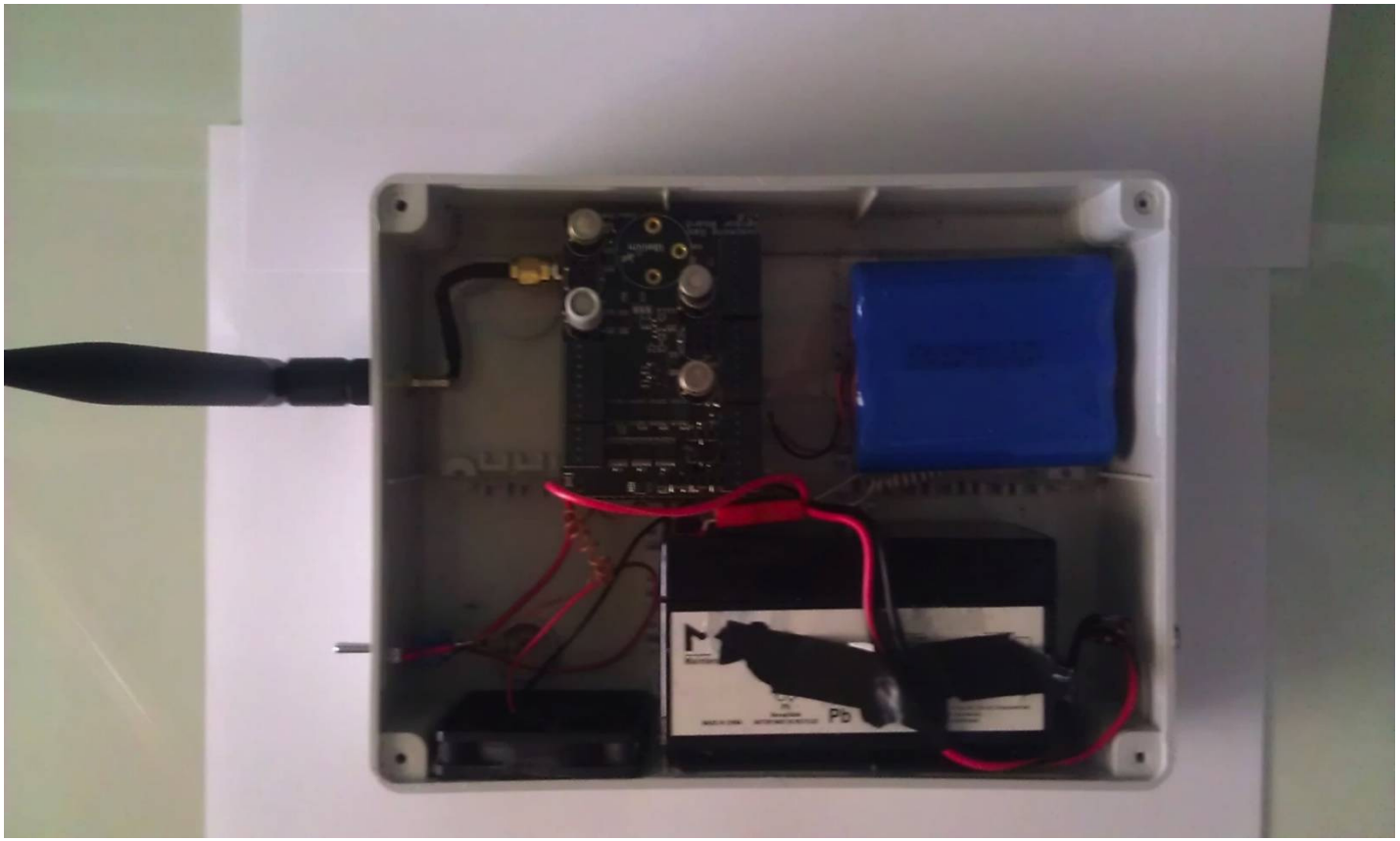


External Box

PerLab

U-sense

- Packaging
  - External PVC box
  - Includes fan, activation buttons, led indicators …
  - And an extra 12V battery to power the fan



Experimental Setup

- 30-day in-site experimentation
  - May 1-31, 2014
- Three different sensor nodes
  - Deployed in different locations
  - with different traffic conditions
  - and expected pollution levels
- Measurements
  - Gas concentration (every 30 min)
    - ⇨ CO
    - ⇨ CO_2
    - ⇨ NO_2
    - ⇨ O_3

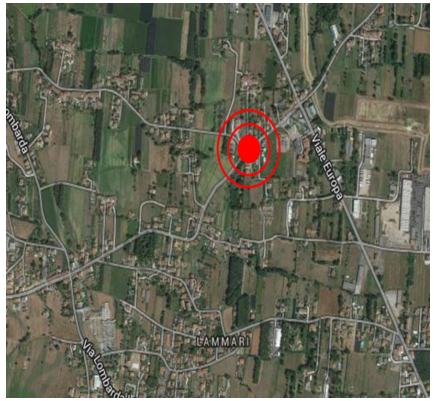
Experimental Setup

PerLab

- We considered 3 locations with different traffic conditions

Moderate Traffic Conditions

ZONE A

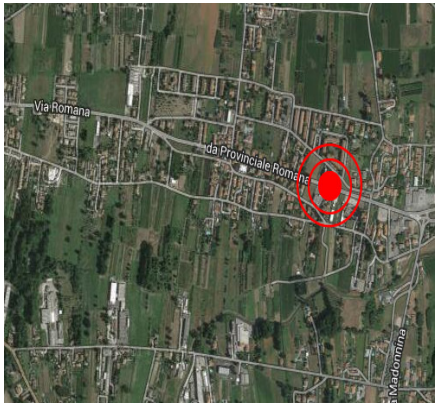


Low Traffic Conditions

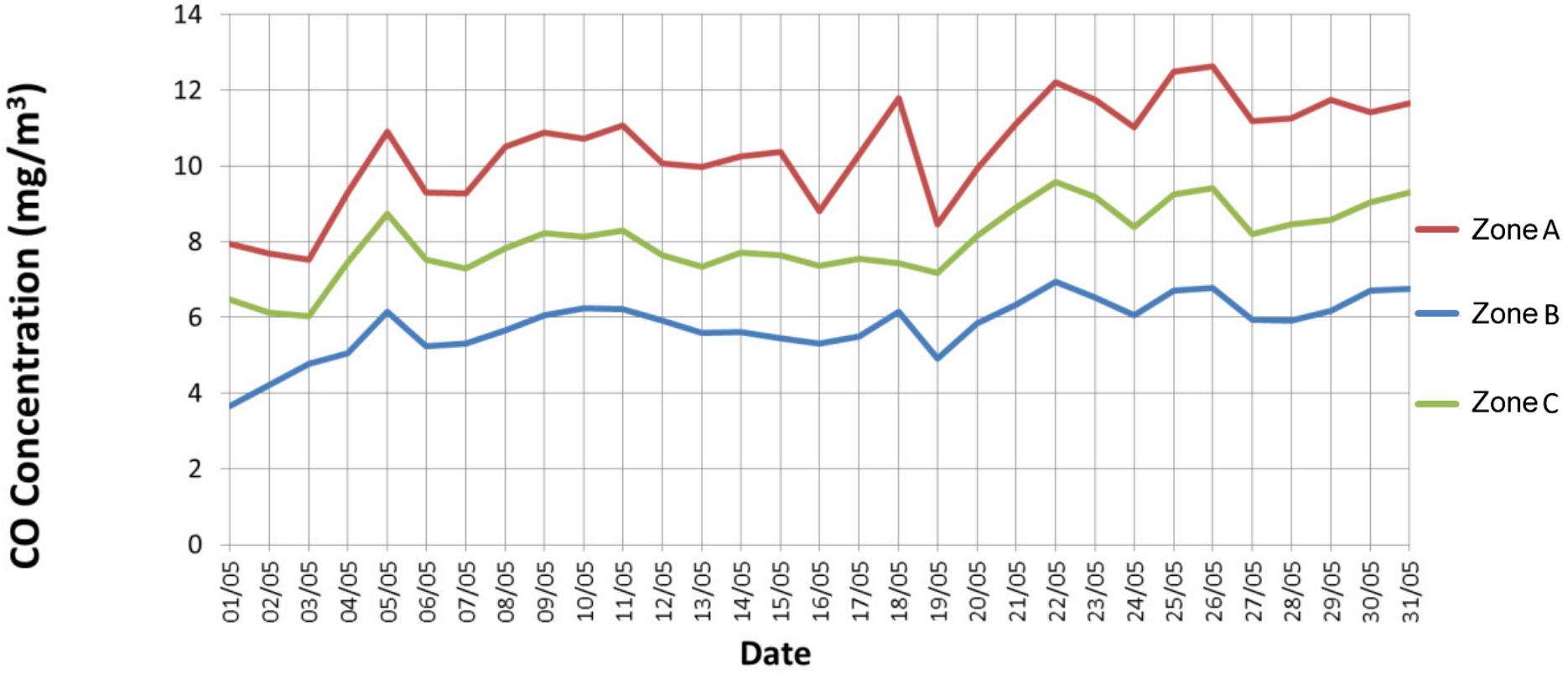
ZONE B

Moderate Traffic Conditions

ZONE C



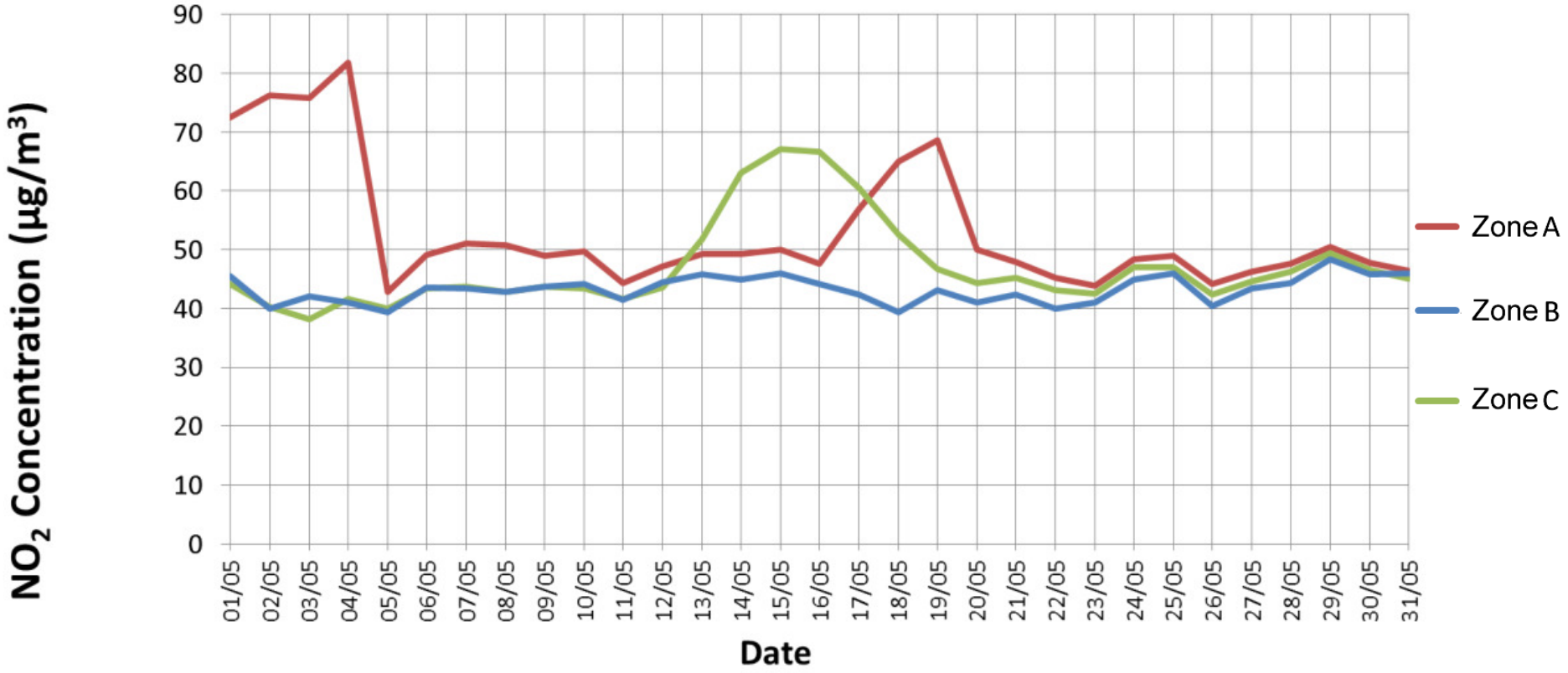
Experimental data



Experimental data

PerLab

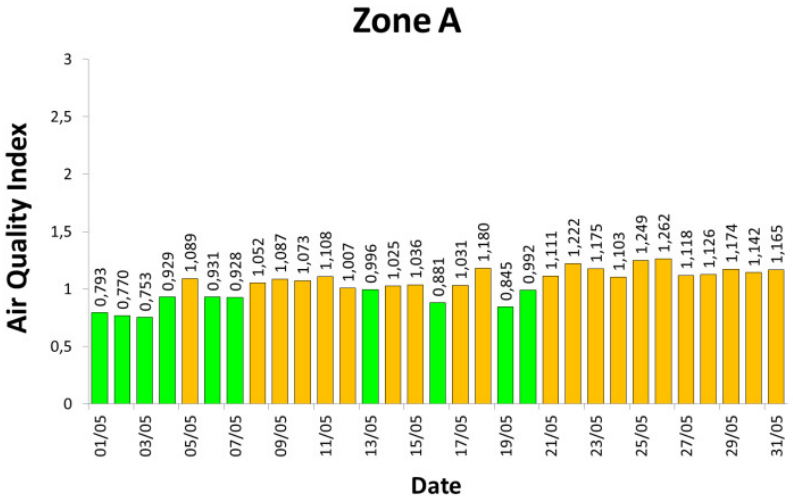
U-sense

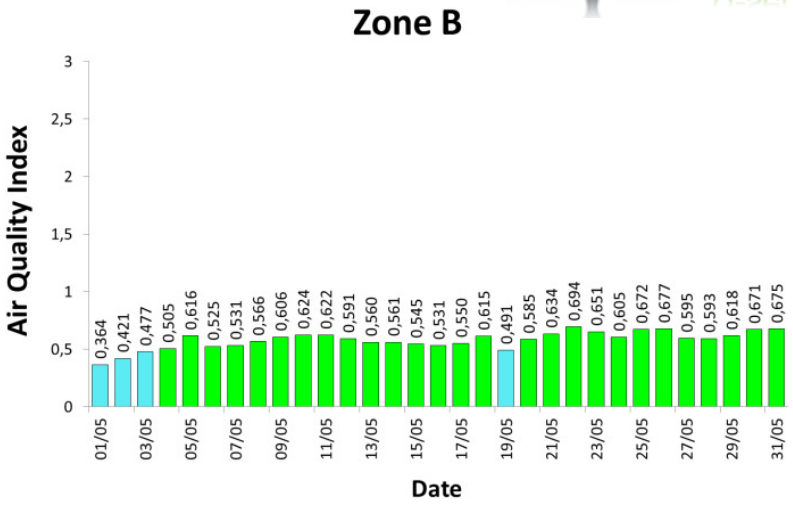


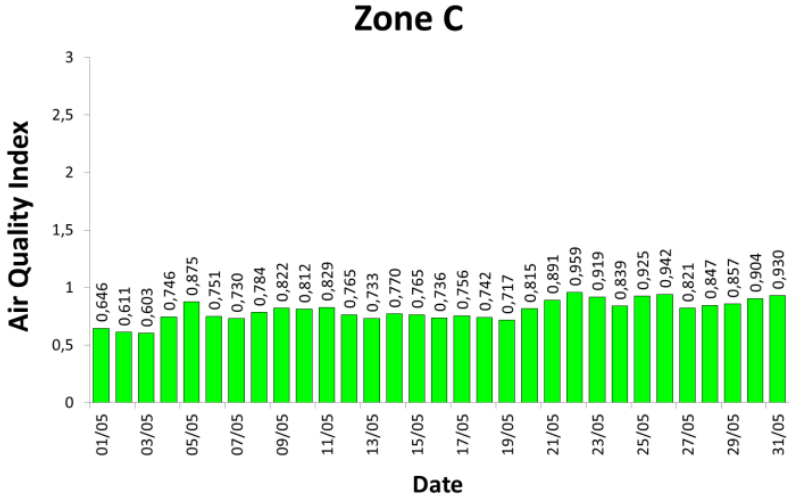
Experimental data

PerLab

U-sense



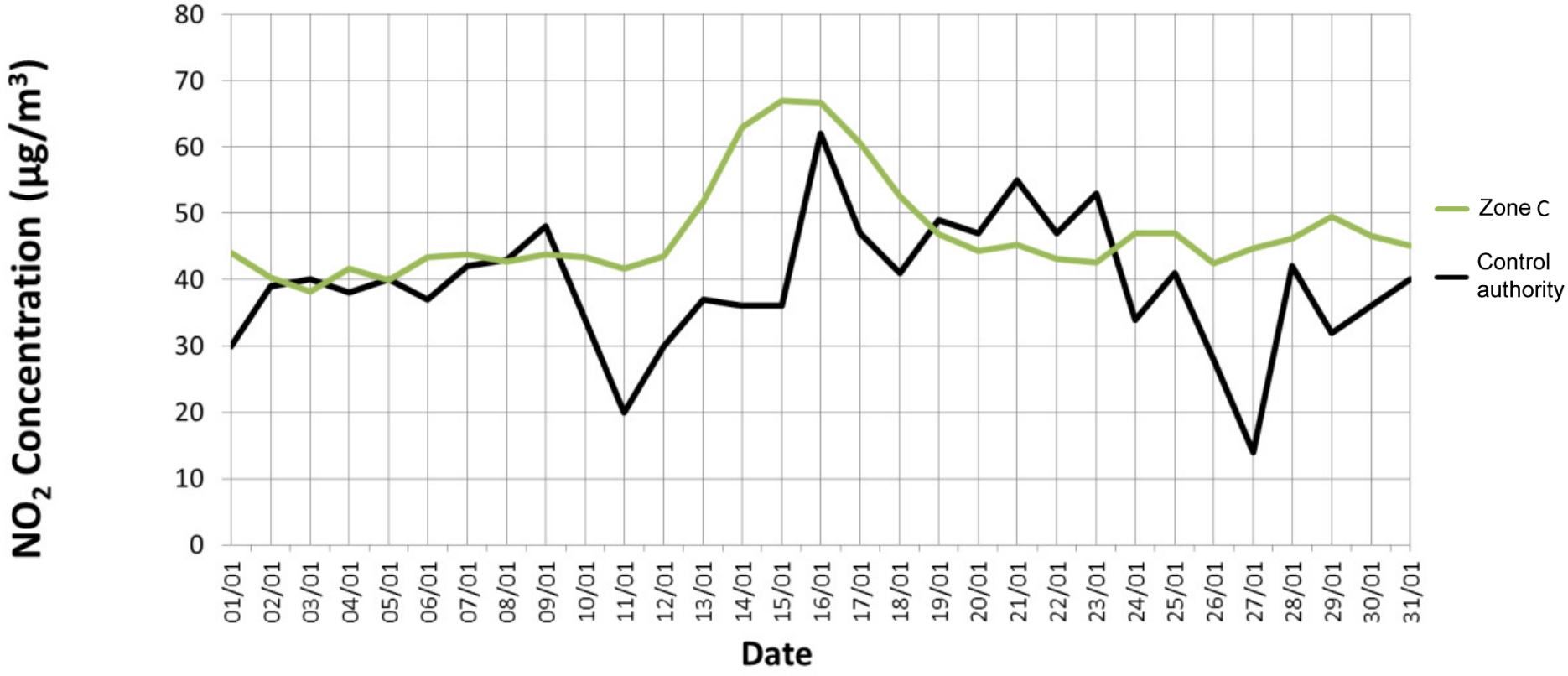




Experimental data

PerLab

U-sense

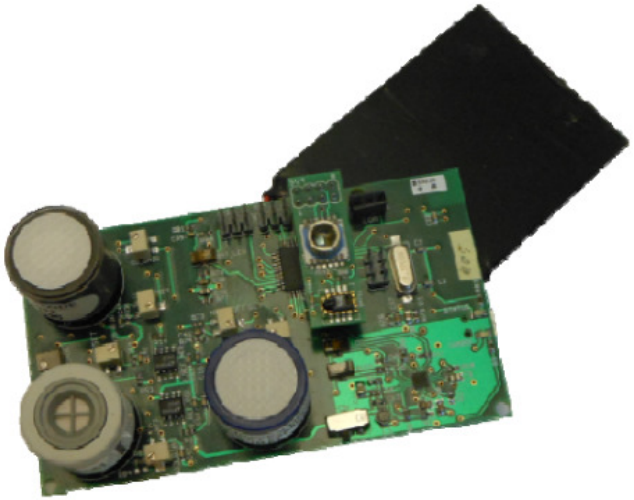


Next Steps

PerLab

Personal Air Quality Monitoring

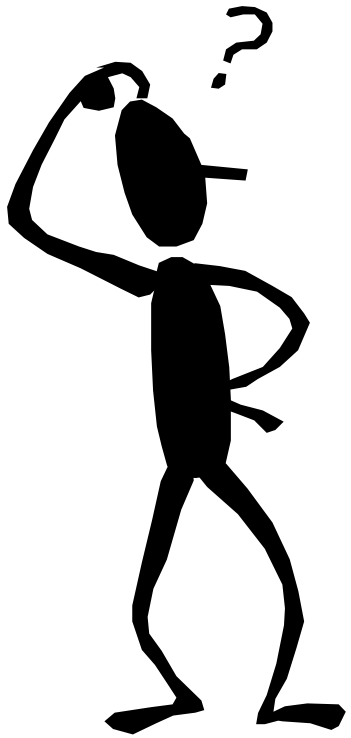
- Low-cost devices based on open-platform hardware
  - Wearable sensing device connected to the SmartPhone
  - Sensing device mounted on bikes/scooters/baby strollers
  - Geo-localization and data sharing
    - through social networks
- Indoor Air Quality Monitoring



UNIVERSITÀ DI PISA

Activity Funded by University of Pisa in the Framework of the PRA 2015 Program

Questions?



Next Steps

Traffic-Air Pollution Correlation

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- 2 monitoring stations
  - Managed by ARPA
- 3 more low-cost stations
  - UniPI-PisaMO project

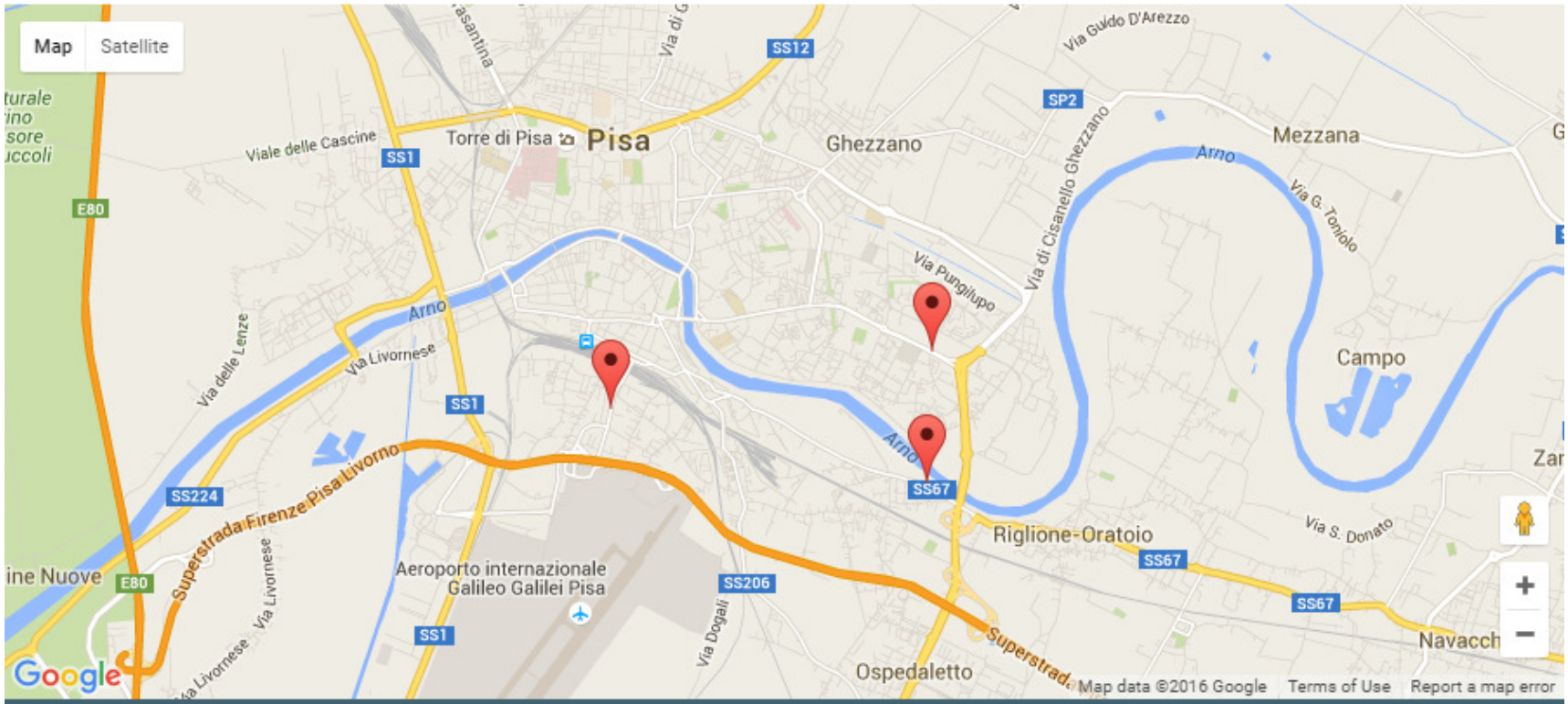
Low-cost Stations

PerLab

UniPISAmo

Home Sensors Map

Click on a marker for information on air quality at the selected point



Low-cost Stations

PerLab

UniPISAmo

Home Sensors Map

Data from sensor 3 (, Pisa)

Look day (dd/mm/yyyy) Visualizza dati

Download CSV format data file

Open Graph:

Temperature - Humidity - Battery - CO - O3 - NO2 - SO2 PM1 PM2.5 PM10

Ora	Data	Temp (°C)	Humid (%)	Batt (%)	CO (PPM)	O3 (PPM)	NO2 (PPM)	SO2 (PPM)	PM1 (ug/m3)	PM2.5 (ug/m3)	PM10 (ug/m3)
19:02:33	04-07-2016	30.59	49	93	1.005	0	0.088	0	2.8898	9.8197	36.5529
18:47:17	04-07-2016	30.82	49	93	1.43	0	0.082	0	1.9368	5.3974	29.2854
18:32:03	04-07-2016	30.65	51	93	1.168	0	0.085	0	1.7572	4.5892	8.0421
18:16:40	04-07-2016	31.21	48	93	0.584	0.059	0.091	0	2.0674	6.1429	23.0078
18:01:17	04-07-2016	30.9	49	93	1.028	0	0.092	0	1.8631	4.3893	12.8938
17:45:58	04-07-2016	31.44	49	93	1.03	0	0.098	0	1.9582	4.131	6.2343
17:30:31	04-07-2016	31.39	49	93	0.776	0.056	0.094	0	2.8508	6.2902	8.7065
17:15:17	04-07-2016	31.21	48	93	0.909	0.043	0.079	0	2.1306	4.1025	4.9122
16:59:50	04-07-2016	31.23	47	93	0.796	0	0.087	0	2.1627	5.4366	24.1856