MIMAQ - Technical Documentation

Website: http://mimaq.org

Project Description

MIMAQ = Mobile Individual Measurement of Air Quality.
This document describes the technical setup of the MIMAQ project for the pilot in Leiden.

Outline

The project is about measuring air quality, looking for pollutants which affect the health and general well-being of individuals. This is achieved by using mobile sensors, measuring NOx and various other key parameters (used for calibration), together with the current time and location, in regular time intervals.

Measurement values are transported to a central control center in real-time and analyzed, aggregated and visualized on web browser based maps and mobile phone based Augmented Reality. The way the measurements are presented is easy to understand (e.g. by using traffic light colors) and based on standards regarding maximum daily doses for NOx.

Within the scope of this project it is sufficient to discriminate between low, mid and high levels of pollution without achieving highly calibrated scientifically proven measurements.

Sensors

Specifications

Physical specifications

The sensors used are of the type City Senpod from Sensaris.

Some characteristics include:

- small form factor and light weight (wearable or easily attachable to a bike frame etc)

- robust, resistant to normal vibration during outside activities (biking, running etc)
- bluetooth communication with a mobile phone for real time data upload.
  - in our setup the Senspod is used with a Nokia model 2630
- power autonomy for approx. 4 hours when fully charged
- data capture to internal storage card (not used in this pilot)
- the following parameters are sampled every second (adjustable):
  - Location {Latitude, Longitude} as raw GPS frame including datestamp in UTC
  - NOx level as raw sensor output (Voltage)
  - CO level as raw sensor output (Voltage)
  - Noise level in dBA (uncalibrated)
  - Temperature in °C
  - Relative Humidity, percentage
  - Battery Voltage (used for reference only)

The core of the environmental sensor is the commercial available MiCS-4514 integrated NOx and CO sensor chip from E2V.

The specification sheet is attached in Appendix A.

Calibration

Output of the MiGS gas sensor is the raw voltage of each sample. In order to calculate the corresponding gas concentrations the sensor needs to be calibrated.

The following calibration steps were proposed:

1. calculated values based on typical sensor output (see appendix A).
2. calibration by an independent laboratory
3. verification of spread in characteristics between sensors and drift over time

It is assumed that there is a considerable dependency between environmental factors and MiGS response. We have asked the vendor (E2V technologies) for more specific calibration curves and dependencies between various environment conditions (temperature, humidity, other oxidizing gasses) but more accurate data appeared not to be available.

Also the sensitivity to other gasses than NO2 / NOx is unknown regarding influence upon measurement output.

Quoting the vendor:

> *NOx measurement is particularly difficult, as our sensor senses also ozone which is an oxidizing gas too. Being operated at colder temperatures, the baseline of the sensor is rather long to establish.*
>
> *I presume that if your goal is not to give accurate NOx values, this can work. As the NO2 sensor has a huge sensitivity, what we see during our road tests is that the influence of pollution gases is much greater than the influence of temperature or humidity. You will probably see this during your field tests too. Go with the sensor inside a polluted tunnel, or an underground garage, beyond a diesel truck and you will see the resistance of the NO2 sensor multiplied by 10 or 20…*

We have approached a number of laboratories but to our surprise none of them was able to do the calibration for (or even with) us, giving lack of time or accuracy or a reason.

We have made a rough assessment of the influence of temperature and humidity by testing a senspod in a relative stable environment.

The conclusion was that temperature and humidity have an influence which is relatively small compared to the whole measurement range. Although we can not determine reliable figures in terms of absolute values of NOx concentration, we can still find relative differences during a trip where the other condistions don't vary too much. See Appendix B for details.

Senspod data

Out of the box the City Senspod samples data for every sensor once every second and broadcasts the raw data as a single text line on the Bluetooth serial profile. The data is written on the embedded memory card as well.

The following events are posted:

- GPS frame containing {latitude, longitude, date, time, status}
- Real Time Clock (not used for MIMAQ)
- Temperature in °C and rel. humidity in %
- Noise level in dBA
- NOx level, raw sensor output, inverted voltage
- CO level, raw sensor output, voltage
- Battery level (not used for MIMAQ)

The exact format of these events varies and is documented in comments in the source code (see dataConverter.php).

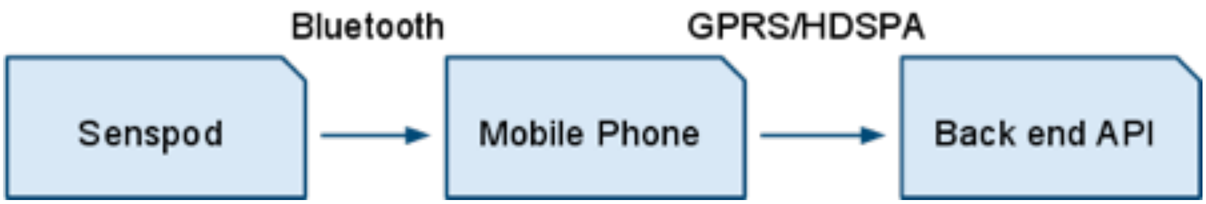
Apart from these, some administrative status events are sent, e.g. booting and shutting down. These are not used for MIMAQ.

Network specification

Sensor connectivity

The Senspod outputs sample data over Bluetooth; for a real time connection to the internet a relatively simple mobile phone can be used (requirements: Bluetooth, Mobile data access, GPRS is sufficient). A low cost flat fee - or pre-paid data subscription is recommended.

The sensor data is transferred in exactly the same format as it is logged to the internal storage card of the Senspod.



For the mobile phone we have considered various common platforms like Android, iPhone and Java MIDP 2.x.

iPhone appeared not to be feasible because Apple has not opened up the Bluetooth stack for 3rd party development.

An Android version was promising but the developer left the project halfway before he got it working on recent Android versions.

Finally we were left with the MIDP application, which appeared to run reasonably well on the cheap Nokia 2630 phone.

Phone setup

First, the mobile phone needs to be enabled for mobile data, a basic GPRS subscription is sufficient.

The next step is to connect the phone to a computer using Bluetooth and to push the MIDP files using file exchange:

- SensLink.jad
- SensLink.jar

The Nokia 2630 puts the MIDP application automatically in the Games directory. The default settings are good if you want to use the Sensaris data API, otherwise two alternative host names (and possibly port numbers) need to be configured in the Settings section.

Please see the document “Gebruikershandleiding-MIMAQ.pdf” for instructions how to start the application.

See “Senspod-General-User-Guide1.pdf” for more detailed instructions how to operate the City Senspod. In this document you can also find all details how to setup the Bluetooth connection on other devices than mobile phones and how to configure and read data from the internal storage card of the Senspod.

Data acquisition
In the default configuration of the mobile client (the Senslink MIDP application) all data is sent to the Sensaris data endpoint.

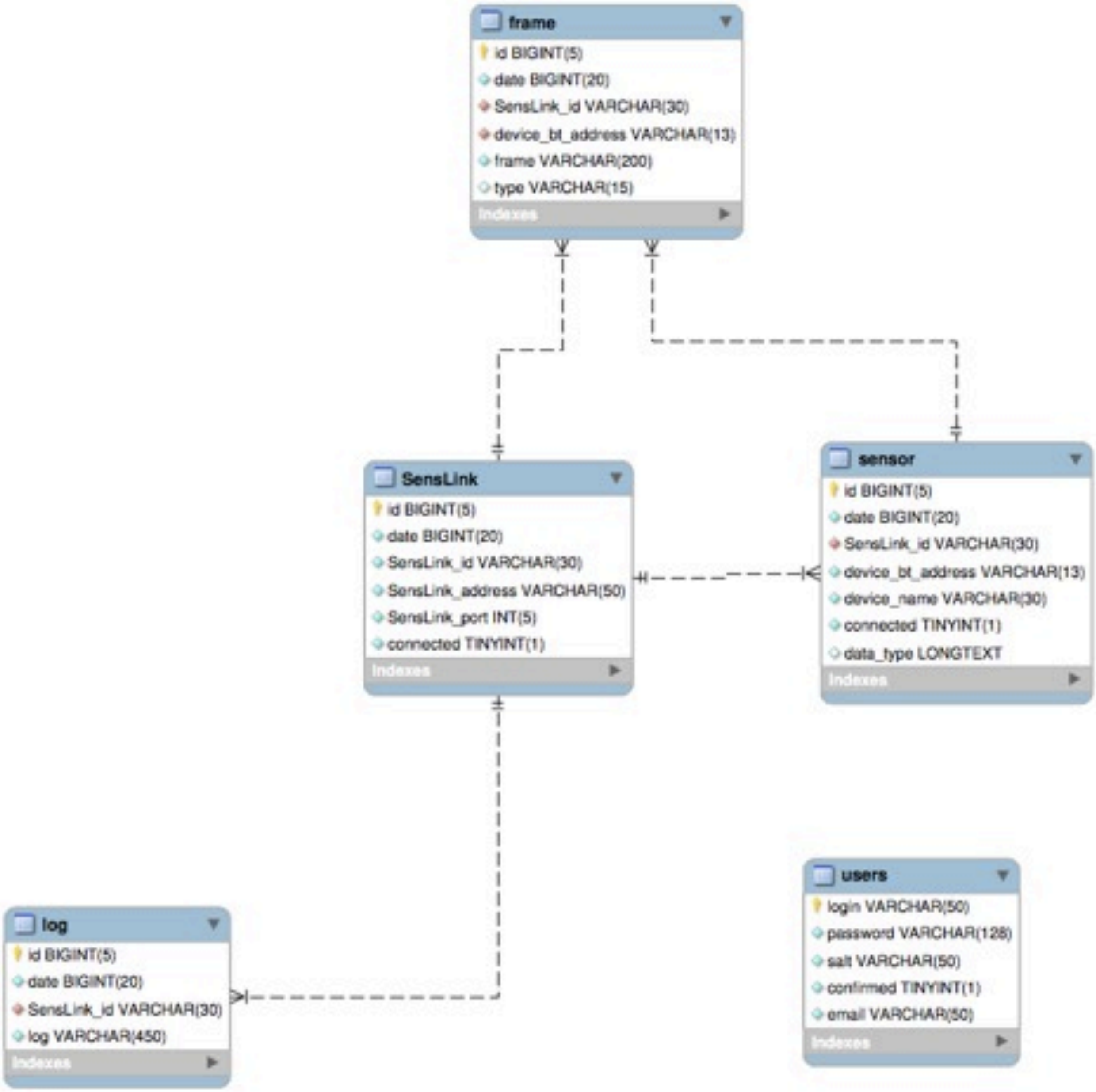
The application sends data to the SensWriter application, using UDP, port number 33333. Data consists of exactly the same text lines as the raw data stream which is written to internal storage and the Bluetooth serial port.

Data specification

Data model and storage

All measurements are broadcast as independent events of a specific type.
These events are logged in raw format to a database (i.e. the format as received from the sensor, one text line per event, together with some metadata like sensor ID, timestamp).

All raw data is stored at Sensaris in a MySQL database, see the schema diagram below.



Only the table *frame* is relevant within the scope of the MIMAQ project, all other tables are used for administration and controlling of the Sensnet website. Within the MIMAQ pilot users have all access they need to be able to start the measurements, without having to do any administrative tasks and without having to log into the

Sensnet site themselves.

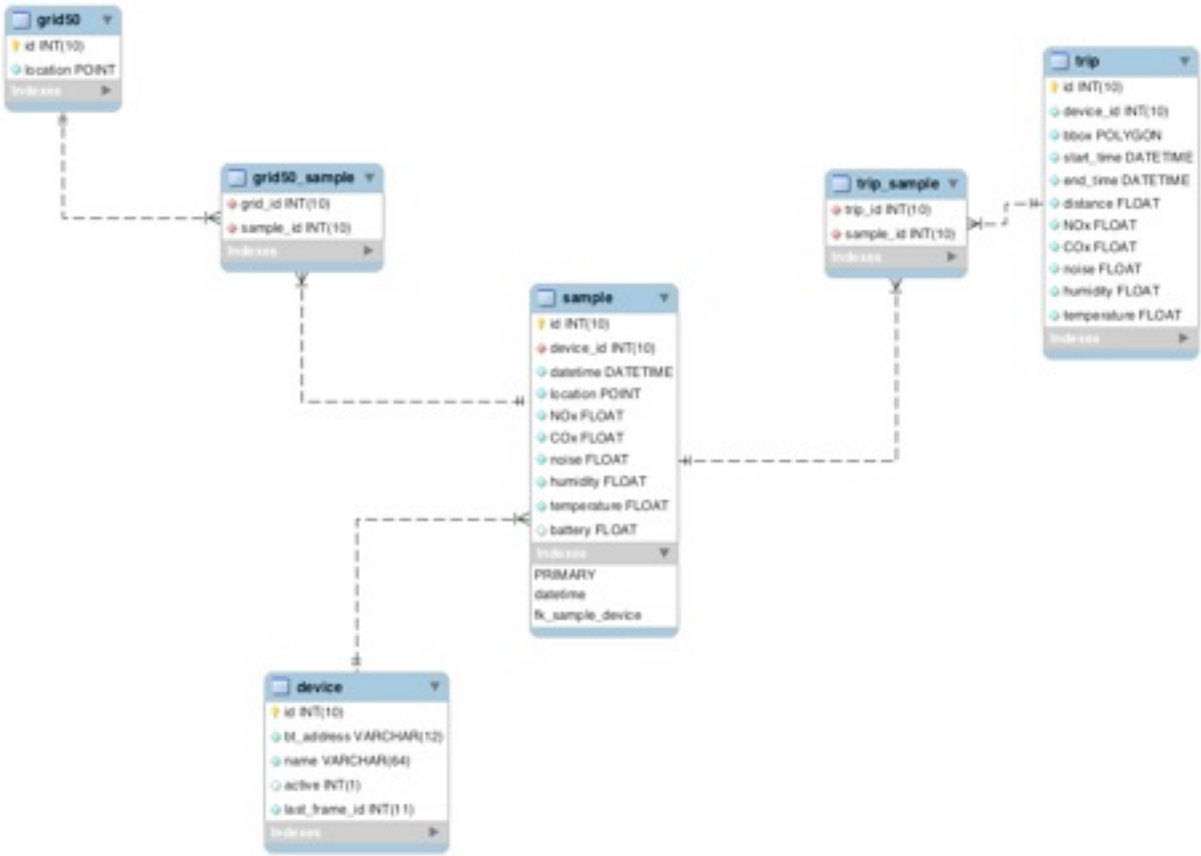
MIMAQ database

Raw sensor data is retrieved from the Sensaris database using a PHP script which runs every minute from a unix cron job.

The script - dataConverter.php - reads events for each active (configured) Senspod and aggregates all separate sensor values in one event per timestamp (e.q. once every second). As the sensor events themselves have no reliable timestamp attached, this grouping is done on a best-effort basis which will never be more than one second off unless frames are dropped. In our field tests this never was a problem.

The resulting data in table *sample* consists of measurement points with the values of all sensors aggregated in one measurement vector.

This provides a trail of GPS locations together with all values at that point in space and time.



Derived data tables are:

- grid50 - group samples by nearest geolocation in a 50x50m grid
- trip - group samples by a trip with no more than 30 minutes pause

Visualization

Trails on maps

For the display on Google Maps all data is grouped per day (or trip) and plotted as line segments on the map. Line segments are colored according to relative pollution level (Sensor output representing NOx concentration) in three color shades:

- green (clean)
- yellow (moderate)
- red (polluted)

Every line segment can be clicked and shows a pop-up display with average measurement values within that segment.

Augmented Reality view

The Augmented Reality view works with Layar.

To use this application, start Layar on your mobile device and find the 'MIMAQ' layer in the catalog.

This view uses the grid50 table to determine the nearest measurement points and displays the most recent sample for every point. Values are visualized using colored clouds, in three shades:

- blue (clean)
- brownish (moderate)
- dark grey (polluted)

Focusing or clicking a cloud opens a bubble with some more detailed information like pollution level, date and time of measurement.

API

Measurement data can be retrieved from the API both in JSON and GPX format.

General syntax:

```
GET /map.php?type=XYZ [extra parameters per type]
```

Output is in JSON format. This is used as basis for the Google Maps visualization. The following *type* queries are possible:

devicelist

- no parameters

Outputs a list of valid devices (Senspods) together with their internal ID, e.g.


```
[
    {
        "id": "2",
        "name": "SENSPOD_0045"
    },
    {
        "id": "6",
        "name": "SENSPOD_0050"
    },
    ...
]
```


datelist

- id (device ID)

Outputs a list of dates when measurements are available, e.g.


```
[
    {
        "date": "2010-10-17"
    },
    {
        "date": "2010-10-16"
    },
    {
        "date": "2010-10-14"
    },
    ...
]
```


track

- id (device ID)
- date (YYYY-MM-DD)

Outputs a list of measurement samples, together with a bounding rectangle and center point of the measurement area.

Sample data is given as raw sensor readings. Units are:

- NOx: output voltage*
- COx: output voltage*

- noise: dBA
- temperature: degrees C
- humidity: relative in %

*) these are raw values and not calibrated, as discussed elsewhere.


```
{
    "results": 3155,
    "pois": [
        {
            "lat": 52.15284,
            "lon": 4.483398,
            "timestamp": "2010-10-14T15:58:08+00:00",
            "NOx": 1.585,
            "COx": 1.25,
            "noise": 37,
            "humidity": 61.88,
            "temperature": 17.63
        },
        {
            "lat": 52.152843,
            "lon": 4.483402,
            "timestamp": "2010-10-14T15:58:02+00:00",
            "NOx": 1.564,
            "COx": 1.286,
            "noise": 55,
            "humidity": 61.72,
            "temperature": 17.52
        },
       ...
    ],
    "bbox": [
        52.152465,
        4.480303,
        52.166632,
        4.492025
    ],
    "center": [
        52.1595485,
        4.486164
    ]
}
```


track-gpx

- id (device ID)
- date (YYYY-MM-DD)

Outputs a track in GPX format.

GPX is a standard GPS Exchange Format by Topografix, see http://www.topografix.com/gpx.asp

The MIMAQ measurements are in a separate MIMAQ namespace and wrapped in the standard extensions element within each track point.

Measurement values are the same as in the JSON output.

```
<gpx xmlns:m="http://mimaq.org/ns/measurements/1/0"
    xmlns="http://www.topografix.com/GPX/1/0" version="1.0"
    creator="MIMAQ http://mimaq.org">
    <trk>
       <name>MIMAQ track 2010-10-14</name>
       <copyright>(c) 2010 CC BY-NC-SA</copyright>
       <link>http://mimaq.org</link>
       <trkseg>
          <trkpt lat="52.15284" lon="4.483398">
             <time>2010-10-14T15:58:08+00:00</time>
             <extensions>
                <m:NOx>1.585</m:NOx>
                <m:COx>1.25</m:COx>
                <m:noise>37</m:noise>
                <m:humidity>61.88</m:humidity>
                <m:temperature>17.63</m:temperature>
             </extensions>
          </trkpt>
          <trkpt lat="52.15284" lon="4.483398">
             <time>2010-10-14T15:58:07+00:00</time>
             <extensions>
                <m:NOx>1.591</m:NOx>
                <m:COx>1.301</m:COx>
                <m:noise>48</m:noise>
                <m:humidity>61.83</m:humidity>
                <m:temperature>17.65</m:temperature>
             </extensions>
          </trkpt>
...
```

Software hosting

All MIMAQ software is available under the terms of the BSD license and hosted in the Google Code repository under http://code.google.com/p/mimaq/

The code can be retrieved by checking it out from Subversion, using the following command line:

```
svn checkout http://mimaq.googlecode.com/svn/trunk/ mimaq-read-only
```

Appendix A

Calibration
Input from the following sources

  - spec sheet from manufacturer (see below)
  - test results by independent laboratory
  - Sensor ID is connected to every measurement for future reference
  - A selection of sensors in the test pool will be tested in pairs (two or more) together to compare responses for each measurement type
- Response variation over time will be monitored in well known conditions to get an idea of measurement stability
  - Determine dependencies between battery voltage, temperature and humidity for each measurement type

The way to calibrate the sensors is as follows:

- Switch on the device together with a previously calibrated sensor
- Wait for both devices to acquire a stable GPS fix (indicator led)
- Connect the devices to the upload link or enable offline storage
- Keep the devices within a few centimeters together
- Make sure free airflow is possible for all devices
- Make test run through varied conditions (heavy traffic, clean air out of town)
- Analyze registration curves to determine:
  - systematic offset from calibration curves
  - random measurement variation ("noise levels")
- Determine individual calibration curve for each sensor and measurement type

To be determined: re-calibrate after a month to see if there is drift over time.
General note about measurement accuracy: as this project is primarily aimed at indicating differences in pollution levels between places and during time of day, the accuracy needs not to be very high. It is essential though that trends are visible and

comparison between low, mid and high levels can be made for the relevant indicators (i.e. NOx levels).

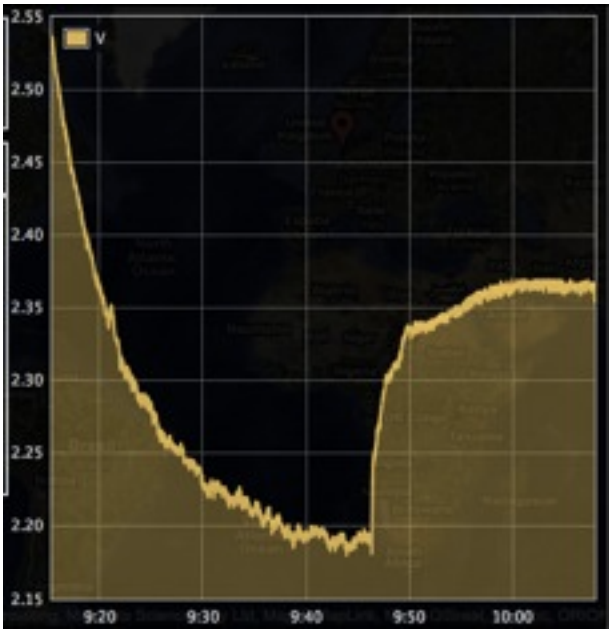
For more info about the MiGS 4514 Sensor see the Data Sheet: MICS-4514.pdf

Appendix B

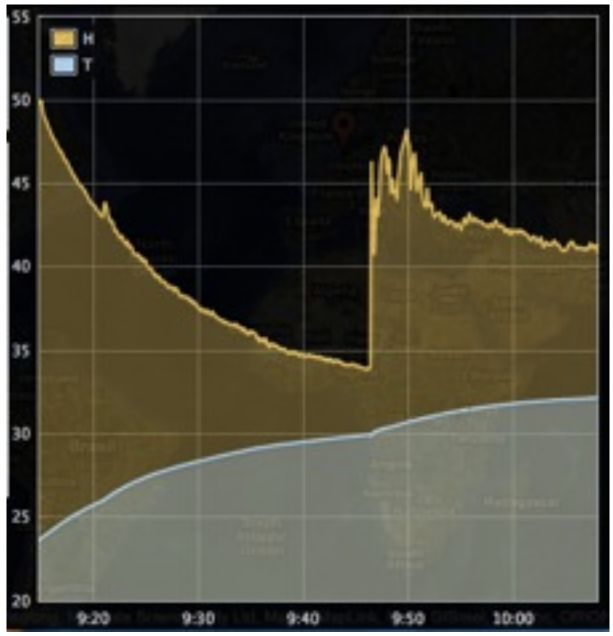
Practical sensor Test

In this test a Senspod was powered on and running for almost an hour in a stable, indoor environment with hardly any airflow.

During the first half of the test the Senspod was in a typical living room environment, in the second half the sensor was quickly moved to a hotter room with high relative humidity.



NOx sensor output, Voltage. The complete range is between 0.3 and 3.3 V



Temperature (T in °C, blue line) and relative humidity (H in %, yellow line)

A few observations:

The sensor temperature keeps increasing for more than half an hour; even then the equilibrium with the environment is not yet reached.

Relative humidity decreases in the same rate as temperature rises, this is expected when there is not much air circulation in the sensor encasing.

Output of the NOx sensor is very consistent with both temperature and humidity changes. Again, it is expected that there is not much air circulation and the NOx level stays more or less constant.

The NOx sensor has a slightly slower response to changes than the humidity sensor (temperature changes too slow to draw any conclusions in this test).

The following are unknown:

- whether the sensor influences NOx level e.g. by catalytic processes which reduce the amount of NOx in the very limited air sample over time
- what the individual influence of temperature and humidity are; the net effect is a virtual decrease of NOx sensor output over time as the temperature increases and rel. humidity decreases.
- whether the NOx levels were significantly different during the second part of the test; NOx is water soluble so it can be expected that the levels were at least somewhat lower.

Test Conclusions

There is an effect from both temperature and relative humidity.

The total output range in this test was between 2.53 and 2.18 V (0.35 V difference) for the NOx sensor as the temperature raised from 23.5 to 30 °C and relative humidity dropped from 50% to 34%. The total measurement range is from 0.3 to 3.3 V so the effect is slightly more than 10% of the sensor output range.

As long as we are measuring while walking or driving and have a lot of airflow this means that temperature fluctuations due to sensor- and electronics power dissipation will be limited.

Within this pilot we ignore the effect of temperature and humidity for visualization purposes under the assumption that the effect of variations in NOx (and possibly other oxidizing gasses) will outweigh the temperature effects.

This also means that we can only look at relative differences of sensor output during one trip or any other situation where fluctuations in temperature and humidity are relatively low.

On the other hand this means that those relative differences during one trip can be significant and indicate at least differences between relative clean and polluted spots. We decided to focus on this interpretation.

Approximation of NOx levels

Regarding gas calibration, in cities the following typical values are reported:

NOx High: 300 ppb   Mid range: 100 ppb   Low: below 30 ppb

CO: High 4 ppm   Mid range: 2.5 ppm   Low: below 1 ppm

MIMAQ measurements are displayed in the the same three steps: clean, moderately polluted and badly polluted.

Based on Dutch regulations we found some limits these levels should be based on:

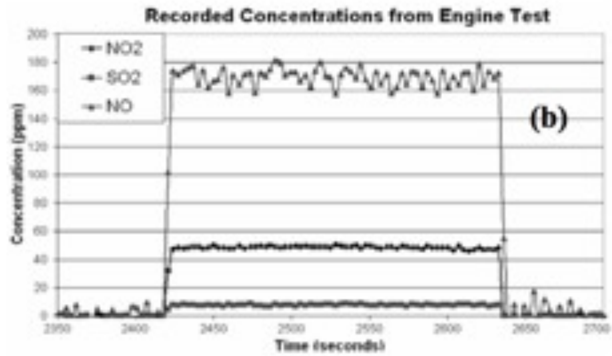
- average NO2 concentration over a year: 40 µg.m-3
- upper limit, may not be exceeded for more than 18 hour per year: 200 µg.m-3
- alarm level: 400 µg.m-3

Limits we choose for MIMAQ are:

- Clean < 60 µg.m-3
- Moderate: between 60 and 160 µg.m-3
- Alert > 160 µg.m-3

Note that these values are all limits for NO_2; we could not find anywhere what the values for NO_x are and even worse, there seems not to be an official definition of what the composition of NO_x actually is.

Typical values for car engine exhaust gasses seem to be 70 NO : 30 NO_2 (source: *DOAS NOx monitoring*[1] and *Spot on NOx*[2])



The following table[3] lists the correspondence between ppm and µg.m3 for some gasses:

- CO: 1 ppm = 1.145 mg/m3
- NO: 1 ppm = 1.230 mg/m3
- NO_2: 1 ppm = 1.880 mg/m3
- O_3: 1 ppm = 2 mg/m3
- NO_x (NO/NO_2 in ratio 70/30 = 0.7*1.230 + 0.3*1.880) = 1.425 mg/m3

The City Senspod voltage output is given by:

$$V\_NO2\ out = \frac{5 \times R\_load\_NO2}{Rs + R\_load\_NO2}$$

1 http://iopscience.iop.org/1742-6596/76/1/012021

2 Spot-on NOx http://www.isa.org/InTechTemplate.cfm?Section=Article_Index1&template=/ContentManagement/ContentDisplay.cfm&ContentID=76182

3 Source: UN Habitat: http://ww2.unhabitat.org/wuf/2006/aqm/tool28.htm#3

As a first approximation, we assume a linear relationship from the MICS 4514 datasheet (curves for 40 % RH and at 25°C) and take that 3.3 Volts measured by the City Senspod correspond to 30 ppb of NOx and 0.3 V output to 300 ppb.

Therefore, for the bar graphs, we can approximate 3.3 Volts as 10 ppm and 0.3 V as 1 ppm.

NOx: *0.3V - 3.3V* correspond to *300ppb - 30ppb *(L/M/H: 30/100/300)

COx: *0.3V - 3.3V* correspond to *1ppm - 10ppm *(L/M/H: 1/2.5/4)

We want display values in µg/m3 as this is the value used in official Dutch regulation documents.

For pure NO2: 1 ppb corresponds with 1.88 µg.m-3 so we get:

- 0.3V => 564 µg.m-3
- 3.3V => 56 µg.m-3
- Linear interpolation: s = 615 - 169v (µg.m-3)

For NOx (as 70/30 mix of NO/NO2) we get 1 ppm ~ 1.425 µg.m-3

- 0.3V => 300*1.425 = 427.5 µg.m-3
- 3.3V => 30*1.425 = 42.8 µg.m-3
- Linear interpolation: s = 465 - 128v (µg.m-3)

Using these calculations we got some pretty high average values for NOx concentrations. We don’t know if this is caused by actual NOx or influences from other gasses like O3, moisture and temperature. Also, the calculated values in µg.m-3 suggested much more accurate results than we can support by all of our assumptions, so we decided to go with the simple “traffic light” visualization: low, mid or high levels.