Flue smokes monitoring system: how a *LoRaWAN* based sensors network can reduce gas accidents and improve checks on pollutions in the air

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Abstract

Developed countries such as our European Community suffer from the problem of air pollution: from the quality of air in public and private spaces, to the concentration of ”sentinel” gas and the risk of fires. The major sources of pollution can be easily observed and managed, such as heavy industries, power plants with non-renewable sources and pollution from road transport vehicles.

On the other hand the rest of the air pollution sources are more rooted, speedily distributed and not easily reachable by technical checks from authorized public authorities: just think of domestic boilers and flues, which are present in most of apartments and offices, need constant maintenance carried out by the owners; this causes, in most cases, a degradation of the systems, due to their negligence, which produces a decrease of efficiency and an increase in polluted gases production, up to the worst cases, of accidents and explosions.

The recent incidents in Italy[1] and the interest in preserving the environment have led us to seek a solution to the problem, based on the qualitative monitoring of air quality, therefore of toxic and explosive agents, in small areas through a *simple use*, *cost-effective* and *battery-powered* tools, able to be used by the majority of private citizens and institutions, in order to create a geolocalized network through which map air quality, even in areas with historical-cultural constraints, wooded and rural areas or otherwise difficult to reach environments (such as, for example, the exhaust flues of heating systems).

Through the recent tencologies of *IOT*, *Cloud Computing* and *Edge Computing*, the aim of our research is to create a monitoring network based on individual cost-efficient sensor devices, capable of reaching and therefore mapping even the smallest and unreachable risk zones. The capillary network is also able to analyze and evaluate densely populated areas and is able to offer a monitoring service for private citizens, local and national authorities.

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1 Introduction

According to the *Federchimica* last research on *"Comparative research on gas emissions"*[2][3] the 60% of fine powders $PM104$ are generated from stoves, fireplaces and gas boilers; in a decade, from 2005 to 2015, $PM10$ emissions from gas heating systems for homes, public places and workplaces, increased from 14000 to 21000 *tons*, while emissions caused by transport systems have been reduced. The problem therefore lies in heating systems, as well as polluting, need continuous quality control of their emissions and how they work to prevent a fire hazard or, in the worst cases, explosions and accidents.

1.1 UE Parliament council of 21 May 2008: *"On ambient air quality and cleaner air for Europe"*

> *"In order to protect human health and the environment as a whole, it is particularly important to combat emissions of pollutants at source and to identify and implement the most effective emission reduction measures at local, national and Community level. Therefore, emissions of harmful air pollutants should be avoided, prevented or reduced and appropriate objectives set for ambient air quality taking into account relevant World Health Organisation ì standards, guidelines and programmes."*[10]

1.2 Growth of accidents by gas boiler and use of LPG in the latest years

There is also another big problem associated with gas utilization: the growth of domestic accidents. According a recent "*Statistic from gas accidents*" elaborated by *CIG*[4] in 2017, there has been an increase of 5.5% of natural gas put in the Italian network and so an increase also in the accidents happened: a growth from 123 to 140. In particular accidents with explosions and fires have growth from 83 to 106. The same trend is for LGP. Analyzing this survey we find that in the 29% of accidents there was absence or non-suitability of smoke evacuation system and in the 27% the causes were an incorrect installation. The majority of accidents could be avoided with a more accurate and immediate alert system positioning near the boiler.

1.3 Our work

This type of problem can be faced by the recent growth and spread of *IOT*, *Cloud* and *Edge Computing* technologies. Our work aims therefore to the creation of cost-efficient tools for data acquisition and creation of a network can provide to citizens, private organizations and public authorities a comprehensive and extensive mapping and a broadcast warning system.

The realization of simple battery-powered qualitative sensors, with low consumption and minimum overall footprints, is the key to managing the problem of flue smoke control. We have ignored technical issues such as the accuracy and sensitivity of sensors for greater simplicity of implementation and use (following the paradigm of "*easier, less expensive, less subject to breakage*"[1]) but above all we intend to create a network information accessible to all for the diffusion of the concept "smart cities" in conjunction with the energy saving, pollution control and monitoring of fires and explosions.

2 Implementation

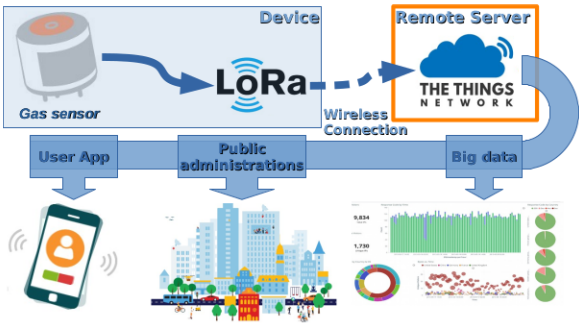

Figure 1: System workflow.

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[1] *"Frustra fit per plura quod fieri potest per pauciora."* Occam's razor.

2.1 ***LoRa Network* as transmission base layer**

In the context of low-power consumption, long life and battery-powered devices (for the realization of extremely portable devices), the choice of the transmission system fell on *LoRa Network*[5]. The technical details are given in the manuals available on the manufacturer's website[6]. Here, a brief list of the main reasons why our choice fell on this system:

- Emergency signals must be sent and received without power supply.
- Enclosed spaces, such as chimneys, have little space available for the construction of complex systems with spacious antennas and high power supply.
- The data to be sent is made up of small information packets, so a low channel capacity is sufficient.
- The data are not sensitive or highly accurate and transmission timing is not a specific problem.
- The transmission must be extremely low power.
- The transmission range must be long range and can vary greatly among the various environments of use.
- The network created must have future expansion capabilities.
- Data should be geolocalizated easily.

LoRa Network is a long range transmission technology (up to $10\,km$ in open space area) particularly well suited for IOT devices; its noise profile is very low and is also characterized by a strong resistance to noise, working in fact below the noise threshold characteristic of the non-shielded environments. There are many low-cost solutions for "*embedded*" implementation of this transmission system, all with the same power consumption characteristics, range and cost compatible with our project.

2.2 Sensors

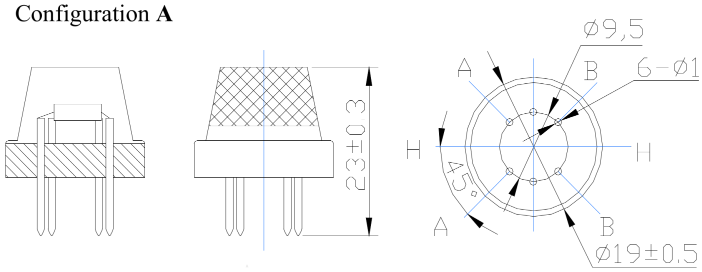

Figure 2: MQ-x series, gas sensors.

There are many low-cost solutions for the "embedded" implementation of this transmission system, all with the same power consumption characteristics, range and cost compatible with our project. The $MQ-x$ series of sensors for the detection of various gases in the air has as main features:

- Wide detecting scope
- Fast response
- High sensitivity stable and long life
- Simple pilot circuit
- Low energy consumption

2.2.1 MQ-x series, pros and cons

They are used in air quality control equipment for buildings/offices and are suitable for detection of NH_3, NO_x, alcohol, benzene, smoke, CO, CO_2 gasses and many more. Connection with the external components is very simple, but most importantly it is standard: this implies that the different devices implementation is possible only through the change of the sensor.This is a considerable advantage in terms of ease of use, implementation of management and low cost.

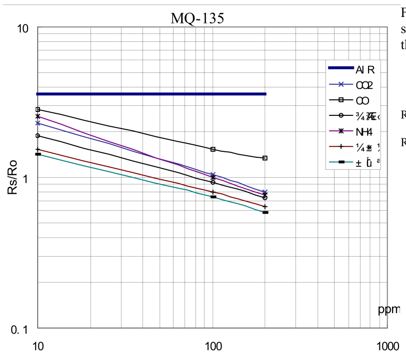

Fig.3 is shows the typical sensitivity characteristics of the MQ-135 for several gases.
in their: Temp: 20
Humidity: 65%
O_2 concentration 21%
RL=20kΩ
Ro: sensor resistance at 100ppm of NH_3 in the clean air.
Rs:sensor resistance at various concentrations of gases.

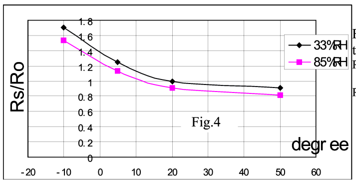

Fig.4 is shows the typical dependence of the MQ-135 on temperature and humidity.
Ro: sensor resistance at 100ppm of NH_3 in air at 33%RH and 20 degree.
Rs: sensor resistance at 100ppm of NH_3 at different temperatures and humidities.

Figure 3: MQ-x series, sensibility and response to humidity and temperature variations.

As noted in the sensor data, the output response (analog signal) strongly depends on the temperature and humidity conditions. This is an important problem but for our purposes (the acquisition of quantitative but not qualitative data) it can be solved by simple software algorithms, even if they are not extremely optimal.

2.2.2 Sensitivity adjustment

Resistance value of $MQ - x$ series is difference to various kinds and various concentration gases. So, sensitivity adjustment is very necessary. In order to calibrate the detector for $100\,ppm\ NH3$ or $50\,ppm$ Alcohol concentration in air and use value of Load resistance about $20\,K\Omega$ ($10\,K\Omega$ to $40\,K\Omega$). When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

2.3 LoRa for transmission and three different environment according the final use

First, we have designed and built a prototype for generic use of the sensor, to which we added the transceiving system of low consumption and long-range *LoRa*[5] Network. The collected data is distributed in three "*end-user services*" in order to provide the same number of overall system capabilities:

- Private telemetry
- City administrative certification and monitoring
- Big data analysis.

We have configured a *dragino* gateway and send data from our device to *The Things Network*[7]. In *The Things Network* servers, data are not collected because is only a hub for distribute it over the web. *TTN* has several plugins to redistribute data, depending which services you would use; in our case we used two different plugins always based on *REST* and *MQTT* protocols.

3 Services to users

The use of devices with the characteristics described above (in short: small footprint, ease of construction, ease of use, low energy consumption, long-range connection and low noise profile, geo-localization capability) for the acquisition of data, allows the creation of a useful database with the following features:

- Local and global air pollution maps
- Statistical analysis of the presence of various polluting and non-polluting gases

- Fire risk monitoring in rural, wooded or sparsely populated areas
- Monitoring of densely populated urban areas with historical and cultural constraints
- Exhaust gas monitoring and analysis of boilers in private and public environments
- Boiler operation and efficiency monitoring for the user
- Alarm network located in large urban and non-urban areas
- Quality Mapping urban areas and places of public and private workplaces

3.1 Smart cities capabilities

We have understood that low-cost IOT technology can meet the three great needs of a modern smart city:

- A robust and widespread alarm system, surveillance and security tools for local administrations
- Quality control tools for the certification of domestic systems
- A database accessible to all, to manage all this kind of data

The solution to these three major problems inevitably leads to the growth of eco-sustainability, informalization and security of the entire urban environment. For this reason we focused on the choice of as many three services realized in an ”ad hoc” way to respond to these three major problems in order to emphasize the qualities of our idea.

3.1.1 Database

We decided to use a structure as much as possible common to all three requirements described above. The basic operation is simple: the LoRaWAN device connects with *TheThingsNetwork*[7] service that collects various information and increases with data such as geo-location, user, etc. The message is then routed to the database *DynamoDB*[8]. Data collected and stored in this database can be made available to the public Both private and public organizations for analyzing pollution purpose, through the `Restfull API`: a common API easy to use and very often implemented in various web services.

Amazon DynamoDB is a key-value and document database that delivers single-digit millisecond performance at any scale. It's a fully managed and durable database with built-in security, backup and restore, and in-memory caching for internet-scale applications. It can handle more than 10 trillion requests per day and can support peaks of more than 20 million requests per second.

3.1.2 Private users

For the use of the private user, a simple smartphone application accesses the database, thus creating a simple analysis and control tool, low-budget and easy-to-use.

3.1.3 Survellaince monitoring and Big Data analysis

We decided to use *Elastic Search*[9]: a search engine developed in Java, accessible via `http request` (or web interface) and a schema-free *JSON* documents. In case of public dataset with low-sensitive data collection, we provided a very powerful solution in search capability with *near real-time search.* Overall this service has tools like *Beats* (a very useful tool for transferring IOT data to the engine) and an analytics and visualization tool named *Kibana*[9]. *Kibana* is an extreme powerful tool for viewing data in real time, implementing machine learning algorithms evaluations and send notification on a trend.

4 Conclusion

We tested our prototype, made with various development tools for everyone, achieving remarkable results in terms of:

- Design cost
- Design, analysis and testing times

- Cost of realization
- Robustness of signals and sensors
- Quality of data sent and received
- Speed of transmission protocols
- Ability to use the end user both as a data analysis, as a smartphone application, and as a map of the sensor network.

We then collected a lot of data from a single home chimney in real time: the connection between *TheThingsNetwork Amazon DynamoDB* and *Elastic Search* allowed us to analyze the data in three different ways. Through Kibana and the use of numerous devices it will also be possible to implement Machine Learning systems that can prevent the risk of fire and alarm in a preventive way: something that we have moved into "*future developments*".

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